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ECHO Development Notes

MICROCONTROLLERS: APPLICATIONS FOR SMALL-SCALE AGRICULTURE

The main purpose of this article is to create awareness of microcontrollers as a low-cost approach for real-time monitoring of environmental factors related to small-scale agriculture.

A DEEP LITTER SYSTEM FOR NATURAL CHICKEN PRODUCTION

ECHO network member Noah Elhardt shares a system that focuses on rearing healthy chickens from the ground up.

'KDV-1' MAIZE SEED AVAILABLE

ECHO's global seed bank is now offering variety trial packets of the variety 'KDV-1' which is a drought-resistant, white-seeded, open-pollinated variety from Kenya.

ECHO is a non-profit Christian organization.

For further resources, including the opportunity to network with other agricultural and community development practitioners, please visit our website: www.ECHOcommunity.org. ECHO's general information website can be found at: www.echonet.org.

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Low-Cost Microcontrollers: Applications for Small-Scale Agriculture

by Tim Motis

The main purpose of this article is to create awareness of microcontrollers as a low-cost approach for real-time monitoring of environmental factors related to small-scale agriculture. The first section presents potential uses of data, such as air and soil temperature, which can be monitored using a range of technologies. For those interested in exploring the use of microcontrollers, there are additional ECHO resources including programming code for microcontroller projects undertaken at ECHO and a question and answer page on ECHOcommunity.org. We will do our best to respond to your questions.

Usefulness of field monitoring

Small-scale farmers base their livelihoods on the productivity of small parcels of land, which is influenced by environmental factors like temperature, soil moisture, rainfall, sunlight, and humidity. Farmers and gardeners manage their crops and livestock based on these factors. Seasonal rainfall and soil moisture, for example, affect when farmers plant and irrigate. Through experience and up-close observation of their crops and soils, farmers develop a keen awareness of weather and soil conditions affecting crop performance. There is no substitute for this kind of innate knowledge in making daily management decisions.

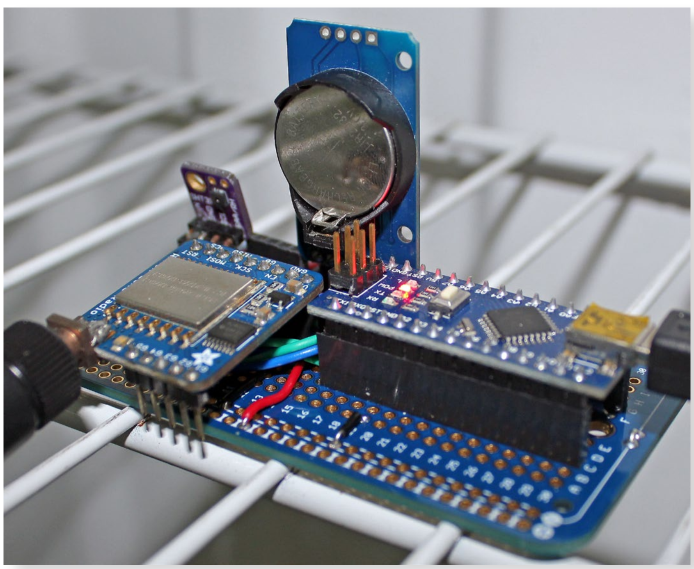


Figure 1. An Arduino® Nano microcontroller that monitors temperature and humidity in a seed storage room at ECHO. *Source:* Tim Motis

Yet, the ability to precisely measure and monitor growing conditions can benefit smallholder agriculture in important ways. Farmers could utilize such data to help inform decision-making. Field data is also helpful for evaluating innovations or practices for their potential to improve crop production. Imagine a scenario in which a farmer field school is testing a new variety of maize. Considering how weather can vary from year to year, or even from one field to another, it would be helpful to track temperature and rainfall during the trial. That way everyone would know the exact conditions under which the new variety succeeded or failed. A technician or development worker assisting in the research could play a role in acquiring and setting up data collection devices in experimental plots. Table 1 lists a few other applications for monitoring environmental conditions.

Table 1. Potential applications for monitoring environmental conditions.

Monitoring parameter	Potential agricultural applications
Air temperature	**Crop production:** 1) evaluating crop varieties for heat tolerance; 2) crop selection based on prevailing temperatures, 3) calculating growing degree days (heat units)[1] for predicting crop growth stages and making related management decisions **Seed banking:** evaluating the effectiveness of storage techniques (e.g., earthbag structures or burying seeds in airtight containers underground) to stabilize the temperature for extended seed life **Poultry:** monitoring conditions for newly hatched chicks or ducklings
Soil temperature and moisture	**Soil husbandry:** 1) evaluating the effectiveness of crop residues or mulch in moderating against temperature extremes and preserving soil moisture; 2) determining the effectiveness of watering/irrigation practices

Table 1. Potential applications for monitoring environmental conditions.

Rainfall	**General agriculture:** 1) evaluating crops for drought tolerance; 2) deciding when to plant based on the amount of rain received and its effect on soil moisture; 3) deciding when to irrigate
Humidity	**Seed banking:** 1) evaluating the effectiveness of desiccants and containers for keeping orthodox seeds dry; 2) monitoring storage spaces to prevent humidity levels from rising to levels favorable to mold **Plant disease management:** 1) anticipating times when disease incidence could be high; 2) evaluating when to plant so that grain/seeds mature when mold and fungal diseases are least likely to be a problem (this is related to rainfall as well)
Light	**Cover crop management:** evaluating the extent to which cover crops shade the soil **Agroforestry:** evaluating the extent to which different trees or combinations of plants shade the understory

Automated monitoring of conditions affecting crops, seeds, and animals involves electronic measuring devices equipped with desired sensors. With growing usage of mobile phones, real-time data is increasingly achievable in low-resource settings. Even without internet access, it is possible to log and store data automatically. Perhaps the most significant barrier to farmers' use of these technologies is the need for a computer for downloading data or uploading software. My hope, however, is to shed light on affordable technology that 1) is useful for conducting agricultural experiments; 2) makes data accessible to farmers; 3) can be used to monitor conditions in agricultural spaces such as seed banks (Figure 1); and that 4) farmers can potentially use (after prototyping and programing).

❶ Formula: GDD = ([maximum temperature + minimum temperature]/2) - minimum temperature for crop growth

For example, let us say that on a given day temperatures reached a minimum of 25°C and a maximum of 32°C.

The crop for which we are calculating GDD stops growing if temperatures drop below a minimum of 10°C.

Therefore, the number of GDD for that day = ([32 + 25]/2) - 10 = 18.5. This is done for each day that the crop is grown, allowing you to track the cumulative number of GDD over the growing season.

Proprietary versus open-source technology

Proprietary technologies are typically produced in factories with copyright restrictions on coding and design. As long as you install them properly, following included instruction manuals, they usually function as designed and take little time to install. The cost of proprietary loggers and weather stations, however, is often out of reach for small-scale farmers and those serving them. A research-grade weather station can easily cost 800USD or more. Even with warranties and company product support, product maintenance and replacement of damaged components is a challenge in many parts of the world. Additionally, products often require software updates and eventually become "outdated," requiring the end user to purchase newer hardware.

This article focuses on open-source technology related to the Arduino® suite of microcontrollers. These technologies are based on open sharing of software and hardware design. Downsides of these technologies are that they require time to assemble and to develop software code that make them work. Programming, however, is simplified with freely available Arduino IDE software and firmware (programs) can be edited as needed for future modifications. Moreover, components are available through international websites such as AliExpress and Bangood and are easily replaceable. As far as cost, at this writing (March 2022), each of the microcontrollers mentioned in this article can be acquired for less than 10USD.

