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ECHO Development Notes

edited by Dawn Berkelaar and Tim Motis

FARMER-CENTERED CLIMATE CHANGE MITIGATION: PART 2 OF 2

This article outlines strategies familiar to ECHO that have climate change mitigation and adaptation potential.

HOW SEEDS FROM ECHO GREW IN A DRY-SEASON GARDEN

This article is a summary of a seed trial report ECHO received from Chris Peterson, when he was a Peace Corps Volunteer working in Uganda.

GRAFTING SOLANACEOUS CROPS FOR NEMATODE RESISTANCE

Josh Jamison, Garden Manager at HEART, shares his experience in grafting tamarillo and other solanaceous crops for resistance to nematodes.

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Farmer-Centered Climate Change Mitigation: Part 2 of 2

by Tim Motis

How can smallholder farmers help mitigate against climate change? An article in *EDN* 148 described principles on which the strategies presented in this follow-up article are based. Key to any agricultural approach for dealing with climate change is dialogue with farmers (Figure 1), whose knowledge, experience, and participation are critical for success. In our conversations, we should distinguish between adaptation and mitigation. Adaptation strategies increase farmers' resilience and reduce their vulnerability to loss. Mitigation strategies directly reduce the causes of climate change. Some farming practices are helpful both for adaptation and for mitigation. For example, reduced tillage makes a field less vulnerable to erosion (adaptation) while also allowing for more carbon to be stored in the soil (mitigation). Below are a few strategies that are familiar to ECHO and that have mitigation potential in addition to building farmers' resilience (adaptation) to climate change. Content here builds on an *EDN* 128 article on carbon farming by Eric Toensmeier (2015).

Figure 1. Gathering farmer knowledge, as illustrated here, is essential to involving farmers in climate change mitigation. *Source:* Patrick Trail

Annual Cropping Systems

Integrating green manure cover crops (GMCCs) with staple grains

GMCCs cover and improve the soil in farmers' fields. GMCCs are often legumes, which have a unique ability to improve soil fertility by taking nitrogen from the atmosphere and turning it into a form that can be used by plants. Legumes adapted to the tropics include both annual and perennial species (Figure 2). In the second edition of his book *Restoring the Soil*, Bunch (2019) documents 117 ways in which smallholders use GMCCs. The book includes a decision-making framework for matching GMCC systems to your local context. *Selecting Legumes as Green Manure/Cover Crops* (ECHO Staff, 2017) and ECHO's interactive GMCC Selection Tool may also be helpful for selecting context-appropriate GMCCs. Farmers are most likely to grow GMCCs that provide benefits in addition to soil improvement, such as edible beans, fodder, and/or weed suppression.

Figure 2. Cowpea (*Vigna unguiculata*) and gliricidia (*Gliricidia sepium*) as an annual and perennial legume, respectively, intercropped with maize (*Zea mays*). *Source:* Tim Motis

The amount of carbon sequestered in soils by GMCCs depends, in large part, on how much plant material is grown and left on the soil. You can calculate approximately how much carbon is in that biomass by collecting and drying leaves, stems, and roots from a small plot of known dimensions, such as 1 square meter. Ideally, drying will be done in a cabinet with air heated to about 60°C and circulated with fans; however, air-drying in the sun is sufficient for a rough calculation. Weigh the plant material every day or two until the dry weight is reached—the point at which there is no more weight loss. (Cover the biomass or bring it indoors, as needed, to keep it from getting rained on.) Multiply the dry weight by 0.5* to estimate the mass of carbon in the 1 m^2 of biomass. One ha is 10,000 m^2, so multiply the result by 10,000 to calculate the mass of carbon per ha. For greater accuracy, repeat these steps in three or four places in a field, and average the results.

* The percentage of carbon in plants ranges from 46% to 59% (Scharlemann *et al.*, 2014), depending on the crop and plant part (e.g., leaves versus wood). Generally, a value of 50% of dry plant weight is commonly assumed (Gedefaw *et al.*, 2014). Thus, even without knowing the exact carbon concentration as measured in a laboratory, we can multiply dry biomass by 0.5 to estimate carbon in plant material.

Fujisaki *et al*. (2018) found that up to 36% of carbon inputs were converted to soil organic carbon. Despite the fact that not all carbon in plants transfers to the soil (some moves back into the atmosphere, as explained in Part 1), GMCCs can still increase the amount of carbon stored in soils. On a sandy-loam soil in Benin, a system involving maize and velvet bean (*Mucuna pruriens*) added 1.3 metric tons of soil carbon per ha each year to the top 40 cm of soil (Barthès *et al.*, 2004).

Conservation agriculture

Conservation agriculture includes three main elements: constant soil cover, minimum soil disturbance, and crop diversity (ECHO Staff, 2016). Mulch protects soil from erosion, preserving soil carbon. Mulch itself consists of living or dead plant material, so it adds organic carbon to the soil. Zero or reduced tillage is necessary to maintain surface mulch. Reduced tillage methods that preserve surface mulch include planting seeds in holes dug with sharpened sticks or hoes, or planting in narrow furrows created with rippers.

Most small-scale farmers find it difficult to maintain soil cover with staple crop residues alone. Crop residues may be needed for livestock feed or as kindling for cooking fires. The emphasis on crop diversity within conservation agriculture can result in a source of vegetation for mulching, for example through crop rotation and intercropping. Look for crops that maximize carbon inputs above and below the soil. Legumes such as lablab (*Lablab purpureus*) and pigeon pea (*Cajanus cajan*) produce an abundance of above-ground biomass, and their deep roots deposit carbon into the soil. At the same time, they add nitrogen to the soil, which supports crop biomass production.

