AGRI 180
Science, Society & the Food System

Lab 9: The Scientific Method & the Food System

Introduction

Now that you have had some experiences in the lab for the food system class, the time has come to put your experience to work, or more precisely to put the scientific method to work. But first you need some more introductory material and some background about the scientific method.

First and foremost, agriculture is a science. In fact it encompasses many sciences. Science can be distinguished from other fields of intellectual endeavor by two main features.

1. It differs in its content or the type of organized knowledge with which it is concerned.
2. It differs in its strictly empirical (practical or experimental) approach to problems.

Science deals only with rational beliefs which can be verified or disproved by observation or experiment.

"Experimental science has one great prerogative...that it investigates its conclusions by experience." ---Roger Bacon (1210-1292)

Often people think of science consisting of collecting and organizing fact. This is only one aspect of science. Far more important is what scientists do with the facts they have. The way in which scientists draw conclusions, make generalizations, and test predictions form the scientific method. For those seeking to understand science, they need to make a distinction between the content and procedure in science.

Scientific content is the subject matter of science or the generalizations that the scientific community currently recognizes as valid. For example, the Mendelian laws of inheritance, the concepts of natural selection and mutation, hormonal regulation of the estrous cycle represent scientific content. The methods by which such concepts were obtained represent the scientific method.

Learning Objectives

- ✓ List six steps in the scientific method
- ✓ Form a hypothesis based on observation
- ✓ Develop a test for a hypothesis-design an experiment
- ✓ Explain the reason for random sampling

- ✓ Define: replication, variable and statistics
- ✓ Report on the results of an experiment designed to test a hypothesis

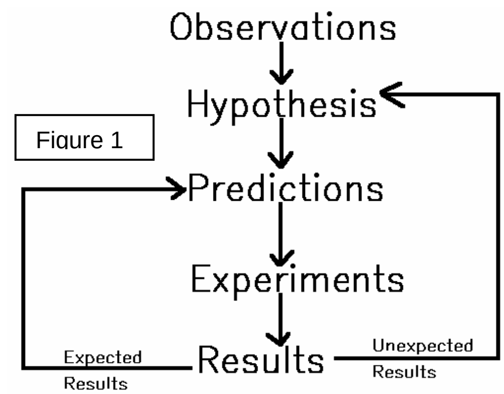
Background

The Scientific Method

The popular person-on-the-street concept of scientists and their methods is a poor one. This concept seems to be that the scientist is a person with secret means of obtaining knowledge to benefit humankind. Explanations put forth by research scientists may be wrong as often as they are right. And not all of their discoveries directly benefit humans. Indeed some seem completely useless or detrimental.

The scientific method is a series of six or seven steps. How rigorous scientists follow these steps varies. Here is one list of steps:

Figure 1



1. Observe the problem situation.
2. Form a hypothesis to explain the observed relationships.
3. Build an experiment to test the hypothesis.
4. Accept or reject the hypothesis
5. Develop the general knowledge from accepting or rejecting the hypothesis
6. Apply the general knowledge for decision making and continue to make observations.

Figure 1 shows the steps and the process in the scientific method. Experimental results are used, when necessary, to modify a hypothesis and to test predictions, but the cycle of testing shown in Figure 1 really never ends.

Some take another view of the scientific method. They say that "science is simply doing one's damnedest with one's mind with no holds barred." This view indicates that the means used by scientists in solving problems are not unique to science. In fact, the scientific method can be used by anyone to solve a variety of problems.

A Hypothesis

Science proceeds by proposing and testing an hypothesis. An hypothesis is simply a tentative explanation---a guess---put forth to account for a set of observations. Sometime hypotheses have been called “educated guesses.”

An hypothesis is a tentative statement or assumption which is made in order to be tested. To formulate a hypothesis is to make a testable prediction about the relationship between variables. A hypothesis is usually stated before any sensible investigation or experiment is performed because the hypothesis provides guidance to an investigator about the data to collect.

A hypothesis is an expression of what the investigator thinks will be the effect of the manipulated (independent) variable on the responding (dependent) variable. A workable hypothesis is stated in such a way that , upon testing, its credibility can be established or refuted. Hypotheses can usually be formed as an "if...then" statement.

