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ECHO Development Notes

FACTORS THAT IMPACT SEED GERMINATION

This article explains factors that impact germination, drawing on input from ECHO staff and network members with experience in seed banking and seed saving.

INTENSIVE MORINGA PRODUCTION

At the Beer Sheba Project, moringa is grown for both leaf and seed production. Managers of the moringa plots have tried different spacing options over time and share their findings in this article.

CLAY BEADS

This article summarizes work being done at ECHO in Florida to develop a method for small-scale farmers and community seed banks to make their own desiccant to dry and preserve seeds.

Books, Websites, and Other Resources | Upcoming Events

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Factors that Impact Seed Germination

by ECHO Staff and Network Members

Introduction

Crops in ECHO's seed banks are selected for their ability to grow under difficult growing conditions and for their potential importance for the smallholder farmer. ECHO's seeds are tested annually for germination percentage, a measure of seed viability. The germination percentage written on ECHO seed packets is based on this annual testing. It is calculated from a sample and cannot be guaranteed. This article explains factors that impact germination, drawing on input from ECHO staff and network members with experience in seed banking and seed saving. For additional factors that impact overall crop success beyond germination, see the article Introducing a New Crop: Reasons why seeds fail from *EDN* 104 [http://edn.link/x3wqdc].

Seed traits

Seed characteristics vary depending on the crop you are working with. These traits can impact seed storage life and germination. Attributes of the seeds themselves are largely out of your control, but should be considered during planning.

Orthodox and recalcitrant seeds

Recalcitrant seeds, like canistel (*Pouteria campechiana*), black sapote (*Diospyros nigra*), neem (*Azadirachta indica*), and jackfruit (*Artocarpus heterophyllus*), do not remain viable for long periods of time. Crops with recalcitrant seeds are harvested and mailed fresh but should be planted very soon after they are received. Often, germination problems are caused by other factors besides the seed itself either from environmental reasons or farmer practices.

Dormancy

Be aware of potential dormancy issues with seeds you plant. Some seeds such as winged bean (*Psophocarpus tetragonolobus*) and many other bean (Fabaceae family) seeds have hard seed coats which is a form of external dormancy.[1] External dormancy is overcome through seed scarification, the altering of the seed coat to allow water to pass through it so that germination can begin. Seed scarification techniques include filing, nicking (Figure 1), and softening (with warm or hot water) the seed coat (Motis, 2009). To scarify smaller seeds, you can place them in a closed container with rocks/stones and shake it to crack open the seed coat or put them on a surface and scratch the other side with sandpaper (Gilroy, 1986). Be careful not to damage the embryo of the seed.[2] Some seed dormancy mechanisms are not fully understood. Several *Annona* species have either external or internal dormancy mechanisms that may require cold dormancy and/or seed coat softening such as *A. crassiflora*, *A. macroprophyllata*, and *A. purpurea* (da Silva *et al.*, 2007; Ferreira *et al.*, 2016).

[1] External and internal are the two main categories of seed dormancy (Geneve, 2003) . External dormancy is controlled by characteristics of seed coverings. Internal dormancy is caused by factors that inhibit the embryo inside the seed. Seeds with internal dormancy may require light (e.g., lettuce [*Lactuca indica*]) or a period of cold (e.g., apple [*Malus domestica*]) to germinate.

Figure 1. Nicked seed coat of bean with fingernail clippers.
Source: Stacy Swartz

[2] See an *ECHO Technical Note* entitled Seed Saving: Steps and Technologies (Motis, 2010) for a photo of lima bean (*Phaseolus lunatus*) seed structures including the embryo.

Environmental factors

Soil texture and moisture

Seeds require moist conditions for germination to take place. Soil texture and organic matter content impact the water holding capacity of soils and therefore the germination of seed. Poor seed to soil contact in sandy soils can cause insufficient moisture for seed germination. Ideally, soil texture and moisture should be such that moist soil is firmly in contact with the seed. After planting seeds into soil, you can compact the soil with your hands, feet, or a roller (Figure 2) to increase the seed-to-soil contact. Do this gently to avoid excessive compaction, which could impede seedling emergence. Clay soils are more prone to over compaction than sandy soils. After rain events, clay soils can also form a crust on the soil surface that is difficult for new seedlings to emerge through. Clay soils hold water very tightly and have very small pores. If too much water surrounds seeds, they can become too soft and rot before root initiation. Conversely, sandy soils drain well but are more likely than clay to dry out. If you are digging furrows to place seed in, you can place an amendment high in organic matter such as compost or worm castings at the bottom of the furrow to help moderate the moisture holding capacity of the soil around the seeds. Organic matter moderates against problems associated with both fine (clay) and coarse (sand) soils.

Figure 2. Simple water roller to help increase seed-to-soil contact in coarse soils. *Source:* Tim Motis

Soil pH

Ideal soil pH for crop growth varies by species. The ideal soil pH for most crops is near neutral (7.0), between 6.5 (slightly acidic) and 7.5 (slightly alkaline). Some crops that grow in acid soils (pH less than 5.5) include rice (*Oryza sativa*), cassava (*Manihot esculenta*), mango (*Mangifera indica*), cashew (*Anacardium occidentale*), citrus, pineapple (*Ananas comosus*), cowpeas (*Vigna unguiculata*), blueberries (*Vaccinium* spp.), and select grasses (FAO, 2023). A pH value outside of a crop's optimal range will probably not keep seeds from germinating, but could slow germination (Pérez-Fernández *et al.*, 2006). If you do not know your soil pH, view the FAO's topsoil pH map. Soil pH can be increased by adding lime, crushed shells, or wood ash and can be decreased by adding sulfur-containing compounds.

Soil salinity

Saline soils are found in arid and semi-arid contexts globally. High soil salinity decreases germination because the high concentrations of salts in the water around the seeds limits the diffusion of water into the seed (the process of imbibing) which is required for germination (Welbaum *et al.*, 1990). Crop varieties (Khajeh-Hosseini *et al.*, 2003) and species differ in the level of soil salinity they can tolerate. For a list of crops that tolerate saline soils and options for growing in saline soils, see *ECHO Technical Note* 84: Understanding Salt-Affected Soils [http://edn.link/tn-84].