Soil carbon storage with conservation agriculture depends on how well the crops grow and, in turn, how much biomass they return to the soil. Studies in Brazil have shown that a combination of vegetative cover and no-till added 0.4 to 1.7 metric tons of carbon per year to the top 40 cm of soil (Bernoux *et al.*, 2006). Gains in soil carbon are most likely to occur when crop selection and farming practices take into account local growing conditions and farmers' needs and constraints. Look for efficient ways to meet crop requirements for fertility and water. Select tillage and seeding practices based on tools that can be made and maintained locally, and that are not unnecessarily laborious. Select intercrops or rotational crops based on what seed is readily available.

System of Rice Intensification (SRI)

Rice is a major staple, often grown in flooded paddies (Figure 3). The water in rice paddies replaces oxygen in the soil, creating anaerobic (lacking oxygen) conditions. Microbes that produce methane (CH_4) thrive in such an environment, which is why rice cultivation accounts for at least 10% of agricultural greenhouse gas (GHG) emissions (Project Drawdown, 2020). The SRI method calls for intermittent watering instead of flooding (Berkelaar *et al.*, 2015), which means less CH_4 is produced. In

Figure 3. Flooded rice production in Tanzania. *Source:* Stacy Swartz

Malaysia, CH_4 emissions were nearly three times less with SRI methods than with conventional flooding (Fazli and Man, 2014). The SRI method also includes organic fertility inputs, which add carbon to the soil. According to Project Drawdown (2020), 4 to 5 million farmers practice SRI, and SRI has the potential to sequester significant amounts of carbon (2.79 to 4.26 billion metric tons of CO_2 equivalents between 2020 and 2050).

Tree-based farming

Agroforestry combines trees and agriculture. Trees and shrubs reduce GHG by storing carbon in their living tissues, in wood products, and in the soil. When considering whether or not to promote trees in an area, take note of the native vegetation. Do trees naturally grow there? If not, it is probably not wise to plant trees there. Plants found in open savannas and grasslands effectively store carbon below-ground, and they generally do so with less water and nutrients than trees (Veldman *et al.*, 2015). Where it does make sense to plant trees, consider tree survival rates in addition to the number of trees planted. Trees that provide needed resources for farmers, and that are integrated into their cropping systems, are much more likely to survive than randomly-planted trees. Below are several practical ways in which small-scale farmers practice agroforestry.

Farmer Managed Natural Regeneration (FMNR)

FMNR is a reforestation approach in which farmers manage regrowth of an "underground forest" consisting of stumps of trees that were previously cleared for growing crops (Rinaudo, 2010). Farmers select which stumps to manage and decide how many stems they will allow to regrow on each stump. They know which trees will benefit their crops and which will compete with them. The trees benefit the soil by dropping their leaves (mulch) and by reducing soil temperature, water evaporation, and erosion. They also store carbon; between 2006 and 2018, FMNR on 2,700 ha of land in Ethiopia sequestered 181,650 metric tons of CO_2 (World Vision, 2019). Community residents reported numerous benefits that included less soil erosion, improved soil fertility, increased rainfall, and better air quality.

Family woodlots

Caretakers and beneficiaries are not always clearly identified in large-scale tree planting projects. This is not a problem with small family woodlots devoted to household use (Figure 4A). As explained by Azor and Blank (2010), a woodlot consists of coppicing tree species such as *Senna siamea* and *Leucaena* spp. A tree that coppices well will produce new shoots after being cut very low on the main stem (trunk). Coppicing allows for multiple harvests from a single tree over time. Trees sequester the most carbon when they are actively growing; this means the regrowth that occurs after coppicing will store significant amounts of carbon. Small woodlots have proven successful in Haiti, where the Mennonite Central Committee promoted them through an effort called "ti fore" (Creole for "little forest" or microforest).

Tree gardens and food forests

Tree gardens consist of fruit trees and other beneficial trees grown together with annual crops (Danforth and Noren, 2011). Farmers protect the trees, along with their crops, from animal grazing and fire. This concept has worked well in Central Africa. Food forests (Figure 4B) are popular in Southeast Asia, where mixtures of edible tree species are grown together in small plots. Tree gardens and food forests work well in small-scale agriculture systems. For more information, see the "Fully Perennial Systems" section of Toensmeier's 2015 carbon farming article in *EDN* 128.

Figure 4. Woodlot (A) and food forest (B) demonstrations at ECHO's Global Farm in Florida. *Source:* Tim Motis

Land-care approaches

Sloping Agricultural Land Technology (SALT)

SALT, an approach that integrates aspects of soil conservation and agroforestry, was developed to reduce soil erosion on hillsides (MBRLC, 2012). Field crops are grown in 3- to 5-m wide bands between double rows of leguminous trees and shrubs that are planted along contour lines. The nitrogen-fixing trees and shrubs are managed as hedgerows, with pruned vegetation used as mulch for the crops between hedgerows. Farmers modify the system based on the types of crops and trees they want to grow. In a five-year study in India, on land with 2 to 5% slope, gliricidia hedgerows in combination with grass strips reduced soil loss by 35% and added 1.35 t/ha/year of organic carbon to the soil 1 m away from the hedgerows (Lenka *et al.*, 2012). Though that system is not quite the same as SALT, their findings document the potential of contoured hedgerows to conserve soil and store carbon.

