Chapter 2

The Effects of Soil Properties on Plant Physiology

Wayne Blizzard

Department of Botany
University of Illinois
Urbana, Illinois 61801

Wayne Blizzard received his B.S. degree in botany at the University of California—Davis and the M.S. degree in botany at the University of Illinois—Urbana. He is presently Visiting Teaching Associate in the Department of Botany at the University of Illinois—Urbana. His professional interests include the development of instructional media for science education, particularly the development of "practical science" materials for lay persons.

17

17

Introduction

These exercises examine the physiological needs of plant roots and how the properties of soils, non-soil potting materials, and containers affect the physiology of plants. This project was developed for our college-level introductory botany course for non-science majors "Botany 102: Plants, Environment & Man". It teaches scientific principles and the practical plant culturing skills that are derived from those principles. The project could be easily adapted for use in a high school biology course through a simplification of the principles (if needed) or by putting greater emphasis on skill learning.

The project uses a variety of teaching methods: informal lecture, demonstrations, student activities and manual skills, visual displays with self-paced questions, class discussion, and take-home evaluation questions. Each method and activity is meant to cover one or more learning objectives (below). Class time is 50 minutes. Set-up is approximately four hours. The plants used in the exercise should be started five to seven weeks in advance.

In order to understand the significance of our methods one must be familiar with the background of the course. Our course is an introduction to botany for non-science majors. Our students are typically in the humanities and social sciences. They usually take our course in order to fulfill a college lab science requirement or as an elective to round out their schedule. These stuuents come with little or no science background. They often complain the first day of class that they find science courses frustrating, boring, or intimidating.

For many years there was only one option for introductory botany: Botany 100, a traditional course designed for life science and agriculture majors. It consisted of two one hour lectures a week, a one hour discussion, and a three hour laboratory. Each discussion class had a maximum of 12 students. Each met once a week for discussions which reviewed the previous week's lecture materials. Each laboratory class had a maximum of 24 students. Lab meetings consisted of an experiment run by all the students in groups of 3 or 4. Student performance was evaluated through lab reports and/or quizzes.

About half of the 350 to 450 students in Botany 100 were non-science majors. These students felt "out of their medium" in a science course and believed that the science majors had an advantage over them on exams. (Our statistics show that the two groups had the same mean and median scores for tests and for the course as a whole; however the standard deviation was slightly smaller for the non-science majors.) Many non-science majors had difficulty seeing the importance of botanical principles to their own disciplines, personal values, and societal problems.

Our goals in developing Botany 102 were to increase student interest and participation and to retain a solid core of scientific information. We were very aware of the danger of losing content while striving for "relevance". This new course utilizes the same lectures as Botany 100. However the Botany 102 students are evaluated using different examinations than are used in Botany 100.

Discussion hour is used primarily for discussion of socially important aspects of science and botany. We explore such topics as herbicide use, endangered species, basic versus applied research, the challenges of recombinant DNA research, and the Green Revolution.

Project hours provide students with practical experience with plant growth and care based on clearly stated scientific principles. We cover grafting, propagation, lighting, watering requirements, fertilization, hybridization, human nutrition, etc. Student performance is usually evaluated by short written responses to questions or scenarios on plant growth and care.

Two general approaches are taken in project hours:

1. Instructor teaching of techniques that require students to physically manipulate plants and produce some end product: e.g., a grafted plant, a new tomato hybrid, or a soil mix.
2. Self-paced learning through displays that require students to use many senses (seeing, feeling, etc.) and expand on concepts but which do not teach new technique.

The topics explored in projects generate high student interest because they are obviously applicable at home. It is difficult to portray in writing the dynamic atmosphere in the classroom during a project hour. We have tried to maximize actually working *with* plants and to minimize printed lab instructions, handouts, and quizzes.

