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Cornell Institute for Biology Teachers

Lab review date: 10/08

Title:

The Plant Game: "Plants' Strategies for Growth"

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Appropriate Level: Life Science, High School, Honors, or Advanced Placement Biology

Abstract:

This exercise presents an opportunity for students to think about—in a fun and enticing manner—how plants grow. In the Plant Game, teams of students "grow a plant" composed of "leaves," "roots," and "flowers." The goal of the game is to produce a maximum number of flowers. This is possible only if the students have a good strategy to keep their "roots" in water and produce enough "leaves" to support adequate photosynthesis. Students "grow their plant" in a graduated cylinder in which the paper clip roots dangle in water. Measured amounts of water are added to and removed from the system by "rainfall" and "transpiration," respectively, which are determined according to a roll of the dice. The game ends when another roll of the dice indicates a "frost." Since the rate of growth of each student's plant is limited by the "weather" and by the students' choices in how they allocate their fixed carbon, a few repetitions of the game clearly demonstrate the functions of leaves, roots, and flowers, and some of the environmental stresses on plants.

The data collected during this game lends itself well to graphical analysis. Students may graph various parameters of their plants' growth and compare the results from one "season" to the next or between strategies for growth in a single season.

Time Required:

One 45-minute class period is enough time to run through two seasons of the game. Substantial teacher preparation time for lamination of game pieces is required the first time the activity is used. After that, minimal teacher preparation is required.

National Science Standards:

Evidence, Models, and Explanation

- Evidence consists of observations and data on which to base a scientific explanation. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- Models are tentative schemes or structures that correspond to real structures, events, or classes of events and which have explanatory power. Models help scientists and engineers learn how things work.
- Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements.

Living Environment:*

4-Content: 1-Living things: 1.1b,1.1e; 3-Change over time: 3.1g, 3.1i; 4-Continuity of life: 4.1a; 5-Dynamic equilibrium:5.1a-c, 6- Ecology: 6.1c,e,f **6-Interconnectedness, Common Themes**: 2- Models: 2.2

Additional Teacher Information

Information with which the students must be familiar

- "Photosynthesis" is the biological process in which plants use light energy to convert atmospheric CO_2 into sugar.
- Photosynthesis occurs primarily in the leaves.
- "Transpiration" is the biological process in which plants draw water from the soil into their roots and up through their stems to the leaves, where ultimately it passes through stomata in the leaf surface and is lost from the plant. As the water travels through, the plant is supplied with essential moisture and nutrients. Plants must constantly have their roots in water or transpiration will cause the plants to dry out.
- Rates of transpiration and photosynthesis are dependent on the weather. For example, more water is lost from the plant in dry weather than in humid weather, and more photosynthesis occurs on sunny days than on cloudy days.
- The reproductive structures of plants are their flowers; seeds form when the pollen (sperm) from one flower fertilizes an egg in the pistil of the same or a different flower.
- The plant uses the carbon and energy in the sugar molecules (formed during photosynthesis) to make leaves, roots, stems, flowers, and finally, seeds.
- Seeds contain all the material necessary to make some root material and a cotyledonary leaf (in monocots) or two (in dicots).
- Plants, like all other organisms, must reproduce in order to be successful.

Supplies needed

For the whole class:

- 1 pair of dice

Per team of 2 students:

- 1 graduated cylinder (100 ml, smaller sizes will not allow sufficient paper clip “roots” to be added. All cylinders in the entire class must be identical!)
- pipet and pipet bulb or pi-pump to add and remove water (a 10 mL pipet works best)
- laminated green leaf cutouts, approximately 15
- small sized vinyl coated paper clips, approximately 10
- laminated brightly colored flower cutouts, approximately 8
- laminated sugar tokens, about 20 monosaccharide and 10 tetrasaccharide
- small beaker to hold water supply
- paper towels
- dowel rod or popsicle stick laid across the top of the graduated cylinder to act as a stem from which the paper clip roots can dangle (see diagram in the student section). The leaves and flowers should have holes punched in them so that they can slide onto the rod or stick during manipulations. Another strategy for the flowers is to have them dangle from the side of the graduated cylinder by making hooks out of paper clips, punching a hole in the flower, and sliding it onto the paper clip hook.