Because it is not possible to prove a hypothesis scientifically, a theorem, scientists frequently phrase their hypothesis as a null hypothesis (H:O), in opposition to an alternative hypothesis (H:A). A null hypothesis is simply a statement of "no difference" between the experimental and control. If there is a difference, we must reject the null hypothesis and accept the alternative. The concept of hypothesis testing is basic to all of science; it is also the most misunderstood by the public. The word "prove" should not exist in the scientist's vocabulary, an infinite number of examples are needed to prove a hypothesis.

No matter how much evidence we gather to support a specific hypothesis, we can never be certain that the same data would not equally support any number of unknown alternative hypotheses. On the other hand, only one piece of evidence is necessary to disprove, and thus reject, a null hypothesis. If we demonstrate that the null hypothesis is invalid, then the alternative must be true.

After forming an hypothesis, a scientist proceeds by designing and performing experiments. The primary purpose of scientific experimentation is to test hypotheses. So, any hypothesis selected by a scientist to explain a natural phenomenon must meet a very important requirement: It must be testable.

Testing Hypotheses

Experiments test hypotheses by testing the correctness of the predictions that can be derived from them. After the hypothesis is formed the prediction can be made in form of an If-then statement. For example: If a bull is homozygous for the polled gene then all of his offspring will be polled.

A true hypothesis leads to a true prediction or conclusion. But a false hypothesis may lead to a true or a false conclusion or prediction. Unfortunately, true predictions do not constitute proof of the truth of an hypothesis. The agricultural scientist can never be absolutely certain that the experiment has eliminated all of the variables that might influence the results. A major problem in agricultural research becomes one of experimental design. The agricultural scientist recognizes the impossibility of eliminating all of the variables which might affect the experimental results. Still, scientists try to design experiments to decrease the likelihood that these variables will occur. Statistics are another tool scientists use to deal with the variables that are encountered in an experimental design.

False Hypotheses

In the past, many false hypotheses have been held by scientists and people in general, simply because accurate predictions could be made from these hypotheses despite their falseness. A true hypothesis always gives rise to true predictions so can false hypotheses. For example, acceptance of the belief that the sun orbits the earth lead people to predict that the sun rises on one horizon crosses the sky and sets on the other horizon. And so it does. The prediction is correct but this does not mean that the sun orbits the earth! To demonstrate that this hypothesis is false other tests must be devised to show that it gives false predictions.

Agricultural scientists rarely deal with cases in which every prediction made by an hypothesis turns out to be correct. The question then becomes: How many or what proportion of a given number of predictions must be verified in order to make the hypothesis a useful one? For this reason, experimental data are subjected to a statistical analysis. Here mathematics is used to determine whether deviations from the pattern that is predicted by the hypothesis are significant.

Applied versus Pure Research
In applied research, scientists may use the scientific method for the purpose of developing products to improve human comfort and welfare. In pure or basic research, the scientist searches for knowledge---knowledge for its own sake---regardless of whether the discoveries will benefit humankind. Still, the results of basic research have contributed as much or more than those of applied research. Science by its very nature is productive.

Experimental Design
Experimental design deals with selection of variables to be studied and the choice of a sampling program. It does not deal with experimental techniques used to gather data. The most commonly used experimental design is the two-sample comparison. To do this you select two situations in which all conditions but one are the same. One situation, usually more "normal" serves as the control and is the basis for comparison. The other situation is the experimental in which you vary the factor of interest. By comparing data obtained from the experimental situation with the control, you can make some conclusions about the effect of the variable you altered on the organism being studied. Be careful, though, to consider other possible explanations.

Bias
A bias is a preconception which can influence your ability to make observations or to interpret data. Try to recognize what your biases might be when designing an experiment, then design your experiment in such a way as to avoid as many biases as possible.

Control
When designing an experiment you want something to compare your results against - this is the control. When designing your experiment, be sure to keep all variables constant, except the one you are interested in examining.

Error

This term has a common usage which is equally applicable in agriculture---making a mistake. In science, however, there are other, more specific definitions. When analyzing the results of an experiment, we are interested in the experimental error---that error due to the specific design of the experiment or the equipment used. For instance, if we are using a thermometer to record temperatures during an experiment, and the instrument was out of calibration, our results will be consistently in error. Another example of experimental error would arise if different members of a group make successive readings of an instrument and they do not read consistently. For instance, one person may misread the meter by not viewing it direct on while another person may round off readings. A third person may interpolate (estimate a fraction between two numbers on the scale) to one additional significant figure, while a fourth may interpolate two additional significant figures. When the data from this group is pooled, there will be an inherent experimental error due to the different instrument reading techniques of the individual group members. Additional errors commonly encountered in biology have to do with statistical testing.