Before the development of our course we conducted two end-of-the-semester student surveys concerning Botany 100. Of the 381 non-science students polled only 29% voted "yes" to the question: "Would you take the laboratory if it were an optional experience?" In contrast 91% of 402 science and agriculture students voted "yes". Many non-science majors indicated that the lab did not link to their interests, that it was too abstract and scientific, and that they would like to learn more about the practical care of plants. In respose to this we designed projects for Botany 102 which overcame these problems.

Enrollment in Botany 102 was 264 during its first semester. Surprisingly this did not have any effect on the number of students enrolling in Botany 100. During the second semester enrollment requests topped 420 of which we could accommodate only 284. Again the increase in requests for Botany 102 did not decrease the number of students enrolling in Botany 100.

We did extensive evaluation of Botany 102 after its first semester. We conducted written surveys and had personnel from the Office of Instructional Resources conduct interviews of randomly selected discussion/project classes in the absence of the instructor. In interviews the students expressed a positive attitude toward the course as a whole. Many however were disappointed by the amount of work that they had been expected to put into the course. This they said was largely due to their belief that the course was a "non-science" course and would thus be easy. There was some confusion for the same reason over what lecture material was "for Botany 100 and what was for Botany 102". Some students assumed that anything difficult in lecture must be for the science majors and not for them! They commented that the discussions were well planned and relatively easy. The students found the projects to be interesting and enjoyable. They especially appreciated the bulletin board displays as helpful and interesting.

Student Materials

Learning Objectives

Through their involvement with these exercises students should understand the following statements:

I. Plant roots require certain environmental conditions in soil to grow properly; these include proper
   A. water
   B. air
   C. minerals
   D. pH
   E. temperature
II. The inorganic and organic portions of the soil affect the soil's ability to provide these conditions.
III. A good soil has the proper proportions of inorganic and organic materials.
IV. Pot porosity, drainage, and size influence the amounts of water and air in the soil and so affect root health and growth.
   A. Flooding deprives roots of oxygen needed for respiration. When respiration drops, so do water and mineral uptake and disease resistance.
   B. Bacteria and fungi thrive in wet conditions.
   C. Soil dries quickly when a plant is potbound.
V. Non-soil potting materials differ in the amounts of water and air they can hold.
   A. Mixtures of non-soil materials can provide conditions nearly identical to those found in "natural" soils.

In-class Questions—Pots and Drainage
Week 10

POTS and DRAINAGE: Look carefully at the display (see Figure 2.1) and answer these questions about the containers labelled A, B, C, and D.

_________ 1. In which pot would a plant be most likely to develop "root rot" due to excess water and low oxygen?

_________ 2. Many ferns require soil which is constantly moist but not water-logged. Which pot would you choose for such a fern?

_________ 3. Some plants do best if the soil is allowed to dry out between waterings. Which pot would you choose for such a plant?