Safety Precautions

Good laboratory practice should be followed when carrying out all aspects of the lab.

Helpful Hints

- Only a few simple rules must be followed when playing the Plant Game. For Life Science students, the most difficult aspects of the game are multiplying the number of "leaves" times the "weather factor" to determine the amounts of carbon "fixed" and water "transpired," and then measuring the amount of water to be removed from or added to the graduated cylinder. Encourage them to use scratch paper and a calculator.

  More advanced students could discuss the type of genetic regulation a plant must have to make the sort of growth "decisions" observed during the game. They could also compare game results with real life plant biology (i.e., plants' abilities to close stomata to conserve water, C_4-type photosynthesis, etc.).

- To introduce the concept of transpiration set up a pair of beakers containing identical volumes of water three to five days before playing the game. In one of the beakers, place a small potted plant. In the other beaker, place a soil-filled pot (no plants). Due to transpiration, the water level in the beaker with the plant should drop noticeably faster than the control beaker. (Note: This works best if the diameter of the beaker is only slightly larger than the pot since the more water surface area exposed, the faster the rate of evaporation.)

- Teachers may wish to change the weather matrix shown on page 2 of the student section. These values were chosen arbitrarily because they make for challenging-yet not impossibly difficult-play when a 100 mL graduated cylinder and small-sized paper clips are used. It may be helpful to discuss the weather matrix with the students before playing the game. For example, ask them which day's weather (which roll of the die) might be a plant's "favorite."

- Teachers may change the number of sugars it "costs" to buy a root, leaf, or flower, i.e., to simulate a different type of plant. However, note that flowers must be the most costly, since they symbolize material equivalent to that of a seed (material to make cotyledon leaf and root) plus the additional structures of the flower itself (scent, pigments, etc.).

- During the game, the teacher must keep track of the number of days in order to know when the frost dates are approaching. To have time to play for 2 complete "seasons" in a 45-min class, you may wish to choose a 17-day growing season. You would begin rolling the pair of dice on "day 17." It is a good idea to discuss the game in advance of conducting the actual "growing seasons." Form the student teams and work through several days of weather. Have them pipet, keep records, and generally work together. Provide them with time to plan their strategy for success when playing the **real** game.

- The exercise can be extended in many ways, some of which the students may suggest. For example, what if certain randomly chosen "plants" lose a "leaf" or two due to "insect attack"?

- Students may also use associated Macintosh software available through Intellimation to apply what they have learned to study how scientists build a computer model. In this simulation, students answer 3 straightforward questions about sugar allocation. From this, the computer builds a simple model in which a plant appears to grow according to the three parameters. A built-in random generator establishes each day's weather, and animated sequences illustrate that the computer is indeed "growing the plant" in response to the student's preset rules. The students can then alter their choices to adjust the model to try to achieve optimal flower production. If the teacher chooses, more advanced modeling concepts can also be studied by shifting weather and growth parameters.

Answers to Questions

1. Answers will vary with how successful the team strategy was in producing flowers. Be sure to check that all aspects of the question were addressed. The graphs will also vary.

2. Examine the histogram. Be sure that the data plotted is what the class actually generated. Students should perceive that weather does influence what the graphs look like and that different strategies are successful in different situations.

3. Be sure that each student thoughtfully addresses each of the sections of the question. Answers will vary depending on weather, weather, and strategies employed.

The Plant Game: "Plants' Strategies for Growth"
New York State Learning Standards

Standard 4: Content

Key Idea 1: Living things are both similar and to and different from each other and from nonliving things.

1.1 Explain how diversity of populations within ecosystems relates to the stability of ecosystems.

By giving each group of students the freedom to make choices they begin to understand how different life "strategies" effect viability. In each growing season a different strategy will work better, resulting in overall stability of the system.

Key Idea 3: Individual organisms and species change over time

3.1- Explain the mechanisms and patterns of evolution.

Students are introduced to the idea of natural selection: some plants will prove to be "less fit" for a particular growing season than other plants.

