Environmental Science Practicum Final Report: Sustainable Farming and Innovative Solutions with Agriculture for Africa

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Abstract

Agriculture is the mainstay of Cameroon's economy, engaging an estimated 70 percent of the economically active population and accounting for an estimated 80 percent of the primary sector's contribution to the country's GDP (Kenfack Essougong, 2019). Agriculture for Africa (A4A) is a nonprofit in Cameroon that works to reintegrate incarcerated youth into society by teaching them agricultural and entrepreneurial skills. Our Environmental Science senior practicum team within the Institute of the Environment and Sustainability at the University of California, Los Angeles, partnered with A4A to research and implement sustainable solutions to the prison populations in Cameroon. We focused on three main areas of research: sustainable farming, sustainable technology advancements, and site-based map making techniques. We traveled to Cameroon to test our research-based solutions and work with A4A agripreneurs to create a biosite where many of the recommendations would be implemented. Our recommendations included an intercropping strategy; a native, organic pesticide to replace chemical pesticides; and the creation of a hydroponic system to grow plants with limited land disruption. In addition, we supported the installation of solar panels and a well to create a solar-powered drip irrigation system to surmount challenges of the dry season. We also created farm site maps using a handheld, battery-powered GPS device for continued use by the agripreneurs. In this report, we discuss our specific framework for rural, sustainable agricultural development in Nkongsamba and propose universal recommendations for applying these methods to other rural agricultural projects.

Introduction

Agriculture for Africa

Agriculture for Africa (A4A) is a nonprofit in Nkongsamba, Cameroon, founded by Dr. Vijitha Eyango. A4A provides opportunities for incarcerated youth to master agricultural skills, engage in collaborative teamwork, and receive mentorship and leadership training. With limited opportunities for economic reestablishment, individuals released from prison today often return to their prior ways of life, resulting in repeat incarceration. To combat this, A4A teamed up with the prison in Nkongsamba to offer climate-resilient agricultural and entrepreneurial education. The goal is to inspire the participants – aptly named "agripreneurs" – to re-enter society economically and socially with the knowledge they gain in the program. The skills they develop with A4A both combats the food crisis at the community level, and cultivates a sustainable future for a region facing climate change and habitat loss.

A4A stakeholders believe the agricultural sites could greatly benefit from sustainable agricultural innovations and alternative technology options. The sites in Nkongsamba do not have access to an electric grid nor a consistent year-round water source. These setbacks affect the program's ability to sustain crops and meet the agripreneurs' basic needs. Our UCLA IoES Practicum Team has partnered with A4A to research and implement farm innovations, with particular focuses on mapmaking, sustainable planting and pesticide techniques, soil and water testing, hydroponics, and solar applications and installations.

Creating Site Maps Using GPS and Drones

Agriculture for Africa currently works on three existing farm sites: the Reinsertion Camp site, the Agro-pastoral site, and the Melong II site. One additional site, the Biosite, was created while our team was in the field in Nkongsamba. Gaining an understanding of the topography within and around each of these farm sites can help A4A make more informed decisions about planting, watering, and insect control (Rains, 2009; Mutanga, 2019). Agriculture programs like A4A can take advantage of data from general mapping (Shadieva, 2022; Chandra-Pandey, 2021) and global land data (Matunga, 2019) and apply it towards understanding atmospheric, vegetative, and land use patterns in a particular area of interest.

More precise mapping information than can be seen on satellite imagery is necessary to understand intricate changes in vegetation and elevation on A4A sites. A common mapping technique in remote locations is taking point coordinates with a GPS device (Bishop, 2002). A modern technique for creating detailed imagery of agriculture sites is the use of drones with software to process aerial data and produce high definition pictures (Budiharto, 2019). Our team researched the costs and benefits of GPS versus drone mapping techniques to provide recommendations specific to A4A.

Agricultural Management Techniques

A4A delegated one site, hereafter referred to as the 'Biosite,' for us to implement science-based organic farming techniques that may enhance ecosystem services. Ecosystem services include water filtering, pollination, pest management, carbon sequestration, nutrient cycling, and crop production (Garbach et al., 2014). These aspects are important to farmers in Nkongsamba because they promote resilience against climate change (Foley et al., 2005). Over time, conversion of natural ecosystems for crop production can have a deleterious effect on species richness, which in turn has been found to actually reduce crop yield (Dainese et al., 2019).

