Making Sense of Sensors
Sensors and Satellites in Ag Technology

Objective

Students will read about technology in agriculture and focus on recent technology based on sensors. Students will conduct an experiment with infrared light to see how thermal imaging helps farmers determine the fertilizer needs of plants.

Background

American agriculture owes much of its success to the innovative thinking of farmers looking for ways to solve problems and make farming easier. Thomas Jefferson was an avid farmer and inventor who saw a problem with the crude wooden plows used by farmers in his day. They barely scratched the surface and merely loosened the topsoil, making it susceptible to washing away at the first hard rain. Jefferson's solution was the moldboard plow, which lifted and turned the sod. With this tool he could plow to a depth of about six inches. This enabled farmers to contour-ridge erodible fields, plow out shallow ditches, and ridge poorly drained flat lands.

The Industrial Revolution brought more complicated machines. Instead of harvesting grain by hand with a sharp blade, wheeled machines cut a continuous swath. Instead of threshing grain by beating it with sticks, threshing machines separated the seeds from the heads and stalks. The first tractors appeared in the late 19th century and displaced horses as a power source.

Agriculture today makes use of planes and helicopters, and even unmanned aerial vehicles (UAVs, or drones) for planting and spraying fumigants to control insect pests and diseases. The internet transmits vital weather data and other important information. Global Positioning Systems (GPS) and Geographic Information Systems (GIS) are widely used to make the most precise use of resources and to protect the environment.

Precision farming uses data at the level of the square meter or decimeter or even of a single plant. It uses the data to determine precisely how much seed, fertilizer and crop protection to use within a field or among fields. It turns plows, planters, spreaders, sprayers and other add-ons into intelligent equipment with sensors, software and wireless connectivity.

Some of the most modern tractors can even drive themselves, steering with the help of satellite technology (GPS). Computers on board download data about crops and soil that go straight to agronomists and farm managers. They link with ground sensors and UAVs using infrared thermal cameras and can tell to within a square meter where the most fertile or waterlogged places are in a field.

Sensors are critical to some of the most important developments

in agriculture in recent years. A sensor detects events or changes in its environment and responds with a corresponding output. Sensors may provide various types of output, but typically use electrical or optical signals. For example, a thermocouple in a heating system generates a known voltage (the output) in response to its temperature (the environment). A mercury-in-glass thermometer converts measured temperature into expansion and contraction of a liquid, which can be read on a calibrated glass tube.

Some of the most important sensor technology in agriculture relies on infrared light to provide the trigger for desired outputs. Infrared mapping helps farmers diagnose their fields and predict crop yields. Areas where the crops are growing poorly may be a result of poor soil nutrition, or irrigation problems, and the infrared data can help farmers spot problems early.

An important sensor system in agriculture uses infrared and near infrared (NIR) light to determine the nitrogen level in a crop. Nitrogen levels are determined based on the crop's normalized difference vegetative index (NDVI). The NDVI is an index of plant "greenness" or photosynthetic activity. Vegetation that is photosynthetically active absorbs most of the red light that hits it while reflecting much of the near infrared light. Vegetation that is dead or stressed reflects more red light and less near infrared light. By taking the ratio of red and near infrared bands from a remotely-sensed image, an index of vegetation "greenness" can be defined. Using satellite imagery, the system determines the NDVI of a test strip that is rich in nitrogen and compares it with the rest of the crop to calculate nitrogen requirements for the growing season. Better nitrogen management not only helps producers get more value for their nitrogen investment but also reduces the risk of environmental pollution.
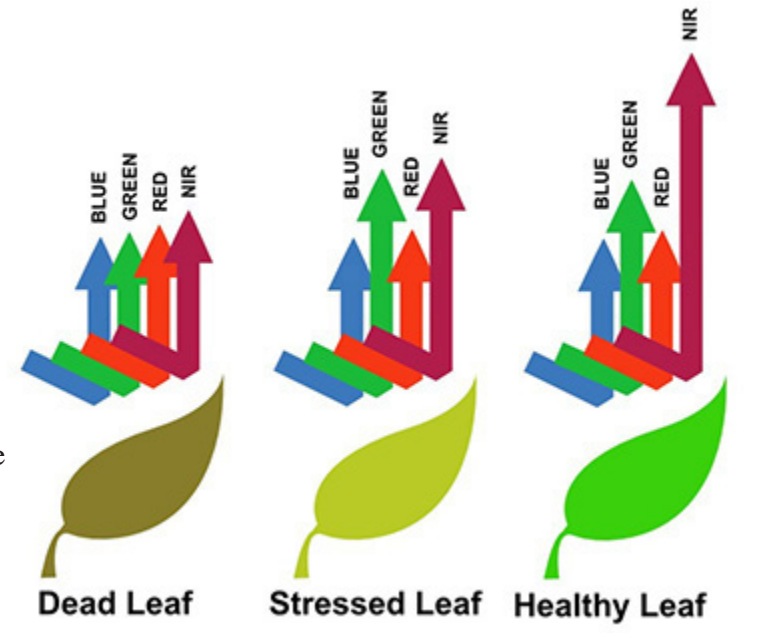
Science

