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Findings and Conclusions: There are many problems and projects that can be used to make the teaching of higher plants interesting and challenging to the students. They should be chosen and varied to fit the experiences and needs of the group of students. The experiments can be so devised that they will require only inexpensive or easily obtainable equipment. In many cases, the students will be able to plan and carry out their projects, but the teacher should be prepared to guide them in the right direction. The project may consist of experimental work, careful observations, checking of data, as well as confirmation of results by the use of some source of authority. The solution of each problem should have some definite contribution to an understanding of life.

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PROBLEMS AND PROJECTS FOR THE TEACHING OF THE HIGHER PLANTS

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INTRODUCTION

The teaching of biology is interesting and inspiring if the teacher makes use of the living world about him. If a student reads the first chapter of a biology text or listens to the first lecture, he will find out that biology is the study of life. If the student did not go any further, he would probably believe this. Unfortunately, in far too many cases, if he stays in the class much longer, that definition is soon put aside. The class becomes a study of dead specimens, pictures, charts, slides, models, etc. It is realized, of course, that preserved study specimens, materials of visual aid, and objective education have their place in teaching a concrete subject such as biology, but they should be regarded by both teachers and students as merely aids in the understanding of the living organisms.

One of the most effective teaching methods for using living organisms suggested by many authorities is the problem and project method. This paper presents the teaching of the higher plants by this method. This is only one part of a large continuous project, from which many problems would branch to complete the project. One example of this might be the problem: "What are some of the common enemies of the plants?", which might lead to the study of insects, bacteria, or fungi.

According to Miller and Blaydes[1] this method offers many advantages over other methods but there is also some strong opposition raised against it. This is the most difficult method for the teacher, requiring more planning and more effort of execution. It calls for somewhat more materials and equipment than the strictly demonstration method. The amount of time consumed by the projects may be so great as to make it impossible to cover a wide variety of topics and may result in a lack of proper coordination of subject matter when individualized. Difficulties of the method increase in proportion to the number of classes per day which the teacher must have. In spite of these objections it offers advantages not inherent in most other methods. Many of its advantages consist of overcoming its disadvantages and those who use it are notably in favor of the method whenever it is possible to use it. The results of the method, when it is properly executed, more than compensate for the extra work that is required. The problems and experiments can be so devised that they will require nothing that cannot be had at little or no expense. There is much doubt as to whether time well spent upon less subject matter might not be worth more to the student than the same time spent in hurrying over more subject matter. The lack of coordination which sometimes is the result of individual work is little more than the result of poor planning and lax execution upon the part of the teacher. In no other method is there equal provision for those essential factors demanded by our objectives. The solving of problems is essential to the training in scientific thinking and the following projects are a vital part of the production of those attitudes which should be the outgrowth

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[1]Glenn W. Blaydes and David F. Miller, Methods and Materials for Teaching Biological Sciences (New York, 1938), pp. 45-46.

of science teaching. Proper planning will provide for group or even class participation as a means of diminishing the problem of numbers of students and numbers of classes that must be taught and will still make possible a sufficient amount of independent work to provide for the necessary individualization.

This paper is part of the preplanning for such teaching. Burnett[2] stresses that the most important part of the problem-solving approach in teaching is the preplanning. The big task is to plan what is to be done and to organize the possible materials and techniques of instruction into a master plan. If the teaching is then done on the basis of this flexible master plan and if it is done through the process of group planning and on the basis of real problems that emerge from such planning, the work will have real, functional values, and the classroom and laboratory will achieve a unity that is impossible under a formal, textbook approach. The author realizes that it would be impractical to include all the problems presented in this paper in a general biology course. An attempt has been made to cover many possible problems that might arise. It cannot be overemphasized that this is a guide for the teacher in directing the students in solving the problem and not to be used as directions for laboratory work. If confronted with these problems, in many cases the students will be able to plan as good or better projects than are presented here, but the teacher should be prepared to guide them in the right direction.

Many of these problems can be combined into one project. The problems should not be carried out in a small, unrelated way, but

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[2] R. W. Burnett, _Teaching Science in the Secondary School_ (New York, 1957), p. 187.

there should always be a continuity between them. It would depend on the class and their experiences as to which ones would be used. According to Beck[3] if these problems are to be real problems rather than artificial ones, they should be difficult enough so that the student will not immediately guess the results. If they are to be interesting, they must be within his own experiences. If they are to be challenging, they must be presented to him in need of solution. The problem may consist of experimental work, careful observations, checking of data, as well as confirmation of results by the use of the textbook and other sources of authority. The solution of each problem should have some definite contribution to an understanding of life.

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[3]Paul V. Beck, "The Organization of High School Biology on the Problem Basis," School Science and Mathematics, XXXVI, 615-626.