We use statistical tests to help us determine if observed results are sufficiently close to the expected results to be accepted or sufficiently different to be rejected. A type I error is when we reject a null hypothesis when it is true. The probability of making a type I error is the level of significance of a statistical test. A type II error is when we accept a null hypothesis when, in fact, the alternative is true. We can avoid a type I error by making our statistical test more rigorous. But of course, that increases the likelihood of making a type II error!

<u>Precision</u>

Results which are predictable and repeatable are precise, but precise results may or may not be accurate.   For instance, if your measuring instrument is not calibrated properly you may get exactly the same result on ten successive measurements, which would be extremely precise, but your results would be inaccurate to the degree that the instrument was out of calibration.

<u>Random</u>

Random means without definite aim, direction, intention, or method; of equal probabilities—in other words, without bias.   Random selection is a key assumption of statistical analysis, and as such, is critically important in designing scientific experiments and analyzing data. If one cannot be reasonably certain that samples were obtained in a randomized manner, the results obtained will be questionable. Experimental treatments must be randomized.

In sampling, it is important to decide where, how much and how many samples should be made ahead of time so as not to bias samples, like subconsciously choosing the largest steers for a test. One way to do this is to select steers with a random numbers table.

Sampling

A scientist can rarely collect all of the data about which she wants to draw conclusions. For example, it may be of interest to draw conclusions about the body weight of all 18 year old males in the United States. The only way to make statements about body weight of these men, with 100% confidence is to weigh each individual - an impossible task. Instead, only some of the total number of 18 year old males are weighed and we infer from the results the total weights of all the individuals of interest. The men who are actually weighed are a statistical sample of the population.

The key to having a sample accurately represent the population is to obtain a random sample. Random sampling implies that each individual in the population has an equal chance of being selects as part of the sample, that is, there is no bias for or against any individuals being sampled. If samples are taken at random from a population, valid conclusions may be drawn about that population from a small sample - with a known chance of error. We can control the amount of error by varying the size of the sample. In general, the smaller the sample, the larger the chance of error; the larger the sample, the smaller the chance of error.

A random number table is useful in obtaining random samples. Decide ahead of time how you will use the table, for example, read the last three digits down a row or the first three digits across line, etc., then enter the table at a random point and begin to sample. A randomly selected number could represent an individual in a row of plantings, number of feet from a starting point, number of measurements taken of a dimension, and so on.

Replication

A single measurement is not adequate to draw conclusions about a population. This is because it is not possible to know how reliably a character was measured. Repeated measurements may vary greatly, especially if made by different people. Therefore a series of repeated measurements, or replicate measurements, should be taken. From the collection of replicates, the mean and standard deviation will provide an estimate for the population as a whole. There are techniques to determine how many replicates are needed to achieve a certain level of reliability. As a general rule, three is a minimum number.

Statistics

There are three reasons statistics are important to scientists

1. Allow data to be quantitatively described and summarized
2. Allow generalized conclusions to be drawn based on relatively small sets of data
3. Differences and relationships between sets of data can be objectively analyzed

You have now had two laboratories on statistics. These will be helpful to review.

Variable

A variable is any factor in a situation that may change or vary. Investigators in science and other disciplines try to determine what variables influence the behavior of a system by manipulating one variable, called the independent variable and measuring its effect on another variable, called the dependent variable. As this is done, all other variables are held constant. If there is a change in only one variable and an effect is produced on another variable, then you can conclude that the effect has been brought about by the changes in the manipulated (independent) variable. If more than one variable changes, there can be no certainly at all about which of the changing variables causes the effect on the responding variable.

In a scientific investigation, measurements of the variables are made; however, you, the investigator, must decide how to measure each variable. An operational definition of a variable is a definition you determine for the purpose of measuring the variable during an investigation. Thus, different operational definitions of the same variable may be used by different investigators.