1. Read and discuss background and vocabulary.
2. Provide copies of the "Discovering Infrared Light" worksheets.
   —Students will conduct the experiment described to recreate the discovery of infrared light.
   —Students will record the results of their experiment using the worksheet provided.

Social Studies

1. Provide color copies or project onto a whiteboard the information on the Soil Moisture Map.
   —Discuss the information provided with the map.
   —Students will answer the following questions, based on the map and map legend:
   • Which region of the US has the most soil moisture?
   • Which region has the least?
   • Which part of Oklahoma has the highest amount of soil moisture?
   • Which has the least?
   • Find the part of the state where you live. What does the map tell you about soil moisture where you live?
   • If you were a farmer in the southeastern part of Oklahoma, would you be more or less likely to try putting your heavy equipment into a field, based on the soil moisture map? Why?
   • Where in the state would you most likely need to irrigate?

2. Students will explore the Oklahoma Mesonet site, https://www.mesonet.org/, to find current data about soil moisture.
   —Find the map at the top of the page, and click on the "More Maps" link.
   —Click on "Soil Moisture."
   —Students will find the mesonet station nearest your school. What are the soil moisture conditions near your school?
   —Students will formulate their own questions about planting based on the data they find on the Mesonet website.
3. Divide the class into groups of three or four, and tell each group that they will be analyzing three satellite images of the same piece of land. The information in the images provides information about the land that would be useful to a farmer. One image shows vegetation density on the land, one shows where there is water deficit and one shows places where crops are under stress..
   —For each group, provide color copies of the satellite images included with this lesson or project the image for groups to inspect one at a time.
   —Students will answer the questions included with the satellite images.
   —Each group will develop a plan for best use of the land, based on what they see in the satellite images.
   —Each group will present its plan to the class.
   —The class will vote on the best paln.
   —Lead a class discussion about the usefulness of satellite images in agriculture.

Vocabulary

agronomist— a specialist in the branch of agriculture that deals with the raising of crops and the care of the soil

contour-ridge— a method of tillage in which ridges follow the contour of a field. Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. Crops are planted on both sides of the furrow.

data— facts about something that can be used in calculating, reasoning, or planning

erodible— susceptible to wearing away by or as if by the action of water, wind, or glacial ice

fertile— producing vegetation or crops plentifully

fumigant— a substance used in the application of smoke, vapor, or gas especially for the purpose of disinfecting or of destroying pests

fungicide— a substance that destroys fungi

Global Positioning System (GPS)— a multi-use, space-based radionavigation system

infrared— being, relating to, producing, or using rays like light but lying outside the visible spectrum at its red end

innovate— to introduce something new

nitrogen— a colorless tasteless odorless element that occurs as a gas which makes up 78 percent of the atmosphere and that forms a part of all living tissues

nutrient—something that furnishes nourishment

optical

precision—the quality or state of being very exact

sensor— a device that detects a physical quantity (as a movement or a beam of light) and responds by transmitting a signal

simulation— the imitation by one system or process of the way in which another system or process works

swath— a row of cut grain or grass

thermal— of, relating to, caused by, or saving heat

thermocouple — a device for measuring temperature in which a pair of wires of different metals (as copper and iron) are joined and the free ends of the wires are connected to an instrument (as a voltmeter) that measures the difference in potential created at the junction of the two metals

thresh — to separate seed from a harvested plant especially by using a machine or tool

topsoil — surface soil usually including the rich upper layer in which plants have most of their roots and which the farmer turns over in plowing

unmanned aerial vehicle (UAV) — an aircraft with no pilot on board. UAVs can be remote controlled aircraft (e.g. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems.