Intercropping, a method of growing two or more crops simultaneously in the same field, is believed to be more sustainable than monoculture because it mimics natural ecosystems (Vandermeer, 1992). It has been found to increase resource utilization efficiency, especially water use efficiency (Yin et al., 2020). Intercropping may not guarantee yield improvement, but rather offers a promising alternative to conventional monoculture farming.

Composting is a low-cost, widely-accepted farming technique that decomposes organic waste into a concentrated natural fertilizer (Sayara et al, 2020). Our objective was to refine the previous year's practicum team's compost guide and officially establish the system during our trip.

Biochar is a fine-grained, black charcoal material that is created by burning organic materials in an enclosed system with little to no oxygen. Smoke that is released is redirected back to the heat source, which further generates more fuel and energy to continue burning. Enclosure means fewer gas pollutants are released into the atmosphere compared to open combustion. Biochar has a high pH and carbon content, and a slower decomposition rate than the original biomass (Allohverdi et al., 2021) It also has a charged surface and high surface area, which helps it support nutrient (like nitrogen, phosphorus and carbon) retention in the soil.

Neem oil is a great alternative to chemical pesticides, which are harmful to the environment and humans (Bjørling-Poulsen et al., 2008; Mahmood et al., 2016). Neem oil is a naturally-occuring, non-toxic solution that is safe to use around people and wildlife. Due to its natural active ingredient, *azadirachtin*, neem oil has been shown to disrupt the life cycle of pests by preventing them from feeding, mating, and laying eggs (NPIC, 2018). Over time, this can help to reduce the pest population when applied as a foliar spray or soil drench. Neem oil can also kill fungal diseases like powdery mildew, black spot, scab, anthracnose, and leaf spot. Moreover, unlike chemical pesticides, neem oil can actually improve soil health, promote root growth, and increase plant resistance to disease (NPIC, 2018).

Soil Testing Technology

It is crucial to maintain soil health to support high crop yields. Some researchers hypothesize that low yield on organic farms can be attributed to soil nutrient imbalance (Saha, 2011). Farmers have a continuous duty to maintain soil nutrients, because fertility declines with each year of cultivation (Hartemink, 2006). Therefore, soil tests are a key tool for farmers to monitor fertility and apply fertilizers accordingly (Saha, 2011). There are soil tests available to analyze presence of elements such as phosphorus, potassium, calcium, magnesium, sodium, sulfur, manganese, copper, and zinc; as well as to measure pH, humic matter and exchangeable acidity (Penn, 2016) Crops all have unique soil preferences for optimal growth, so soil tests can help agripreneurs decide where to plant and how to maintain each one. Regular tests are useful to monitor fertility improvement or decline.

Hydroponics Systems

Hydroponic systems allow farmers to cultivate crops year round in a controlled environment without the use of soil. A4A can utilize this sustainable technology solution as it is beneficial to farm sites that operate on a small scale, are located in areas with seasonal constraints, or ones with a soil nutrient imbalance. Hydroponic systems can maximize yields while minimizing resource use (NPS, 2021). Instead of using soil as a growth medium, hydroponics systems submerge plant roots in nutrient-dense water. The correct balance of NPK fertilizer, PH levels, and EC levels is necessary to supply the crops with the micro- and macronutrients found in healthy soil. Hydroponics systems can be constructed vertically for areas with limited space. There are multiple types of hydroponic systems, and the variety encourages customizing the design to best fit the space. Compared to traditional agricultural methods, there is a reduction in water consumption which is helpful for areas that suffer from water scarcity.

Sustainable Technology for Farm Site Innovations

The A4A sites completely lack electricity and do not have a modern irrigation system. For the biosite and the reinsertion camp site, water needs to be carried from nearby rivers or water wells. A solar water pump system has various advantages over conventional water pump systems: it does not require fuel, it has low maintenance costs, it does not generate local pollution, and it has lower noise levels (Mekhilef et al., 2012). Subsurface drip irrigation is one of the most efficient irrigation systems (Rasheed, 2020). By transporting water directly to the roots of the crops, drip irrigation significantly increases soil moisture, resulting in an increase in yield gains and water conservation (Maisiri et al., 2005). A simple solar-powered drip irrigation system would include a solar water pump system, a reservoir, and a low-pressure drip irrigation system (Burney et al., 2009).