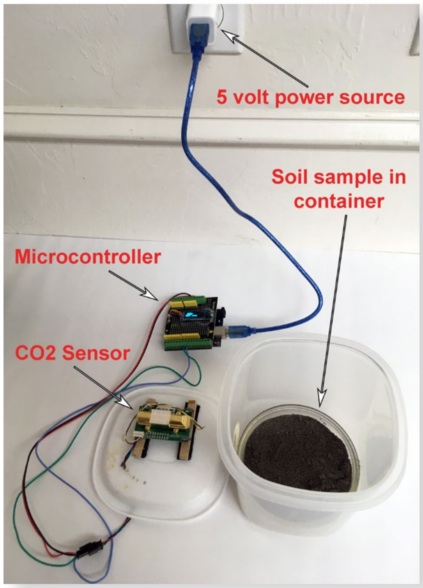


Figure 2. Carbon dioxide sensor. *Source:* Tim Motis

❷ Most microcontrollers operate at either 3.3 or 5 volts. I often use 3.7 volt lithium ion batteries, for the following reasons:

They power the 3.3 volt microcontrollers I use most frequently (Arduino Pro Mini and Wemos Lolin ESP32).

They are easily paired with inexpensive boost converters to power 5 volt microcontrollers; to find options online, use a search phrase like "DC-DC 3.7v to 5v boost converter step up module"

They are rechargeable.

Other battery options include alkaline (non-rechargeable) and rechargeable nickel metal hydride (NiMH) double A batteries. Websites with information on the use of batteries include Sparkfun and Battery University.

What does a microcontroller do?

Think of a microcontroller as a tiny computer that does specific tasks, like reading a sensor every hour. Once programmed, the microcontroller and any sensors connected to it can operate apart from a computer. The usefulness of microcontrollers goes beyond data logging. Microcontrollers can perform actions triggered by sensor readings. You could turn on a heat source if temperatures drop too low or turn on a solenoid valve if soil moisture levels indicate that water should be applied to a garden or field.

Use of microcontrollers at ECHO

My interest in microcontrollers started with a hobby of keeping fish and corals in a saltwater aquarium. I was "hooked" after discovering that I could use an Aruduino® Uno to automate light exposure and the addition of compounds (e.g., calcium) for coral growth. I soon realized that what I was learning was relevant for agricultural systems. I do not consider myself an electrician or computer programmer, but below are some of the devices that I have built at ECHO through my own independent learning and practice. Perhaps they will lead to ideas for your own applications.

Carbon dioxide sensor

As living things respire, they release carbon dioxide. Carbon dioxide release from soil serves as an overall indicator of soil microbial activity (Gyawali *et al*., 2019). An internet search for carbon dioxide sensors will result in a range of options. I am using the MH-Z14A sensor, which measures up to 5000 parts per million (ppm) carbon dioxide. The concentration of carbon dioxide in outdoor air is a little over 400 ppm. With the setup shown in figure 2, readings stay well under the measurable limit of 5000 ppm. Before taking measurements, we sieve the soil to exclude respiration of plant roots. The rate of carbon dioxide release from the soil will be higher for moist than dry soil, so we take steps, such as collecting soil samples at the same time, to ensure that all samples have the same moisture.

Light meter

The meter in figure 3 measures light intensity from four sensors along a bar measuring approximately 1 m in length. Powered with a 3.7 volt battery,❷ it displays the average lux of the four sensors. We use it for measuring shade from trees or cover crops. In each plot we take a reading above (full sun) and below the crop canopy. From these readings we calculate percent shade. Full sunlight can exceed 100,000 lux (Ferrante and Mariani, 2018). The sensors I used only read up to 55,000 lux. This would be a problem if I wanted to know the absolute (actual) value of sunlight hitting the sensor. Since I only want to calculate percent shade, I placed the sensors in dark-colored glass bottles. With

Figure 3. Light meter with lux sensors in dark glass bottles for measuring percentage shade. *Source:* Tim Motis

the bottles being dark enough to keep readings below 55,000, the lux readings continue to increase with increasing sunlight, allowing for calculation of percent shade even during the brightest time of day.

Weather stations

Rainfall is critical to plant and animal life and is an important weather parameter to measure on any experimental farm. The simplest and most reliable way to do this is to measure rain collected in a cylinder.[3] It is not always possible, however, to manually read and empty the gauge every day. There is also the issue of evaporation loss between readings, particularly in hot climates which can distort values. Automating the task of measuring rainfall addresses these problems and is commonly done with self-emptying tipping bucket rain gauges.

With a tipping bucket rain gauge, water is funneled to two small buckets on a horizontal axle. As the first bucket fills, the added weight causes it to tip downwards, positioning the second bucket under the funnel. This action repeats as it rains. With each tip, a magnet attached to the bucket assembly moves across a reed switch connected to a power source and a microcontroller. You can program the microcontroller to count the resulting pulses of electricity and then calculate rainfall based on the volume of one tipping bucket and the area of your rain collector.[4]

Tipping bucket rain gauges are usually just one component of weather stations that also measure other parameters such as air temperature and relative humidity.[5] While not necessarily cost prohibitive to purchase a weather station, they can be difficult to repair when components malfunction. By building your own, you can customize it with replaceable parts.

The first weather station I assembled measured rainfall with a Misol WH-SP-RG rain sensor (Figure 4A) commonly sold as a replacement part for home weather stations. Figure 4C shows a weather station I built for my garden with a rain gauge consisting of a metal funnel glued to the top of a tin can placed over tipping buckets made from a thin sheet of metal as described by Hampton (2016). The weather stations shown in

Figure 4. Solar-powered weather stations with manufactured (A and B) and homemade (C) rain sensors connected to microcontrollers. *Source:* Tim Motis

[3] You can make your own manual rain gauge, using commonly available containers. See Make a Rain Gauge by AlphaRomeo (2011).

[4] Steps involved in calibrating a tipping bucket for use with a microcontroller:

1) Balance the two tipping buckets so each of them tips downward with the same volume of water. This is done by using a screwdriver to adjust the height of a screw under each bucket.

2) Determine the volume of water per tip. Since 1 milliliter (ml) equals 1 cubic centimeter (cm), it works well to do this in ml. Slowly pour 100 ml of water into the rain gauge and count the tips. Do this three or four times and calculate the average number of tips per 100 ml of water. Let's say you get 25 tips. 100 ml/tip divided by 25 tips = 4 ml/tip. 4 ml = 4 cubic cm.

3) Calculate the catchment area in cm. The area of a square is length X width. That of a circle is pi (3.14) X the square of the radius (half the diameter). Let's say your catchment area is 100 square cm.

4) Rainfall height per tip = tip volume in cubic cm /catchment area in square cm. Rain height per tip, then, would be equal to the number you calculated in step 2 divided by that calculated in step 3. In this case, rain height per tip = 4/100, 0.04 cm of rain per tip.

5) In the code you use to program your microcontroller, define 1 tip as 0.04 cm or the equivalent in mm or inches.

[5] Reviews and links to cost information on home weather stations can be found on websites such as The Weather Makers and Weather Station Advisor. Hannan (2020) reviews several weather stations from the perspective of plant pest and disease management.