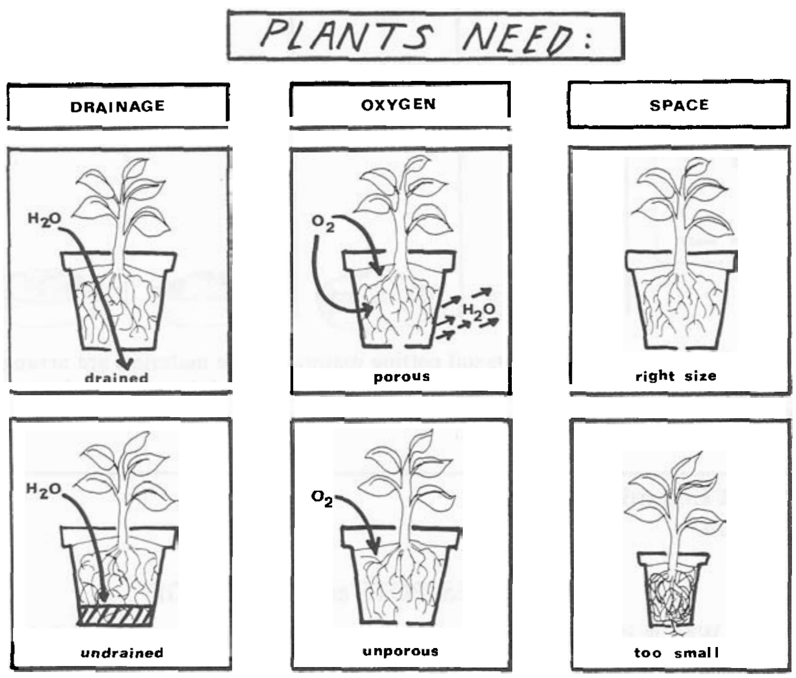

Figure 2.1. Visual display of pots and drainage. Pots with combinations of these characteristics are arranged on the lab bench directly beneath the display for student inspection.

SOILLESS POTTING MATERIALS: Carefully compare the water- and air-holding abilities of these potting materials (see Figure 2.2). TOUCH, FEEL, POKE, AND SQUEEZE EACH OF THEM! Rank them using the scale below:

Holds — Holds
1 ------------ 2 --------------- 3 ------------- 4
Most — Least

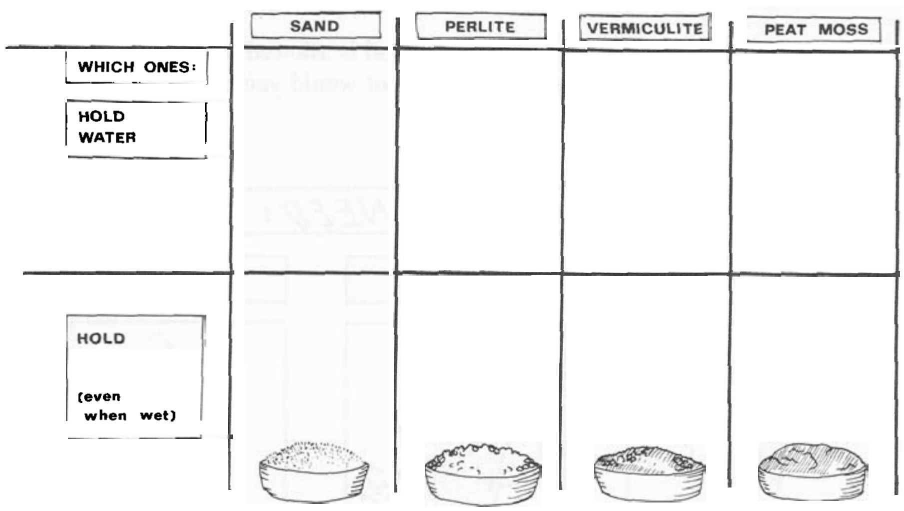

Figure 2.2. Visual display of non-soil potting materials. The materials are arranged on a bench beneath the columns. Numbers are placed in each box during class discussion.

Project Evaluation Questions
Week 10

SOIL MIXES/POTS and DRAINAGE

1. Why is it that many times a mix of soilless potting materials* will work just as well as "real" soil for growing house plants? (5 points)

   Each soilless component has one or more properties possessed by natural soil components (water or mineral retention, forming air spaces, etc.). When properly mixed the soilless mixture plays all the roles of "real" soil—providing the plant with what it needs.

*Perlite, peat moss, vermiculite

2. Give two reasons why it is important for most plants to have a soil and a container which provide good drainage. (4 points)

   Prevents excessive fungal and bacterial growth (due to too much water).

   Good drainage keeps soil air spaces open allowing roots to get the oxygen they need for respiration (energy release).

3. Circle the 3 pot characteristics that together would result in the most rapid soil drying. (6 points)

Drained	Undrained
Porous	Unporous
Large	Small

Instructor's Materials

Outline of Class Activities

I. Class Introduction: Instructor briefly introduces the soil requirements of plants, general soil properties, and soil mixing.
II. Soil Mixing: Students mix a 1:1:1 (loam:peat moss:perlite) potting mix.
III. Repotting: Instructor demonstrates and students perform repotting of plant(s) using potting mix prepared above.
IV. Display Introduction: Instructor briefly explains the use of the displays on the properties of pots and of non-soil potting materials.
V. Display Investigation: Students study displays using question sheets provided by the instructor.
VI. Class Discussion: Class participates in a summary discussion of the project activities.
VII. Evaluation Questions: Students take home and answer questions on the projects.