Sand dams for restoring watersheds

Stern and Stern (2011) describe a sand dam as "a reinforced concrete wall built across a seasonal river to hold underground water in sand." Sand dams are an excellent option for harvesting rainwater in dryland regions. Water stored in the sand provides drinking water. Sand dams also increase groundwater, especially when multiple dams are constructed within a watershed. Based on satellite imagery, Ryan and Elsner (2016) found that sand dams consistently increased vegetation. They concluded, "Sand dams can…be a promising adaptation response to the impacts of future climate change on drylands." Sand dam initiatives can be accompanied by agricultural activities that sequester carbon (Maddrell, 2018). Contour-based plantings, for instance, reduce erosion on either side of a dam and have the potential to increase soil carbon. Indigenous groups in Kenya and elsewhere have done extensive work in promoting and constructing sand dams.

Concluding thoughts

Farmers are well-positioned to implement site-specific solutions to climate change. Here we have highlighted a few cropping systems that farmers can and/or are using to produce food in ways that reduce GHG. No single system or strategy works for--or is acceptable to--every farmer. Work with farmers to identify approaches that address climate change while also meeting their needs. An article titled *Farmer Engagement in Agriculture Extension* suggests practical ways to support farmers' efforts to develop and test agricultural improvements (Flanagan, 2015). Those ideas are also relevant in engaging with farmers to identify strategies for dealing with climate change.

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From ECHO's Seed Bank: A Seed Trial Report

How Seeds from ECHO Grew in a Dry-Season Garden in Uganda

Below is a summary of a seed trial report ECHO received in 2013 from Peace Corps Volunteer Chris Peterson, working in Uganda (Nalugala, Wakiso District). Sharing the results of Peterson's efforts serves as an example of what to expect from a seed trial. Trying new crops can be very challenging, and likely not all crops will be successful. Nonetheless, seed trials are valuable, low-risk methods to inform agricultural development plans.

Overview

Many Ugandan farmers do not work the land during the dry season due to a common perception that nothing can be grown during that time. However, crops like sorghum and millet are able to tolerate dry conditions. Chris Peterson set out to develop a "dry season" demonstration garden at the Bega kwa Bega Uganda Orphans (BKB) organic demonstration farm, using seed of drought-tolerant plants from ECHO's Global Seed Bank. He hoped that lessons learned about extending farm productivity would help ensure local food security. The trial also offered a chance to demonstrate inexpensive water conservation techniques.

Figure 5. Part of the organic demonstration farm at Bega kwa Bega. *Source:* Chris Peterson

Site description

The BKB farm (Figure 5) is situated approximately 1177 m (3850 feet) above sea level, on Lake Victoria between Entebbe and Kampala, Uganda. The plot grade is nearly level to slightly sloping. The soil is high in clay, prone to stones, and dusty when dry. The site performed poorly in past years. A previously planted citrus grove did not do very well, even when intercropped with cabbage, beans, or eggplant.

According to Peterson, "Numerous old termite mounds (not breaking the current surface) exist within the plot. A perception exists that termite mound soil is poor, because mound soil is difficult to dig even when wet, and impossible to dig when dry. However, mound soil is rich in nutrients (from deep soil nutrients being brought to the surface by termite activity) and organic matter (from termite feces and saliva) (Peterson, 2010) and is quite beneficial to plants when the hard clumps are allowed to weather and crumble. Farmers should be encouraged to chip away at old termite mounds and disperse the soil within their farms."

At BKB, and more commonly in the region, farmers and farm workers removed crop residue from the fields due to pest problems. However, that practice resulted in loss of organic matter and nutrients from the plot.

Seeds

Peterson obtained ten sample seed packets of drought-tolerant plants from ECHO's Global Seed Bank. Table 1 lists the seeds by name, date of planting, germination date, germination success, plant growth, and harvest success.

Peterson planted a high proportion of bean species in the trial, because the local community already viewed beans as a valuable crop. He shared, "It should be readily adopted if it grows well." He continued, "I had initial concerns regarding jicama, as the beans and pods are poisonous and the community is likely to expect to eat them rather than their tubers. I have a similar concern with egusi melon, although watermelons are common: the community is going to expect to eat the melon (which is not edible) rather than go through the work of dehulling and processing the melon seeds."

Figure 6. Raised beds covered with mulch. *Source:* Chris Peterson

Planting

Peterson planted each species on both a raised bed (Figure 6) and non-raised bed. He reasoned that, while raised beds were familiar to the local community, flat ground would hold water better. He worked the soil with a modified "double dig" approach, where the top 12 inches (30 cm) of the soil is removed in a two-foot (60 cm) wide trench, and then mixed with animal manure (cow, goat, or chicken) as it is replaced.

Initial Irrigation

After planting, each bed was watered enough to wet the soil beyond the seeds. Then, each bed was watered once per day for the first week and once every two days in the second week. After that, plants were watered

Table 1. Seeds from ECHO's Global Seed Bank, planted in 2013 at Bega kwa Bega organic demonstration farm.