variable rate application — in precision agriculture, the application of a material, such that the rate of application is based on the precise location, or qualities of the area that the material is being applied to. Variable Rate Application can be, Map Based or Sensor Based.

virus — any of a large group of very tiny infectious agents that are too small to be seen with the ordinary light microscope but can often be seen with the electron microscope, that are considered either very simple microorganisms or very complicated molecules, that have an outside coat of protein around a core of RNA or DNA, that can grow and multiply only in living cells, and that cause important diseases in plants and animals including human beings

yield — the amount or quantity produced

Discovering Infrared Light

Infrared is a form of light that we cannot see with our eyes but that we can sometimes feel on our skin as heat. Visible light, the only light our eyes can see, makes up just a tiny sliver of all the light in the world around us.

Infrared light falls just outside the visible spectrum, beyond the edge of what we can see. Sir William Herschel discovered the existence of infrared light by passing sunlight through a glass prism in an experiment similar to this one. As sunlight passed through the prism, it was dispersed into a rainbow of colors called a spectrum. A spectrum contains all of the visible colors that make up sunlight. Herschel was interested in measuring the amount of heat in each color and used thermometers with blackened bulbs to measure the various color temperatures. He noticed that the temperature increased from the blue to the red part of the visible spectrum. He then placed a thermometer just beyond the red part of the spectrum in a region where there was no visible light and found that the temperature was even higher! Herschel realized that there must be another type of light beyond the red, which we cannot see. This type of light became known as infrared. Infra is derived from the Latin word for "below."

MATERIALS

- Halogen lamp, 100-watt bulb
- One glass prism (plastic prisms do not work well for this experiment)
- Three alcohol thermometers
- Black paint
- Scissors or a prism stand
- Cardboard box (photocopier paper box works well)
- 1 blank sheet of white paper

Note: The quality of the prism and the thermometers will impact the success of this experiment. The experiment can be conducted outdoors but will work better with an artificial source of light (halogen lamp). If you conduct the experiment outdoors, results will be best on a sunny day, around solar noon, late in the spring, in the summer, or early in the fall. You might also try conducting the experiment with both natural and artificial light for comparison purposes.
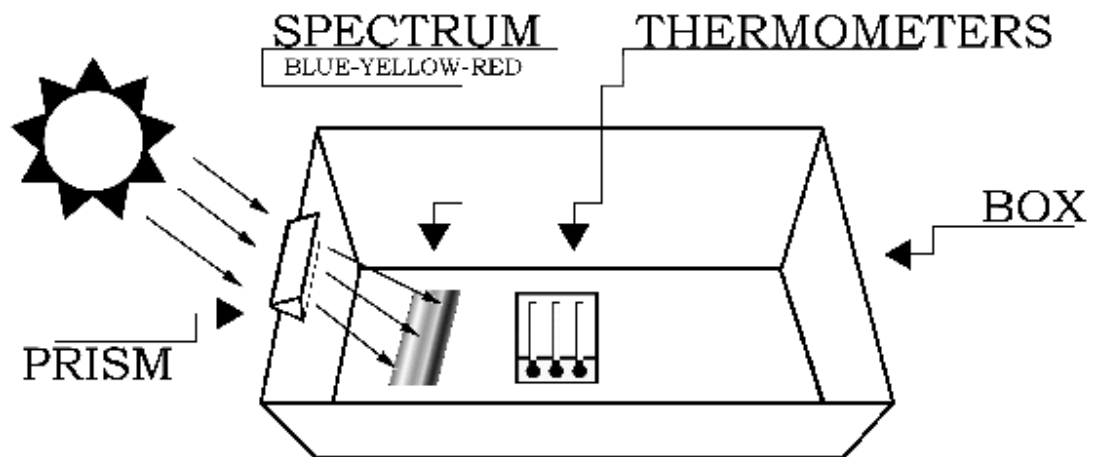

Figure 1

1. Blacken the thermometer bulbs with black paint or marker, covering each bulb with about the same amount of paint. (The bulbs of the thermometers are blackened in order to better absorb heat.)
2. After the paint or marker ink has completely dried on the thermometer bulbs, tape the thermometers together such that the temperature scales line up as in Figure 1.