Research Questions

We identified agricultural innovation and alternative technology as two of A4A's main needs at this time. The following questions helped shape our methods for addressing these needs:

1. What strategies will create the highest resolution maps and topography models for the agricultural sites, and are these strategies replicable?
2. What soil tests should A4A use, and what crops should they plant based on these results?
3. What sustainable agriculture techniques are feasible and profitable for small-scale farms?
4. How can a green innovation like hydroponics support A4A's mission?
5. Which sustainable technological innovations can best support A4A's development?

Methodologies

Our team was created in October 2023. The first action item was to conduct literature reviews answering the above research questions. At the same time, we pursued fundraising opportunities to finance our project. In the winter, we prepared our action plan for the field visit, which took place over the break between the winter and spring terms. Springtime was spent analyzing our field work, preparing our final presentation, and writing this final report.

Fundraising

Our team worked with UCLA SPARK Campaigns to fundraise for travel and accommodation expenses. We prepared a video and website to describe our goals, and shared these materials with family, friends, colleagues, and faculty via the SPARK website.

The Green Initiative Fund (TGIF) at UCLA offers a $10,000 grant to students working on sustainability projects that benefit the UCLA community. We submitted an application and presented our research in front of TGIF board members.

Figure 1

A study site, the Biosite, in Nkongsamba.

Field Sites

Cameroon is in Central Africa, located roughly between 2 and 10 degrees north of the equator. Cameroon's topography includes an active volcano and many scattered, uneven mountains and hills, particularly in the western regions. Its proximity to the equator gives Cameroon one long rainy season, one long dry season, and a shorter dry-and-wet season. The southern region of Cameroon is covered by dense tropical rainforest with high rainfall,whereas the northern regions contain semi-arid savanna. The middle region of Cameroon is an ecotone between these habitats, having less dense tree coverage and many low-growing plants.

Nkongsamba is a village located in the Littoral region of Cameroon. The Littoral region extends from the western coast to the center of the country. This region is in the aforementioned transitional middle region. Its lower tree density and regular rainfall in the wet season makes Nkongsamba well-suited for agriculture. Nkongsamba is relatively large compared to surrounding villages, with a commercial area in its center. The periphery is a residential area with many simple family homes. Beyond these homes are dispersed agroforestry plots and farm land, accessed by a dirt road. The A4A farm sites were all located in this agroforestry area.

There is a small dwelling for the agripreneurs at the Reinsertion Farm site, with the farm site located directly adjacent to the dwelling and heavily covered by various trees. A two minute walk down the dirt road is the Biosite, which was unmanaged land at the time of our arrival. A five minute drive further down the dirt road is the Agro-pastoral site. This is the largest site, bordering a stream with strong flow during the wet season. It also has the largest visible elevation changes. The final site, the Melong II site, is located across Nkongsamba's city center. The road to the Melong II site is paved because it is the primary route for vehicles coming from Yaounde, the country's capital. This site was previously managed by the Ministry of Agriculture and has various crops growing throughout the plot.

Creating Site Maps Using GPS and Drones

Our literature reviews revealed that traditional mapping techniques such as total stations, satellite, and precision drones have high financial and technical skill barriers. There are very few simple cost effective mapping techniques for remote locations. Hobby drones and handheld GPS devices, while less traditional, are viable tools for meeting A4A's mapping goals.

The first step was to use A4A-provided coordinate points to view the general location of A4A's sites at 30m resolution, using publicly available satellite data from NASA. We created an account with Google Earth Engine, a free code editor commonly used by spatial data scientists to analyze larger scale plots of land.

We began to research different techniques for making onsite maps (Shannon, 2002; Pandey, 2021). Driving factors in our decision were affordability; feasibility, with consideration of resource access and the site remoteness; and user-friendliness, to accommodate A4A team members without prior mapping experience. Under this criteria, we settled on two mapping methods. The first uses a Garmin GPS 65S device. The Garmin is low-cost, appropriate for remote settings, and user-friendly during the data collection process (Bishop, 2002). However, it requires knowledge of mapping computer software such as QGIS to produce more advanced maps. The second method uses a DJI mini 2 drone. The DJI is user-friendly and produces high-definition pictures of the sites that would show elevation or distance. However, it is slightly more expensive and requires access to a smartphone to control the drone remotely. We tested both devices in Los Angeles before the trip to confirm they worked as expected.