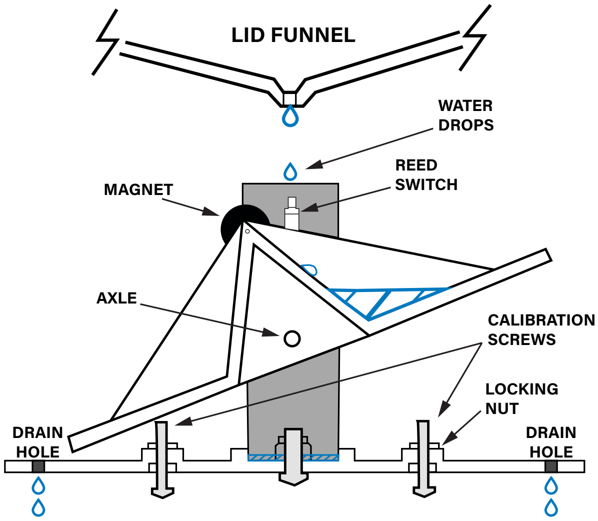


Figure 5. Diagram of tipping bucket rain gauge components. *Source:* Renee Gill adapted from https://www.instructables.com/Arduino-Weather-Station-Part3-Rain/

figure 4 are powered with solar-charged 3.7 volt batteries, log data to a microSD card, and send data to the internet for monitoring via mobile phone. Through the process of testing and problem solving, I have found that missed readings with these weather stations are usually due to power (batteries run down with inadequate solar power) or mechanical issues (debris falling into the rain gauge and preventing movement of the tipping bucket). A manual gauge could serve as a backup rain gauge in the event a tipping bucket rain gauge (Figure 5) malfunctions.

Seed bank temperature and humidity monitor

Some of our seeds at ECHO in Florida are kept in a room cooled by a window air conditioner connected to a CoolBot controller. We needed a way to monitor temperature to ensure that the CoolBot is working properly. Using some of the same components used for weather stations, I was able to make a temperature and humidity monitor (Figure 1) that sends data to a receiving unit in an adjacent building where there is wireless internet connection. Interfaced with a website called IFTTT (If This Then That), the receiving unit sends an email alert if the temperature in the seed storage room gets above 16°C.

Examples of microcontrollers and sensors

Microcontrollers

In learning how to use microcontrollers, many people start with the Arduino Uno. It has a great deal of functionality. For battery-operated applications in the field, I prefer to use the smaller Arduino Pro Mini or Arduino Nano microcontrollers, which consume less power than the Uno. The Pro Mini and Nano are the two microcontrollers that I have had the most success with for tracking rainfall.

Another microcontroller that works well in the field is the Lolin ESP32. It is optimized for power from 3.7 volt lithium ion batteries. I use it to log soil temperature and moisture. Like the Pro Mini and Nano, you can prolong battery life by programming the microcontroller to operate in sleep mode between readings. It also has Bluetooth® and WiFi (internet) capability.

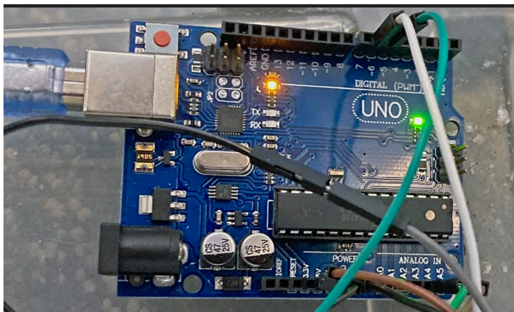
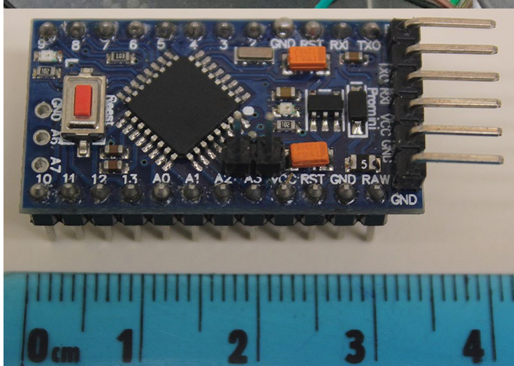
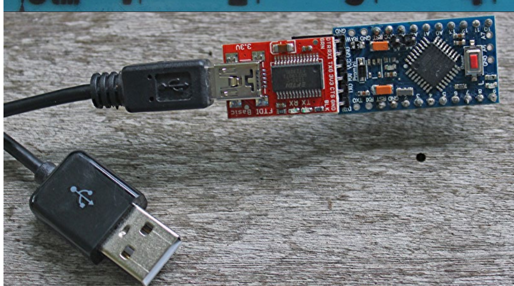
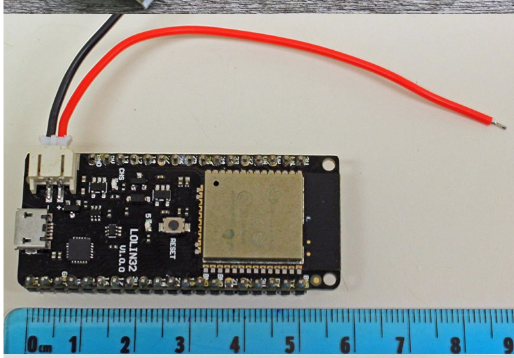
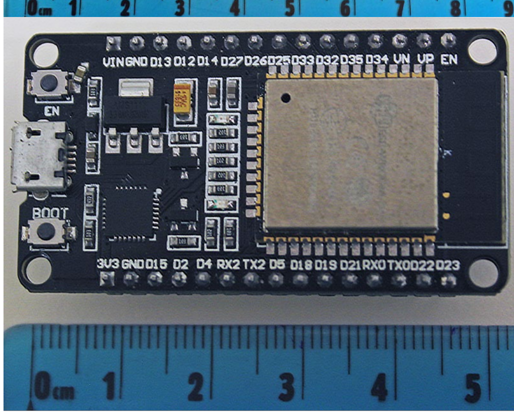
The Lolin ESP32 is better optimized for low power than the ESP8266, but I have found the ESP8266 to be useful for receiving data from other microcontrollers and sending that data to the internet.

A few factors to consider in selecting a microcontroller for your project are:

- Power supply needed
- Low-power options for battery-powered applications
- Whether or not you need WiFi or Bluetooth® capability
- Compatibility with sensors you plan to use; design is easiest if the operating voltage of the sensor and microcontroller are the same

All of the microcontrollers in table 2 are available through websites like AliExpress and Bangood that ship internationally. When purchasing a

Table 2. Examples and brief descriptions of a few microcontrollers.

	**Arduino Uno** Operating voltage: 5 volts USB connector: Type B Cost on AliExpress: 8.80 USD[1] Speed: 16 megahertz
	**Arduino Pro Mini** Operating voltage: 3.3 volts Cost on AliExpress: 4.94 USD[1] Speed: 8 megahertz NOTES: The six pins on the right connect to what is called an FTDI adaptor (red component in bottom photo), which connects to a computer via USB (cable needed depends on the USB connector on the FTDI adaptor you purchase).
	There is also a 16 megahertz version that operates at 5 volts. A similar microcontroller called the Arduino Nano (Figure 1) also operates at 5 volts and does not require the FTDI adaptor.
	**Lolin ESP32** Operating voltage: 3.3 volts Cost on AliExpress: 5.15 USD[1] Speed: 240 megahertz USB connector: micro USB NOTES: To power with a 3.7 volt lithium ion battery you need a PH-2, 2.0 mm connector, usually sold in packs. The photo to the left shows a connector with red and black wires
	**ESP8266 (Nodemcu 12-E)** Operating voltage: 3.3 volts Cost on AliExpress: 1.90 USD[1] Speed: 80 megahertz USB connector: micro USB NOTE: Works great for receiving data and transmitting it to a web server.

[1]Costs in this table, obtained in 2022, could change over time. They do not include shipping, which could vary by country. By ordering from websites such as Amazon, you can receive items more quickly, but costs will be higher.

microcontroller, pay close attention to any other items you might need. These include the appropriate USB cable and, in the case of the Lolin 32, a wire connector to connect a battery power supply.

Sensors

What do you want to measure? So far in this article, I have mentioned rainfall, temperature, humidity, soil moisture, and light. For just about any agricultural parameter, there is probably a sensor for it! Below are brief descriptions and suggestions for sensors I am familiar with.