Oxygen

The embryo inside a seed is alive and respiring, using oxygen and releasing carbon dioxide as food stores are converted into energy. In cool, dry storage, seed respiration is kept at a minimum to preserve seeds. Once exposed to oxygen, warm air temperature, and moisture, a seed will start to respire more rapidly. Normally, pore spaces in soil contain air that allows for the transfer of gases and uptake of oxygen for seeds and soil life. When pore spaces are very small or are filled with water, oxygen becomes limited. This causes respiration and germination to halt for most crops. Oxygen-limiting conditions are a consequence of excessive compaction or water. Over compaction is often associated with high clay, low organic matter, and the breakdown of soil particles/structure with excess tillage. Overly wet conditions are caused by flooding, waterlogging, and poor drainage (linked to

Figure 3. Earth swale used to direct and/or retain water. *Source:* Tim Motis

❸ Gilroy's book entitled "Starting Right with Seeds" [http://edn.link/fcfd044] contains optimal soil temperature ranges for germination of a number of tropical crops.

Figure 4. Greenhouse wall with plastic siding that can be partially or completely rolled down to moderate temperature and airflow inside the greenhouse. *Source:* Tim Motis

Figure 5. Damping off symptom in a young seedling. *Source:* Eustacio Gonzales

compaction and low spots in a field). Semi-aquatic (rice) and aquatic (water spinach; *Ipomoea aquatica*) crops tolerate flooding conditions when mature but may still have sensitivity during seed germination. You can mitigate some of these problems by building soil organic matter content through mulching and crop retention, minimizing tillage, planting on raised beds, and the use of swales to direct or hold water in areas of your field (Figure 3).

Light

Seeds without innate dormancy germinate after exposure to adequate temperature, water, and oxygen, while seeds with innate dormancy require an additional stimulus (Frankland and Taylorson, 1983). Light is one potential stimulus for germination that some crops require for germination to begin. Crops that require light to germinate include lettuce, celery, dill, and onion (Steil and Jauron, 2023).

Most crops do not require light for germination to occur, but all crops require light for proper shoot elongation after germination. When plants are grown in areas with too little light, they become leggy (tall with little leaves) because they are searching for light. This stresses the crop and results in a weaker stem structure. To encourage germination and healthy growth, vegetable seeds should be started in a nursery context with moderate light then moved to full sun. Grain and pulse crops should be sown directly into areas with full sun.

Temperature

In general, seeds germinate in warm temperatures between 20°C and 25°C (Gilroy, 1986).❸ Most seeds require at least 24°C for germination, although sensitive species will not germinate if temperatures are slightly higher or lower than a preferred range (Ashworth, 2002). Eggplants and peppers germinate at temperatures around 27°C which is on the high range for lettuce seeds but low range for Malabar spinach (which requires 29°C). Temperatures should stay consistent throughout the germination process, minimizing large flucuations. In the field, moist soil acts as a natural buffer to drastic temperature changes because changes in water temperature take much longer than air temperature shifts. In a greenhouse, closing the walls at night to retain heat or opening them during the day to allow air circulation can help moderate extreme temperatures (Figure 4).

Pathogens

Fungi, bacteria, and other microorganisms can cause rot or damage seeds in other ways. Some of the most common pathogens are *Fusarium* and *Phytophthora* spp. These fungi cause rot that often leads to seedling collapse (Figure 5). Soil and water borne fungal diseases can damage the stems of tender seedlings, causing them to wilt and die. Most of these organisms thrive in warm, moist environments which are also ideal for seed germination. In the nursery, crack or remove seed coats of crops such as canistel, mango, and mamey sapote (*Pouteria sapota*) to prevent premature rotting of the seed coat before the embryo emerges. Combine frequent watering (given the small volume of planting trays and containers) with good drainage to help control pathogens. In the field, monitor low spots for fungal diseases and replace plants at early signs of infection. You can also treat seeds with pesticides (natural or synthetic) before sowing to mitigate soil and seed-borne infections. Many synthetic options are difficult for smallholder farmers to obtain. Table 1 lists some low-resource options that have been tried for various pests with variable success. More options are likely available locally such as those described by Sridhar *et al.* (2013). Try local seed treatment options on a small subset to test effectiveness and minimize risk.

Seed predators

Birds, rodents, ants, millipedes, weevils, and other pests consume seeds. You can treat seeds with pesticides (natural or synthetic) before sowing to deter some seed predators. See table 1 for some ideas. Grain pests such as

Table 1. Low-resource options for seed treatment.

Active ingredient	Control pest	Methods	Effectiveness	Source(s)
Gliricidia sepium	Seed-borne pathogens	Chop 1 kg bark, add water to cover. Soak seed in liquid for 12-14 hours. Discard floating seeds.	Effective for corn (*Zea mays*). Unknown effectiveness on other crops.	Stoll, 2000
Vinegar	Seed-borne pathogens	3% acetic acid solution. Dip seeds into solution then dry before sowing or storing. Household vinegar is about 5% which does effect germination.	Effectively tested for 14 common garden cultivars.	Gilbert, 2023
Bleach	Seed-borne pathogens	0.6% NaOCl dilution. Dip seeds into solution then dry before sowing or storing.	Effectively tested for 14 common garden cultivars.	Gilbert, 2023
Hot Water	Seed-borne pathogens	Suspend mesh or cotton bag of seed in hot water (must be appropriate temp) for recommended amount of time (specific to species). Remove and place in cold water to stop the heating process. Dry before sowing or storing.	Highly effective against *Alternaria* and *Phoma* species. Also good effectiveness against *Xanthomonas campestris*.	Nega, 2003
Azadirachtin (Neem)	Various (micro-organisms, insects, and pathogens)	Coat seeds in dried neem leaf powder or in neem oil before sowing. Rates vary based on plant material used (leaves, kernal, seed cake, etc.)	Variable based on target pest. Pre-treating rice seeds with 5% or 10% neem seed oil solution significantly reduced growth and development of two rice insect pests at their larval stage. Neem leaf extract (1.95 mg/ml) inhibited *Pythium* spp. growth in laboratory contexts.	Kareem *et al.*, 1989; Kareem *et al.*, 2018
Ash	Seed-borne pathogens	Apply in various ways to or with seeds before sowing.	Effective partial control (up to 42% compared to commercial pesticide) for corn against several seed-borne fungi and seedling blight. Variable control of other pests recorded in literature.	Ekpo and Banjoko, 1994
Garlic	Fungal pathogens	Extract garlic juice and dilute in water at a rate of 1:1 to 1:5 (juice to water). Soak seeds in dilution 24 hours before sowing.	Antifungical properties have been reported effective at reducing fungal pathogens up to 52% in infected wheat (*Triticum* sp.) seeds. Effectively reduced fungal seed born infection in rice.	Perelló *et al.*, 2013; Ahmed *et al.*, 2013

Table 1. Low-resource options for seed treatment.