Key Idea 4: The continuity of life is sustained through reproduction and development.

4.1- Explain how organisms reproduce their own kind.

The activity stresses the importance of producing flowers as they hold the reproductive capacity for the plant.

Key Idea 5: Organisms maintain a dynamic equilibrium that sustains life.

5.1- Explain the basic biochemical processes in living organisms and their importance in maintaining dynamic equilibrium.

Students are introduced to basic biochemical processes of Photosynthesis, Transpiration, and Reproduction.

Key Idea 6: Plants and animals depend on each other and their physical environment

6.1- Explain factors that limit growth of individuals and populations.

A seedling without their roots in the water is incapable of growth, just as one without leaves doesn't produce enough sugars to be truly successful. Students experience first hand what factors are most important and how this depends on the immediate environment.

Standard 6: Interconnectedness, Common Themes

Key Idea 2: Models are simplified representations of objects, structures or systems used in analysis, explanation, interpretation, or design.

2.2- Collect information about the behavior of a system and use modeling tools to represent the operation of the system.

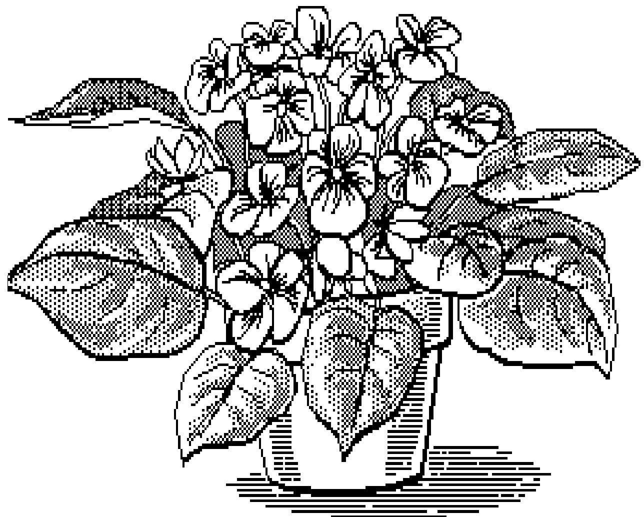
This game is an extended model of a basic plant system.

CIBT

Student Laboratory Exercise

The Plant Game

To win at any game—football, Monopoly, checkers, or cross-country—players must have a good strategy. In most cases, the best strategy is one that allows the player to "go on the offensive," and take advantage of conditions and other players. At the same time, a good strategy also allows for "defensive play," that is, being prepared for the worst thing that



might happen. It may surprise you to learn that living organisms, too, can be said to have "strategies" for survival. The "strategies" that organisms "play" are genetically programmed, but responsive to environmental stimuli. Different species have evolved different "strategies" which allow them to "win" (survive) in their habitat. If they are removed from their particular habitat and moved to a different one, it's unlikely that they will be able to survive successfully with the "new rules" or conditions.

In this lab, you and a partner will try to devise a strategy that will allow your plant to thrive and reproduce (make flowers). A winning strategy will be one that makes a lot of flowers before the first killing frost of autumn strikes! After all, in nature, the most successful organisms are those that reproduce, passing more of their genes to the next generation than do others of their species.

To make flowers you must first make both leaves and roots. Leaves are necessary because they are the part of the plant where **photosynthesis** occurs. Leaves are the site where the sun's energy is absorbed to power the conversion of CO_2 gas and H_2O into sugar. The more leaves you make the more photosynthesis your plant can carry out, which in turn allows you to make more sugar. With this sugar, you can choose to make leaves, roots, or flowers. Therefore, making a lot of leaves might seem like a good strategy for rapid flower production. However, the more leaves your plant has, the faster **"transpiration"** will occur. Transpiration is the loss of water from the leaves. Because the plant must have a constant supply of water you must also make roots. Roots are a their only way to acquire water.

In this game, each leaf will be represented by a green leaf cut-out, each length of root by a paper clip, and each flower by a brightly colored flower cutout. The level of water in the "soil" will be shown by the water in a graduated cylinder.

