INTRODUCTION TO AGRIVOLTAICS

What is Agrivoltaics?

Agrivoltaics is the co-location of an 'understory' of agriculture below an 'overstory' of renewable energy production in the form of photovoltaics (converting light into electricity using semiconducting materials). Agrivoltaics (AV) can help us maximize food *and* energy production and transform how we grow agriculture in the drylands of the world. AV works by placing elevated solar panels over agricultural plants (Fig. 1).

Figure 1: Solar panels above agave.

Tucson's AV project is led by University of Arizona (UA) Assistant Professor in Biogeography and Ecosystem science, Dr. Greg Barron-Gafford, who began the experiment with several garden beds below solar panels at the UA's Biosphere 2. Located in Oracle, Arizona, the Biosphere 2 is a "unique large-scale experimental facility housing seven model ecosystems with active research led by teams of multidisciplinary scientists" (biosphere2.org).

How can students participate in Agrivoltaics science?

Agrivoltaics (AV) citizen scientists can be anyone—students, teachers, and community members alike—interested in becoming a significant part of the UA's agrivoltaics research. Citizen scientists monitor plant and solar panel data, collect information, and process their findings to improve Tucson's AV science at replica sites. Citizen scientists do not need to be adults, formally trained or educated, or consider themselves a "scientist". Citizen scientists *do* need to be people willing to help the larger AV project by collecting plant data to the best of their ability at their local AV site. With help from many citizen scientists, Biosphere 2 and UA scientists will be able to collect much more data about plants, AV panels, and AV sites that would not be feasible otherwise. We invite you to join us in this collaborative effort.

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What are the benefits to Agrivoltaics for plants and solar panels?

It has been shown that agrivoltaics (AV) can be beneficial to both plants and solar panels. AV systems create a microclimate (unique climate in a certain area) where plants are shaded from the sun's direct rays during the day. This shade cools the temperature below the panels, ultimately decreasing evaporation rates from soil and plants. This cooling effect leads to using less water on an AV garden than would occur otherwise. When evaporation *does* occur, the solar panels above the garden are cooled by the water vapor from the garden. This cooling effect can increase panel efficiency.

Plants benefit in other ways too. As the panels above the garden shade the plants during the day and absorb the sun's heat, that heat is released at night creating a warm microclimate when plants need it most—during cold desert nights or when temperatures drop below freezing. Therefore, plants are protected during the day *and* night. It has been shown that this protection allows AV gardens to have a longer growing season. In some cases, this means more fruits and veggies year-round. The solar panels insulate the understory from freezing nights, extending the growing season of fall, winter, and spring crops.

There are human benefits too! It's much nicer to work in a garden during those hot Tucson days when the garden is shaded from the sun's direct rays. Longer growing seasons mean more produce for the community, lower watering rates helps us be water smart, and local solar panels that are producing efficiently are great for going green.

How can Students be Involved in Agrivoltaics Research?

To date (Spring 2018), the UA's agrivoltaics sites include Biosphere 2 (lead site) and Tucson Unified School District's University & Rincon High School and Manzo Elementary School. These school sites have simulated the Biosphere 2 lead site by planting garden beds below their school's solar panels, and communicated directly with UA scientists to plant similar crops and collect useful data at their AV site. Data includes closely monitoring plant growth, fruit and vegetable production, soil moisture, and temperature to determine how well different types of plants respond to the AV environment. Students compose our AV citizen science teams and are learning to integrate their learning of biology and physics with their understanding of food production. AV is a great way to experience new ways of problem solving, become an effective communicator, and inspire student learning. The tools that were used at the abovementioned school sites are listed below and our data sheets and tracking tables can be found on this site. Please join us in this amazing citizen science project!

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Tools included:

- **Rulers, pencils, printed data sheets and…**

- **ANGGO Infrared Digital Temperature Thermometer** ($12.99 on Amazon)

- **ALOTPOWER Soil Tester 3-in-1 Moisture, ph, Light** ($9.50 on Amazon)

- **GOPLUS 66 LB Digital Produce Scale** ($32.00 on Amazon)

- **ORIA Digital Thermometer for MIN/MAX Records** ($9.99 on Amazon)

- **Pima County Public Library, Seed Library** (Free seeds w/ library card)

DATA COLLECTION PROTOCOLS

Please read the *AV Introduction* document before beginning.

What information is being collected at Agrivoltaics sites?