Active ingredient	Control pest	Methods	Effectiveness	Source(s)
Worm tea	Fungal pathogens	Various dilutions of aqueous vermicompost (whether aerated or non-aerated) from 0.1 to 5%.	Extracts of vermiculture compost are most commonly sprayed on plant leaves as a foliar anti-fungal agent. Some researchers have looked into effects of seed treatments with extracts and found that aerated vermicompost tea effectively helped control *Fusarium moniliforme* in rice seedlings.	Sarma *et al.*, 2010
Fermentation	Seed-borne pathogens	Ferment seeds in pulp/juice of ripe fruit for 24 to 72 hours. Wash and dry seeds before storage or sowing.	Effective for some seed-borne diseases, but not others. Varied reports for controlling *Acidovorax citrulli* in watermelon (some reports effective others not). Ineffective for controlling tomato mosaic virus in tomatoes.	Ge *et al.*, 2021; Broadbent 1956; Hopkins, *et al.*, 1996; Ashworth, 2002
Thyme oil	Seed-borne pathogens	For fungistatic effects: dilute thyme oil to 2% in water. Agitate seeds in solution for 5 minutes. Dry before sowing or storing. For bacterial disinfection: dilute thyme oil to 1% and treat for 0.5 hours.	Highly effective against *Xanthomonas campestris* pv. *campestris*, *Clavibacter michiganensis* subsp. *michiganensis*, *Alternaria dauci* and *Botrytis aclada*, *Aspergillus flavus*. No negative effect on germination.	Nakada-Freitas, 2022; Wolf, 2008
Aerated Steam	Seed-borne pathogens	Expose seeds to aerated steam at 85%-95% humidity. Ideal temperature and duration varies by seed type and target pathogen. Temperatures between 50 and 60° C for durations around 5 minutes were common in the literature cited. Cool rapidly and dry before sowing or storing.	Effective against various species of *Fusarium*, *Drechslera*, and *Alternaria*. Highly effective against *Magnaporthe grisea*, *Cochliobolus miyabeanus*, and *Gibberella fujikuroi* in rice. Effective against *Xanthomonas campestris*, *Botrytis aclada*, Stemphylium, Septoria, *Ascochyta pisi*, *Phoma medicaginis*, and Pinodella.	Forsberg, 2004
Baking Soda (sodium bicarbonate)	Fungal pathogens	Soak seeds in a 2:1 to 3:1 dilution of baking soda: water before sowing in the field.	Has broad effectiveness against fungi. Researchers verified effectiveness of five different species across soybean and cowpea seed-borne fungi.	Kareem *et al.*, 2018; Afolabi and Kareem, 2018

rice, bean, and maize weevils feed on seeds in storage and can damage the embryo or the food storage structures in seed. For options for controlling pests in stored seed, see *EDN* 158.

In *EDN* 104, Motis (2009) mentions the following:

> You may need to build sturdy fences to protect plantings. In areas where chickens cannot be excluded, consider transplanting more established plants (e.g., at ECHO we root sugar cane cuttings in pots before transplanting out where chickens are present), or placing obstacles such as palm branches on garden beds or around the base of plantings.

> If low-cost and farmer-accepted methods of insect control exist, it could be advantageous to monitor insect activity and intervene as needed to keep infestations to a manageable level. It is wise to decide ahead of time the level of inputs and intervention you will devote to a particular crop. Fruit trees, for example, would merit much more care than a forage crop.

For more information and ideas for pest management, see *ECHO Technical Note* 98 on Integrated Pest Management.

Agronomic practices

Seeding depth

Another important cause for seed germination or seedling failure includes planting seeds too deep or too shallow. If seeds are planted too deeply, the seed may not contain enough energy to push the shoot out of the soil before it exhausts its food reserves (endosperm). If seeds are planted too shallow, roots may not be anchored deep enough, or seeds may dry out easily. As a general rule, you should plant seeds three to four times the width of the seed (Gilroy, 1986). Small seeds need little or no soil covering but are extremely vulnerable to drying out so make sure to water frequently during the first few weeks of these seeds' life. Larger seeds have greater amounts of energy to push the first shoot (plumule) through the soil and into the air above the soil. Orientation of the seed being sown is not vital as seeds innately sense gravity and will send shoots up and roots down.

Length of storage and storage conditions (packet sent vs. when planted; time between opening packet and planting)

Strive to plant soon after opening a seed container. Once the container is opened, humidity can adversely affect seed viability. If you store seeds in hot or humid conditions, the viability will quickly decrease, and seeds could die or be compromised in a short period of time. If you do not use all the seeds in one planting, you should store them in a hermetically sealed (airtight) container to exclude humidity. Place unused seeds in sealed containers while they are still dry, as hermetic sealing of moist seeds will lead to mold. The practice of hermetic sealing can be optimized by combining it with vacuum sealing and/or desiccants. Vacuum sealing withdraws air from a container, lowering humidity and oxygen in the container; reduced oxygen, in turn, slows respiration and the activity of insect pests. For more information about vacuum sealing, see *ECHO Technical Note* 93: Vacuum-Sealing Options for Storing Seeds. Desiccants like toasted rice absorb humidity, helping to keep seeds dry in containers that need to be opened from time to time (e.g., to take a few seeds out for planting). Species vary in shelf life or life span in storage. The seed storage life of lettuce or melons is not the same as maize or beans. For more information and options for seed storage, see *ECHO Best Practice Note* 5: Seed Storage in the Tropics.

Watering

Watering too much, too little, or inconsistently can impact germination. After initial sowing, allowing the soil to dry out can kill emerging seedlings. Consistent watering with adequate drainage is essential.

Seed should stay moist but not saturated during germination. Some crops such as jack bean (*Canavalia ensiformis*) can germinate with very little rainfall or irrigation while others such as pumpkins and squash (Cucurbitaceae) require considerable water supply[4] for successful germination. These crop seeds could be soaked in water before sowing to help with seed water absorption (imbibition; Gilroy, 1986).

[4] *From ECHO Network Member who is a seed breeder:* Water quality/purity, as well as water temperature, may impact quality of seedlings. I see pollution of our water sources more than ever before, and especially runoffs of certain herbicides. As seedlings are most susceptible to absorption via new growth, the presence of any ppb of herbicide retained in water may negatively impact seedlings' ability to grow normally. I have firsthand experience, and witnessed the drastic impact on a whole crop of seedlings.

Variability in nursery conditions

When working in a nursery setting, people often optimize tray space by sowing two or more crops in each seedling tray. While this saves resources, the two crops may have different light and moisture requirements, resulting in poorer germination for one or more crops in the tray (Figure 6). If two or more species are grown in the same seedling tray, make sure they have similar requirements and growth patterns.