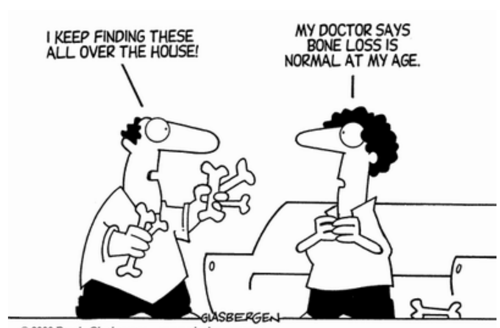
Descriptive Statistics
Living things are, by their nature, variable; a single individual, population, community etc. will not be exactly the same as any other. In order to describe any group of living things, statistics, descriptive measures derived from sample data, must be computed. One of the most common descriptive statistics is the mean, or average. The magnitude of the variation between means is inversely proportional to the sample size. That is, the larger the sample size, the more precise the estimate of the population mean. Large samples generally give better results than small samples!

Note: You can learn more about the mean, mode, median, standard error and standard deviation in the "Introduction to Statistics" laboratory handout.

Comparing Two Means
Frequently two means of two samples need to be compared to draw conclusions about similarities or differences. For instance, are the results of a particular experimental treatment significantly different from the control? In some cases the difference may be very large and obvious, but in other cases the means and variances may be quite similar and an objective method is required to determine the degree of difference or similarity.

Student's t-test is commonly used to compare two means where the null hypothesis is that the means are the same.

Limitations of Science
Science is one of humankind's most productive ways of exploring, exploiting, and trying to understand the environment. It is by no means the only way. Historians have their way, theologians their way and philosophers have their way. Despite the many contributions science has made to human's intellectual growth, as well as to health and general welfare, science does have limitations. Oddly, one limitation comes from one of its greatest attributes. As the philosopher George Boas points out---



"...what science wants is a rational universe, by which I mean a universe in which the reason has supremacy over both our perceptions and our emotions."

Science deals only with that set of phenomena which can be directly or indirectly be experienced through human's senses and placed into an experimental situation. This excludes from that set of phenomena which do not have these qualifications. Experimental science can only attempt to explain how a natural phenomenon may occur, and hypothesize its causes. Scientists can only speculate why these phenomenon occur.

The unemotional basis of science is another strength and weakness. Science is necessarily objective and detached from emotional prejudice. To keep its basic nature and succeed in dealing with contemporary problems, experimental science must remain objective and detached.

Despite the logical basis of science, it would wrong to give the impression that scientists are never wrong. Nothing could be further from the truth. The astronomer Johannes Kepler once wrote---

"How many detours I had to make, along how many walls I had to grope in the darkness of my ignorance until I found the door which lets in the light of truth."

Scientists do not always reason correctly. In fact, scientists are known for "going off the deep end," particularly when writing in areas other than their own specialty. True too, if scientists can be wrong so too can science. The strength of science does not lie in its infallibility. Nor does it lie in its logical basis, for the conclusions of a perfectly logical argument can be pure nonsense.

Science is a tradition of beliefs that have rational foundations, subject to continual review and discussion. Science is separate from the scientists. As an individual the scientist is only a human being, with all the emotions and weaknesses that come with being human.

Student Taste Test Results

We conducted a blind taste test of five different waters. Each student ranked the five waters from Best Taste to Worst Taste. Most students predicted that Calistoga water or Distilled water would be the favorite and that tap water from our room would be the least favorite. Here is a summary of our results.

We were surprised that all of us really disliked the taste of Distilled water. Two waters tied for first place; one was soft and one was hard so we don't think that the hardness or softness of water made a difference.

Visit a taste test lab at this website: http://www.markettrends.com/field_tab/taste.htm

In science, truth is a well-supported hypothesis. Hypotheses are supported by experimentation but not proved.

Materials

- Team members (3 to 4 class members)
- Paper and pencils for notes
- Time to brainstorm
- Other materials will be determined by the experiment you design

Procedures

1. Meet as a group and brainstorm ideas for conducting a scientific investigation of the food system; for example, list observations or ideas that are popular in the press or some concepts that seem to be cultural observations.
2. Develop a hypothesis and state it as a null hypothesis
3. Design an experiment (keep it simple) to test your hypothesis
4. Decide what items you will need to conduct your experiment
5. Determine the data you will collect and how you will present/analyze the data

6. Have your experiment approved by the instructor
7. Determine a timeline for conducting your experiment
8. Submit the timeline to your instructor and have it approved
9. Conduct your experiment keeping in mind randomizing your experiment and the importance of replication
10. Decide whether to accept or reject your hypothesis
11. Report on your experiment and the results in your lab report