Common Name	Scientific Name	Planting Date	# Planted	Date Germinated	Germination	Growth	Harvest	Worth growing again?
Chickpea/ Garbanzo	*Cicer arietinum*	2/20	23	2/26	Excellent	Good	Failed	Yes, with attention paid to pest control
Jicama/ Yam Bean	*Pachyrhizus erosus*	2/25	28	3/15	Good	Fair	Good	No, not likely to be popular
Dragon's Claw Millet	*Eleusine coracana*	2/26	Broadcast	3/8	Excellent	Excellent	Excellent	Yes
Cowpea	*Vigna unguiculata* 'Bettergro Blackeye Pea'	2/20	48	2/24	Excellent	Good	Failed	Yes, if proper attention paid to crop spacing and disease control
Mung bean/ Green gram	*Vigna radiata*	2/19	67	2/24	Excellent	Excellent	Excellent	Yes
Okra	*Abelmoschus esculentus*	2/19	50	2/24	Excellent	Excellent	Excellent	Yes
Lablab	*Lablab purpureus* 'White'	2/25	30	3/5	Excellent	Excellent	Poor	Yes, if proper attention paid to spacing
Egusi	*Citrullus lanatus* ssp. *colocynthoid*	2/20	12	2/26	Poor	Poor	Failed	No
Tarwi	*Lupinus mutabilis*	2/20	24	2/27	Poor	Poor	Failed	No
Sorghum	*Sorghum bicolor* 'Striga Resistant'	2/20	110	2/26	Excellent	Excellent	Excellent	Yes

as needed (about once every three or four days, since the mulch mitigated water loss).

The plants under the fine grass mulch (Figure 7) had higher and faster germination rates and fewer weeds than plants under coarse mulch. Overall survival of seedlings was sporadic, with high plant mortality in some areas but not others. Peterson commented, "The coarse mulch may have attracted termites that ate the seeds or the sprouts. Another hypothesis is [that] the presence of phytotoxins from coarse mulch, especially mango leaves, [inhibited germination and/or plant growth]."

Peterson shared, "The rains returned approximately one month after planting, which illustrates one of the limitations of a dry season garden. It might take longer for the plants to mature than the dry season lasts. In that case, land devoted to dry season crops cannot be used for other things during part or even all of the wet season. Depending on productivity of the crops, the farmer might be better served by waiting out the dry season and planting more productive crops when the rains return. This will, of course, depend on the specific locale and the length of the dry season."

Figure 7. Okra seedling emerging from fine grass mulch. *Source:* Chris Peterson

Results

Most plants from the trial were mature and harvested by the end of the rainy season in May. By this time, Peterson had an idea of what worked and what did not in his context. Sometimes even when plants grew and produced well, they were not "successful" for cultural reasons.

Figure 8. Cotton stainers on okra. *Source:* Chris Peterson

Okra: Fifty seeds were planted, and ten plants survived. The okra plants sustained some minor damage from insects. Cotton stainers (which feed on seeds inside the pods; Figure 8) appeared in large numbers about halfway through the plants' lives. A few curled pods were found to be infested by burrowing insect larvae (perhaps let in through cotton stainer feeding). Nevertheless, over 200 pods were harvested. The final pods were allowed to mature and produce seed; they yielded enough to mostly fill a small glass jar. Peterson wrote, "The farm staff responded well to the crop, and have begun growing okra on the farm and consuming it cut up into pots of beans. Many of the local residents have expressed interest in growing okra and in its preparation. The farm will begin selling produce in the coming months, and we have confidence that okra pods and seeds will be popular items."

Mung beans: Sixty-seven mung beans seeds were planted, and nearly all germinated. Plants produced 20 to 30 pods per plant, and each pod contained at least 10 seeds. The pods matured about two months after planting and dried down well. The mung beans finished producing new pods after about three months, and the final pods matured a few weeks later. Peterson commented that maybe the plants could be replaced with something else once the initial crop was harvested. He also shared, "A cultural barrier exists to their use: 'I see the Indians eating them' is a common comment. Indians are not actively discriminated against here, but Indian food is 'not Ugandan.'…This surprised me, because the beans are small and therefore will require little time or fuel to cook, and the readiness with which the farm staff adopted okra led me to believe there would be more enthusiasm for mung beans."

Figure 9. Caterpillar destroying chickpea pod. *Source:* Chris Peterson

Tarwi: All tarwi plants died within three months of planting. They produced neither pods nor seed.

Chickpeas: After three months, the chickpea plants had produced many pods. However, caterpillars ate the pods (Figure 9) and mealy bugs attacked the roots. Only about a dozen seeds were collected (harvested early so insects would not get them). Peterson theorized that chickpeas might grow better in cooler areas less favorable to insect pests.

Cowpeas: The cowpeas grew a lot, but produced few pods. Some plants succumbed to a fungal plant disease (Figure 10; about one plant per week), with an outbreak after the rains returned. Peterson commented, "Substantial insect feeding along the [vines] was observed, but the plants appeared to tolerate the damage. It appears there were other diseases present, as the pods were irregular in shape and seemed to contain few seeds. This might have been due to a failure of pollination. Because cowpea was reported to tolerate some shade, I planted them in the shadiest part of the garden. Lack of direct sunlight might have allowed a moist microclimate to develop, leading to a disease outbreak. Wider spacing at the next planting might alleviate these problems. Birds or squirrels

Figure 10. Disease-infested cowpea pods. *Source:* Chris Peterson

(unknown culprit) destroyed the few healthy pods I had been watching. No beans were collected, which was surprising because cowpeas are known in this part of Africa and can be bought in the local markets. Therefore, it seems my agronomic practices (planting too close together, planting in the shade) are responsible for the failure of this crop."

Egusi: Peterson commented, "The vines succumbed to a plant disease between two and three months after planting. The seeds in the salvaged fruits had been eaten by beetles or dried to nothing. The seeds were not mature by the time the plants died. No seeds were collected."