Figure 6. Seedling tray with multiple species and varying germination success per species. *Source:* Holly Sobetski

Post-harvest handling of seed

Germination and seedling success can be altered by poor post-harvest handling of the seeds during production. If the grower handled seeds roughly during harvest, threshing and winnowing, or cleaning, the seed coat (pericarp) may have been cracked or damaged, allowing humidity to enter the seed and decreasing the life span and vigor of the seed. You should receive seeds from suppliers securely and promptly. Seeds should be completely clean, free of fruit pulp which can rot and cause fungal infections, and free of weed seed or chaff.

Assessing Seed Quality

Seed viability

Seed viability is a measure of how many seeds are alive and relates to the number of seeds that could develop into productive plants under farmer field conditions (Bicksler, 2011). The greater the viability of your seeds, the fewer seeds will be needed to establish a desired number of plants in the field or nursery. The most common way to assess viability is with a germination test (Figure 7).

Seed vigor

Seed vigor relates to the overall capacity of seeds to grow well under a range of field conditions and stresses. This can be assessed, in part, by recording germination percentage each day and noting the number of days to reach 50% germination. Another indicator of seed vigor is

Figure 7. Simple germination tests of beans using a wet paper towel (left) or directly seeding into soil (right). *Source:* Stacy Swartz

the percentage of seedlings that are normal. Normal seedlings are not stunted and have well-developed roots and shoots (Figure 8). It is possible to conduct germination tests in soil from farmers' fields, but this is not always practical and disease and pest-related factors can make results difficult to interpret. Test the germination of stored seeds on a regular basis (at least once a year) to assess their viability over time. This will tell you the rate at which seed vitality is deteriorating. For details on how to conduct simple germination tests, see *ECHO Asia Note 11* [http://edn.link/an11].

Figure 8. Malformed okra (*Abelmoschus esculentus*) seed with shoot emerging before root. *Source:* Stacy Swartz

What went wrong? Diagnostic table

Table 2. Possible causes of failed seed germination or seedling success. Source: Gilroy, 1986.

Problem	Potential cause
No sprout	Seed not viable, diseased, planted too deeply, overwatered, or underwatered
Slow sprout	Soil too cold, not enough water
Seedlings are yellow and leggy	Too little light, too warm
Seedlings are leggy	Too much water, too little light
Seedlings collapse at soil line	Damping-off, encouraged by low light and soil that is too warm or wet
Seedlings are stunted	Too little water, aphids
Seedlings are healthy but grow slowly	Not enough soil space for roots

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Echoes From our Network: Moringa Spacing Considerations

by Noah Elhardt and Emile Diouf, Beer Sheba Project and Stacy Swartz

At the Beer Sheba Project in Senegal, *Moringa oleifera* is grown for both leaf and seed production. Managers of the moringa plots have tried different spacing options over time and would like to share their thoughts on the frequently asked question, "What spacing should I use for moringa?".

The most important factor affecting the spacing of moringa trees is what you will use the tree for. If trees are used for leaf production for human or animal consumption, they can be planted close together. If they are planted for pod or seed production, whether for seed multiplication, vegetable pods, or oil production, they need to be planted farther apart. See table 3 for recommendations from the literature. These ranges vary due to soil type, water, inputs, harvest frequency, management practices and other on-farm considerations.

Table 3. Minimum and maximum spacing recommendations for a few production commodities based on published literature.

	Minimum	**Maximum**
Leaves	5 cm x 10 cm (Amaglo *et al.*, 2006)	50 cm x 100 cm (Leone *et al.*, 2015
Seeds and pods	2.5 x 2.5 m (Kumar *et al.*, 2014)❺	5 x 5 m (Emongor, 2011)
In agroforestry systems	2 m between rows (Leone *et al.*, 2015)	4 m between rows (Leone *et al.*, 2015)

❺ *Another ECHO network member shared the following about their moringa production for seed:* The 2.5 m x 2.5 m would be a minimum. But the farther you plant them apart (from my experience) the wider they tend to grow instead of vertically. So if you want to keep the branches low, you can cut it at 60 cm and force it to branch out, then after some good regrowth, cut all the branches again at about 1 m. Keep repeating this until you get a wide tree. But what I can't say is if doing this will produce more or fewer seeds than just letting it do what it wants to naturally. One thing I did observe when I let them grow naturally, is that branches tend to be tall and vertical. That's fine until it's full of pods and then the slightest wind will break the branch. I lost lots of moringa tree tops to wind in Sept-Oct (the normal harvest time in East Africa).

Leaves and stems

For leaf production, we initially direct-seeded 0.5 ha at 1 x 1 m spacing (Figure 9A). Tree survival rates were high and gave good harvests of leaves with lots of stems. After the second year, production lessened somewhat. At this wide spacing, managers of the plot spent a lot of time weeding.

We have since switched to intensive cultivation in 4 x 4 m blocks (Figure 9B), with plants spaced at 10 to 20 cm. These plantations need intensive

Figure 9. 1 x 1 m spacing (A) vs. four blocks of 4 x 4 m moringa intensive production (B). *Source:* Noah Elhardt

inputs and regular reseeding and are highly productive. They also need very little weed management, and water and soil amendments are more easily and efficiently applied than in wider spacings.

To prepare for planting, we dig a 4 x 4 m bed to a depth of 50 cm. We add 15 sacks of chicken bedding, and then cover this amendment with the removed soil. We water the bed for 3 to 4 weeks, after which further soil is added to raise the plot to about 5 cm above ground level (Figure 10). After leveling it with a rake, we seed (one seed per hole) and mulch the plot. Emergence typically follows in 5 to 7 days. We water daily, with a weekly application of compost tea (liquid organic fertilizer). After each harvest, we reseed any missing plants and add two wheelbarrows of compost. Moringa regrows rapidly after being coppiced (cut back) during harvesting with several branches often emerging below the last cut. In this manner, we have had plots in production for three years, though there is a slight decrease in production after the first year (Figure 11). We have not had to re-establish plantings yet. When re-establishing you may have to completely remove moringa stems to keep old trees from re-sprouting. Beds could be rebuilt, and plantings re-seeded as explained earlier.

Figure 10. Complete bed ready for planting. *Source:* Noah Elhardt

Here in Senegal, we harvest these blocks every 2 to 3 months during the dry season by cutting them about 10 to 15 cm above the ground (Figure 12). The average yield of fresh leaves across 204 harvests in the last two seasons was 9.3 kgs, or about 6 tons/ha. These same cuttings also produced 31 kgs of stems on average, which we use as high-protein livestock feed. We typically manage three to four cuttings in a dry season on each plot, before rainy season conditions in Senegal lead to a degradation in leaf quality. Plots are harvested during the rainy season to feed livestock and maintain plot health. We cut about one block per day so that we have a continuous supply of leaves to use or dry.