PROBLEMS AND PROJECTS

1. WHAT IS THE FUNCTION OF THE ROOT?

By an oblique cut sever the main roots of healthy plants about half an inch below the ground, disturbing the earth as little as possible. Support the plants with a stick and study their reactions, compared with controls. Allow some uninjured plants to go unwatered for a time. Do they show the same symptoms?

2. WHAT DIRECTION DOES THE MAIN ROOT GROW?

Does the main root always grow straight down? Pin soaked seeds in various positions and allow the corks to float on water in such a way that the seeds will remain partly submerged and cover the dish with a piece of glass. Put some soaked seeds in various positions on the surface of moist soil and cover with an inverted tumbler, or place them in a pot half full of soil and lay a piece of glass on the top, to keep the air moist. If the roots bend downward, change the position of the seeds so that they point upward or lie horizontally. Another way to study the effect is to cut several pieces of blotting paper about four inches square. Place these between two squares of glass. Place several radish or mustard seeds between the blotting paper and glass on each side and secure with rubber bands. Wet the blotting paper and then stand the apparatus upright in a shallow saucer of water. When the seeds have sprouted and the rootlets are about an inch long, turn the squares through ninety degrees and allow them to remain undisturbed. Repeat the turning and observe the effect on the roots. Do they begin to grow downward?

3. WHAT STARTS THE ROOT IN THE RIGHT DIRECTION?

The idea has been advanced that the tip of the root, being not very rigid, droops downward of its own weight and that this starts the growth in the right direction. Place some mercury in a small dish and fasten several clips to the side. Attach germinating seeds with perfectly straight embryos about half an inch long and let the embryos, especially at the tip, rest on the surface of the mercury. Pour in enough water to partially submerge the seed. In place of the mercury, gelatine (one part of gelatine dissolved in five of water) may be used. In which case no water is to be placed in the dish, but it should be covered with a piece of glass to prevent the roots from drying out.

Is it light, moisture, air, warmth, food or gravity? We may test the first five simultaneously by a very simple experiment. Fill a box, having a bottom of wire netting, to one half its depth with damp sawdust. On this lay the seeds, well soaked, and add enough damp sawdust to fill the box even with the top. On top of this put several layers of well-soaked cloth or blotting paper, and keep this wet during the experiment. Hang the box up so that the under side may be easily observed. Air, light, and warmth now come mostly from below instead of above, while moisture, ordinarily more abundant below the seed, is now about equally abundant above and below, it cannot influence the roots to grow in one direction more than in another.

Another means of showing the reaction of roots to gravity is to line a beaker or glass funnel with filter paper. Fill the lined container with peat, sand, or sawdust, and thoroughly moisten it.

Carefully place several corn grains between the glass and paper, distributing the grains one inch or more apart. Place them in a warm situation, keep moist, and wait for germination. If soaked seeds are used, roots will appear within two or three days. Note that the primary roots grow in direction of the pull of gravity. After the roots are about one inch long carefully remove half of the germinating grains. With a sharp razor blade or other knife cut off about one-eighth inch of the root tips of two or three specimens, leaving the other uninjured. Replace all the specimens in the beaker or funnel so that the primary roots are pointing upward, or away from the direction of gravitational pull. Keep moist and warm as before. With twenty-four to forty-eight hours the inverted roots with the tips intact will have curved and turned downward in response to gravity. The decapitated ones remain upright and uncurved, indicating that the tips are necessary in responding to gravitational force. Note the results and compare with the roots which were not removed from the container.

To show the response of roots to light, make up about 500 cc. of very dilute erythrosin in water. Place this in a cylinder of about 500 cc. Tie the muslin over the mouth of the cylinder. The liquid should come almost to the top of the cylinder and just touch the cloth. Place about a dozen wheat grains on the muslin, covering them with sand to keep them moist. Set the apparatus in a warm dark situation until germination occurs and roots one inch or more in length have developed and are growing straight down. Then place the cylinder in a window so that the roots will be brightly illuminated from one side. This exposure should continue for twelve to twenty-four hours. Usually by this time the root tips will have bent at right angles and toward the bright light. The erythrosin in some way causes the roots to become sensitive to light. This should be checked by a similar setup in which no erythrosin is used.

4. WHAT HAPPENS IF THE ROOT IN ITS DOWNWARD COURSE MEETS WITH A DRY REGION?

When seeds are grown in damp sawdust, in a box provided with a bottom of wire neeting, how do the roots behave as they grow down through the netting into the dry air? Do they turn because they are trying to avoid the air and light, or are they attracted by something in the sawdust? Fill a beaker one third full of water and tie a piece of cheese cloth over the top; on this put damp sawdust, and in the sawdust place several soaked seeds. Invert another beaker over the whole set-up. Do the roots on emerging from the sawdust, turn back to it? The air now contains much more moisture than before, but in other respects there is no essential change.