Millet: The millet plants matured about four months after planting. They had no significant pests (other than goats occasionally nibbling the tops of the plants) and produced around 2 L of millet seed. According to Peterson, "Millet is a popular staple crop in certain parts of Uganda, used to make a starchy food item called in various places tapa, kalo, or millet bread ("bread" is a misnomer; the product is not leavened or baked, but instead the flour is boiled in water into a blob of a consistency between mashed potatoes and bread dough, and is eaten hot with a sauce). Millet brews and breakfast porridges similar to runny oatmeal are also common."

Figure 11. Birds eating sorghum seed from the stalks. *Source:* Chris Peterson

Sorghum: Peterson shared that the sorghum plants grew well and were ready to harvest after four or five months. He said that the plants produced very well but, "Once the seeds matured, weavers and lovebirds came to eat them [Figure 11], and foil scarecrows did nothing to keep the birds away." Peterson added, "Different types of sorghum are used throughout Uganda for different purposes: porridge, for animal feed, and for a fermented local brew. Sorghum is used in some commercially produced brands of beer. I had hoped to leave the old stalks in place as poles for beans, but termites destroyed the stalks before the beans could be planted."

Figure 12. Jicama tubers. *Source:* Chris Peterson

Jicama: Jicama plants grew slowly from seed, but were relatively unscathed from insects and diseases. It was one of the last crops to mature; vines died down five months after planting. The plants yielded few seeds and the tubers varied in size from 1 to 4 inches (2.5 to 10 cm) in diameter (Figure 12). Peterson wrote, "I left some tubers in the ground to see if vegetative growth would be better when the tubers resumed growth. The sprouting tops of harvested tubers were planted to observe how well they grew, but that effort has just begun. Jicama proved to be unpalatable to the Ugandans, and marginally palatable to me. Unless the tubers produce many more and larger tubers than the seeds did, I don't think it will be able to compete with Irish potatoes, yams, or cassava as a tuber crop. In addition, jicama is often eaten raw (it's said they get tough when cooked) and Ugandans are hesitant to eat any raw vegetable. I encountered the same barrier when growing radishes and lettuce. The Ugandans I talked to insist all vegetables must be cooked. Perhaps this is good and reflects an awareness of the danger of contracting worms or other parasites from soil."

Figure 13. The lablab plants grew vigorously but produced few seeds. *Source:* Chris Peterson

White Lablab: Peterson wrote, "The white lablab proved to be an aggressive climber, three-foot stakes not being tall enough to contain the plants. The plants grew all over the place, but relatively few seeds were produced [Figure 13]. The plants are still actively growing five months later, but by now I am confident I know what to expect from this plant. Although the beans are reported to be edible, not many produced and [for me] the true value in this crop is (as we already know) its use as a livestock feed. Plants grown singly rather than in rows produced more seeds although vegetative growth was about the same. Pods sometimes appeared to be infested with a black-colored fungus, and the seeds within were discolored or wrinkled. It is unclear at this point if such seeds will germinate well. The few stored seeds were quickly infested with stored grain beetles, but this might have been prevented by better storage. In subsequent plantings, I hope to note the effects of regular slashing on regrowth. If the plant regrows well, and since it survived the second (and more severe) dry season, it could greatly improve the farm's supply of cattle and pig feed."

Longer-term reflections

In the fall of 2019, six years after the initial seed trial report was written, Peterson shared some longer-term reflections. He commented, "The main success [of the seed trial] was convincing the farm staff of the value of mulching. When they saw the germination results they were [convinced] and mulched their planting beds from then on; seeing that only a thin layer was necessary made a difference."

Introducing new and unfamiliar foods proved challenging. "Okra…grew well and [farm staff] enjoyed it when I cooked it for them, [but] they didn't know what to do with it when they grew it themselves. I shared some saved seeds, only to be presented several months later with wooden, shattered okra pods and being asked how they were supposed to be cooked. The idea of harvesting a non-mature product was not familiar, and they struggled with knowing when they were supposed to harvest." Lablab was familiar, but not as a human food. "Because lablab is only grown for animal forage [here], they weren't interested in the beans, probably because of the work required in preparation and the ready availability of other beans requiring less effort to prepare."

Overall, Peterson concluded, "the idea of dry-season gardening did not take off because this ties up land that would be more productive once the rains returned. With two rainy seasons per year in that part of Uganda, there was little reason to invest the real estate in [attempting to produce] a meager supplemental crop in the relatively short dry seasons. The approach might be more successful in areas with longer dry seasons."

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Echoes from our Network: Grafting Tamarillo and Other Solanaceous Crops for Nematode Resistance

by Josh Jamison, HEART Garden Manager

The problem of nematodes

Many of the world's most important vegetable crops originate from the Solanaceae plant family, including tomato, eggplant, and peppers. This family also includes a host of lesser-known but locally important species, such as naranjilla (*Solanum quitoense*), tamarillo/tree tomato (*S. betaceum*), and goldenberry (*Physalis peruvianus*). Unfortunately, many plants in this group are plagued by root-knot nematodes and other root-born diseases (such as fusarium wilt) that greatly complicate cultivation. This difficulty is especially pronounced in the tropics where harmful nematodes are prolific. My article highlights a simple, low-input strategy for working around this problem that may be relevant to smallholder farmers in the tropics and subtropics.

Root-knot nematodes are a group of microorganisms from the genus *Meliodogyne*. They infect the root systems of many crops, compromising the plants' abilities to efficiently move water and nutrients through their vascular systems. In solanaceous crops, a severe infection often results in persistent wilting despite the ample availability of water in the root zone. The nematodes ultimately undermine the entire health of the plant and lead to collapse of the crop.