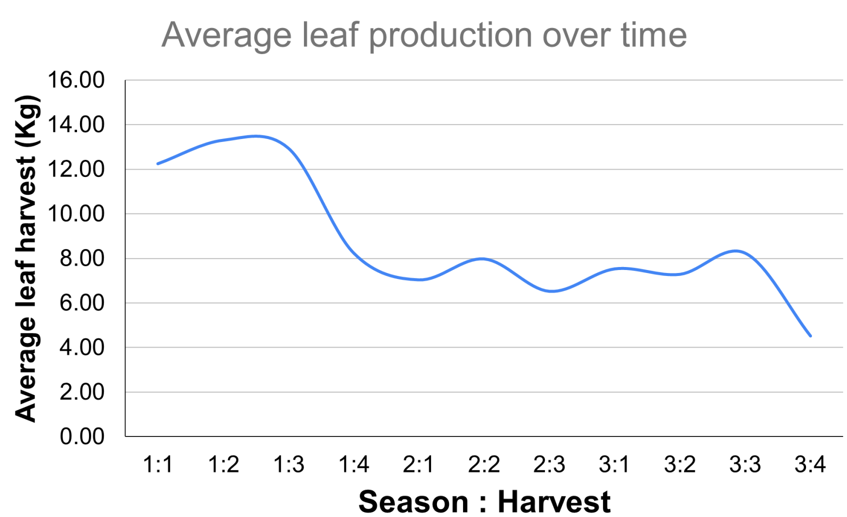

Figure 11. Average harvest in Kg of leaves per season and harvest. *Source:* Noah Elhardt

Figure 12. Cut vs. uncut moringa block. *Source:* Noah Elhardt

In a recent trial, we planted six to eight intensive plots at each of three different grid spacings (with equal distance within and between rows): 10 cm, 15 cm, and 20 cm. Over five harvests, the plots spaced at 15 cm have shown the highest leaf production (Figure 13). The 20 cm spacing produced a higher ratio of stems to leaves. Most of our leaf production plots now use 15 cm spacing.

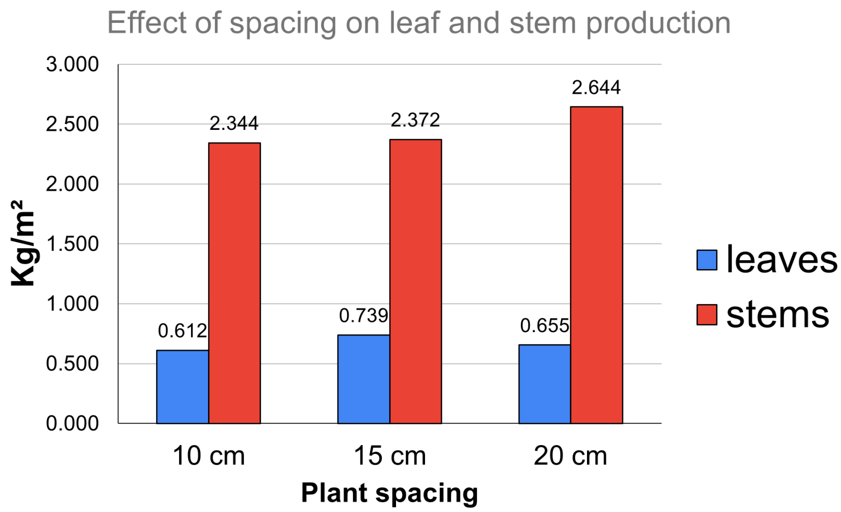

Figure 13. Spacing impact on stem and leaf production.
Source: Noah Elhardt

Impact of harvest intervals

Minimizing spacing between moringa plants seems to increase the ratio of leaves to stems. The interval between harvests also has an impact.

Our harvest data from the last two seasons shows little correlation between harvest interval and the weight of fresh leaves produced (Figure 14A). Additional growth time beyond 60 days does not appear to increase leaf production at these close spacings.

However, the weight of harvested stems continues to increase with harvest interval (Figure 14B). The time between harvests strongly influenced the ratio of stems to leaves in our harvests (Figure 14C). The ideal harvest interval therefore depends on whether you have a need for leaves, stems, or both.

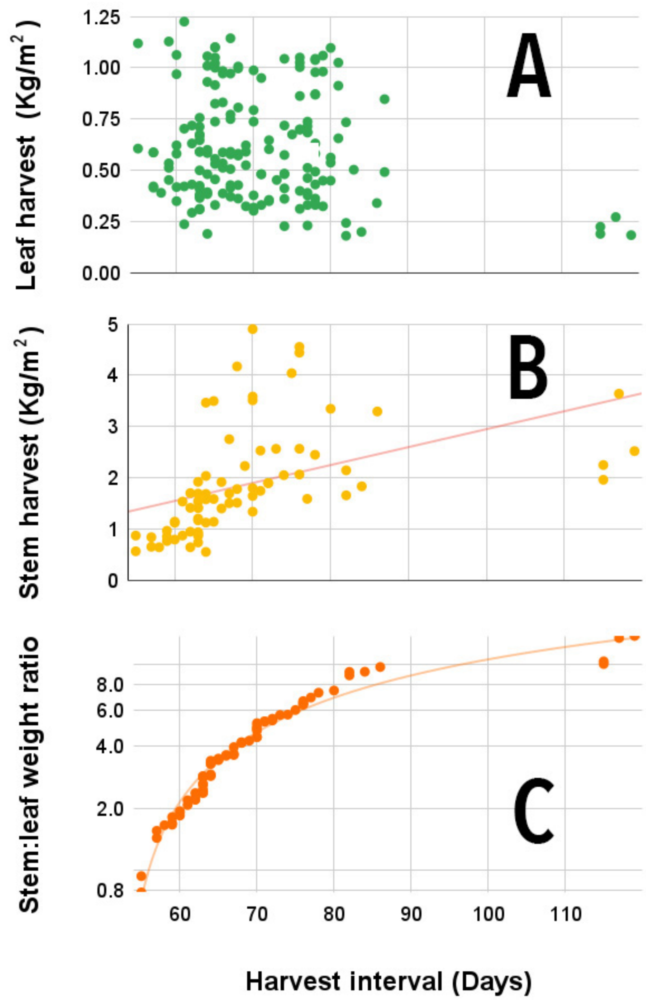

Figure 14. Impact of harvest time on leaf production (A), stem produciton (B), and stem:leaf ratio (C).
Source: Noah Elhardt

Seed production

For seed production, we grow trees on a 4 x 4 m grid, which seems to work well for us. We use the seeds for oil production and to reseed leaf production plots.