In the above experiments the roots are not under perfectly natural conditions. We may approach these more nearly by the following arrangement. In the middle of a box of soil place a flower pot, the hole of which has been tightly closed. Let the soil be reasonably moist when the well-soaked seeds are placed in it, but do not water it further except by pouring water into the flower pot, from which it will diffuse through the soil. After a few days examine the roots, to see what direction they have taken. By using a shallow box with a glass bottom, and placing the earth directly on the glass, we can watch the growth of the roots without disturbing them. A similar project can be set up by growing some seedlings in one end of a glass dish or pan. When they are about two inches tall begin watering them on one side only and a little distance away from the nearest plants. Continue the watering daily for about a week and then dig away the soil and see if the watering has had any influence on the direction of growth of the roots.

5. WHAT DIRECTIONS DO THE SECONDARY ROOTS TAKE?

Place some well-soaked seeds in moist sawdust of a germinating box or box that has a glass front so that they may be watched. When the secondary roots have grown some distance, tip the box to one side. Carefully mark on the glass the position of each side root. Leave the box undisturbed and make daily observations. Do the secondary roots change their direction? Do the rootlets which spring from them change theirs?

6. HOW DO ROOTS REACT WHEN THEY ENCOUNTER OBSTACLES?

Using the same kind of equipment as in 5, fasten small pebbles or blocks of wood to the glass with sealing wax. Do the roots diverge from their course more than is absolutely necessary to avoid the obstacles? Do they resume their original course as soon as they have passed the obstacles?

7. DOES THE AMOUNT OF MOISTURE AFFECT THE GROWTH OF THE PRIMARY ROOTS, SECONDARY ROOTS, AND ROOTHAIRS?

Use a series of pots, with the soil varying from very wet to fairly dry. The seeds should be well soaked when placed in the pots. After the plants have grown a few inches, remove the soil carefully and examine the roots.

8. HOW DO THE ROOTS ABSORB THE WATER FROM THE SOIL?

Bore a hole from the top of a carrot or turnip well down into the center. Fill the hole with colored sugar or syrup. Fit two single-hole stoppers to a three foot length of glass tubing. Place one stopper at one end and the other one about eighteen inches or so above it for clamping the whole assembly to a ringstand. Insert lower stopper and tubing in the hole bored in the carrot or turnip and seal with melted paraffin. Place the carrot in a battery jar of water. After a few hours, the solution will rise in the tube. The smaller the bore of the tube, the higher it will rise.

Active absorption results in the so-called root pressure. This can be shown by using a potted, vigorously growing plant of dahlia, tomato, or pigweed. With a sharp knife cut the top from the plant so that about two inches of the stem remains above the soil. Connect a piece of glass tubing about one foot in length to the cut end of the stem by means of a short piece of gum tube. The connections must be made water tight. Care must be taken not to injure the stem. It may be necessary to use grafting wax or some other sealing compound in making this connection. Support the glass tubing in an upright position in some convenient way. Add water to the glass tube until the water level is just visible above the connection with the gum tube. Saturate the soil about the roots. Observations for the rise of the water column should be made at intervals over a period of two to three days.

9. WHAT EFFECT DOES THE SALT CONCENTRATION HAVE UPON THE RATE OF ABSORPTION BY THE ROOTS?

Prepare a series of calcium chloride in distilled water solutions such as five-tenths, one, two, three, four, and five per cent. Place these in separate bottles and label accordingly. Fill the seventh bottle with distilled water. Carefully wash adhering soil from about roots of the seedlings (sunflower or tomato seedlings of as nearly equal size and development as possible). Place a seedling in each bottle, plugging the bottle mouth about the seedling with cotton. Support the seedling by means of the cotton in such a way that the root system is completely submerged. Place the series of bottles in moderately diffuse light and observe over a period of forty-eight hours. If directions are properly followed, wilting of plants in the two, three, four, and five per cent solutions is to be expected, and usually does not occur in the other concentrations.

10. DOES THE ROOTS GIVE OFF CARBON DIOXIDE?

Place just enough soda or very weak base in a test tube to color phenolphthalein solution pink. Place a seedling with roots down in the pink solution. In two or three days or sometimes less, the solution will turn clear showing that carbon dioxide (carbonic acid) has neutralized the base. A control showing that acid or carbon dioxide will do the same thing should be made.