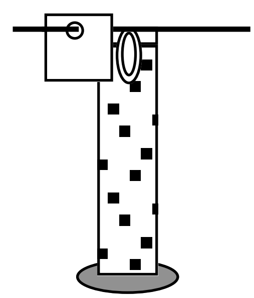
Materials Needed Per Team

- 20 small vinyl coated paper clips
- 1 set of about 40 sugar tokens
- 1 set of about 10 flower cards
- 1 pipet and Pi-pump or bulb
- 1 small beaker to act as water reservoir
- 1 Weather Report and Growth Costs Card
- 1 dowel or straw or wooden splint
- 1 set of about 20 green leaves
- 1 100 mL graduated cylinder
- 1 calculator or piece of scrap paper

Playing the game

Starting the game:

Everyone begins with a full graduated cylinder, one leaf, and one paper clip "root"



1. Set up your "seedling" as shown in the diagram above. This resembles a newly germinated plant in the spring, when the soil is soaked with water from the spring rains. The tiny plant has already produced a short root and a cotyledon from materials in the seed. Now you and your partner will decide how the seedling will grow. But-the weather will affect your decisions.

2. A plant in nature cannot control the weather. Neither can the teams playing this game. To randomly determine each day's weather, Mother Nature (your teacher or another student) will roll a standard die. The roll, or "weather report" for the day may be sunny (a good day for making sugar), cloudy (not much sugar made), dry (a lot of water lost through transpiration), or rainy (add water to your graduated cylinder). Based on the number that comes up during each roll of the die, the **Weather Table** shows how much photosynthesis you can carry out, and how much water gain

(rainfall) or water loss (transpiration) will occur. Rolling a 4 on the die, for example, means the day is warm and partly sunny. It is sunny enough to allow your plant to make 3 sugars for each leaf on the plant. But it is warm enough for the soil to lose 2 mL of water through each of the plant's leaves.

Weather Table

Number on Die	WEATHER	PHOTOSYNTHESIS	RAINFALL OR TRANSPIRATION
1	Chilly, downpour	no photosynthesis	gain 20 mL of water
2	cool light rain	make 1 sugar X number of leaves	gain 5 mL of water
3	very humid overcast	make 2 sugars X number of leaves	lose 1 mL of water X number of leaves
4	warm, partly cloudy	make 3 sugars X number of leaves	lose 2 mL of water X number of leaves
5	humid, sunny	make 4 sugars X number of leaves	lose 2 mL of water X number of leaves
6	sunny, very dry, hot	make 4 sugars X number of leaves	lose 4 mL of water X number of leaves

The Weather Report Card is a key to the weather conditions for each roll of the die. It also indicates the amount of sugar produced by photosynthesis, and the amount of water lost by transpiration.

After the day's weather has been determined, you and your partner will calculate the number of sugar tokens you'll receive and the change in the water level. For example, if you have 3 leaves and the roll of the die is "4" you will gain 9 sugar tokens (3 sugars multiplied by 3 leaves), and remove 6 ml H_2O from the graduated cylinder (2 ml multiplied by 3 leaves). To do this, take 9 sugar tokens from the token pile and put them next to your plant. Measure 6 ml of water out of the graduated cylinder using your pipet, and transfer the water to the discard beaker. Now you are ready for the next "day" (the next roll of the die). Whenever the roll of the die comes up 1 or 2, add water to your graduated cylinder from the beaker, according to the **Weather Table**.

3. As the days pass, you can save up enough sugars (tokens) to "make" a leaf (or leaves), root(s), or flower(s). Simply trade in the sugar tokens in exchange. Attach each to your growing plant. **NOTE:** the more leaves you have, the faster you'll accumulate sugars, and the faster you'll lose water due to transpiration!

   Here are the "costs" for plant growth:

   To make a **leaf**, the cost is **10 sugar tokens**.

   To make a **root**, the cost is **10 sugar tokens**.

   To make a **flower,** the cost is **21 sugar tokens**.

   You do not have to "buy" anything, even if you have enough sugars; you're free to store sugars for as long as you wish.