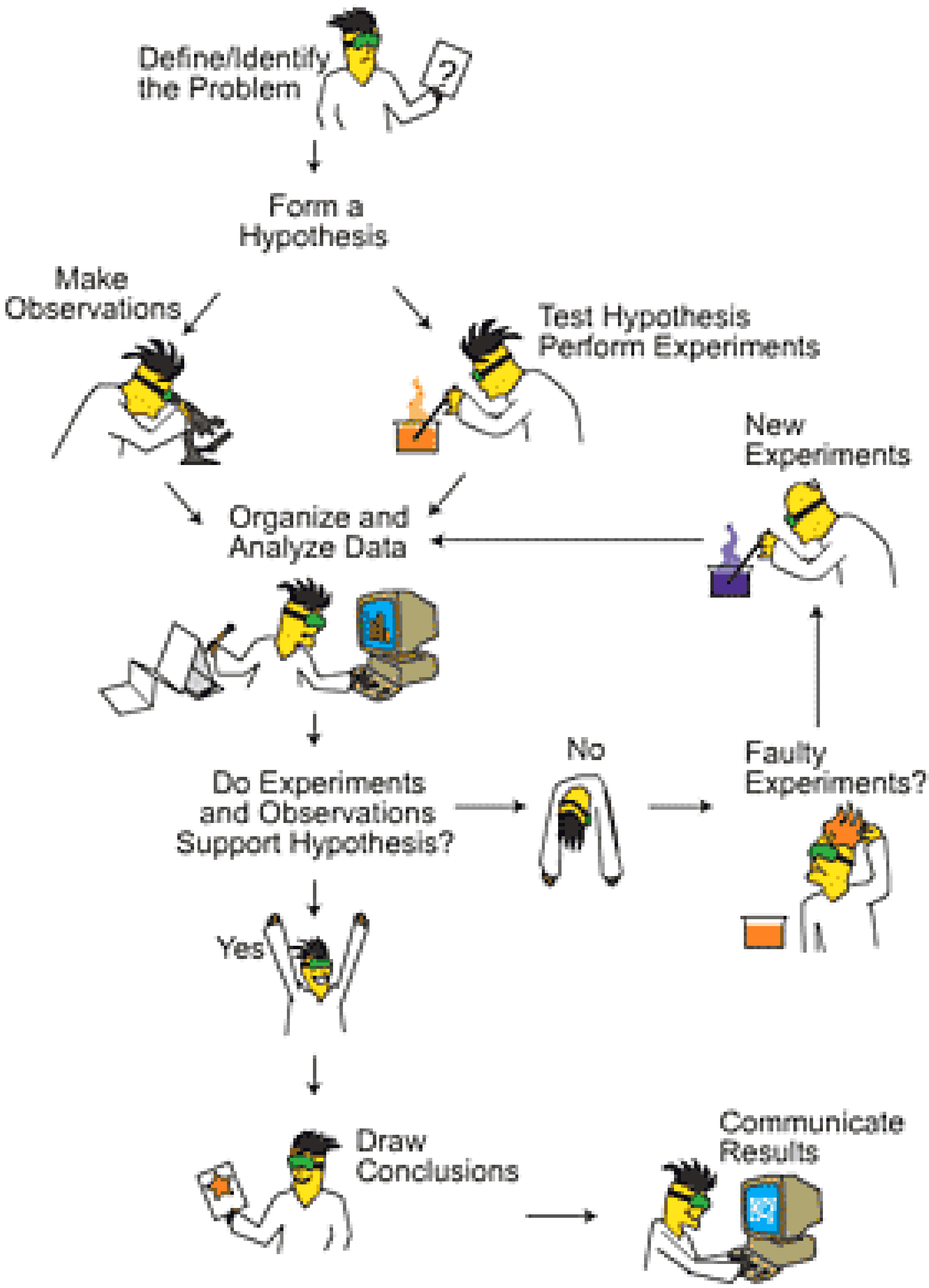
Results and Discussion

Write up you the results of your taste test in a lab report. Use the information you developed during the Procedures part of this lab and answer these questions in your lab report:

1. What is a hypothesis?
2. What control measures did you take?
3. Why is randomness important in an experiment?
4. How many replications did you do?
5. What descriptive statistics did you use to summarize your results?
6. What errors occurred during your experiment?

***Remember*: Read this entire laboratory handout. The ideas and information will help you write a better lab report and will expand your understanding of the scientific method.**

Summary



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