11. WHAT IS THE FUNCTION OF THE SEED-LEAVES?

Remove the seed-leaves from a number of plants about an inch high, and mark them by loops of colored twine. Mark a number of uninjured plants of the same size with white twine to serve as controls. Vary the experiment by removing one or both of the seed-leaves from the soaked seeds before they are planted. Place them on the surface of moist earth in a container and cover with a glass. Does the removal of the seed-leaves check the growth of the plant? We notice the longer the seed-leaves remain on the plant the more they shrivel and lose substance. It looks as though the plant were absorbing the substance of the seed leaf to obtain food for its growth.

12. DO THE SEED LEAVES CONTAIN FOOD SUBSTANCES?

The presence of glucose can be shown by testing the seed-leaf with Benedict's solution or Fehling's solution. When either of these blue solutions is added to something which contains glucose, and the mixture is heated, a greenish-yellow and then an orange or brick-red color shows. The presence of fat can be detected by crushing a seed-leaf on a piece of brown paper and warming it. If oil is present, a transculent or clear spot shows on the paper. Proteins can be tested for with nitric acid. Substances which turn lemon-yellow in nitric acid contain proteins. If dilute ammonia water is then added, an orange color shows. Apply a drop of an iodine solution to the seed-leaf, if starch is present the iodine will change to a blue or bluish-black color.

13. HOW IS THE FUNCTION OF THE SEED-LEAF AND FOLIAGE LEAF RELATED?

Remove the foliage leaves from some young plants which have not yet exhausted the supply of food in their seed-leaves and also from some older plants in which this supply is exhausted. In each case have control plants for comparison. Does the removal of the leaves check the growth? In which of the two cases is this most apparent? Does the result indicate that the foliage leaves, like the seed-leaves, nourish the plant?

14. DO THE FOLIAGE LEAVES CONTAIN FOOD SUBSTANCES?

Test for starch by boiling the leaf in water, removing the green color with alcohol and then apply iodine. Test the sap for sugar and the dried leaves for oils and fats.

15. IS THE ELONGATION OF ROOTS, STEMS, AND LEAVES RESTRICTED TO A CERTAIN REGION?

Mark off fine lines with India ink about one millimeter apart on the hypocotyl (about one inch long) of germinating lima bean seed. Allow the ink to dry. Suspend the bean in a moist chamber made from a closed bottle. A hooked pin may be inserted into the seed coat, a string tied about the pinhead is attached to the bottle cap, or the cap screwed down on it, suspending the bean over a water surface in the moist chamber. After twenty-four to forty-eight hours remove the bean and examine the marks for distances apart. This will definitely show that elongation occurs just back of the tip but not entirely to the point of attachment to the remainder of the seed. In instances of the sweet pea, garden pea, castor bean, sunflower (dicotyledonous plants), place India ink marks similar to those for the roots, but extending from the tip of the seedling back three or four nodes. Place the plant in a suitable environment for growth. Observe the marks for distances apart after a period of forty-eight to sixty hours. Here again the region of elongation is just back of the tip and often extends throughout about one inch of the stem. In the wadering Jew (monocotyledonous plant) a different situation is soon apparent. Mark the stems in the same way, over a distance including three or four internodes. Make observations after about seventy-two hours. Note that the elongation occurred in regions just above each node. This is characteristic of many monocotyledonous plants. On a vigorously growing young plant select a leaf large enough to handle conveniently. Mark it off into one-eighth inch squares, being careful not to injure the leaf. Replace the plant to good growing conditions and observe the marked leaf after a week or ten days. The larger squares in the basal portion indicate location of greatest enlargement.

16. IS OXYGEN GIVEN OFF BY PLANTS?

Seal two copper wires in a rubber stopper that fits the top of a bell jar. Connect copper wires to a small piece of resistance wire carefully placed and supported exactly at the wick of a candle placed in the bell jar. Put a potted plant with plenty of green leaves under the bell jar. When ready to start the experiment turn on the current causing the resistance wire to glow and light the candle, which will burn a short while until all the oxygen is used up. Leave the plant in best light available until next day or until ready to try again. With only a couple of hours of sunlight the candle will light and burn.

Another way to show this is to invert a large bottle over a lighted candle set in a cork floating on water. After a short time the candle goes out, indicating that some of the oxygen of the air has been converted into water and carbon dioxide by burning. Withdraw the candle and introduce a leaf, the stalk of which passes through a hole in the center of a cork. Do this without lifting the bottle above the surface of the water. After a day or so, lift the jar very carefully, so as not to admit any air, and introduce a lighted candle. As a control use a bottle without a leaf.