Agrivoltaics (AV) citizen scientists collect information on plant growth, fruit and vegetable production, soil moisture, and temperature. The protocols outlined below are to maximize data collection efforts and quality. AV and non-AV plants are tracked through time to account for variation. AV citizen scientists are encouraged to plant both an **experimental** (i.e., a garden bed below the solar panels) and **control** (i.e., a garden bed outside of the solar panels) garden that exactly mirror each other if they would like to compare and contrast any differences that may arise from the influence of the solar panels. Data sheets provided on this site can be used as a template to guide you through the creation of a local AV data table.

Which plants should I monitor?

Depending on the size of your garden and how much time you have, you may be able to monitor all of your plant species or just a subset. The more plants within the same species that are monitored, the better you will be able to capture plant variation.

Flag a plant! Find at least one representative plant from each plant species in both your experimental *and* control beds. Mark the plant with a flag, stone, piece of cloth, or any material that will remind you which plants you are monitoring.

DATA COLLECTION PROTOCOLS

Datasheet Variables, Step by Step

- **Observer:** name of the person observing. This can be especially useful in group-monitoring efforts.
- **Date:** as the plants and seasons change, it is important to note the day, month, and year you recorded your data.
- **Time:** time of day can play a major influence on the temperature and soil moisture of your garden.
- **Rainfall (inches):** whether you have your gardens on an automatic watering system or are hand-watering your beds, it may be important to track additional water going into your AV system, especially if you are comparing and contrasting beds outside versus below the solar panels.
- **Temperature Min and Max:** record the min and max temperatures below the solar panels and away from the solar panels. This will require mounting two separate min/max readers in different locations.
- **Temperature Range Outside (No shadows, full sunlight):** record the outside temperature away from your AV system and in full sunlight using the digital temperature reader.
- **Temperature, Back of Hand (below solar panel and outside of solar panel):** are the people (not just the plants) under the AV system cooler?
- **Temperature of Bed:** capture the temperature in your AV beds near the base of *each* plant species you are monitoring using the digital temperature reader.
- **Height (centimeters):** use a ruler or measuring tape to capture the height (from the base of the plant to its tallest point) of *each* plant species you are monitoring.
- **% Soil Moisture:** use your soil moisture probe to capture the % soil moisture near the base of *each* plant species you are monitoring.
- **Moisture Stress:** note any dry or wilted plants for *each* plant species you are monitoring. Mark this category with a check mark or written description.
- **Plant Sprouts:** track approximately how many seeds you planted and how many sprouted for *each* plant species you are monitoring. Once plants have matured a bit, you no longer need to collect information for this category.
- **% Open Flowers:** mark the range of % open flowers that most accurately represents *each* of your monitored plants. % open flowers consider the amount of open flowers out of the total number of flowers *and* flower buds.
- **% Flower Buds:** mark the range of % flower buds that most accurately represents *each* of your monitored plants. % flower buds consider the amount of flower buds out of the total flowers *and* flower buds.
- **% Fruits:** mark the range of % fruits that most accurately represents *each* of your monitored plants. % fruits consider the amount of fruits out of the total flowers, flower buds and fruits on a plant.

*Depending on the plant species, it may be feasible to count the *total* flowers, flower buds, and fruits rather than calculate a *percentage* of overall coverage.*

DATA COLLECTION PROTOCOLS

- **Dried Fruit or Seeds Dropping:** track approximately how many ripe fruits and seeds drop to the ground. Mark this category with a check mark, number count, or written description.
- **Insects, Animals, and Additional Comments:** track any pollinators, animal species, and other interesting facts that you observe while at your AV site. Did you need to replant a bed due to extreme weather? Mark it here!

Weighing the Produce

One of the major questions we want to gather information on is the amount of produce being produced by AV plants. Each time you pick or harvest produce from *each* of your monitored plants, record it for the larger AV research program. If available, simply calibrate your scale with a produce bucket and keep a running record of your plant's total produce throughout a growing season.

Don't see any flowers, fruits, or not sure of an answer?

If you don't see some of the data (i.e., you have yet to see flower buds, fruits, or even sprouts in your AV system), that's perfectly ok. The plant's phenophase (the timing of its life cycle events) may not be happening just yet. Simply mark that row or column with an N/A. If you aren't sure of an answer, simply mark that row or column with a **?** We prefer that our scientists and citizen scientists alike answer with "I don't know" to ensure we get the best quality data available. It is much better to put a **?** than a false answer.