On the first day in Nkongsamba, we visited all four A4A sites. We mapped each of the sites with the GPS by walking the perimeter of the site and manually marking individual points every meter. We uploaded these points to the computer through the BaseCamp application, and used QGIS to create a digital elevation map from the point coordinates. We set the latitude and longitude coordinates as the x and y variables and the elevation as the z variable. Then, we used the triangulation feature in QGIS to develop a 3D model of the site, which we converted to a digital elevation map using the DEM feature.

At each site, we also flew the drone overhead to collect the same data points. In order to understand the initial layout of the farmsite and necessary statistics for the flight path, we did a preliminary flight of the drone at each site. We walked to the four edges of the site to place a point marking the edge of the flight plan (*Figure 1*). After delineating the clear edges of the farm and selecting the minimum altitude, we set the other flight plan characteristics.The map application requires a 20-photo minimum to process the images. By balancing the elevation and speed of the program, we could ensure that the minimum photo threshold was met. MapPilotPro takes a photo roughly every 3 seconds, so we set the speed between 3-5m/s depending on the size of the farm site. Once the drone began following the flight path, we closely monitored both the drone and controls to avoid complications and verify the photos are usable.

Figure 2

Digital Flight Path using MapPilotPro.

We used a free account on MapPilotPro that links with MapsMadeEasy to seamlessly add all the data from each flight. The website processes the images into the final output maps with very little user input. We uploaded all images for each site onto the website from the SD card in the drone. MapsMadeEasy compiled all the images and used the GPS coordinates to produce a map and accompanying DEM. With the free version, the map can take over 24 hours to produce. The final map was shared by email and could be viewed on the associated website, or downloaded to be used offline or in other map processing softwares. There is a high-quality image and elevation map associated with each map that can be toggled using the layers tool. The website contains tools for measuring to find the area and perimeter of the entire site or individual features.

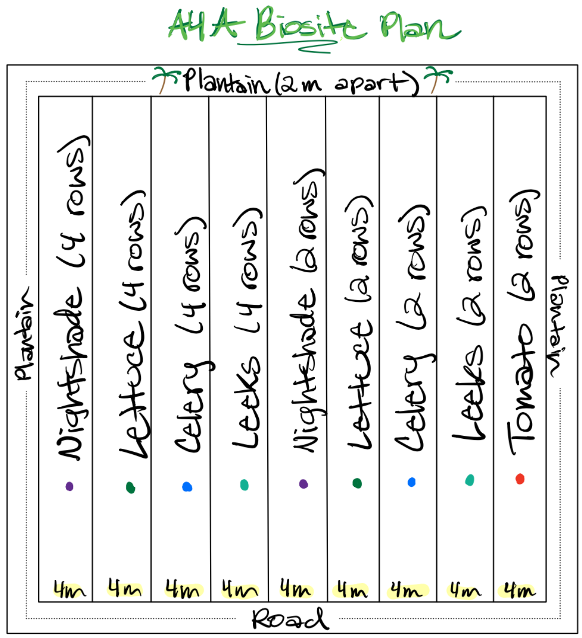
Agricultural Techniques to Promote Ecosystem Health

Our literature reviews informed our understanding of which organic techniques have proven successful at improving ecosystem services and reducing need for synthetic inputs, especially in Cameroon and ecologically similar regions.We prioritized techniques that are easy to implement and low or no-cost, so they would be scalable in A4A and similar rural, non-profit organizations. Our research indicated the importance of embracing closed-loop systems and avoiding over-modification of the biosite's natural landscape. When we had our list of suggestions, we communicated with Dr. Eyango and Dr. Michelle Carole Djouhou to select the best options for this project. We narrowed our findings down to simple strategies of intercropping, composting, biochar application, and natural pesticides, specifically neem oil.

Some pairings, such as leeks and celery, have been found to perform better when intercropped (Baumann et al, 2000). The plot map in Figure 3 depicts the intercropping arrangement we designed for the site. We alternate among each of the five crops, with a plantain border to delimit the site.

Figure 3

Intercropping planting map for biosite.