Preparations and Procedures

I. *Class Introduction*

Plant roots require the proper soil environmental conditions for good growth. These conditions include the appropriate amounts of water, air and minerals, the proper pH and the proper temperature. These requirements are related to the physiology of the plant. Water is essential for the transport of minerals, for leaf turgor pressure, and for photosynthesis. Too much water may encourage the growth of bacteria and fungi which might cause disease in the plant. When water fills the air spaces of the soil the roots may not receive the oxygen they need for respiration. Low rates of respiration inhibit mineral and water uptake and reduce the health of the roots, making them more vulnerable to infection. Minerals are needed as co-factors in enzyme reactions and as constituents of some complex organic molecules. The pH of the soil influences mineral ion availability. Temperature has a great influence on the rate of water uptake, on enzyme reactions, and on the general health of the roots.

The inorganic and organic components of the soil affect the soil's physical properties. Inorganic matter includes mineral particles of various sizes: gravel, sand, and clay. Organic matter includes living and dead organisms: twigs, stems, worms, bacteria, etc. Water retention is influenced by the size (surface area) of the inorganic and organic particles in the soil. Water holding capacity is also affected by the absorption qualities of organic matter. Air spaces are formed when there are many different-sized particles of inorganic and organic matter. Minerals are released by the breakdown of both inorganic and organic sources. Rock particles weather and release mineral ions. Leaves and twigs decay and release ions. Furthermore, mineral ions may be bound to charged sites of both organic and inorganic particles and be taken up by plants later. pH is primarily influenced by the nature of the organic constituents of the soil. Dead plant tissues may be high in organic acids for example. Limestone may cause a soil to be quite basic. Temperature is related indirectly to the amount of water held in the soil. Water changes temperature slowly and so a moist soil will cool or heat more slowly than will a dry soil.

A good soil has the proper proportions of organic and inorganic materials. Garden soils are usually high in loam. Loam is a soil class having 30–50% sand, 30–40% silt, and 10–25% clay. The high proportion of very small particles (clay and silt) results in a dense, poorly drained, sticky soil. When loam is used in a pot it usually lacks air spaces and becomes hard and cracked when dry. Such soil can be used in growing potted plants if it is given higher amounts of organic matter and coarse inorganic matter to improve drainage, aeration, and mineral retention.

Potting mixes made from loam commonly contain peat moss and perlite. Peat moss is the milled, partially decomposed remains of bog plants. Peat is rather hydrophobic when dry. If it is premoistened before mixing into a soil it will wet easily and provide a great deal of water holding capacity. It is also quite springy and helps to maintain abundant air spaces. Although peat is rather acidic it is generally satisfactory for most all houseplants. Perlite is a crushed volcanic rock material. It holds 3 to 4 times its weight in water but it also allows good drainage and ample air spaces in the soil. It has a neutral pH and cannot hold minerals.

A useful formula for a potting mix is a 1:1:1 mix of loam:peat:perlite. This mix has good water retention, drainage and aeration, mineral holding capacity, and a slightly acid pH.

II. *Soil Mixing*

½ cubic foot garden loam
½ cubic foot peat moss
½ cubic foot perlite
20 8-oz wax paper cups
20 1- or 2-gallon plastic tubs (or similar container)

Obtain about ½ cubic foot of garden soil (loam) for every 20 plants to be repotted (20 students with one plant each). This soil will have to be broken into small clods (6 to 3mm diameter). You may find that the soil is easier to work if you add a little water.

Obtain about ½ cubic foot of peat moss for every 20 plants. Premoisten the peat moss by working small quantities of water into it by hand until the peat is slightly damp—avoid saturating it.

Obtain about ½ cubic foot of perlite. Slight premoistening will keep the dust down.