3. Place the white sheet of paper flat in the bottom of the cardboard box.
4. Carefully attach the glass prism near the top edge of the box facing the sun. If you do not have a prism stand (available from science supply stores), the easiest way to mount the prism is to cut out an area from the top edge of the box. The cutout notch should hold the prism snugly, while permitting its rotation about the prism's long axis (as shown in Figure 2). That is, the vertical "side" cuts should be spaced slightly closer than the length of the prism, and the "bottom" cut should be located slightly deeper than the width of the prism.
5. Slide the prism into the notch cut from the box, and rotate the prism until the widest possible spectrum appears on a shaded portion of the white sheet of paper at the bottom of the box. The sun-facing side of the box may have to be elevated to produce a sufficiently wide spectrum.
6. After the prism is secured in the notch, place the thermometers in the shade and record the ambient air temperature. Then place the thermometers in the spectrum such that one of the bulbs is in the blue region, another is in the yellow region, and the third is just beyond the (visible) red region (as in Figure 3). Note: Depending on the position of the prism relative to the Sun, the colors of the spectrum may be reversed from what is show in the figures.

Figure 2

7. It will take about five minutes for the temperatures to reach their final values. Record the temperatures in each of the three regions of the spectrum: blue, yellow, and "just beyond" the red. Do not remove the thermometers from the spectrum or block the spectrum while reading the temperatures.
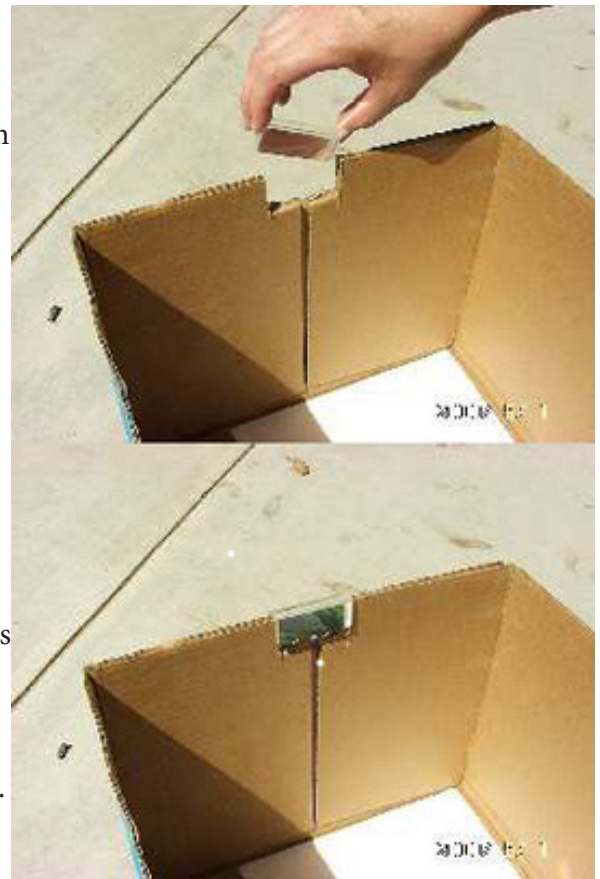
The temperatures of the colors should increase from the blue to red part of the spectrum. The highest temperature should be just beyond the red portion of the visible light spectrum. This is the infrared region of the spectrum.