Temperature and humidity

Many sensors measure both temperature and humidity. One of the simplest is the DHT22 sensor (Table 3A), available as a module that already has the required resistor. It works well for measuring temperature and humidity in a room or seed storage container. When placed outside, the humidity sensor tends to stay at 99.9% during the early morning hours, a problem caused by condensation on the sensor. For an outdoor weather station, I prefer a Sensirion SHT3X sensor (e.g., SHT31) in a plastic or ceramic enclosure. These can be found on AliExpress for 11USD. Shield the sensor from the sun, while maintaining air circulation around the sensor, to avoid overestimating the temperature (Tarara and Hoheisel, 2007); you can make your own radiation shield with small plates or bowls (Jakub_Nagy, 2017).

Soil temperature can be monitored with the waterproof version of the DS18B20 sensor (Table 3B). I bury them in the soil as is, but waterproofing could be optimized further by inserting them into a PVC pipe sunk into the ground.

Rainfall

To make your own rain gauge you need a reed switch, a small magnet, and a tipping bucket assembly. Look for what is called a ***normally open*** reed switch. A pack of 10 switches costs less than 1USD on AliExpress. Magnets can be as small as 2 mm wide, costing under 3USD on AliExpress. The tipping bucket assembly involves a little creative craftsmanship. You can use local materials to make the tipping buckets and a bracket to hold the buckets and reed switch in place. A simpler approach would be to buy a rain sensor or use one from an old weather station. Any tipping bucket rain sensor will work if you can access the two wires attached to the reed switch.

Soil moisture

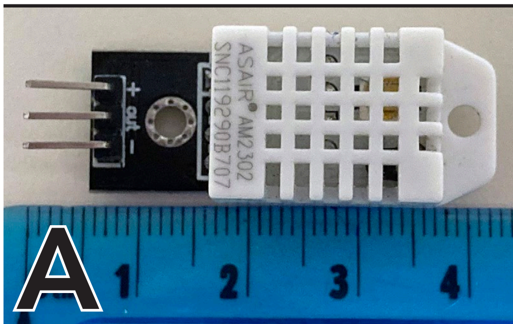
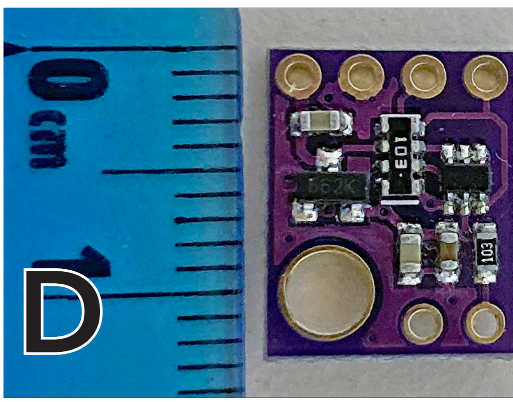
Monitoring soil moisture helps you assess the impact of rainfall or irrigation. You will likely bury a soil moisture sensor at a depth where most of your crop's feeder roots are located. Sensor readings will indicate whether water from a rainfall or irrigation event is sufficient to wet the soil at that depth. There are sensors based on resistance and capacitance.[6] To avoid corrosion, use a capacitive sensor like that shown in Table 3C.

[6] Seeedstudio, a supplier of soil moisture sensors, features an article entitled Soil Moisture Sensor – Getting Started with Arduino that explains the difference between resistive and capacitive soil moisture sensors.

Light

Table 3C shows a light sensor that measures visible light in a unit called lux. Not all visible light can be used by plants for photosynthesis; however, a lux reading does provide an indicator of light intensity at the time it is taken. Lux measurements can be used to assess the

Table 3. Examples and brief descriptions of sensors commonly used with microcontrollers.

	**DHT22 temperature/humidity sensor** Tutorial: Arduino- Temperature Humidity Sensor Voltage: 2.3 to 5.5 volts Cost on AliExpress: 2.40 USD[1] NOTE: To avoid having to purchase and connect a required resistor, buy the sensor in module form (pictured left); the module will already have the resistor attached.
	**DS18B20 waterproof temperature sensor** Tutorial: Adruino-Temperature Sensor Voltage: 3.0 to 5.5 volts Cost on AliExpress: 1.67 USD[1] NOTE: The sensor requires a 4.7 kilo ohm resister; it can be purchased with a module that includes the resistor, thus, avoiding the need to purchase an external resistor.
	**Soil moisture sensor** Tutorial: Capacitive soil moisture sensor Cost on AliExpress: 0.57 USD[1] Voltage: 3.3 to 5.5 volts NOTE: Protect the electronics at the top of the sensor from water/rain. I house these sensors in short sections of PVC pipe.
	**MAX44009 light (lux) sensor** Tutorial: Wemos and MAX44009 ambient light sensor example Maximum lux: 188,000 Voltage: 1.7 to 3.6 volts (connect to 3.3 volt pin on microcontrollers) Cost on AliExpress: 4.45USD[1]

[1]Costs in this table, obtained in 2022, could change over time. They do not include shipping, which could vary by country. By ordering from websites such as Amazon, you can receive items more quickly, but costs will be higher.

effectiveness of cover crops for shading the ground. Young seedlings in greenhouses and nurseries often require protection from full sun; lux readings can be helpful for estimating the amount of shade under shade cloth or shade-providing structures.

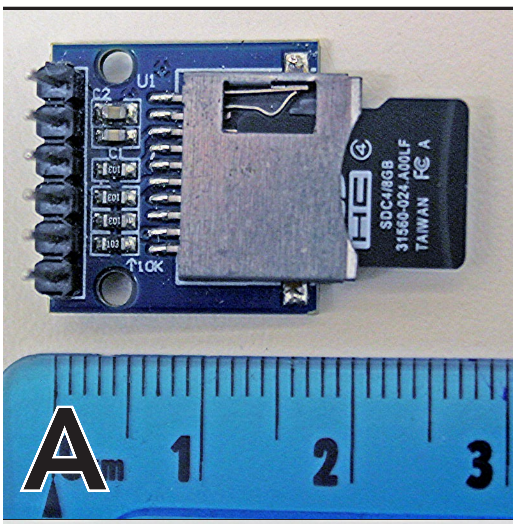
Supporting hardware

Other components are needed to make a microcontroller device perform desired functions. In a remote area, with no phone or WiFi signal, you can store readings (e.g., temperature) onto an SD card and then periodically transfer the data to a phone or computer. To track growing conditions over time, you will want to know the date and time of each reading. Storing time-stamped data on an SD card can easily be done by connecting microSD (Table 4A) and clock (Table 4B) modules to your microcontroller. Readings can also be displayed on a small screen (Table 4C).

Immediate, remote access to readings measured in the field helps with time-sensitive decision making. To monitor conditions in real time, I prefer LoRa (long range) radio transceivers (Table 4D) for low-power communication. A transceiver can transmit or receive data, allowing you to send data from one microcontroller to another. To do this you need a LoRa transceiver on each microcontroller. Incoming data from the field can be viewed on a display screen and/or posted online. Thingspeak and Adafrut IO are web-based platforms that allow you to view continuously updated graphs from field measurements on your phone or computer. The capacity of their free accounts is sufficient for most applications.