Supply each student with an 8-oz. wax paper cup for measuring these soil components before mixing. Also supply plastic tubs large enough to allow mixing of the components by hand. Have a source of water available as the students may wish to moisten the mix a little to make it easier to work with.

Instruct the students to mix loam, peat, and perlite in equal (8 oz.) parts in their tubs. They usually really enjoy this and you can help foster a relaxed atmosphere by mingling with them and chatting about what they're doing, how it's going, etc. They should mix the soil thoroughly, breaking clumps of loam and peat apart, and, if necessary, adding a little water.

III. *Repotting*

21 5- to 7-week old plants
21 4-inch plastic pots

Supply yourself and each student with a four-inch plastic pot for each plant they will repot and with one or more five to seven week old plants. If you start your own plants you will have to prepare them about five to seven weeks in advance (See Appendix I).

Demonstrate the following repotting procedure to the class. Add about an inch of potting soil to a four-inch pot. Cover the top of the pot with your fingers, pick up the plant and turn it upside down. Tap the pot gently until the soil ball slips from the pot. Carefully turn the plant right side up and set the soil ball down in the four inch pot. Fill in the spaces around the soil ball with fresh potting soil. The top of the soil ought to be about 12 mm below the top of the pot for easy watering. Lightly firm the soil. Water the plants carefully from the top or from the bottom in a tray of water.

The students may wish to take their plants home right away. In cold weather provide plastic bags to cover the plants. A paper sack or some newspaper should be used as well if the temperature is below 5°C.

IV. *Display Introduction*

(See Appendix II for a list of suppliers of all materials mentioned in this chapter)

6 15″ × 15″ pieces of illustration board (artwork)
11 4″ × 10″ pieces of illustration board (labels)
6 2″ × 8″ pieces of illustration board (labels)
4 broad-tip colored felt markers (green, black, blue, brown)

1 porous (clay), drained pot
1 porous (clay), undrained pot
1 non-porous (plastic or glazed), drained pot
1 non-porous (plastic or glazed), undrained pot
Assorted other containers and pots

8 trays or containers for display of non-soil potting materials
½ cubic foot coarse sand
½ cubic foot perlite
½ cubic foot vermiculite
½ cubic foot peat moss

Much of the information that we choose to teach through a visual display could be taught through a lecture or a handout, but we believe that displays provide the student with an interesting change of pace that requires them to seek out and understand information and concepts on their own. Interpreting visual information gives them a chance to use different modes of thought than do lectures and reading assignments. And it allows them to move at their own pace (within prescribed time limits). In addition, visual displays are flexible: they may be used in self-paced investigation, as an aid to discussions and lectures, and as nearly wordless explanations of procedures. Visual displays should be big, bold and simple. The visual elements should be carefully selected to communicate important information precisely and to minimize confusion, misinterpretation, and irrelevant information.

The essential elements needed to teach the remainder of the project are a table and an upright surface on which to affix the artwork. The artwork for our displays is usually done with broad-tipped colored markers on inexpensive illustration board. Our display surface is a cork bulletin board covered with Herculon upholstery fabric. We glue squares of Velcro hooks (available in ribbons from any fabric store) onto the backs of the artwork. These hooks allow us to quickly and securely mount the artwork onto the fabric of the display board. This method eliminates tack holes in the art and makes repositioning quick and easy. A lab table runs the length of the display board allowing us to set up demonstrations and materials beneath the artwork.

In this project we use the displays with a set of questions which aid investigation and understanding of the displays. Since the displays provide fairly general information about pots and potting materials, our question sheets can be very flexible. We can compose questions which require simple observation or which require more challenging thought. It is usually best that questions start out with simple observations and comparisons and build toward deriving general principles and predictions. An example of the questions we have used recently are on pages 21–22.

The first display compares the characteristics of various containers used in potting houseplants. Figure 2.1 shows the display. This arrangement is basically tabular and allows quick comparisons. On the bench in front of the display are a variety of containers which demonstrate the characteristics shown in the artwork. Students examine the artwork and the containers guided by the questions. The questions focus the student's attention on the important information contained in the display and help them to draw conclusions on how to apply that information.