Tremendous effort is expended in controlling this pest in the tropics. In the book *Of Plants and People*, Charles Heiser (1992) reported incredible deforestation tied to nematode infestation in naranjilla farming in Ecuador. Farmers would clear new patches of forest to farm naranjilla and experience a year or two free of nematode infestation. Eventually, nematodes would find their way in and wreak havoc, spurring farmers to clear-cut new patches of forest for their farming ventures. Other control measures include the use of hazardous and expensive agro-chemicals, crop rotation, and the breeding of crop varieties that have resistance to nematodes. For many smallholder tropical farmers, these strategies may be challenging to achieve or be undesirable for many complex reasons.

Figure 14. A successful tree tomato graft beginning to take off in a pot. *Source:* Josh Jamison

Grafting as a solution to nematodes

In agriculture, grafting is most often employed to preserve the genetics of the scion (the piece grafted on) for predictable quality, seasonality, and other traits. In the case I describe, the goal is to employ the nematode-resistant qualities of the rootstock (the plant the scion is grafted onto). By grafting a desired solanaceous crop onto appropriate rootstock, it can grow unimpeded by the aforementioned root problems (Figure 14). This results in longer-lived plants that are more productive, yielding more food and income for the farmer. In my experience, it is sometimes the difference between total crop death and success. In some countries, tomatoes [of a given variety] are regularly grafted onto other select nematode-resistant tomato varieties, usually when plants are quite small and tender.* Here, I share about using other hardy, tropical species as rootstock for sensitive crops.

*[Editor: This is an example of *intraspecific* grafting, in which the rootstock and scion are the same genus and species. Josh's article deals mainly with *interspecific* grafting, in which the rootstock and scion are related but are not the same species. Graft compatibility is often easiest to achieve with intraspecific grafting, since the rootstock and scion are so closely related. However, as Josh has found, interspecific grafting has potential to expand production of a vegetable into areas where it might not otherwise be able to grow (Petran and Hoover, 2014).]

Context and initial inspiration for grafting

My experimentation with nematode-resistant rootstocks has been in the context of Central Florida, a region with sandy soil that has high populations of nematodes that harm solanaceous crops. I have used two species of hardy tropical shrub as rootstock: *Solanum torvum* (turkey berry) and *Solanum macranthum* (potato tree). Turkey berry is cultivated as a food crop in Southeast Asia and the Caribbean, and potato tree is a cultivated ornamental. Both species grow vigorously in our soils, seemingly unaffected by harmful nematodes. [CAUTION: Be aware of toxins in solanaceous crops (discussed later in this document). Additionally, *S. torvum* can spread rapidly as a weed; click here for a CABI datasheet with more information.] The main scion species I have experimented with are eggplant (*Solanum melongena*), naranjilla (*Solanum quitoense*), and tamarillo (*Solanum betaceum*).

My interest in grafting solanaceous crops began with tamarillo, a crop that is widely believed to be impossible to grow in Florida. The general view is that the climate here is too hot, and that this plant requires the cooler, more moderate temperatures of its native habitat in the Andes. That was also my perception as I briefly experimented with the plant years ago, writing it off as something unable to grow in Florida.

Then, while visiting a farm in Florida last year, I noticed I was standing under the canopy of a fruiting tamarillo! Upon inspection and inquiry, I learned that the plant was grafted to a sucker at the base of an ornamental potato tree, *S. macranthum*. Also grafted to the potato tree (and fruiting), was cocona, *S. sessiflorum*. Cocona is another species with which I had briefly experimented in the past and gave up on after lackluster results. I had an epiphany! Perhaps climate was not the reason that tamarillo and cocona failed in gardens; what if the problem was with the root systems instead? I promptly gathered seed of the potato tree and made plans to use it as a rootstock.

Grafting method used

The technique I have employed is cleft grafting, using terminal growth as scion (Figure 15). I plant the rootstock and the desired crop in the nursery on the same day, so that I can work with plants of roughly the same size. For grafting, I prefer a stem diameter around 0.5 to 1.0 cm. I cut the top of the scion seedling, remove the top of the rootstock seedling, and then graft the scion piece (top of the scion seedling) of my desired crop onto the remaining (bottom) portion of the rootstock seedling. Then I remove all leaves from the scion, taking care not to damage the emerging terminal bud. I wrap the graft union and scion tissue with parafilm to exclude water from the graft union and keep the tissue from desiccating. The very tip of the scion can be left unwrapped, which allows new growth to easily emerge. Another option to prevent desiccation, besides wrapping the graft union with parafilm, is to bag the plants with clear plastic. Bagging the grafts can help increase humidity, but be sure you do not leave them in the sun, or they will cook. Keep freshly grafted plants in the shade under highly humid conditions.

Slowly acclimate grafts to sunlight over a period of a week to ten days. For bagged grafts, this process starts with removal or tearing of the bag to expose the graft to ambient conditions. I tend to tear a hole in the bag and, over a few days, make the tear larger. This is why I prefer parafilm with the terminal bud uncovered, as it eliminates the step of removing the bag over each graft. I move the plants a little further out of the shade each day during morning watering.