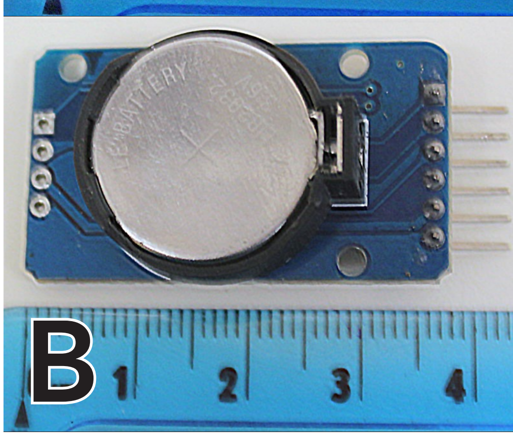
Supplying the correct voltage to a microcontroller requires other components. The microcontrollers mentioned in this article can be powered with 5 volts; those that operate at 3.3 volts have internal power regulators that convert 5 volts into 3.3 volts, as long as the regulator is not bypassed. An easy way to supply 5 volts to a microcontroller is to connect it with a USB cable to a 5 volt wall plug used to charge mobile phones. Battery power works best for outdoor devices. Table 4E shows a charge controller useful for integrating rechargeable batteries with solar power. If not already built into your solar panel, use a diode (an electrical component that allows electricity to flow in only one direction) to prevent battery power from flowing to the solar panel at night. Use a step-up voltage booster if the voltage of your power supply is less than what your microcontroller requires.

Table 4. Examples and brief descriptions of supporting hardware components commonly used with microcontrollers.



Micro SD card expansion module
Operating voltage: 3.3 volts
Tutorial: SD card module with Arduino: how to read/write data
Cost on AliExpress: 2.28 USD for 10 pieces[1]

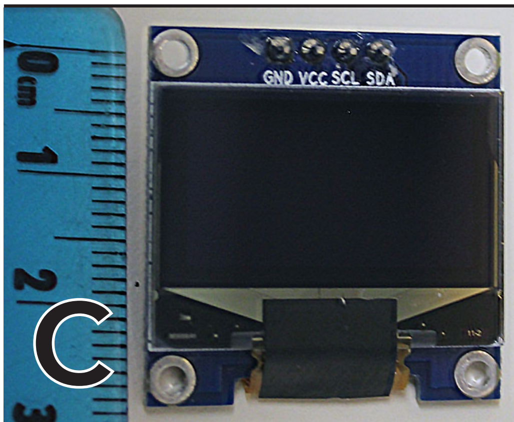
NOTE: If your microcontroller operates at 5 volts, use a micro SD card module that accepts 5 volts.



Real time clock (DS3231)
Operating voltage: 3.3 or 5 volts
Tutorial: Arduino - RTC
Cost on AliExpress: 3.89 USD[1]

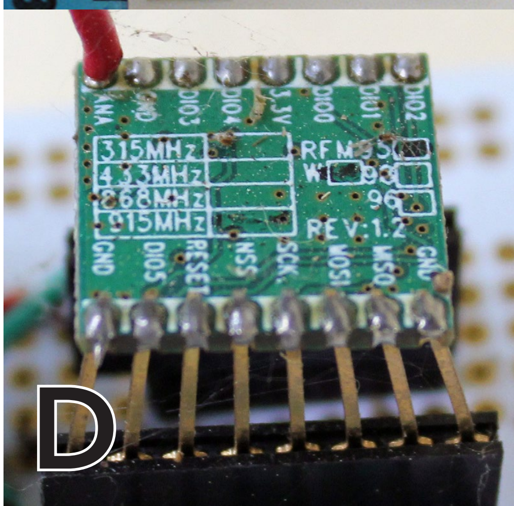
NOTE: Power the clock with a CR2032 or LIR2032 battery so that the time is retained even if power to the microcontroller is lost.

Table 4. Examples and brief descriptions of supporting hardware components commonly used with microcontrollers.



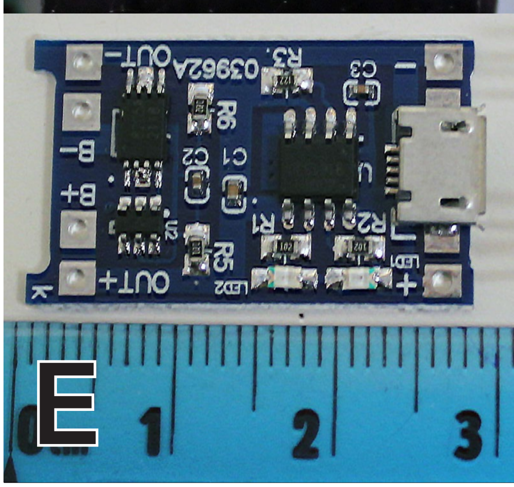
OLED display module
Cost on AliExpress: 1.68 USD[1]
Operating voltage: 3.3 to 5 volts
Tutorial: Arduino - OLED

NOTE: These come in varying sizes including 128 X 64 (pictured left) and 128 X 32 pixels.



RFM95 LoRa transceiver
Operating voltage: up to 3.7 volts
Tutorial: Introducing LoRa
Cost on AliExpress: 3.40 USD[1]

NOTE: Suppliers such as Adafruit offer the transceiver as a module that is easier to work with and compatible with both 3.3 and 5 volt systems.



TP4056 lithium battery charger
Input voltage: 0.3 to 8 volts
Tutorial: DIY-solar battery charger
Charge voltage: 4.2 volts
Cost on AliExpress: 0.20 USD[1]

NOTE: Works well for charging rechargeable 3.7 volt lithium batteries (e.g., 18650 battery) with 6-volt solar panels.

CAUTION: The TP4056 has built in overcharge protection. Nonetheless, take time to learn how to use batteries safely.

[1]Costs in this table, obtained in 2022, could change over time. They do not include shipping, which could vary by country. By ordering from websites such as Amazon, you can receive items more quickly, but costs will be higher.

Tips for getting started

Programming

Most microcontrollers come with a USB port. As mentioned earlier, purchase the right USB cable for your microcontroller; table 2 specifies the correct USB connector for the corresponding microcontrollers. Connect one end of the cable to a USB port on your computer and the other end to the USB connector on your microcontroller.

I use Arduino IDE software to program my microcontrollers. It is free of charge and is available for Windows, macOS, and Linux computer operating systems. Programs developed in Arduino software are called ***sketches***. They are written in ***Arduino Programming Language*** (based on C++) and then uploaded to your microcontroller. Fortunately, you don't have to be an expert programmer to come up with sketches for your projects. For everything I've built so far, I have found multiple tutorials and examples that not only explain how to connect sensors to microcontrollers, but also provide sketches with an explanation of how the programming code works. Go to the Getting Started page on the Arduino website to learn how to download the software and get started with programming.

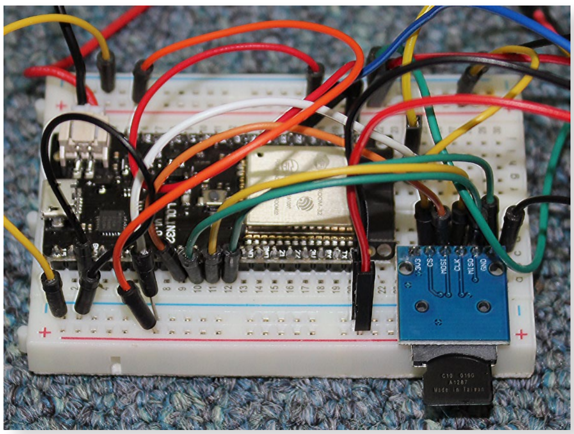


Figure 6. Solderless breadboard (white plastic base) and jumper wires (colored wires). *Source:* Tim Motis

My advice is to start small. Many people begin by learning how to blink a small LED light; Arduino starter kits often come with LEDs, connection wires, and other small parts. Get one sensor or function to work at a time. Save sketches that you have success with for future use. Small victories will lead to a growing body of code that becomes useful for later projects.