Herschel's experiment was important not only because it led to the discovery of infrared light, but also because it was the first time that it was shown that there were forms of light that we cannot see with our eyes.
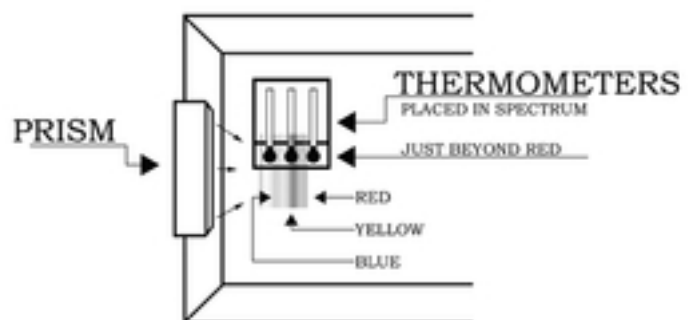

Figure 3

Source: "The Herschel Experiment," Cool Cosmos, Infrared Processing and Analysis Center, Science and Data Center for Infrared Astronomy, NASA: http://coolcosmos.ipac.caltech.edu/page/lesson_herschel_experiment

Oklahoma Ag in the Classroom is a program of the Oklahoma Cooperative Extension Service, the Oklahoma Department of Agriculture, Food and Forestry and the Oklahoma State Department of Education.

Name_____

Discovering Infrared Light Worksheet

DATA/OBSERVATIONS

Record the temperature of the three thermometers in the shade

	Thermometer #1 (blue)	Thermometer #2 (yellow)	Thermometer # 3 (just beyond red)
Temperature			

Place the thermometers in the box in the spectrum such that one of the bulbs is in the blue region, another is in the yellow region, and the third is just beyond the (visible) red region. Now record the temperatures in each of the three regions of the spectrum: "blue", "yellow" and "just beyond red" after 1, 2, 3, 4 and 5 minutes.

	Thermometer # 1 (blue	Thermometer # 2 (yellow)	Thermometer # 3 (just beyond red)
Temperature at 1 minute			
Temperature at 2 minutes			
Temperature at 3 minutes			
Temperature at 4 minutes			
Temperature at 5 minutes			

Calculate the differences between the final temperatures measured in the spectrum and the temperatures measured in the shade for the three thermometers.

	Thermometer # 1 (blue	Thermometer # 2 (yellow)	Thermometer # 3 (just beyond red)
Temperature in the spectrum (Tspectrum)			
Temperature in the shade (Tshade)			
Difference (Tspectrum - Tshade)			

Calculate the differences between the final temperatures in each part of the spectrum

Tyellow - Tblue	Tjust beyond red - Tyello	Tjust beyond red - Tblue

Class Average Temperatures
Compute the average final temperature measured by the class in each part of the spectrum.

	Sum of all class temperatures (Tsum	Total number of obervations (N)	Class Average (Tsum/N)
Yellow			
Blue			
Just Beyond Red			

Compute the average differences measured by the class between the final temperature in the spectrum and the shade temperatures for the three thermometers.

	Sum of class temperature differences (Tsum	Total number of observations (N)	Class Average (Tsum/N)
Tyellow-Tblue			
Tjust beyond red - Tyellow			
Tjust beyond red - Tblue			