In the past, we had mixed fields with both coppiced (for leaf production) and uncoppiced (for seed production) trees. We found that the uncoppiced trees developed larger canopies and stronger root systems, outcompeting the smaller coppiced trees. These latter trees soon became unproductive, and we removed them. We recommend growing trees meant for leaf production separate from those intended for seed production.

Conclusion

Recommendations for moringa planting differ widely based on the moringa product being harvested as well as biogeographical region and agronomic practices. We highly recommend that you try different spacing options in small blocks first to determine what spacing works best for your region and your management preferences. Remember that moringa may do well during some seasons and not others (it typically loses leaves during rainy seasons). Another factor to consider is how frequently you cut the trees. Base this consideration on the local demand or use of the commodity you are growing. Your intended consumption and management resources will help narrow in on what spacing, and harvest frequency will be best for your context.

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From ECHO's Seed Bank: Clay Beads for Drying and Preserving Seeds

by Guinevere Perry, PhD

Preliminary findings of ECHO research

This article summarizes work being done at ECHO in Florida to develop a method for small-scale farmers and community seed banks to make their own desiccant to dry and preserve seeds. The three main requirements are clay, wood ash, and a way to heat the beads. Wood ash is a common byproduct of wood-burning cookstoves, and clay can be obtained from clay soil found in many parts of the world. Heating can be done with a forge used by local blacksmiths.

Introduction

A desiccant is a hygroscopic drying agent. Hygroscopic substances take up and retain moisture from the air. There are many types of desiccants including molecular sieves, activated alumina, activated carbon, bentonite, calcium sulfate, montmorillonite clay, calcium chloride, zeolite, and silica gel (Cohen, 2000; SorbentSystems, 2022; Figure 15). Desiccants have many everyday functions from absorbing moisture from a damp room in your home, keeping electronics dry, to drying freshly harvested seeds for long-term storage.

Desiccants to dry seeds for seed preservation

There are many methods to dry seeds. Examples include hanging seeds from trees, drying seeds in the sun, using desiccants, using simple local driers, drying seeds on tarps, drying seeds on curing tables, and using wood ash (Chua and Chou, 2003). Methods used to dry seeds have evolved over time with indigenous knowledge and advances in agricultural technologies (Matsa and Mukoni, 2013; Shaila and Begum, 2021). We now know the seed drying process is vital to a seed's emergence and crop productivity (Harrington, 1959; Saipari *et al.*, 1998). For this reason, many seed banks and home gardeners use desiccants like silica gel or zeolite (drying beads) to absorb moisture from freshly harvested seeds and reduce humidity in storage containers. Drying capacity varies between desiccants and is influenced by the ratio of seeds to desiccant in a container. Placed in airtight containers, desiccants can typically dry seeds to a moisture content of 10% or less.

Figure 15. Silica gel as an example of a desiccant. *Source:* FREEPIK

Why not just buy desiccants?

Desiccants like silica gel and zeolite are effective for removing moisture from seeds and reducing fluctuations in seed moisture content over time. However, these products are not readily available in low-resource settings. It may be difficult for a smallholder farmer or rural community seed banks to purchase and ship desiccant from another region or country. Some materials, like rice or salt, are more available, but have competing household uses. A product that farmers can make themselves addresses issues of cost and availability.

How a locally made desiccant could compliment traditional practices

Many smallholder farmers use containers like gunny bags, mud bins, clay pots, bamboo structures, wooden bins, underground structures, and in woven bags hung near stoves or from trees to store seeds (Wright and Tyler, 1994). Such containers have been used by farmers for generations and are readily available. These containers differ in their porosity. Some, like gunny bags or sisal sacks, have large holes and are not airtight. Under warm, humid conditions seeds kept in porous containers are subject to mold, resulting in reduced viability and increased risk for aflatoxin contamination (Bankole *et al.*, 2004). With traditional open storage, seed moisture levels have been shown to fluctuate by 2% to 3% over a 12 month storage period (Rickman and Aquino, 2004). Other traditional containers are less porous or can be modified to exclude humid air more effectively. Clay pots are often made with a top or lid that can be sealed with mud or clay. Pots and bins can also be lined with plastic. More examples of commonly available, less- or non-porous containers include tin cans, plastic or glass bottles, and polyethylene bags.

Seeds remain viable for longer periods of time in airtight containers than in those with large holes. In Ethiopia, for example, the germination percentage of *Oxytenanthera abyssinica* (a species of bamboo) seeds after 12 months of storage was 70% or higher with tin cans and glass bottles, but only 7% with sisal sacks (Ayana *et al.*, 2012). In their work with French bean (*Phaseolus vulgaris*), Khalequzzaman *et al.* (2012) found that the incidence of seed storage fungi (*Fusarium oxysporum*) was lower with the seeds kept in tin cans than in gunny bags. Remember

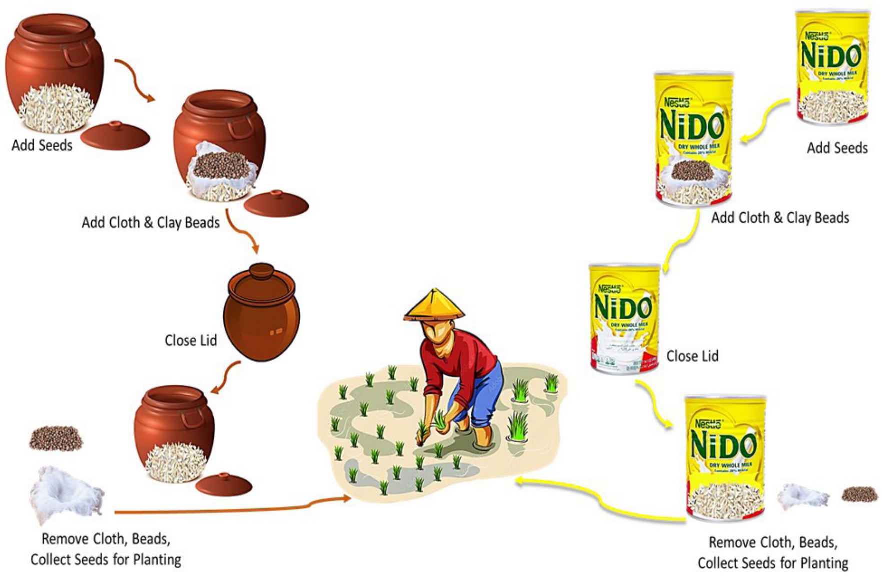

Figure 16. Illustration of clay-bead desiccant in pots (left) and tin cans (right). *Source:* Guinevere Perry

that seeds placed in a sealed container need to be dry to begin with, to keep from trapping moisture in the container.