Prototyping

Make sure your project will work before attempting to build something permanent. There are starter kits available for beginners. Look for one that has a few solderless breadboards and sets of pre-made jumper wires (Figure 6). A solderless breadboard is a plastic component with rows and columns of holes, marked by letters and numbers, into which you can insert pins and wires. No soldering [7] is needed. The pins and wires are held in place by metal strips inside the breadboard that connect rows and columns of holes.

[7] Soldering involves melting solder to permanently bond metal parts. Solder is a metal alloy available in various forms. For soldering small electronic parts, most people use lead-free solder wire (Figure 8). The Arduino Guide to Soldering by Bagur (2022) explains more about what kind of solder wire to look for and how to solder.

Jumper wire is electrical wire for connecting components on a breadboard. You can make your own jumper wires with non-stranded, 22 AWG (AWG is a standardized unit for wire thickness) electrical wire and a wire stripper for removing the plastic sheath around the ends of each wire. Pre-made jumper wires, however, are easiest to use for quickly wiring and testing a breadboard circuit. They come in varying lengths with male and/or female connectors on the ends.

Fabricating

The metal strips inside solderless breadboards work well for testing circuits, but wires can easily come loose. For more permanency, transfer your circuit to a perma-proto board (Figure 7A), a metal version of a solderless breadboard with the same layout of holes. This is done by soldering pin headers, wires, and any additional components to the board (Figure 7B).[8] With the appropriate pin header soldered to the board (female) and microcontroller (male), place the microcontroller onto the board as shown in Figure 7C. With this approach, you can easily take the microcontroller off the board to replace or reprogram it if needed. The same applies to supporting modules.

[8] There are many tutorials and videos online that explain how to solder wires, pins and other components onto solderable breadboards. Adafruit and Sparkfun, guides illustrate how to install pin headers.

Soldering, like anything else, takes some practice but is not difficult to learn. I use tape to hold components in place while soldering. You will need a soldering iron, and some solder (Figure 8A). Look for a soldering iron with replaceable tips and, preferably, adjustable temperature. Trim off excess wire with a snipping tool like that shown in Figure 8B.

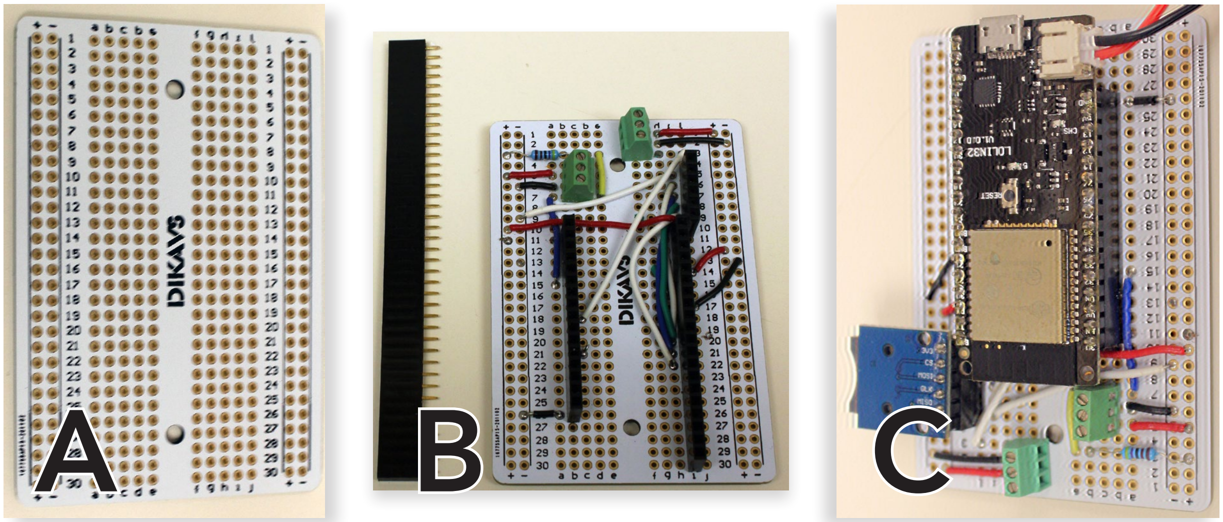


Figure 7. Perma-proto board before (A) and after soldering pin headers and wires (B), and plugging an ESP32 Lolin and MicroSD card module into female pin headers (C). The green components are screw terminals for connecting sensors to the mircrocontroller. *Source:* Tim Motis

When ready, you will need to install your project in its permanent location. Protect electronics from sun, heat, and water. Protection from these elements is particularly important in the tropics. I have found that microcontrollers placed in plastic containers exposed to the sun start to malfunction as flux (material used in solder to improve connectivity) in the solder spreads across connections. For that reason, I prefer placing components inside simple wooden boxes. Wood blocks the transfer of heat but needs protection from rain. Options for covering a wood box include aluminum foil and pieces of tin. Any holes for wires going to outside sensors should be drilled in the bottom of the box if possible, allowing any water leaking into the box to drain out.

Figure 8. A soldering iron and solder (A) and wire snipping tool (B). *Source:* Tim Motis

In addition to heat and rain, protect electronics from insects and rodents. Ants are not immediately destructive but will eventually cause problems. If ant baits fail, you could house your microcontroller project in an airtight container, such as a capped PVC pipe or Tupperware®, and then place everything inside a wood box or bury it underground. Figure 9 illustrates an example of an airtight container with an air pump accessory and tire valve cap to make a leak-proof connection for wires.

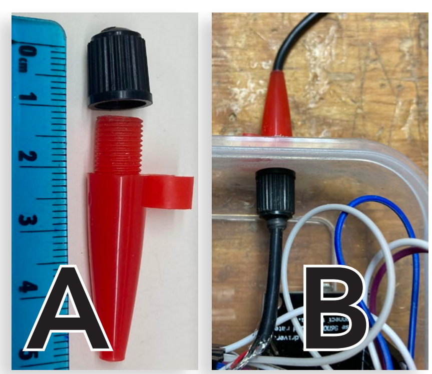


Figure 9. A commonly available air pump accessory in combination with a tire cap (A) to make a solid pass through for wires going outside a plastic container (B). Silicon glue or putty can be added to make it leak proof. Drill a hole through the tire cap and cut the tip of the air pump accessory to match the diameter of the wire. *Source:* Tim Motis

In some cases it makes sense to use small-diameter PVC pipe as conduit. Supply tubing for drip irrigation systems also works well. If your wires are too long to push through the tubing, try this:

- Find a non-stranded length of wire that is thick and stiff enough to push all the way through the drip tubing
- Solder one end of your sensor wire to one end of your push (thick) wire (Figure 10A)
- Insert the other (non-soldered) end of your push wire into one end of the tube and push it through the tube until the non-soldered end emerges out the other end of the tube

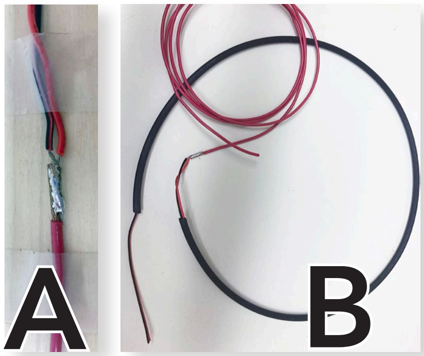


Figure 10. Sensor wire (A; top) soldered to one end of non-stranded wire (A; bottom) used to pull sensor wire through ¼ inch diameter drip irrigation supply tube (B). *Source:* Tim Motis

- Grasp the non-soldered end of the push wire and pull it along with the sensor wire through the tubing (Figure 10B)
- Once your sensor wire emerges, sever the push wire from the sensor wire

Conclusion

Microcontrollers offer an affordable means of monitoring environmental factors that influence plant and animal life. Select sensors with the specifications and appropriate level of accuracy for your application. With low-cost microcontrollers you can both monitor and even control environmental factors. Control of factors such as soil moisture and conditions in small spaces is accomplished by using sensed values to switch intervention measures on and off (e.g. irrigation valves, fans, and heat sources). Thus, there is potential to automate some tasks. Knowledge of electronics and computers helps, but you do not have to be an electrician or computer programmer to build useful devices. Over time, the availability of sensors and examples of useful microcontroller projects will likely increase, leading to more options. The References and Further Reading sections below will steer you to more information on this topic.