   If your roots are completely out of the water, you will **not** be able to carry out photosynthesis, and you lose more water due to transpiration. However, if you have stored sugars, you may use them to "buy" roots (or leaves or flowers) even while your roots are out of water. If your roots are out of water and you don't have enough sugars to make more root, you must wait for a rainy day.

4. The end of the game may be sudden and to the unprepared plant, crushing! Such natural signs as shorter days and longer nights autumn is approaching and the need to make seeds warn plants. As in nature, you won't know exactly when the game will end. Mother Nature determines when autumn will approach. For example, Mother Nature may decide that the growing season might be as short as 15 days. That means that on day #15, Mother Nature will roll a pair of dice and if any identical pair comes up, it's a frost! GAME OVER!!! If it's not a pair, a single die will be rolled and the game will continue as before for another "day." However, for each day after #15, the pair of dice will be rolled first to see it there's a frost.

5. The winner of the game will be the team with the most flowers, symbolizing that their plant may have the best chance of making lots of seeds and producing many progeny during the next season!

Data Analysis

Write out the answers to the following questions using complete sentences.

1. How did your plant grow? On a sheet of graph paper, label the X-axis "Days" and the Y-axis "Total Number." Then, using 3 different colored pens or pencils, plot a line for "Number of Roots" (paper clips), another for "Number of Leaves" and a third for "Number of Flowers" on the same graph.

   Compare your graph to that of the other students, or to your own results from a different "season" of play.

   - Do successful strategies have a certain period in time where there is rapid leaf growth? Rapid root growth?
   - When do successful strategies seem to make the most flowers? Did this plan work every time? Explain.

2. Divide the number of leaves by the number of roots in your plant as it looks at the end of the game. Write this leaf/root ratio on the board. When the whole class has calculated their leaf/root ratios, tally the results in the table shown below and prepare a histogram in which the "number of flowers" (Y-axis) is compared to the leaf/root ratio (X-axis).

leaf/root ratio	total number of flowers
_ 2.5	
2.0 - 2.49	
1.5 - 1.99	
1.0 - 1.49	
0.667 - 0.99	
0.5 - 0.666	
0.4 - 0.5	
__0.4	

- What does the histogram tell you about the success of different teams' strategies?
- Does the graph look the same regardless of the weather?

3. Write a report that analyzes the success or failure of your strategy. Things to consider in your report:

    - How did you decide whether to make a root or a leaf with your sugars?
    - Did your strategy prepare you for bad whether, such as extended droughts or rainy periods?
    - Is it a good strategy to “buy a flower” as soon as possible, or are there advantages to waiting until later in the season?
    - Did you have a winning strategy, or are you likely to become extinct?

