Digging Deeper into Helmont's Famous Willow Tree Experiment

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THE willow tree experiment of Jean Baptista van Helmont (1577–1644) is variously recognized as "the first quantitative experiment in plant nutrition" (Epstein 1972), "the first experiment in vegetation undertaken for a scientific purpose" (Sachs 1890), or "one of the first experiments in modern biology" (Gabriel & Fogel 1955). Although authorities vary somewhat in scope, there is agreement that Helmont's experiment was a milestone in the history of biology since it marked the start of experimental plant physiology (Morton 1981). Unfortunately, mention of Helmont's experiment is often about as brief as his original description of it. Helmont's experiment seems simple, but it becomes complex when trying to ascertain the exact methods he used, to explain why he used these particular materials and methods, and to suggest more appropriate experiments for testing his hypothesis. When considered in greater detail, an interesting class discussion can develop.

Original Idea

Helmont's experiment was not necessarily an original idea since Nicholas of Cusa suggested the same experiment in 1450, in the Book *De staticis experimentis* (Howe 1965). Nicholas himself may have gotten the idea from a Greek work, *Recognitions*, dating from the years 200 to 400 (Howe 1965). Leonardo da Vinci (1452–1519) conducted a similar experiment with pumpkins and reached the same conclusions as Helmont, but his results remained unpublished in his notebooks (Bodenheimer 1958).

Helmont's willow experiment was not published until after his death, in *Ortus Medicinae* (1648). A translation of Helmont's concise description of the experiment follows:

> "By this apparatus I have learned that all things vegetable arise directly and in a material sense from the element of water alone. I took an earthen pot and in it placed 200 pounds of earth which had been dried out in an oven. This I moistened with rain water, and in it planted a shoot of willow which weighed five pounds. When five years had passed the tree which grew from it weighed 169 pounds and about three ounces. The earthen pot was wetted whenever it was necessary with rain or distilled water only. It was very large, and was sunk in the ground, and had a tin plated iron lid with many holes punched in it, which covered the edge of the pot to keep air-borne dust from mixing with the earth. I did not keep track of the weight of the leaves which fell in each of the four autumns. Finally, I dried out the earth in the pot once more, and found the same 200 pounds, less about 2 ounces. Thus, 164 pounds of wood, bark, and roots had arisen from water alone." (Howe 1965).

Of course Helmont's conclusion was in error because he did not know that plants absorb mineral elements from the soil and carbon dioxide from the air. Ironically, Helmont is credited with discovering carbon dioxide (Gabriel & Fogel 1955) and made significant contributions to chemistry, including the modern concept of gases (Pagel 1982). His willow experiment was straightforward and is still repeated today, although on a more modest scale, using radishes and 200 g rather than 200 lb. of soil (Dempsey 1990).

Wrong Experiment

While justly famous, Helmont's experiment is also notable because although carefully conducted, the conclusions derived from the experiment were wrong because the theory on which it was based was incorrect (Russell 1973; Magner 1979). Helmont actually conducted the wrong experiment to test his theory that plants are nourished entirely by water. Instead of using soil, Helmont should have used water alone as his root medium, as done in later research, such as John Woodward's 1699 experiments with spearmint grown in rain water (Russell 1973). The fact that Helmont used soil contradicted his hypothesis that only water was needed for plant growth. How should Helmont have tested his hypothesis that plants need only water? Had Helmont filled his earthen pot with rain or distilled water and tried to grow a willow tree for five years, the plant would likely have grown poorly or died, since rain or distilled water does not contain substantial quantities of all the essential elements needed by plants. Thus, had he done the appropriate experiment needed to test his hypothesis, he would probably have reached exactly the opposite conclusion.

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Replication & Control

By modern standards, a weakness in Helmont's experiment is his lack of replication. Using five 40-pound pots of soil and growing the plants for one or two years would have provided the necessary replication without using more soil, would have saved time and would have made the pots easier to handle. The disadvantage of such an approach was that additional plants and pots would have been required. This probably would not have been too great a problem since Helmont was a wealthy doctor, which afforded him the opportunity to experiment in the first place.

Helmont's experiment also lacked a suitable control. What control should he have used? An identical container of soil without a plant as a control would have answered the question of whether a change in soil weight might have occurred independent of the plant, possibly due to decomposition of soil organic matter, to leaching of soluble materials from the pot wall, or to dust accumulation, which concerned him since he went to the trouble of using a metal lid for the pot.

Root Separation

A particularly great difficulty faced by Helmont was the process of separating roots from soil. Even today this is nearly impossible because we have basically the same tools as Helmont—hands, trowels and patience. Bits of soil remain adhered to the roots, and pieces of root remain behind in the soil. Students can be asked to try separating roots from soil to demonstrate how difficult it is. One can rationalize for either a net loss or net gain in soil mass due to these processes, depending on the care taken by the investigator. Other potential losses of mass could have occurred during drying or weighing of the soil at the end of the study. Helmont does not provide sufficient detail of his drying and weighing procedures. Was the soil removed from the pot prior to weighing and weighed in small batches, or was the entire container dried and weighed, and the weight of the empty container subtracted? If the latter method was used; chipping of the container during handling may have caused a weight loss. If the former method was used, then losses of soil may have occurred during transfer or incomplete removal of soil from the pot.