A simple method to test this is to place an inch of sand in a battery jar. Wash with running water until water in the container remains clear. Plant four or five elodea or eel-grass plants in the sand. Allow it to stand for a week or two to become established. Place stones in the bottom near the jar wall. Invert a funnel with the mouth down over the plants and support on the stones. Fill a test tube with water and invert it over the stem end of the funnel, being careful to allow no air to enter. Set the appartus in bright sunlight and leave it until water in the test tube is half displaced by a gas which arises as bubbles from the leaves. Lift the test tube and seal immediately by means of a thumb. Ignite a splinter of soft wood in a flame. Allow it to burn for a few seconds, extinguish the flame, and insert the glowing end in the gas of the test tube. A burst of flame or brighter glow indicates that the gas contains oxygen.

A small amount of a dilute solution of brown thymol blue is added to a beaker of aquarium water to turn it just blue. Then carbon dioxide is blown in from a generator (or from breath) and the brown thymol blue will turn yellow. Now place some elodea or any thriving green water plant in a test tube of this solution and close with a rubber stopper. Place in strong sunlight. If the water turns back to blue, it shows that the plant decomposes the carbon dioxide. Use a control.

17. IS CARBON DIOXIDE NECESSARY FOR PHOTOSYNTHESIS?

Place three coleus plants in the dark until they are starch free. Place two of the starch-free plants under bell jars, sealing one airtight to a pane of glass by means of vaseline, and the other to a box through which a gas inlet is passed to inside of the jar; allow the third plant to remain uncovered. Place all three plants side by side in the sunlight. Allow carbon dioxide from the generator to enter the bell jar on the box for fifteen seconds every five or six hours. After two days make the starch test on leaves from all three plants. If starch is found in the uncovered plant and also in the covered plant, to the atmosphere of which was added carbon dioxide, and not found in the other covered plant which received no carbon dioxide, the inference that carbon dioxide is necessary in the process of photosynthesis becomes apparent.

The effect on starch formation by the prevention of air from entering the leaf can be shown by this method. Keep a plant in the dark until the leaves no longer give a good starch test. Remove the plant to the light and treat several of its leaves by covering both sides of a portion of the leaf with vaseline. Remove some of the untreated leaves from the plant, and place them in beakers of water so that the stalk of the leaf and about half of the blade dip under water. Place all of the leaves where they will get abundant sunlight. In two or three days, test all the leaves for starch. Do you find starch in the portions from which air has been excluded?

18. IS THE RATE OF PHOTOSYNTHESIS AFFECTED BY ADDITION OF SMALL AMOUNTS OF CARBON DIOXIDE?

Prepare a jar with several elodea or any thriving green water plants rooted in sand and submerged in water. These should stand for a week or two to become well established. Place the jar aquarium in bright sunlight and watch for chains of bubbles arising from the leaves. The gas of these bubbles contain oxygen. Count the number of bubbles which escape per minute. Then add some carbon dioxide from the generator. If this apparatus is not available, blow through a glass tube into the water. Make a recount of the gas bubbles escaping from the leaves. An increase in the number of bubbles escaping per minute indicates roughly an increase in the rate of photosynthesis.

19. IS LIGHT NECESSARY FOR PHOTOSYNTHESIS?

Place a coleus plant in a dark roon or light-tight box for two or three days and another coleus in the sunlight or under electric light for a day or so. Test a leaf from each plant for starch. No starch is present in the leaf which was kept in darkness, while starch is found in the leaf which has been exposed to light. Chlorophyll is present in both and environmental conditions were the same except for light. Therefore, light must be necessary in the process of photosynthesis.

The same phenomenon may be demonstrated readily by covering a single leaf on a coleus plant with black paper or tinfoil. In the paper or tinfoil cut out the work "starch," or some geometrical figure. Carefully cover the leaf with the paper or tinfoil, holding it in place with ordinary wire paper clips. The only part of the leaf exposed to light is the area directly opposite the opening made in the paper. Allow the plant to remain in sunlight for two days. An uncovered leaf, when given the iodine test, will show starch throughout. The covered leaf shows starch only in the exposed areas.

20. IS CARBON DIOXIDE RELEASED BY PLANTS?

Germinate some oat, wheat, or corn grains in a wide-mouthed bottle. When the seedlings are growing rapidly stopper the bottle and set it in the dark for six to ten hours. Replace the stopper quickly with one which has a funnel and bent glass tubing inserted. Immerse the outlet end of the tube in a test containing limewater. Flood the seedlings by pouring water through the funnel until the bottle is nearly filled. This forces gases that have accumulated around the seedlings through the outlet tube into the limewater. If carbon dioxide is present the limewater soon becomes milky.

Partly fill a bottle or jar with water, put in as many leaves with their stalks dipping in water as it will conveniently hold. Then insert a small vial partly filled with clear limewater. Set the bottle away for a day or two in darkness. Prepare a control bottle in which no leaves are placed. Both bottles should be sealed air tight. In which is more carbon dioxide produced, as shown by the limewater test?