Questions

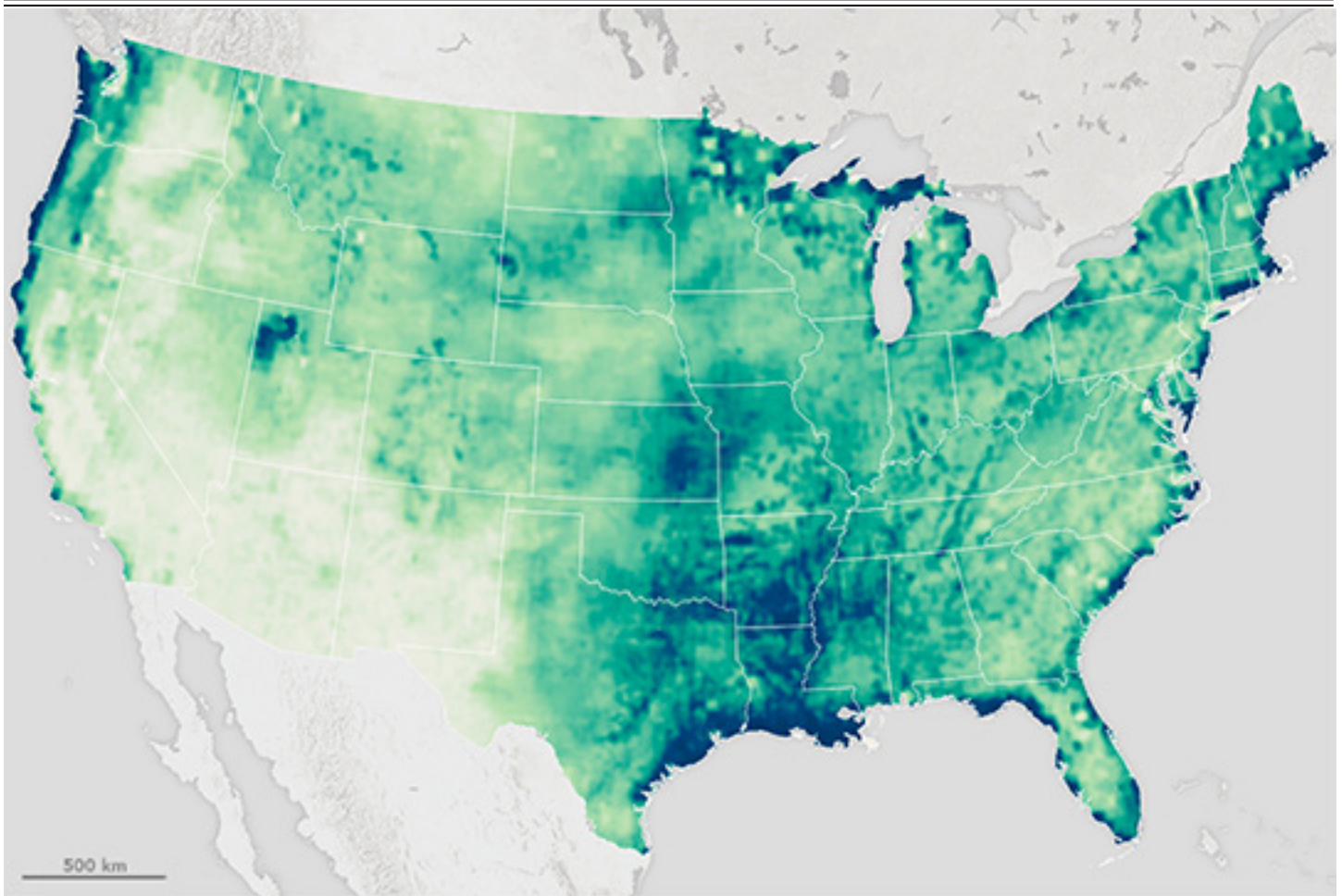What did you notice about your temperature readings?

Did you see any trends?

What was the highest temperature?

What do you think exists just beyond the red part of the spectrum?

Discuss any other observations or problems.

Soil Moisture Map

Soil Moisture (m^3 water/m^3 soil)

0   0.05   0.15   0.25   0.35   0.45   0.55   0.65

Knowing something about the moisture in the soil is important before, during, and after the growing season. For example, will mud prevent a tractor from safely plowing through the fields? How much water will crops have available at each stage of growth, from germination through harvest? Satellite and ground-based sensors are helping scientists find out.

The map above shows the amount of moisture in the top 5 centimeters of the ground across the US. It was produced with data collected with the radar and radiometer instruments on NASA's Soil Moisture Active Passive (SMAP) satellite. Colors show the volume of water contained in a volume of soil. Dark green and blue areas are progressively wetter, up to a the point of saturation.

At the same time, ground-based sensors monitor soil moisture over small areas—typically less than one square meter. There are more than 1,200 ground-based stations across the US.

In Oklahoma, ground-based stations are part of an environmental monitoring network called Mesonet. More than 100 stations across Oklahoma measure soil moisture at depths down to 60 centimeters (24 inches). Mesonet is just one of 31 networks, which together account for nearly 1,500 stations in North America.