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Further Reading

Suppliers that provide tutorials with microcontrollers and sensors

- Adafruit
- Sparkfun

Weather stations

- A video with information on how tipping bucket rain gauges work and how to improve accuracy by interfacing a reed switch with what is called a Schmitt trigger: https://www.youtube.com/watch?v=KHrTqdmYoAk&t=872s
- Weather station that logs temperature and rainfall: https://github.com/DesiQuintans/sneesl-rain-logger (in the Firmware folder, click on the first file [01_Datalogger] for code that works well with Arduino Nano and Pro Mini microcontrollers])

Sample code for ECHO microcontroller projects: https://github.com/ECHOInternational/Microcontrollers

Soil moisture sensing with capacitive soil moisture sensors: Hrisko, J. 2020. Capacitive soil moisture sensor calibration with Arduino. Maker Portal. https://makersportal.com/blog/2020/5/26/capacitive-soil-moisture-calibration-with-arduino

Echoes from our Network: A Deep Litter System for Natural Chicken Production

by Noah Elhardt, Beersheba Project, Senegal

Introduction

The modern poultry industry has made huge strides in the efficiency and productivity of chicken operations, with hybrid broiler chickens reaching 2.26 kg (5lbs) in as little as five weeks (Hinsemu *et al.*, 2018). To achieve this, genetics, temperature, humidity, light, biosecurity, and nutrients are all meticulously controlled, while potential diseases are preventatively controlled with antibiotics. These operations can be very profitable, but also smell bad and have significant environmental and health risks.

Many small-scale farmers in the tropics cannot control all the factors necessary for success with these types of operations. In Senegal, small flocks are routinely wiped out by disease, heat stress, or other complications. This article presents an alternative growing system originating in Korea utilizing a deep litter.

This system (Figure 11) prioritizes chicken health and robustness by attempting to recreate conditions natural to chickens. This system does not produce as much as industrial systems, but can be more profitable for small-scale farmers by reducing both risks and costs. It focuses on growing vigorous chickens with a balanced gut flora (microbial population) raised in healthy conditions, so that these chickens can ward off diseases themselves. Benefits and challenges encountered with the deep litter chicken system are listed in table 5.

Figure 11. An 8x20 m deep litter coop operational in Senegal since 2017. *Source:* Noah Elhardt

Design attributes (Figure 12)

This deep litter coop design has three main distinctions from other coops: an organic layer as the floor of the coop, increased ventilation on all sides of the coop, and a gap in the roof. These three attributes help create a healthy environment for chickens to thrive.

Table 5. Benefits and challenges of the deep litter system.

Benefits	Challenges
Low building costs Low operational costs Healthy chickens Little to no smell or flies Less time spent cleaning the coop Quality, ready-to-use compost Reduced risk	Sourcing organic litter material, especially in urban or arid areas, can be challenging. Modern fast-growing meat breeds like the 'Cobb 500' no longer possess the strength or instinct to scratch or dig in litter. Raising these breeds requires additional work to turn the litter. Does not produce as much as high-input systems

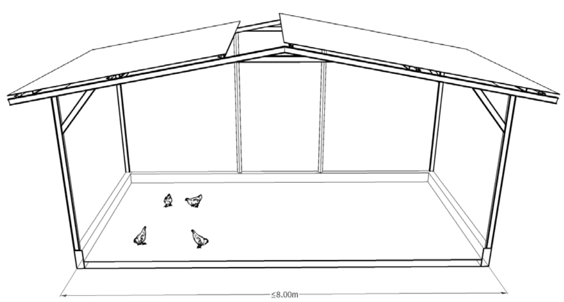

Figure 12. Schematic drawing of chicken coop. *Source:* Noah Elhardt

Figure 13. A littler floor. In Senegal, we use wood chips, peanut shells, and millet chaff for our litter. *Source:* Noah Elhardt

Litter

The litter at the bottom of the entire coop structure should be at least 15 cm deep. Inadequate litter will become wet, compacted, and smell bad. You want to select a litter that is loose, dry, and high in carbon. It will combine with the nitrogen-rich chicken droppings to form a living compost turned by the chickens as they scratch in their litter. Options for litter materials include dried leaves, crushed peanut shells, crop residue, grasses, and sawdust (Figure 13).

A well-established litter teems with microbes, which rapidly break down manure and also outcompete disease organisms. You can immediately tell if a litter is healthy - a healthy litter smells like a forest floor! To accelerate the formation of a diverse and active microbial community in your litter, you can inoculate it with Indigenous Microorganisms (IMO). These can be cultured using inexpensive local materials such as rice bran or milk. We typically apply these when first establishing a litter, or if problems or smells arise later on. For more information, view ECHO's resources about IMO [https://www.echocommunity.org/resources/tagged/Indigenous%20Microorganisms].

Chickens aerate and mix the litter by scratching as they look for food. Because the litter sits directly on the dirt ground, chickens also have access to the ground, allowing them dust baths and cooling. The reduction in cement costs is an additional benefit!

If you are in a dry climate, you may need to occasionally water the litter to keep the decomposition process going. After three to six months, litter materials turn into compost and can be used directly on crops.

Ventilation

Both the chickens and their litter benefit from a continuous supply of cool, fresh air. Coop walls should be made to maximize ventilation. We typically make two to four of our coop walls out of wire mesh or another material that maximizes airflow while keeping chickens safe from predators. The bottom 30-60 cm consists of a short cement or brick wall that protects against predators such as dogs, snakes, or rats (Figures 14-15).

An opening in the center of the roof allows hot air to escape. This creates a convection current that draws in fresh air from the sides even when there is no wind.

Sunlight

The opening in the roof also allows for sunlight to bake the litter floor throughout the day. Orient your coop so that, by sunset of each day, the entire coop floor will have received sunlight at some point. No other light or heat source is needed to keep the chickens warm or to stimulate egg production.

If your coop is small, the morning or evening sun streaming through the sides of the coop might cover the entire coop. If this is the case, you may want to add a shade structure similar to the one shown in figure 14 to provide the chickens with shade in at least part of the coop.

Roofing material, beam material, and bricks should be made with resources that are locally available. The roof in figure 14 is made from plastic tarp covered in grass thatch.

This design can be scaled to your needs for chicken production (Figure 15). We recommend a density of up to 5 birds per square meter.

Give chickens greens

An important part of success for any poultry system is a healthy diet for the chickens. When chickens eat well, they have the energy and health to fight off diseases and to produce quality products (meat, eggs, and offspring). In particular, greens are an important and often overlooked part of the chicken's natural diet. They are a critical part of this system in providing vitamins for the immune system as well as fiber for gut health. At the Beersheba Project, we feed 30-40 g of greens per chicken per day. Options for greens include grass, sweet potato leaves, moringa, katuk, chaya, weeds, and much more (Figure 16). For more information about incorporating greens and other local options into chicken feed, see "Cafeteria Feeding" of Chickens from *EDN* 97 (Peckham, 2007).