The second display compares the characteristics of various non-soil potting materials. Figure 1.2 shows the set-up. The display board has a blank table which compares the characteristics of the potting materials. On the lab bench directly beneath the display are trays of non-soil potting materials. Use about one-half cubic foot each of coarse sand, perlite, vermiculite, and peat moss. Display the materials in both wet and dry form. The table may be done with colored tape. You could also draw the table on a chalkboard and move a lab bench up against it. When the students are done recording their observations of the materials on their question sheets you will fill in the table. We used 10-inch-diameter circles printed with large numbers and backed with Velcro hooks to designate values.

V. *Display Investigation*

Ask the students to use the *In-Class Questions* (see pages 21–22) as a guide in examining the displays. Give them a time limit of about 10 minutes. You may allow them to work in pairs as this often fosters active discussion and thought.

VI. *Class Discussion*

This discussion summarizes the project. It should show the relationships between the different activities and draw general principles from them. Keep the learning objectives in mind while preparing for this discussion.

You could begin the discussion by asking the class what they noted about each non-soil material. While they tell you how they rated these materials for water retention and aeration, you can fill in the blank spaces on the table. Ask them which material(s) should be mixed with soil for a plant that requires well-drained soil (for example, a cactus). They should suggest coarse sand.

Perlite may also be used. Ask them which material they would use in mixing a soil for a plant that required a very airy but moist soil (for example, a bromeliad or an orchid). They should suggest peat moss. What characteristics would they look for in a container for such a plant? A drained, non-porous pot would allow drainage (and plenty of air) and at the same time would cut down excess evaporation that would dry the soil out.

Now start touching on how soil water retention, drainage, and pot porosity could affect root health. They should be able to point out that a poorly drained pot and soil will allow less oxygen into the soil and that excess water will also encourage the growth of disease organisms. You might pursue oxygen requirements, respiration, and mineral uptake with further questions if you like. You could also ask the students to predict the effect of mixing various non-soil and soil materials together. Try to help *them* to come up with as many interrelationships as they can find.

VII. *Evaluation Questions*

Have ready a set of questions which test the project objectives (see pages 22–23). These questions may also be composed to lead the students into further conclusions through requiring synthesis of the concepts presented in the projects. This sort of question is especially important if your summary discussion doesn't work well or doesn't get the time it needs. These questions also provide you with a way of evaluating and grading the students for participation and comprehension.

References

Crockett, J. V. Crockett's indoor garden. Boston, MA: Little, Brown & Co. 1978.

A reliable, practical, and easy to read guide to houseplants. Highly recommended for those who work with plants but don't have elaborate facilities.

Denisen, E. L. Principles of horticulture. New York, NY: MacMillan Publishing Company, Inc.; 1979.

Nice introduction to soil structure and fertility. Some remarks on soil flooding but little on plant responses.

Foth, H. D.; Turk, L. M. Fundamentals of soil science. New York, NY: John Wiley & Sons, Inc.; 1972.

Valuable, easy to read introduction to soils with some reference to plant responses.

Hartmann, H. T.; Kester, D. E. Plant propagation: principles and practices. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1968.

Excellent treatment of soils, soil mixing, and soil additives used in growing plants.

APPENDIX I

Plants for Repotting

We have chosen four plants which are easy to propagate and maintain and which are consistently popular with our students. They are *Coleus*, petunias, *Impatiens*, and tomato. These plants do not need elaborate facilities for propagation and growth. You may start your plants from either seeds or cuttings.

I. *Propagation from Seeds*

¼ cubic foot potting soil
1 8- or 10-inch drained pot
1 package seed (*Coleus*, petunia, *Impatiens*, tomato)
30 2-inch plastic pots

Germination: Sprinkle the seeds on the surface of the potting soil in an 8- to 10-inch pot. More than 50% of the seeds will germinate so don't sow them too densely. Cover the seeds with 6 mm of fine soil. Gently water the pot. This is best done by setting the pot in a saucer of water until the surface of the soil appears moist. Remove the pot from saucer and rewater in the same manner when the soil surface feels dry again.