In most experiments, land plants or portions of them are used in testing for carbon dioxide as an end product or respiration. It is equally simple to use a submerged aquatic plant in such demonstrations. Place about 200 cc. of tap water in each of two bottles. Add two or three drops of the phenolphthalein solution to each bottle, or just enough to give a definite pink color to the water. If a pink color does not appear when the phenolphthalein is added, the water is acid. It may be made alkaline by the addition of ammonia or baking soda. Place elodea or other water plants in one bottle of treated water. Stopper both bottles and set them in a dark place for thirty to sixty minutes. Examine both bottles after this time for the pink color. Some of the carbon dioxide diffusing from an organism into water may dissolve and form carbonic acid. Such acid causes the disappearance of the pink color of the phenolphthalein.

21. WHAT TISSUES ARE INVOLVED IN THE MOVEMENT OF WATER THROUGH STEMS?

In vascular plants xylem is the most important water conducting tissue. This fact may be demonstrated easily by the following experiments. Use potted sunflower plants which are about ten to twelve inches in height or if the sunflower is not available, coleus or sultana, or other plant with a fairly transparent stem may be used for the experiment. Prepare a solution of two and five-tenths per cent basic fuchsin solution made up in ninety-five per cent grain alcohol and dilute 5 cc. of the solution by adding one part of the dye to one hundred parts of tap water. Allow the solution to stand overnight and filter. Remove the plant from the soil by washing. Retain the upper two inches of the root, cutting the lower part off while the whole root system is submerged in water. Quickly transfer the plant to a wide-mouthed jar containing the dye. With a sharp razor cut off about an inch of the remaining root system while submerged in the dye. Record the time. If available, place a bright light back of the stem. This will facilitate seeing the dye through tissues of the stem. Watch for appearance of dye in the veins of the leaves. A rise of four inches within five minutes may be obtained. If the stems available are too opaque to see the stained tissues by transmitted light, the tissues may be cut into with a knife and the colored path exposed.

Ordinarily, the transpiration stream in a stem is under tension. In the water-conducting vessels this water moves by mass movement and not by diffusion. The following experiment permits direct observation of this mass movement as well as the fact that water is conducted through stems in elements of the xylem. Obtain a bean, sunflower, or other convenient plant which has several living leaves intact. Fill a Syracuse watch glass about three-quarters full of water and place three to four drops of India ink in it. Set this over opening on the microscope stage. Cut the plant off near the base. Submerge the stem in water and cut off about a two-inch piece from near the base in such a way that an oblique angle of about fifteen to thirty degrees is formed. Transfer the upper section of the stem with the leaves intact to the watch glass and submerge the cut portion in the diluted India ink. Support the stem in some convenient way and focus on the water conducting vessels. Watch for currents of water entering these vessels carrying particles of carbon. Eventually the vessels are plugged with the carbon and appear as black streaks.

The length of open, water-conducting vessels varies with different species of woody plants and also with position in the plant. In the main stem they are usually longer than in the branches. In the main axis they become shorter as the tip is approached. Obtain stems of some woody species such as elm or grape. These pieces chould be at least three feet in length for the elm and from ten to twenty feet for the grape. With a sharp knife cut off an inch length from one end of the stem to expose fresh tissues. Attach a funnel to the exposed end by the means of rubber tubing. In some convenient way, support the stem with the funnel uppermost in as nearly a vertical position as is practical, according to the length of the stem. Pour about three hundred cubic centimeters of mercury into the funnel. Set a glass container under the lower end of the stem. Cut a short segment from the lower end of the stem to expose fresh tissues. If no mercury globules appear after standing a few minutes, continue to remove segments about one inch in length until very small mercury appears. If only a few ends of open vessels are exposed the mercury can be seen coming from the individual trachea. By this means one can determine rather closely the length of open water-conducting vessels for the particular stem used.

22. DO THE LEAVES LOSE WATER BY EVAPORATION WHEN GROWING ON THE PLANT?

Everyone has noticed that leaves removed from the plant quickly dry up unless placed in water. It would seem that they must lose water rapidly by evaporation. Is this normally the case when they are growing on the plant? Obtain two watch-crystals of about the same size, and fasten them to opposite sides of a leaf by a piece of wire bent to form a clip. Seal the joints between the leaf and the glass air tight with vaseline. The leaf should not be removed from the plant and care should be taken not to injure it in any way. Place the plant in the light and watch for droplets of water formation on the watch-crystals.

Another simple experiment is to insert some of the leaves on a growing plant into a test tube without breaking the connection with the rest of the plant. Suspend the tube in a clamp on a ring-stand and plug the open end with cotton. Water the soil around the plant copiously, and watch for condensed water to appear in the tube.