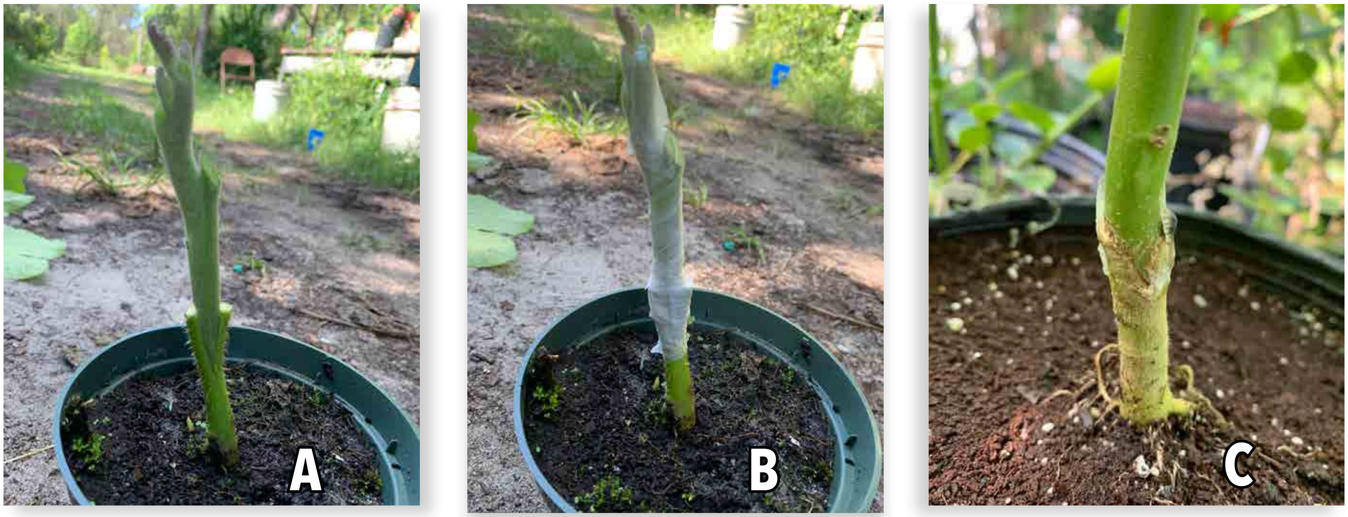

Figure 15. A cleft graft before (A) and after (B) wrapping and a healed, successful graft union (C). *Source:* Josh Jamison

Grafts of herbaceous plants heal and grow much more rapidly than grafted woody plants; an abundance of cambial tissue in these soft-tissued plants means that high precision with cuts is not as important as it is with woody species. If the above-mentioned basic procedures are followed, graft success rate is very high.

Results of personal experimentation

Grafting tamarillo and naranjilla to *S. macranthum* proved to be easy. After a little less than a year of experimentation, I have thriving tamarillo plants that endure the hottest part of the year without much issue. Some of those plants are now taller than I am and are beginning to flower. I have not yet successfully brought tamarillo to fruition, but I count the experience as a major success in demonstrating that this plant and others can greatly benefit from being grafted to nematode-resistant rootstocks. Naranjilla is typically badly affected by nematodes in Central Florida, but my grafted naranjilla plants are thriving and soon will have fruit.

I have also grafted eggplant to *S. torvum*, and the rootstock seems to give the plants more general hardiness and longevity.* A friend grafted tomatoes to *S. torvum* and reported above-average vigor, resistance to disease, and good overall crop performance. In Kenya, where tamarillo is farmed on a broad scale and is widely grafted onto a locally available rootstock (*S. mauritanium*), the interspecific graft is said to increase general crop success and to confer drought tolerance to tamarillo. Increased nematode resistance could help explain the reported resilience of grafted plants.

*[Editor: Josh's impressions are consistent with research results reported by Bletsos *et al.*, 2003. They found that eggplants grafted on *S. torvum* were more vigorous, produced more fruit, and were more resistant to verticillium wilt than non-grafted eggplants.]

The *Solanum* genus seems to have very broad graft compatibility. Every graft combination I have tried thus far (including 7 or more species) has succeeded with no apparent problem. That said, some combinations seem to show more vigor than others. Tamarillo and naranjilla tend to grow better on *S. macranthum*, while eggplant seems to prefer *S. torvum*.

*[Editor: Oshiro *et al.* (2008) reported a case of food poisoning in Japan that was attributed to toxins in a sauce made from eggplant that had been grafted on *Datura metel*, a toxic solanaceous plant. As Josh suggests, select rootstock that has been safely used in the past. For example, the use of *S. torvum* as a rootstock has been well documented (Petran and Hoover, 2014). By comparison, the knowledge base around *S. macranthum* as a rootstock is small but growing (the Further Reading section lists some documented examples).]

A caution about toxins

There is an important question to consider regarding solanaceous grafting: can toxins migrate from the rootstock of a plant up into the scion tissue, generating toxic fruit? I posed this question to the Florida farmer who grew the tamarillo that I had been so surprised to see fruiting (given that *S. macranthum* is a toxic plant). He dismissed my concern and told me that he had eaten from these graft combinations for years with no problems. However, through word of mouth I learned that a well-known fruit specialist in South Florida insists that grafting to *Datura* species (a group of highly toxic plants) creates toxic fruit.* I think caution is prudent. It is wisest to proceed using known edible species or ones that have already been recorded for this use.

Farmer application

Each farmer will need to determine if the increase in plant health and yield outweighs the cost in time and energy spent on grafting. Local economies and specific growing conditions will dictate the outcome of this calculation, but it may depend largely on the density at which a crop is planted. For example, tamarillo is often planted at 1/10 or less the density at which tomatoes are planted, so grafting tamarillos can be more cost effective because the grafting will take much less time. Tamarillos also live much longer, so grafting needs to happen less often. Economic considerations aside, grafting solanaceous crops shows tremendous promise as one way to adapt these crops to less-than-ideal soil conditions. I think it merits attention in the tropics as a practical way to allow more farmers to grow high-value vegetables. Where *Solanum* crops are limited by root problems, grafting is worth a try. While trying various rootstock/scion combinations, look for ways to graft them using locally available materials.