Scorecard

Day Number	Roll of the die	Number of leaves	X	Photosynthesis factor?		Take how many sugar tokens?	total sugars	Make leaf, root, or flower?	Put how many sugars back?	**New total sugars**
1			X		=					
2			X		=					
3			X		=					
4			X		=					
5			X		=					
6			X		=					
7			X		=					
8			X		=					
9			X		=					
10			X		=					
11			X		=					
12			X		=					
13			X		=					
14			X		=					
15			X		=					
16			X		=					
17			X		=					
18			X		=					
19			X		=					
20			X		=					
21			X		=					
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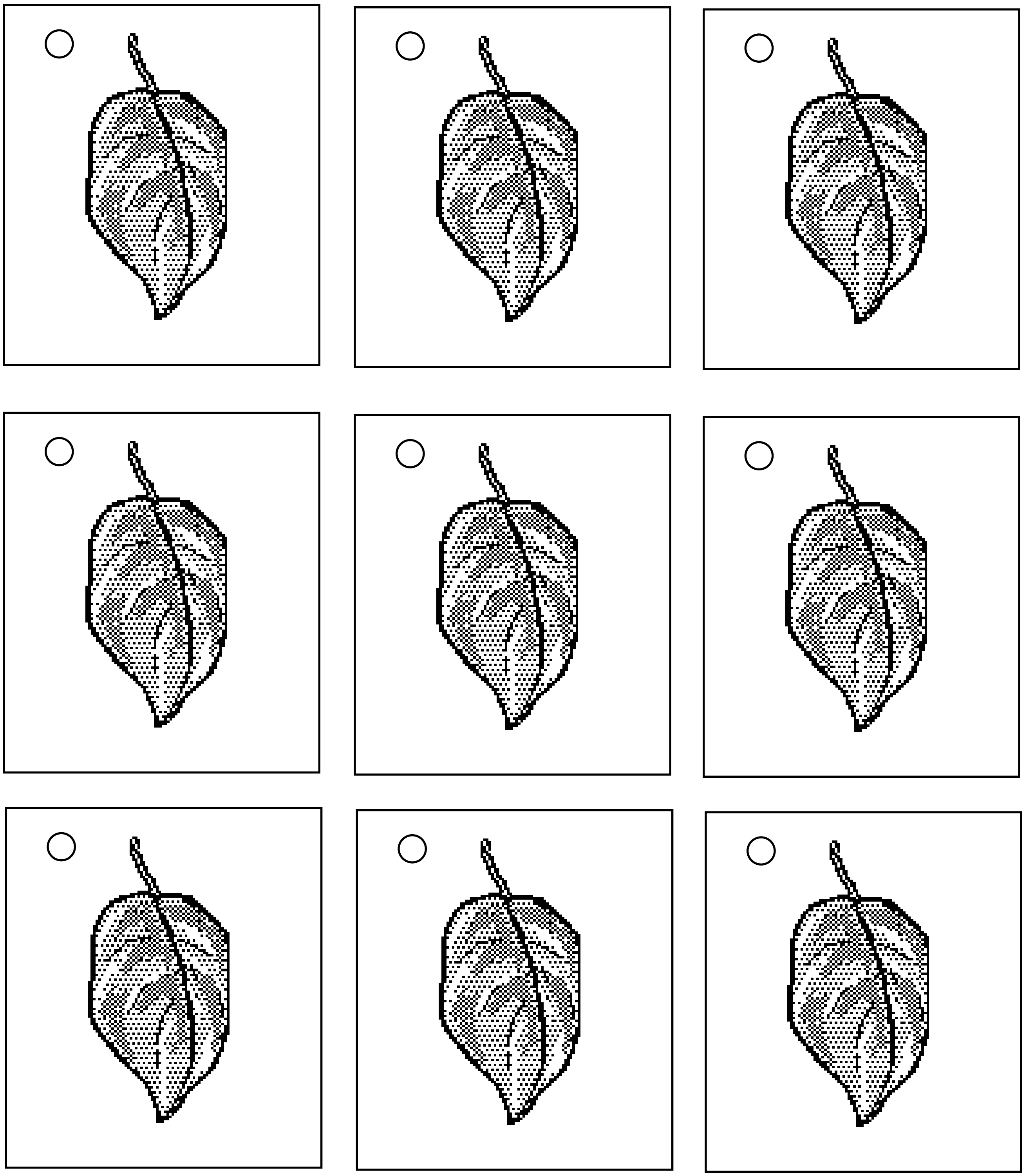