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Videos & Information about Tucson's Agrivoltaics Sites

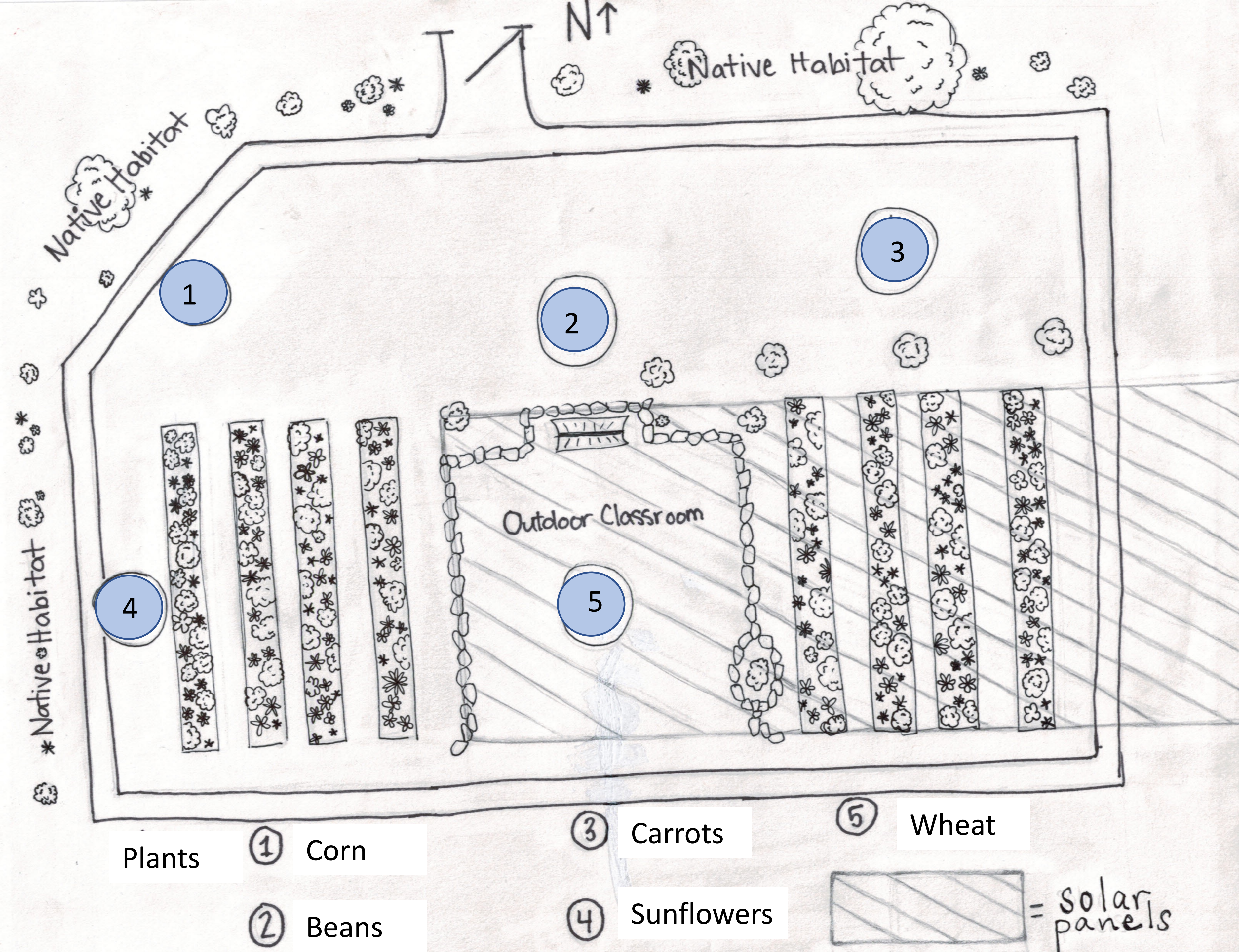
- ***Barron-Gafford Research Group*:** https://goo.gl/pUzCs8

- ***Biosphere 2 Agrivoltaics*** by the University of Arizona**:** https://www.youtube.com/watch?v=R35vs2VTwug

- ***Agrivoltaics with Greg Barron-Gafford*** by the UA's College of Social & Behavioral Science: https://www.youtube.com/watch?v=YphzeV6NeYM

- ***Solar Harvest*** by SciView: Sonoran Desert Science: https://www.youtube.com/watch?v=_fKt_Nj1nos

Drawing by Diana Englert



AV MAP KEY

Manzo Elementary School

Monitored Plant