References

Bletsos, F., C. Thanassoulopoulos, and D. Roupakias. 2003. Effect of grafting on growth yield, and verticillium wilt of eggplant. *HortScience* 38(2):183-186.

Heiser, C.B. 1992. *Of Plants and People*. University of Oklahoma Press.

Oshiro, N., K. Kuniyoshi, A. Nakamura, Y. Araki, K. Tamanaha, and Y. Inafuku. 2008. A case of food poisoning due to ingestion of eggplant, *Solanum melongena*, grafted on devil's trumpet, *Datura metel* [in Japanese]. *Shokuhin Eiseigaku Zasshi* 49:376-379.

Petran, A. and E. Hoover. 2014. *Solanum torvum* as a compatible rootstock in interspecific tomato grafting. *Journal of Horticulture* 1:103.

Further Reading

Hu, B., S. Short, M. Soltan, and M.D. Kleinhenz. (year not given). Grafting Guide 3rd Edition: A Pictorial Guide to the Cleft and Splice Graft Methods for Tomato and Pepper. Bulletin 950. Internet website accessed 15 October 2020: http://www.walterreeves.com/wp-content/uploads/2010/11/tomato-grafting-guide.compressed.pdf [See pages 55 to 65 for detailed explanation and photos of the cleft grafting technique on tomato seedlings.]

Documented examples of *S. macranthum* as rootstock:

- Ledin, B.R. 1952. The naranjilla (*Solanum quitoense* LAM.). Florida Agricultural Experiment Station Journal Series, No. 106:187-190. [This article records Dr. Milton Cobin's success in grafting naranjilla on *S. macranthum*.]
- Whitman, W. 1958. Rare Fruit Council activities 1957-58. *Florida State Horticultural Society Proceedings* 71:278-287. [Grafts of naranjilla on *S. macranthum* were made available for distribution as a Rare Fruit Council activity.]
- Hodge, D. 1995. The archives of The Rare Fruit Council of Australia. Internet website accessed 15 October 2020: https://rfcarchives.org.au/Next/CaringForTrees/Rootstocks9-95.htm. [Mention is made of tamarillo grafted on *S. macranthum*.]

Books, Websites, and Other Resources: AT Fair Summary

by Elliott Toevs

On September 3, 2020, ECHO held its first virtual Appropriate Technology (AT) Fair. As this year has brought many challenges for in-person gatherings, we were grateful for all who took advantage of the shift towards virtual gatherings and participated in this event. It was an enriching time for ECHO staff, and I hope of benefit to the network of attendees.

The event featured a plenary talk on Creative Capacity Building (CCB) by two ECHO East Africa staff members, Harold Msanya and Erwin Kinsey. Harold and Erwin shared the importance of utilizing the CCB approach when developing appropriate technologies, and described their experience using CCB in various communities in East Africa. The CCB approach brings together end-users, manufacturers, engineers, and other community members to address specific local challenges. One wonderful thing about this approach is how it helps us discover that each one of us is creative and can help address the problems we face. Conducting CCB trainings requires that we value all stakeholders' perspectives and create an environment that encourages creativity.

In addition to the plenary talk, three network members shared their experiences of working with appropriate technologies in the field. Craig Bielema, formerly an ECHO intern and AT Manager for ECHO Florida, walked us through the design process for a recent institutional cookstove project he had been working on in Burundi. He pointed out that we must start with a well-defined problem before jumping to solutions.

Tim Tanner, CEO of Kilimo Timilifu in Tanzania, shared ways that Kilimo Timilifu uses appropriate technologies in their work, from dibble sticks to homemade drip tubing. Tim reminded us that even the simplest of technologies can be the right fit, depending on one's constraints.

Greg Bixler, founder and CEO of Design Outreach, shared about Design Outreach's work around the world with the LifePump and other technologies. He also highlighted some considerations and trade-offs to keep in mind when using appropriate technology. From simple technologies to very complex, each one has a place depending on the problem we are trying to solve.

After these talks, participants in the virtual AT fair were able to interact with presenters and fellow network members through four breakout sessions. Session topics included Creative Capacity Building; use of appropriate technologies to increase agricultural production; manufacturing appropriate technologies; and WASH (water, sanitation, and hygiene).

If you were unable to attend the event, don't worry! All the sessions were recorded and can be accessed at: edn.link/2020virtualfair.

Upcoming Event

ECHO Florida Event

ECHO International Agriculture Conference - ONLINE EVENT

November 19th

Registration is $35.00 for the one day event.

Why Attend?

For twenty-six years, ECHO has brought together networks of like-minded individuals devoted to eradicating hunger and improving lives through agriculture and community development. In its 27th year, the ECHO International Agriculture Conference will be completely virtual. Topics to be presented will range from community development principles and addressing needs in crises, to the connection of agricultural development and environmental restoration.

The plenary speaker roster this year features experts in areas of conservation agriculture, public health, agroforestry, and agricultural extension.

Neil Rowe Miller
Conservation Ag

Tony Rinaudo
Agroforestry

Kristin Davis
Ag Extension

Gen Meredith
One Health

Check out conference.echocommunity.org to learn more about our speakers and schedule for the day-long virtual conference.

International Agriculture Conference 2020