Soil Weight Loss

To demonstrate that accuracy of weighing is an important issue, have a student stand on a bathroom scale, with or without 10 quarters in his or her pocket. Ten quarters weigh about two ounces. Have other students look at the scale and try to determine if the student's weight changes by two ounces; they should not be able to detect a change because the scale is not accurate enough. If the student weighs closer to 100 pounds, use five quarters to keep the proportion the same. This demonstration shows that, even today, it is difficult to detect a change in weight of 0.125 pounds (two ounces) in 200 pounds or one part in 1600. The weight change Helmont noted could easily have been less than the accuracy of the balance he used. For comparison, a current scientific supply catalog lists the readability of a 150-pound capacity balance at ±0.05 pounds, and a 1000-pound capacity balance has a readability of only ±0.5 pounds. Helmont's conclusion seemed to imply that the two-ounce difference was an experimental error or within the accuracy of his balance, since he attributes growth to just the water. Some modern authors seem to consider that two ounces of soil were accurately determined to have been lost since references to "the missing two ounces of soil" (Russell 1973) are found. The two-ounce difference cannot be considered significant, so speaking of a loss is not proper.

Based on our current knowledge of plant nutrition, how much of a soil weight loss would be predicted due to nutrient absorption by the roots? Reasoning could go like this: Assume that 20 percent of the 164-pound gain in plant fresh weight was dry matter and 5 percent of the dry matter consisted of mineral elements (Epstein 1972). Thus, mineral uptake would have been $164 \times 0.2 \times 0.05 = 1.64$ pounds. This seems a conservative estimate because the final plant weight of 164 pounds did not include four years of fallen leaves, and a five-year-old tree would consist largely of wood which has a larger dry weight percentage than 20 percent. Why was the reported loss in soil mass only 0.125 pounds? Probably the previously mentioned weighing inaccuracies or incomplete separation of roots from soil were contributing factors. Another important factor is that five years of root growth in a limited soil volume would add substantial quantities of organic material to the root zone as leakage of organic materials from roots and death and decay of roots, root hairs and root cap cells. Thus, Helmont's result of no change in soil weight was probably largely a coincidence. Had he replicated or repeated the experiment, he might have found soil weight increases or decreases due to the several factors previously discussed.

The Willow Plant

What species was Helmont's willow tree? Most people probably envision a familiar weeping willow (*Salix babylonica*), a native of China introduced early into the Middle East (Bailey & Bailey 1976), hence the name *babylonica*. However, we do not know if this is the species used. Helmont may have used one of several *Salix* species described in an herbal of his time (Gerard 1633). Perhaps Helmont used *Salix caprea*, the goat willow, which is native to Europe and has the familiar catkins of the North American native, *Salix discolor* or pussy willow.

One might ask why Helmont chose the willow as his experimental tree. A good reason might be the willow's ease of propagation by shoot cuttings (Hartmann & Kester 1983). Few woody plant shoots are easier to root than willows, and five-pound shoots of few woody plants, besides willows, would have much chance of rooting, even with modern methods of plant propagation. Commercial shoot cuttings today are virtually never that large.

The Earthen Pot

While Helmont's experimental approach was relatively new, especially his careful quantification and consideration of variables, like dust accumulation, growing plants in pots was an ancient practice. Egyptian hieroglyphics show frankincense trees being grown in pots between 3500 and 4000 years ago (Baker 1957).

How large was Helmont's earthern pot? The dry weight of Helmont's soil gives a good clue to the size of the earthen pot. Two hundred pounds (90 kg) of soil with a bulk density of one kg/liter, typical of a loam (Brady 1984), would occupy a volume of 90 liters. A modern equivalent of Helmont's pot could be a typical 30-gallon (113 liter) trash can.

An intriguing question is why Helmont sunk the pot in the ground. There are several possibilities. One would be to prevent toppling of the plant and pot by the wind. However, this would not have been important initially since the tree would have been too small, relative to the great mass of the soil-filled pot. Another reason might have been to reduce evaporation of water through the sides of the pot, assuming it was unglazed. The lower cold hardiness of plant roots compared to their above ground parts might have been another reason. Havis (1976) found that lethal root temperatures of 38 different container-grown woody plants ranged from −5 to −23 C. Brussels, Belgium, where Helmont conducted his experiment, is in the U.S. Department of Agriculture's Plant Hardiness Zone 8 (Krussman 1985) with average minimum winter air temperatures of −12 to −7 C. USDA Zone 8 includes central Texas; northern Louisiana; southern Arkansas; most of Mississippi, Alabama, Georgia and South Carolina; eastern North Carolina; coastal Virginia and Maryland; and portions of the Pacific coast states and Arizona. Sinking of the pot in the soil may have been crucial for plant survival, whether Helmont knew it or not. Above ground containers of soil will tend to reach air temperature but pots sunk in the earth will remain warmer than the air temperature.

Conclusion

Although seemingly very simple, Helmont's experiment becomes rather complex when trying to determine the exact methods he used, to explain the reasons for his methods, evaluate his sources of experimental error and suggest more appropriate methods for testing his hypothesis. An indepth consideration of Helmont's experiment is an excellent way to teach a number of important aspects of research, including experimental design, execution and analysis.

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