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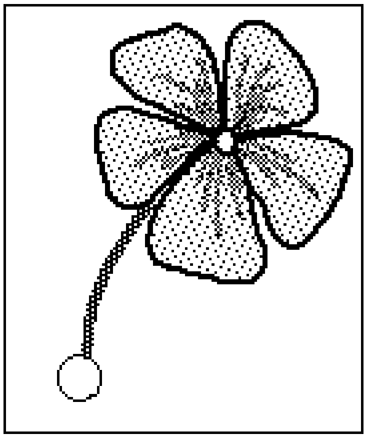
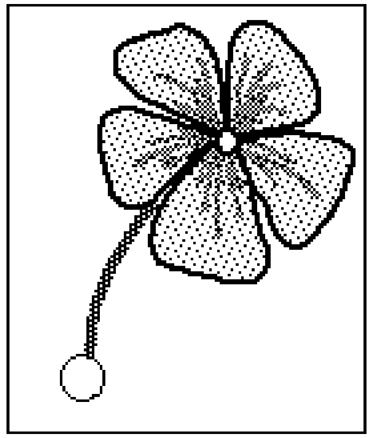
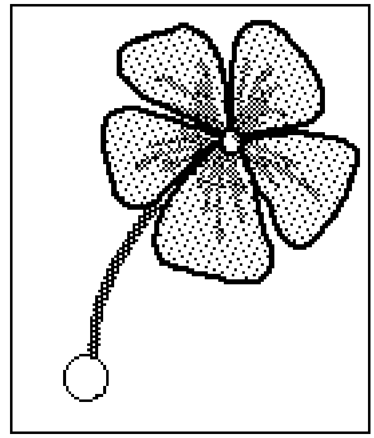
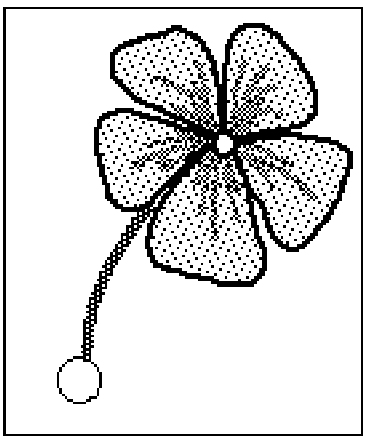
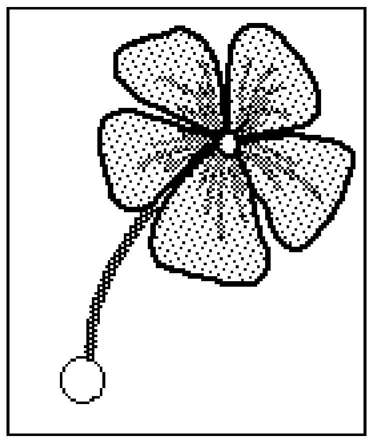
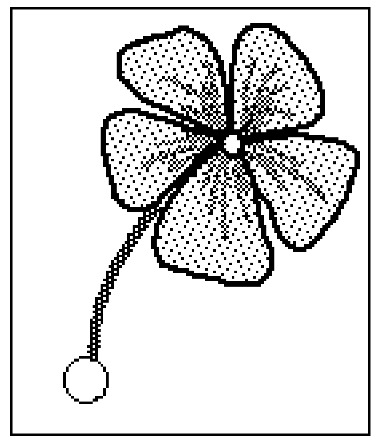
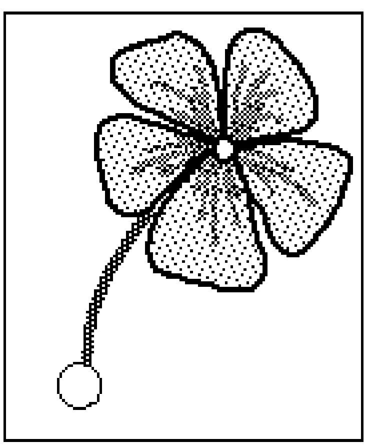
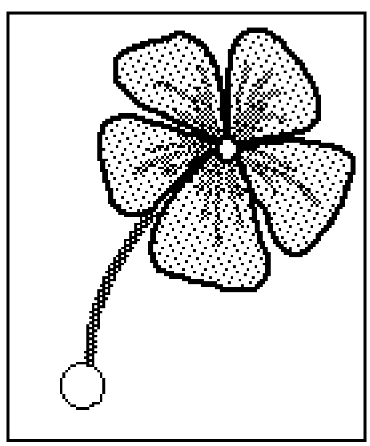
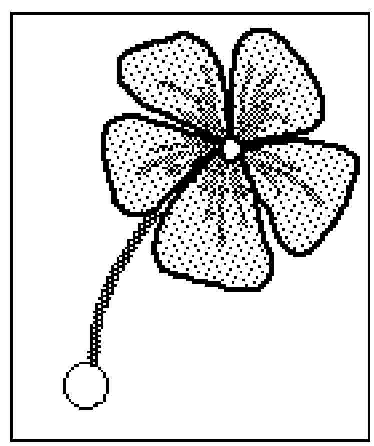

Print in color paper such as yellow, pink, red.

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Print in plain, white paper or any color not used for the leaves or the flowers.