Transplanting: After the first true leaves appear, loosen the soil and gently pull up a seedling by its leaves. Pulling the tender stem may crush it. Transplant the seedling into a two-inch plastic pot. This is done by putting 6 mm of soil into the pot, holding the seedling over the soil and filling more soil in around the roots. Gently firm the soil around the plant and water it from beneath. Repeat for as many seedlings as you wish to use.

The schedule below indicates the approximate periods of time elapsing from germination:

	Germinating	*Transplanting*	*Repotting in Class*
Coleus	0	3 weeks	6 weeks
Impatiens	0	2 weeks	5 weeks
Petunias	0	3 weeks	7 weeks
Tomatoes	0	2 weeks	5 weeks

Growing conditions will affect these time periods. Less time may be required if, for example, low heat (21–24°C) is provided from beneath the pots.

II. *Propagation from Cuttings*

Enough full grown plants (see species above) to provide 30 to 40 stem sections with buds.
¼ cubic foot potting soil, coarse sand, or perlite
30–40 2-inch plastic pots
1 razor blade
1 1-oz. can Root-Tone or other similar rooting hormone powder

Rooting: cut a two-inch segment from a branch. Be certain to take only stem segments with leaves since buds occur in leaf axils. Make the cut far enough below the leaves so that the cutting will stand up when the stem is inserted in the sand or soil. Dip the cut end into rooting hormone powder and tap off any excess. Insert the stem into a pencil hole made in the soil in a two-inch pot. Gently firm the soil around the stem. Water the pots from beneath by placing them into a tray of water until the surface of the soil appears moist. Remove them and rewater whenever the soil surface appears a little dry.

Place the cuttings in a moderately well-lighted location. Avoid conditions that would cause high transpiration rates: direct sun, wind, high temperatures, etc. If the cuttings wilt during the first few days move them to a cool, shady location and cover each with a plastic bag. This will reduce transpiration and allow absorption to catch up with water loss. If plastic bags are not available or if plants do not recover under bags, carefully remove several of the larger leaves from each cutting. Once the cuttings are rooted they will produce enough leaves and branches to make up for this defoliation.

All of the species suggested here will root thoroughly within 3 to 4 weeks. Some root even sooner if mild bottom heat is provided (24–27°C). If bottom heat is used you should be careful to prevent excessive soil drying.

III. *Plant Culture*

Any good houseplant book will give you all the information you need to successfully grow these plants without elaborate facilities. We recommend *Crockett's Indoor Garden* (see bibliography). It is easy to read, practical, and very reliable.

The plants we have suggested here do best in bright indirect light. They prefer temperatures above 13°C.

You may find that your plants fall victim to insect pests. Each of these species of plant appears to attract a particular pest: mealy bugs on coleus, white flies on petunias and tomatoes, and spider mites on impatiens. We recommend you isolate and spray infested plants with an insecticide containing Rotenone. It is easy to use, works quickly, breaks down quickly, and has very low toxicity to mammals. You may find it necessary to spray plants repeatedly if mealy bugs are the problem.

APPENDIX II

Suppliers of Materials

Avoid biological supply houses when ordering potting materials and seeds. Their prices are almost always 2 to 3 times those of horticultural supply companies. The following companies have given us years of excellent service at reasonable prices. Catalogs are available on request.

1. Perlite, vermiculite, peat moss, plastic pots:

   A. H. Hummert Seed Co.
   2746 Chouteau Avenue
   St. Louis, MO 63103

   Florist Products
   2242 North Palmer
   Chaumberg, IL 60195

2. Primarily seeds, some potting materials available:

   George W. Parks Seed Co.
   Greenwood, SC 29647

3. Light shelves for growing and displaying plants:

   Growth Systems
   1739 Chestnut Avenue
   Glenview, IL 60025

4. Herculon fabric for displays:

   Any carpet store, upholstery shop, or remnant house should have this.