Transpiration from plants can be demonstrated readily by the following experiment. A potted plant small enough to be covered by a bell jar is needed. Waterproof the outside of the flower pot with melted paraffin. Also cover the soil about the plant with melted paraffin which is just about ready to congeal. Be very careful not to injure the stem of the plant. Set the plant, in the waterproofed pot, on a glass plate and cover with a bell jar. Seal the jar to the plate with vaseline. Under a second bell jar place a wet cloth, sponge, or an open container of water. Seal the jar to a plate. A third bell jar with nothing in it but ordinary air is sealed to another plate. Condensed water vapor will be found on the jar containing the plant. Since the pot and soil were sealed, the water vapor had to come from the plant.

23. CAN THE TURGIDITY OF WILTED LEAVES BE RESTORED?

Cut three similar leafy branches from a plant and allow them to wilt. Tomato and pigweed are very favorable plants for this experiment. Place one of the wilted branches in a container with water. With a razor blade cut one inch or so from the stem base of a second branch and immediately place the base of this branch in water. Submerge the cut end of the third branch in water and cut off about two inches from the base while under water. Observe the branches closely. The branch which was cut while the stem base was submerged usually regains its turgidity so rapidly that leaf movements may be seen.

24. WHAT EFFECT DOES LIGHT HAVE ON THE GROWTH OF STEMS?

Plant some seeds that grow rapidly such as oats, radish, bean or mustard seeds in two flower pots. When the seedlings are about an inch high, cover one pot with a box that has a hole cut near the top. From time to time lift the box and observe the direction of growth. Turn the box so that light comes from a different direction and observe again after a few days.

Put two light baffles in a long, narrow box and cut a hole in the end. Plant a sprouting potato in a small pot that will fit in the box. Place the pot behind the baffle farther from the hole. Cover the box and place in a window. Observe the direction of growth from time to time.

Plant four flowering pots with some fast-growing seeds as in above. Keep the pots in a darkened room until the seedlings are about an inch high. Place one pot in a sunny window and observe the effect. Turn the plants away from the light and observe. Leave the pot in a place away from direct light for a few days and observe the results. Place each of the three remaining pots of seedlings in a different box. Cut a window in each box and cover each window with a different color of cellophane such as red, yellow and blue. Place the three boxes containing the pots of seedlings in good light with the window facing the light. Observe any difference in the effect produced by different colored light on the growth of stem.

25. WHAT EFFECT DOES GRAVITY HAVE ON THE GROWTH OF STEMS?

Obtain three potted sunflower plants about eight inches in height. Other plants such as coleus or geranium may be substituted. Place one pot on its side so that the stem is horizontal to the pull of gravity. Suspend another upside down so that the stem tip is pointed in the direction of the gravitational pull. The third plant is kept as a check. Allow the experiment to continue for two or three days and note reaction of stems.

26. WHAT EFFECT DOES THE LENGTH OF DAY HAVE ON DEVELOPMENT OF PLANTS?

A demonstration of photoperiodism is fairly simple. Chrysanthemum or poinsettia rooted cuttings, radish seedlings, moth mullein rosettes, and wild prickly lettuce rosettes well established in pots are needed for this experiment. The chrysanthemum and poinsettia are short-day plants, usually coming into flower in late autumn for the chrysanthemum and late November and December for the poinsetta. These may be forced into flowering out of season by giving them a seven to eight hour day instead of the normally longer light period. This may be done keeping the plants in a dark room or box and exposing them for about eight hours to normal daylight. Three to four weeks is required for the development of flowers. Duplicate plants must be kept as checks in the normal light condition. If the experiment is to take place during the normal, short-day period duplicate plants must be kept in a fourteen hour light period. This may be done by the use of a two-hundred watt bulb which is lighted either in the morning or evening of the short days. Place the light about two feet above the plants. If not convenient for someone to turn off the light at the proper time, an alarm clock may be rigged up to cut off the current when desired. Usually plants kept in the long-light condition will remain in the vegetative state while those in the short light come into flower.

For long-day plants prepare two pots of each of the following: radishes, three or four plants to each pot, moth mullein, one rosette to each pot, and the same for prickly lettuce. The moth mullein and prickly lettuce are common weeds which can be transplanted readily. After the plants are established place one of each type in fourteen hour light and keep the other in short-light condition. Plants kept in the long light will soon begin to develop long stems and may come into flower, while those in short light remain in the rosette state.

27. HOW DO PLANTS REPRODUCE?

Secure a box or pot of sand and place it away from the direct sunlight. Wet the sand thoroughly and keep it moist. Propagate plants by planting bulbs, cuttings of begonia and geranium stems, sugar cane stem, carrot, radish and beet tops each with a small piece of root attached, onion, iris stem, pieces of potato containing eyes, branch of a willow, and seeds in the sand.