Desiccant placed in open containers will be quickly saturated with moisture under humid conditions. A desiccant will dry seeds faster and keep them dry for a longer period if placed in a closed container that is as airtight as possible. The clay beads ECHO has been working with can easily be added to clay pots, tin cans, and glass or plastic bottles (Figure 16). Some closed containers are not perfectly sealed. Even glass jars are not completely airtight if the lids do not seal well. In such cases, keeping some desiccant with the seeds, in their storage containers, will help keep seeds dry. If using well-sealed containers, a farmer could 1) use the desiccant to dry seeds initially and then remove it or 2) keep the desiccant with the seeds if she/he will need to open the container from time to time to access the seeds.

Figure 17. Beads made with a mix of clay and wood ash. This is what they look like after they have been heated. *Source:* Guinevere Perry

Figure 18. Forge used at ECHO to heat beads made with clay and wood ash. *Source:* Tim Motis

How do we make clay beads?

We start by extracting clay from soil that has a lot of clay in it to begin with. The beads will hold together best if the clay is free of other particles like sand. We then combine clay, wood ash, and water to form small clay balls. The resulting beads are heated until they glow red or orange, which happens at a temperature of 600 to 800°C. This heating process is known as calcination. Calcination converts calcium carbonate to calcium oxide, giving the clay balls (Figure 17) their absorbent property. We have found that a forge (Figure 18) typical of that used by blacksmiths can heat the beads to temperatures of over 600°C. The above-mentioned video shows how we heat beads placed in a stainless-steel bowl,[6] with the bowl covered (by a second stainless steel bowl of equal size; this keeps debris from contaminating the beads) and surrounded by charcoal. Safety is an important aspect of the heating process. Use tongs and do not touch the beads until they have cooled. The next section on in-house testing contains information on how much wood ash to mix with the clay.

[6] You may be able to think of other creative ways to contain the beads while heating. You just need to be able to keep debris away from the beads, be able to take them out of the forge, and contain them in something that does not melt.

In-house efficacy testing

We have been experimenting with clay beads to validate their effectiveness. We have been working to identify the optimum formulation, optimum heating temperature and time, and optimum shape and design. Initial trials started in

January 2023 and are ongoing. There have been several versions of clay beads with varied performance capabilities (Figure 19).

Beads of the third batch in figure 19, made with a 1:1 ratio of clay: wood ash, were tested to determine if the clay beads could be reused by heating the beads at a low temperature for a short duration of time without reducing prior performance. The beads were placed in mason

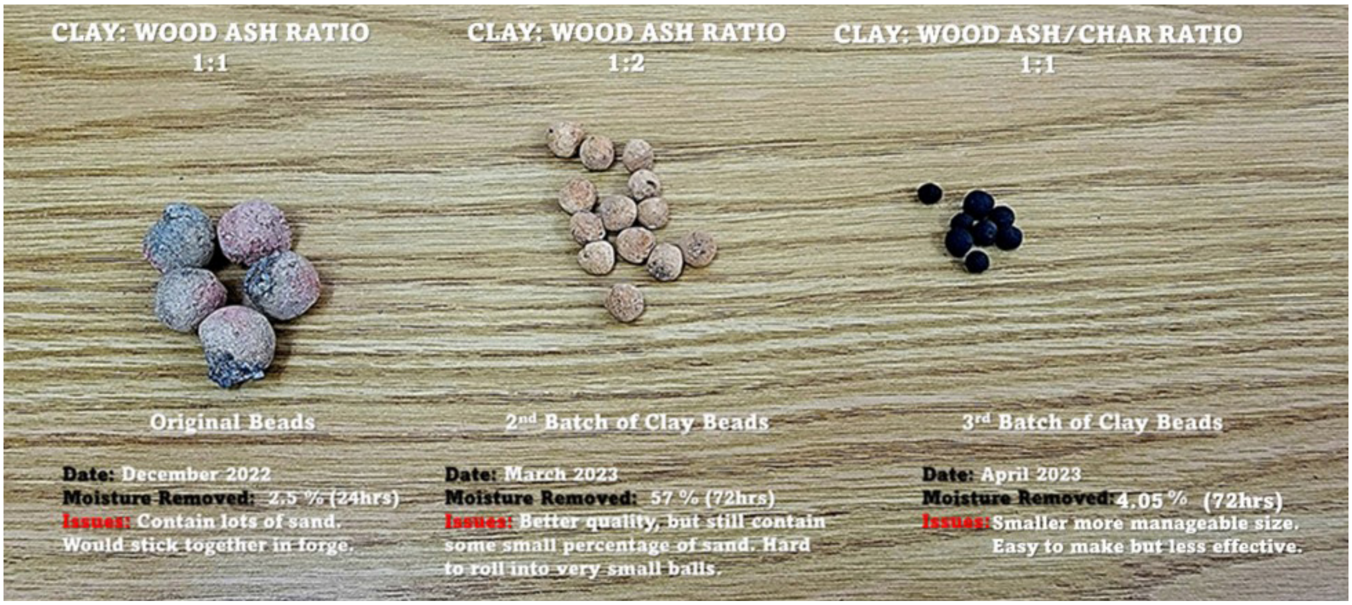

Figure 19. Clay beads and their effectiveness at several ratios of clay to wood ash. *Source:* Guinevere Perry

jars with cowpea (*Vigna unguiculata*) seeds for 24 hours. After 24 hours we measured the moisture content of the cowpea seeds and heated the clay beads at 120°C for 10 minutes to remove moisture. We then placed the reheated beads in a mason jar with a new set of cowpea seeds and repeated the test five times with duplicate samples. Each set of cowpea seeds had an initial moisture content of 12 to 15%. Table 4 shows results of the five tests. Negative values indicate the percentage of moisture lost from the seeds while positive values indicate the percentage of moisture gained.

With no desiccant, the moisture content of cowpea seeds

Table 4. Change in moisture content of cowpea seeds with five tests of the same batch of clay beads. Each test was run over a 24-hour day with the beads reheated at 120°C (for 10 minutes) between tests. Results were compared to no desiccant and zeolite Drying Beads®. Data are averaged over two jars per test for each treatment.