Data from ground sensors, updated every 30 minutes, can help farmers quickly figure out where there is inadequate moisture in their fields.
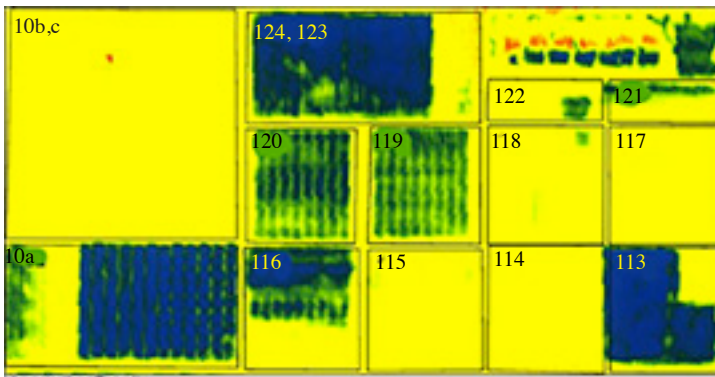
Source: NASA Earth Observatory, http://earthobservatory.nasa.gov/IOTD/view.php?id=87036
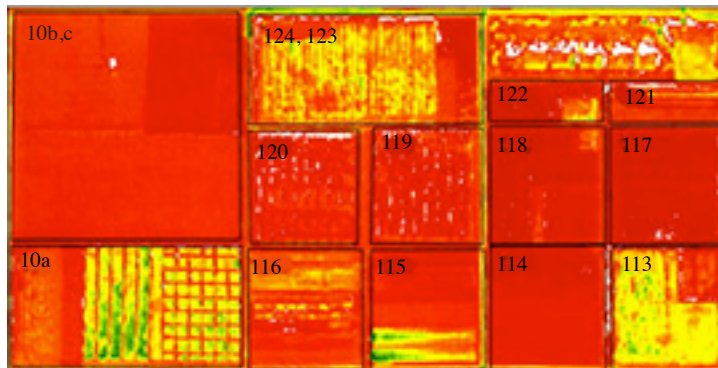Oklahoma Mesonet: https://www.mesonet.org/

Reading Satellite Images

Satellites use remote sensing instruments to collect data, which are transmitted from the satellite to the ground as radar or microwave signals. Raw satellite data are just sets of numbers registered by digital equipment. By itself, raw data do not make an image. Converting raw data into an image requires computer software that converts ranges of radiation values into "false colors," colors we can see.
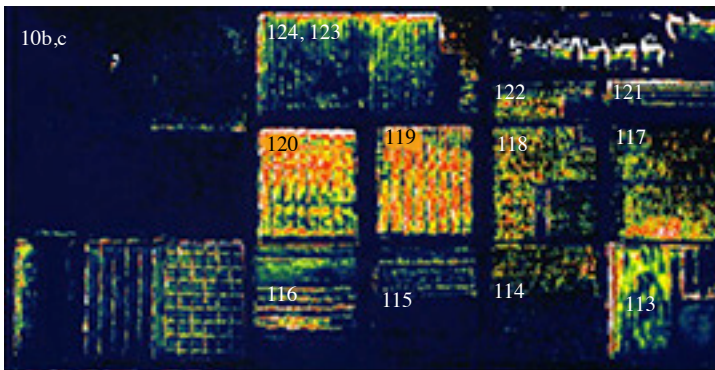
To determine the density of green on a patch of land, researchers observe the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants. When sunlight strikes objects, certain wavelengths are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light. The more leaves a plant has, the more these wavelengths of light are affected, respectively.

Vegetation Density

Water Deficit

Crop Stress

The images at left are all satellite images of the same section of land.

- The top image shows vegetation density, with the darker colors indicating the most dense vegetation.
- The middle image shows water deficit. Green indicates wet soil and red indicates dry soil.
- The bottom image shows crops under stress, indicated by red and yellow.

For example, a farmer looking at field 119 from all three views would see that the field has a moderate amount of vegetation, is fairy dry and is under stress.