28. WHAT IS NECESSARY FOR SEED GERMINATION?

Place six beans in each of two containers filled with sand, soil or sawdust. Moisten each with an equal quantity of water. Place one in a refrigerator and keep the other at room temperature. See that both remain moist. This illustrates the effect of one external factor of the environment upon seed germination. In two other similar sets of seeds, moisten one set and keep the other dry. Keep both in a warm situation. Germination does not occur among the dry ones. The lack of moisture as an external factor of the environment often operates in nature. A lack of oxygen can also prevent germination. In two other similar sets of seeds, place one under water and the other in a small amount of water in an open bottle. It suffices to simply put the seeds in a bottle, which is then submerged in water and tightly corked while under water. Be sure to exclude all air bubbles. Vaseline may be smeared over the cork to make it air tight. Air may be expelled from the water by boiling it for several minutes just before using.

29. DO SEEDS IN THEIR ORDINARY DRY CONDITION CONTAIN WATER?

Place several seeds in a test tube and heat. If moisture is present it will be driven off and condense in droplets toward the cooler end, which should be left open. Another method is to weigh out several grams of seeds, heat them for some time and reweigh. Keep heating until there is no loss of weight.

30. HOW DOES THE SEED ABSORB WATER?

Place several seeds of the same kind in a beaker of water. Observe constantly for half an hour and after that at frequent intervals. Notice whether soaking affects the size, color or texture. Does the cover wrinkle, if so, where does the wrinkling commence, and in what direction does it progress? Does this indicate where water enters the seed? What causes the wrinkles? Why do they disappear after a time?

Place some seeds in water and heat. Stir the water to remove the bubbles that first form on the outside of the seeds and keep them submerged. They can be held under the water by a piece of wire netting or by placing them in a wire spring. Are there openings in the seed coats? How many and where are they located? If any of the seeds do not yield bubbles when placed in warm water it does not necessarily mean that there is no opening; it may simply denote a lack of air in the seed or the seed coat may be broken. Such seeds may be further tested by soaking thoroughly, wiping the surface dry and squeezing to see where the water is pressed out. In the case of nuts, any part of the shell where an opening is suspected to exist may be sealed to the end of a tube, which should then be placed under water and blown into forcibly.

Place several seeds in sand which is kept saturated with water, so that the holes do not come in contact with the water. If water now enters the seed it must be through the cover itself, since the opening is not in contact with the water.

31. IS OXYGEN CONSUMED IN THE RESPIRATION PROCESS OF GERMINATING SEEDS?

Place enough germinating seeds in a jar to fill it about one-third full. Close tightly and allow it to stand for several hours or overnight. Light a long slender stick, remove the stopper and quickly thrust the flaming stick into the jar. The flame is extinquished, showing the lack of oxygen. Repeat the test with another similar jar that has been sealed at the same time as the one with the germinating seeds but which had nothing in it except normal air.

The amount of oxygen needed in the respiration of germinating seeds may be quantitatively as follows: Place about 15 cc. of germinating wheat grains in each of two 50 cc. graduated cylinders. Press a piece of cheesecloth or cotton plug down on each mass of seeds to hold them in place. Invert one cylinder over a saturated solution of sodium hydroxide in a shallow container and the other over acidulated water. Allow the experiment to continue for several hours. The cylinder over the sodium hydroxide will show a rise of the liquid. The check apparatus over the water remains the same as at the start. Sodium hydroxide absorbs carbon dioxide while water does not. In the apparatus over the sodium hydroxide the carbon dioxide released by the germinating wheat is absorbed by the solution. The grains absorb oxygen, reducing the pressure within the cylinder and, consequently, the sodium hydroxide rises. The height of the column of liquid may be noted on the calibrations. The volume of this column of liquid is approximately equal to the volume of oxygen absorbed by the germinating grains since the experiment started.

32. WHAT ACTIVITIES TAKE PLACE IN THE DEVELOPMENT OF GERMINATING POLLEN?

Germinating pollen is a living cell representing all stages in development from birth to death. Many cellular activities can be observed such as cell growth, cell division, formation of vacuoles, formation of cell walls, nucleus, streaming cytoplasm, and various inclusions in germinating pollen. An effective artificial culture medium for the germination of pollen may be prepared by adding to warm distilled water the following: five to ten per cent sucrose, one per cent agar, two drops of boiled yeast extract in 25 cc. of the solution. The materials used in making the medium should be made as sterile as possible. Spread the medium on a cover slip and heat it slightly by holding the slip near a lamp. Deposit pollen on the medium and invert the cover slip over a depression slide into which a drop of water has been placed. Observations may now begin. The moisture supplied will enable the pollen to remain active for hours and in some cases, for days.

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