Test	Negative Control (no desiccant) *	Positive Control (Zeolite - Drying Beads®) *	ECHO Clay Beads (1:1 clay to wood ash ratio) *
1	-0.21	-2.62	-1.35
2	-0.22	-2.44	-1.27
3	-0.2	-2.82	-1.35
4	+0.03	-2.37	-1.15
5	-0.85	-3.08	-2.05
Standard deviation	± 0.33	± 0.29	± 0.35

*Negative values show the percentage of moisture removed from cowpea seeds while a positive value indicates the percentage of moisture gained.

**Tests were run with 20 g of cowpea seeds added to each of two jars per treatment. The negative control jars contained no desiccant while those for the positive control and clay beads contained 20 g of desiccant along with the cowpea seeds.

changed little each time. We observed the highest moisture losses (negative values) with zeolite Drying Beads®; however, the clay beads effectively removed moisture from the cowpea seeds after being reused for at least five times.

Conclusion

Clay beads are very cheap to make. Clay and wood ash are already present on many farmsteads and would cost virtually nothing except the time needed to gather them and remove impurities from the clay. The beads work in high humidity, absorb moisture from the air, and reduce seed moisture content. The most limiting factor to making clay beads is perhaps a means to heat the beads. The initial heating could be done by local blacksmiths or homemade forges. Our trials indicate that you can reuse clay beads a minimum of five times and still maintain efficacy. This may mean a farmer could use the beads for several years before needing to discard them. They can be reactivated by exposure to 120°C to 200°C for 8 to10 minutes. However, remaining questions include:

- How important is the source of wood ash?
- To what extent do differences in clay soils affect the stability and performance of the beads?
- To what extent can the beads be reused if they reach the point where they can no longer absorb moisture before being reheated?
- During the heating process, how long should heating continue once the clay beads glow orange or red? Our best results have been with beads heated for 20 minutes once the temperature exceeds 800°C. The total processing time is usually 30 minutes.
- Are there ways, other than a forge, to heat the beads initially? Options to consider include rocket stoves or grills. Aim for an approach that allows you to reach a temperature high enough for calcination with as little fuel (e.g., wood, charcoal) as possible.

As with any innovation, we encourage you to experiment with local materials to come up with a product that is reproduceable and appropriate for your context. Please let us know of your experience with this or other seed drying approaches.

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Books, Websites, and Other Resources

by Robert Walle

Aprovecho.org: Information on Fuel-Efficient Cookstoves

Aprovecho Research Center

PO Box 1175
Cottage Falls, Oregon 97424

Those seeking wood-burning stove options can find helpful information at the Aprovecho website [http://edn.link/aprovecho]. The Aprovecho Research Center (ARC) invented the now familiar "rocket stove," progressing much further since the original design. ARC specializes in developing stoves that meet ISO (International Organization for Standardization) emissions standards, are marketable, and are locally acceptable.

Exploring the publications section of the ARC website, I found links to numerous papers and books. The 2nd Edition (2021) of Clean Burning Biomass Cookstoves, under "Featured Publication," is available as a PDF download and comes complete with drawings to build your own fuel-efficient stove. They have a history of stove designs that started in Honduras to reduce deforestation and grew to consider health, climate, and gender roles.

Aprovecho's role in Honduras put into practice the cookstove "*Doña Justa*," helping conserve Tegucigalpa's last forest while clearing the indoor air for thousands of households. Poor air quality indoors, because of smoke and particles, can lead to respiratory diseases and a lower quality of life. Today a positive change remains. Chimneys and ventilation take the smoke out of tens of thousands of grateful homes. Locals sustain the effort, through an embedded improved stove culture, with installation kits to technical assistance from "master stove builders."

How they do it

Cooking (and eating) is a complicated and delicate part of daily life everywhere. Like a good cook and their stove, the manufacturer, distributor, and retailer understand their individual responsibilities. Aprovecho considers the entire value chain by including all of these stakeholders. Donors require that the stoves protect the health of users, and that their donations contribute to climate change reduction. Field and lab testing bring accurate data and results into focus for necessary evidence-based decision making. They work together to offer the product at the required location for 20 USD. As Aprovecho says, they know "What to do, how to do it, how to get it to the people who need it."

Household and Laboratory Testing

By comparing stoves through controlled cooking (in the lab) and kitchen performance tests (at the home), using the actual cooking pots and fire-tending methods, ARC generates viable options that work in the real world. An indoor air pollution meter that measures carbon monoxide and particulate matter (2.5 micrometers) provides data under actual household conditions.

Items of Interest

- A new forced air innovation, the Jet Flame improves existing stoves. The jet flame is featured in the 2022 journal article "Retrofitting stoves with forced jets of primary air improves speed, emissions, and efficiency: Evidence from six types of biomass cook stoves." https://doi.org/10.1016/j.esd.2022.09.013
- A recent video section shows how engineers design stoves and their test analysis. The Aprovecho Research Center won the Ashden award in 2009 for climate innovation.
- A current newsletter section keeps interested parties up to date.

The ARC has worked in 60 countries including Haiti, Mexico, Guatemala, China, Laos, Rwanda, and most recently Nicaragua.

For everyone looking for information on biomass cookstoves, check out this link, Aprovecho Research Center- testing and improving biomass cookstoves. The website has what you want, and just what you need to use biomass stoves for efficient cooking and to fight climate change.

Upcoming Events

ECHO Asia

Agriculture & Community Development Conference

Chaing Mai, Thailand
October 16 - 20, 2023

ECHO Global Farm

North Fort Myers, Florida

Agroecosystems for Smallholder Resilience

September 11-15, 2023

ECHO International Agriculture Conference

November 7-9, 2023

There are only a couple weeks left to register for the 30th Annual International Agriculture Conference in Ft. Myers, Florida. You won't want to miss this year's plenary speakers, breakout sessions and workshops. With a broad range of topics relevant to the farmer, agriculturalist, development worker, student and educator, come **learn with us** and come **share with us**! For more detailed information regarding registration, plenary speakers, topics, and how you could be a workshop presenter, please visit the following website [https://conference.echocommunity.org/]. For additional questions please write to the Conference Coordinator at [conference@echonet.org]. **Registration closes on October 22!**

Plenary Speakers:

1. Romina Gazis - University of Florida - Florida
2. Philip Deal - Water4 - Oklahoma
3. Matthew VonHerbulis - New International - Rwanda
4. Lee Myers - Christian Veterinary Mission - Georgia
5. Keith Mikkelson - Aloha House - Philippines
6. Andre Houssney - Jacob Spring Farms - Colorado