1. In which section is vegetation most dense? Can you tell why by looking at the other images?
2. Why do fields 120 and 119 have stripes?
3. Which fields have crops that are under stress? Why?
4. Which field is the best for growing crops? Why?
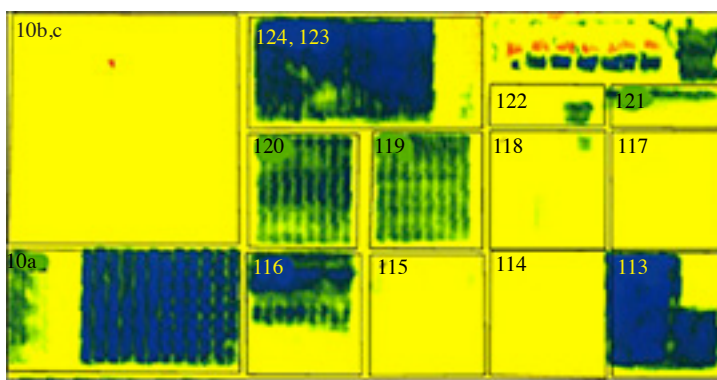5. How would you describe field 10b,c just by looking at the satellite images?

As a group, devise a plan for the best use of this land, based on what you can see from the satellite image. Does it need fertilizer? If so, what? What else does it need?

Sources: http://earthobservatory.nasa.gov/IOTD/view.php?id=1139&src=ve; Susan Moran, Landsat 7 Science Team and USDA Agricultural Research Service
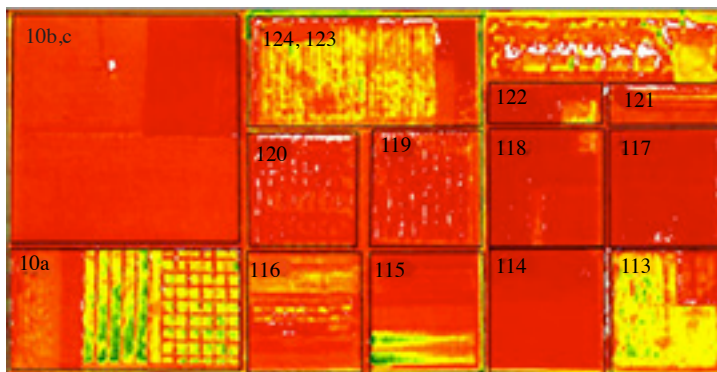
Reading Satellite Images (answers)

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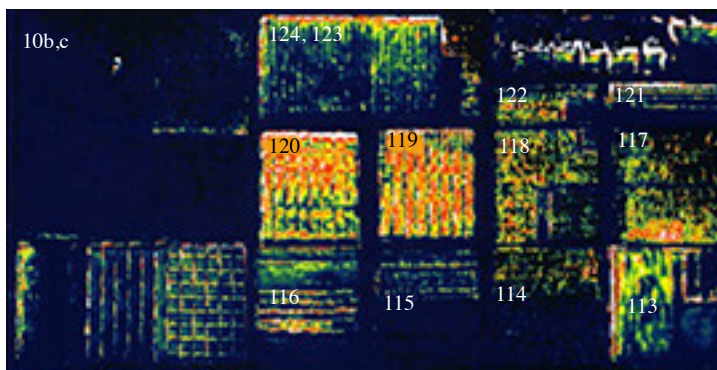
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For example, a farmer looking at field 119 from all three views would see that the field has a moderate amount of vegetation, is fairy dry and is under stress.

1. In which section is vegetation most dense? Can you tell why by looking at the other images?
   Vegetation is most dense in sections 124, 123; 10a, 116 and 113 because they are the fields that do not have a water deficit.

2. Why do fields 120 and 119 have stripes?
   The stripes in fields 120 and 119 are probably cultivated rows.

3. Which fields have crops that are under stress? Why?
   Fields 120 and 119 are under stress because they need water.

4. Which field is the best for growing crops? Why?
   Field 124, 123 is probably the best for growing crops because it has dense vegetation, doesn't have a serious water deficit and doesn't show very much crop stress.

5. How would you describe field 10b,c just by looking at the satellite images?
   Field 10b,c has very little vegetion except in one tiny spot (might be a tree), has very little water and no crop stress. It probably is an unplanted field.