Figure 14. Shade structure made from bamboo. This is often a good idea on one or two sides in these small coops to ensure shade availability in the mornings and late afternoons, and/or for wind protection. *Source:* Noah Elhardt

Figure 15. This system can be scaled for profitable operations in a variety of settings. This 4x4m pen holds 80-100 birds. *Source:* Noah Elhardt

Figure 16. In Senegal, we use forage grasses, leucaena, moringa, and weeds as our chicken greens. We plant foraging material close to the coop to make management and feeding easier. *Source:* Noah Elhardt

Conclusion

The deep litter system described here highlights the use of a simple, creative coop design to harness the benefits of naturally occurring resources –sunlight, air, and microbes– for long-term success in raising healthy chickens. Combine elements of structural design with healthy feed for best outcomes.

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From ECHO's Seed Bank 'KDV-1' Maize

by Rocheteau Dareus

Significance of maize for smallholders

Maize (*Zea mays*, L.) is a cereal crop grown in Tropical and Subtropical regions of the world as a food and feed source for human and livestock consumption. In Sub-Saharan Africa, half of the population is estimated to use maize as a staple food in their daily diet (Infonet Biovision, 2022). Maize kernels have high nutritive value providing carbohydrates, protein, vitamins, and minerals. Maize is consumed in a wide variety of ways including methods that utilize dry (maize meal, porridges, pastes, and beer) and fresh (baked, roasted, and boiled maize) ears. Maize economically impacts smallholders' financial stability and is often grown, in part, for sale. Depending on the region where it is grown, grain, leaves, stalks, tassels, and cobs are marketable either for food or non-food products.

In the Global South, subsistence agricultural systems are predominant, but maize is a crop frequently used both for food and feed for the household and as a cash crop. However, many smallholder maize systems are unable to reach peak performance due to a lack of access or availability of high-quality inputs such as fertilizer, improved seed, irrigation, and labor. Additionally, a lack of access to good credit systems or co-op structures limits farmers' involvement in markets.

Significant breeding efforts have been made over the past decades to help solve some of the problems encountered by small-scale farmers growing maize. Varieties of maize have been developed and released with improved overall yield, seed quality, and/or resistance/adaptation to biotic (e.g. pests and diseases) and abiotic (e.g. drought and heat) factors. In this article, we present the maize variety 'KDV-1.'

'KDV-1' (Figure 17)

The maize variety 'KDV-1' is an open-pollinated variety developed in Kenya as a Katumani composite[9] and is adapted to arid, low altitude areas. It is a short-season (early maturing), white-seeded grain maize that is resistant to Maize Streak Virus (ECHO Staff, n.d.). Its production cycle is 45 to 52 days from seeding to tasseling and 75 to 90 days from seeding to harvest (mature ears; Dryland Limited, 2022). Recommended planting depth and spacing are 2-10 cm and 75-90 X 25-60 cm, respectively (Infonet Biovision, 2022). Deeper sowing (5 to 10 cm) and wider spacing (90 X 30-60 cm) is recommended for dryland areas. With a seed rate of 15-20 kg per hectare (ha), KDV-1 is expected to yield 15 to 42 90-kg bags/ha (2.2 to 3.8 metric tonnes/ha) (Dryland Limited, n.d).

[9] A composite is the result of a mix of varieties grown together with uncontrolled pollination. Katumani refers to a place in Kenya (KALRO, n.d.). Katumani composites are suited to low-altitude, dryland (400-800 mm annual rainfall) (Infonet Biovision, 2022).

Figure 17. 'KDV-1' maize at maturity. *Source:* Holly Sobetski

Due to its earliness and resilience to drought, 'KDV-1' is a good option for farmers looking for a variety that safeguards their food security and resists negative impacts of climate change. 'KDV-1' is also known to produce high quality seeds that farmers can save and use in subsequent planting seasons; the Kenya Agricultural and Livestock Research Organization (accessed 2022) recommends purchasing fresh seed after a third season of seed saving.

Farmers should be aware that:

- 'KDV-1' is an open-pollinated white-seeded grain variety and can cross with other maize varieties. This is relevant in regions where seed coat color plays a key role in people's culinary choices. Where yellow seeded maize is grown and preferred, prevent cross pollination by not growing 'KDV-1' simultaneously with yellow seeded maize.
- 'KDV-1' is a field corn variety often used to make flour or to feed to livestock. The kernels are not as sweet tasting as those of sweet corn.

Conclusion

'KDV-1' is an early-maturing open-pollinated field corn variety adapted to dry areas. It has high yields with white kernels. With the adverse effects on crop production of ever-changing climatic patterns, 'KDV-1' holds promise for small-scale farmers looking for options to increase their food security, feed their livestock, and maintain their household's financial stability. Active development workers who are members of ECHOcommunity.org may request a trial packet of seed. See the website for how to register as a member and how to order seeds.

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Books, Websites, and Other Resources

by Stacy Swartz

WHO Monographs on Selected Medicinal Plants (4 Volumes)

ECHO often gets requests for information about medicinal plants. Although ECHO does not focus on researching or experimenting with the medicinal traits of tropical plants, many of the tropical crops promoted by ECHO for other purposes also have medicinal value. In the past, ECHO has directed interested network members to the work of ANAMED, an international non-profit organization with over 30 years of experience with medicinal plants. It was recently brought to our attention that the World Health Organization also has resources on medicinal plants in a four-volume set. Volumes are organized by scientific name of the plant and include a great deal of information. While some information may not be what most of ECHO's network is looking for, such as the chemical composition and detailed description of the plant appearance, there are sections under each plant description that may be very useful. For each plant the following topics of potential interest are presented in detail if available:

- Plant material of medicinal interest
- Clinically tested medicinal attributes
- Anecdotal reports of medicinal attributes
- Warnings/adverse reactions/precautions
- Pathway or explanation of medicinal activity

The volumes contain information about the following plants that are familiar to ECHO, many of which are offered from our Global Seed Bank:

- Onions (volume 1)
- Senna (volume 1)
- Calendula (volume 2)
- Passionfruit (volume 3)
- Neem (volume 3)
- Jujube (volume 3)
- Cucurbita (volume 4)
- Guava (volume 4)

Volumes 3 and 4 have cumulative indexes so you can use these to see what the current volume you are reading contains, as well as content of previous volumes. There is also a cumulative index for plant part (instead of plant name) such as fruit (fructus) and root (radix). Unfortunately, the monographs do not include an index by ailment.

Find these WHO Monographs on selected medicinal plants and other information about medicinal plants at http://edn.link/qettfp.

Canadian Foodgrains Bank Video Series on Conservation Agriculture and Marketing

Many farmers face difficulties in navigating the complexities of marketing their crops. A single farmer may not have enough to justify bringing his or her crop to market. During the peak of the season when the market is flooded with produce, it may not be economically feasible for a farmer to bring his goods to market.

Canadian Foodgrains Bank has produced and released Conservation Agriculture and Marketing Videos that explain how to work alongside farmers to facilitate marketing decisions on a community level. The video series is broken down into four steps. Each step has a short description and a video demonstrating briefly how to conduct the exercise.

Step 1: Market Mapping and Strategies

Step 2: Seasonal Price Calendar

Step 3: Gross Margin and Comparative Analysis

Step 4: Collaboration and Aggregation Strategies

These videos are practical, succinct, and appropriate for smallholder contexts. The information they provide can and should be contextualized to local preferences and resources. The videos walk you through activities to help facilitate communication and collaboration between farmers within a community. All decisions should be made by the local community. Within a 2 to 3 hour timeframe, practicing the four outlined steps can help a group identify the hurdles they face in marketing their products, discuss realities of local market dynamics, and determine potential collaboration opportunities.

Upcoming Events

ECHO Asia Event
Adoption of Agriculture Innovations Symposium

ONLINE EVENT
April 22, 2022

ECHO Event
Introduction to Tropical Agriculture Development

ECHO Global Farm, USA
September 12-16, 2022