We used the compost guide developed by the Practicum class in 2022 to identify materials readily accessible to the agripreneurs. Our list included egg shells; fallen leaves; plantain peels; corn stalks, husks, and cobs; and animal manure. We also built and started a compost pile using gathered banana tree trunks, stacked 2-3 on top of one another to create a 4 sided border. Then we added in alternating layers of carbon and nitrogen rich material and soil and then watered the compost pile. To maintain the pile, we advised the agripreneurs to keep the pile damp but not too wet as well as monitor the pile by inserting a large stick into the pile and frequently turning the mixture with a shovel. This cools it down, then allows it to reheat, and repeat this process. Organic materials should be added continuously as they become available.. In a couple of months, the materials should decompose into a rich, dark soil that can be applied atop the crops as fertilizer. Compost can also be applied to a field in advance of cultivation, to prepare the soil.

During our trip, we purchased compost and applied it to the biosite. In the future, the compost created by the compost pile can be used in the same way.

The Ministère de l'Agriculture et du Développement Rural (MINADER) provided A4A with two large bags of biochar, which we activated and applied. We researched a few techniques for activation and decided to use the liquid fertilizer method, because it is the fastest. We first created liquid fertilizer by making a compost tea which we left at room temperature for 24 hours. The next day, we strained the compost tea to filter out the liquid, which we then mixed with the biochar. We left this mixture for another 24 hours. Finally, the activated biochar was added to the raised biosite beds to enhance soil nutrient retention.

Our team designed the nursery next to the A4A house and tilled the soil to make 6 raised beds, one for each of the 6 crops planned to grow on the biosite: tomatoes, celery, leeks, lettuce, cabbage, and nightshade. We sprinkled a handful of seeds into rows on the raised beds and lightly covered them with soil. The beds were watered every few days until the seedlings were ready for transfer to the Biosite. To prevent pests and other animals from getting into the nursery, we built a netted enclosure.

Neem Oil

We brought A4A two 1-liter bottles of neem oil, unscented dish soap, and a 4 gallon backpack sprayer to apply the pesticide efficiently. We demonstrated how to emulsify the neem oil and delivered a 4-step guide (Appendix F) with protocols, important notes, and proper usage/maintenance techniques.

Soil Testing

We funded preliminary laboratory soil tests by MINADER. During our visit, we conducted in-site tests using the soil pH meter we researched and purchased. On the Ekangbeng biosite, we took measurements at 5 different spots. At each spot, we took 3 measurements and calculated an average. We followed up with A4A to request soil pH measurements 2 months after the trip to see whether soil pH had changed.

Hydroponics Systems

We researched the various hydroponic systems to determine which would be most beneficial, efficient, and replicable. We settled on a modified version of the Kratky method (Kratky, 2008). It doesn't require electricity to run and can be constructed using recycled materials such as plastic bottles and styrofoam boxes. Instead of using air pumps and grow lights, our system receives light from the sun and leaves an air pocket between the nutrient water and roots to keep the roots oxygenated. When the crops are harvested, the hydroponic materials can be sanitized and reused for the next growing season.

In Nkongsamba, we built one hydroponic system and presented the importance, construction, and components via a demonstration. With our client, we decided to grow lettuce, cabbage, and celery hydroponically. We chose an outdoor site near MINADER's office that has ample lighting. We were able to procure a soldering iron, insulation foam, pool noodles, nutrient solutions, and an EC/PH meter. During our trip we collected water bottles, food bins, and styrofoam boxes. Finally, we created infographics (Appendix J), and a written guide depicting the steps for assembly, maintenance, and replication.

Sustainable Technology for Farm Site Innovations

We included the solar drip irrigation system in our application for the Green Initiative Fund (TGIF) at UCLA. We chose TakuEnergy for the initial assessment and installation of the solar panel system. They dug a hole for the electrical grounding, to protect the system against thunderstorms or lightning. Salt and charcoal were part of the mixture applied for grounding. The different components of the system are shown in Table 1. The drip irrigation system, including the water tanks, the pipes, and the drippers, are currently in the installation process.

Table 1

Solar System Components

System Description	**Quantity**
TakuEnergy 3KW Low Frequency/MPPT Inverter	1
450 WP MONO Solar Panel	4
TakuEnergy Gel Battery 250/200AH@12V	4
1KW Energy Saving Borehole Pump AC	1
Electrical Grounding Reinforcement	1
Battery box, Combiner box, Mounting Rack, and MC4 set	1

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Results

Fundraising

We were fortunate to raise $12,000 through our SPARK campaign, covering our travel expenses. We also indeed received TGIF funding of $10,000 to purchase the solar water pump as well as various other technologies, including the Garmin GPS.

Creating Site Maps Using GPS and Drones

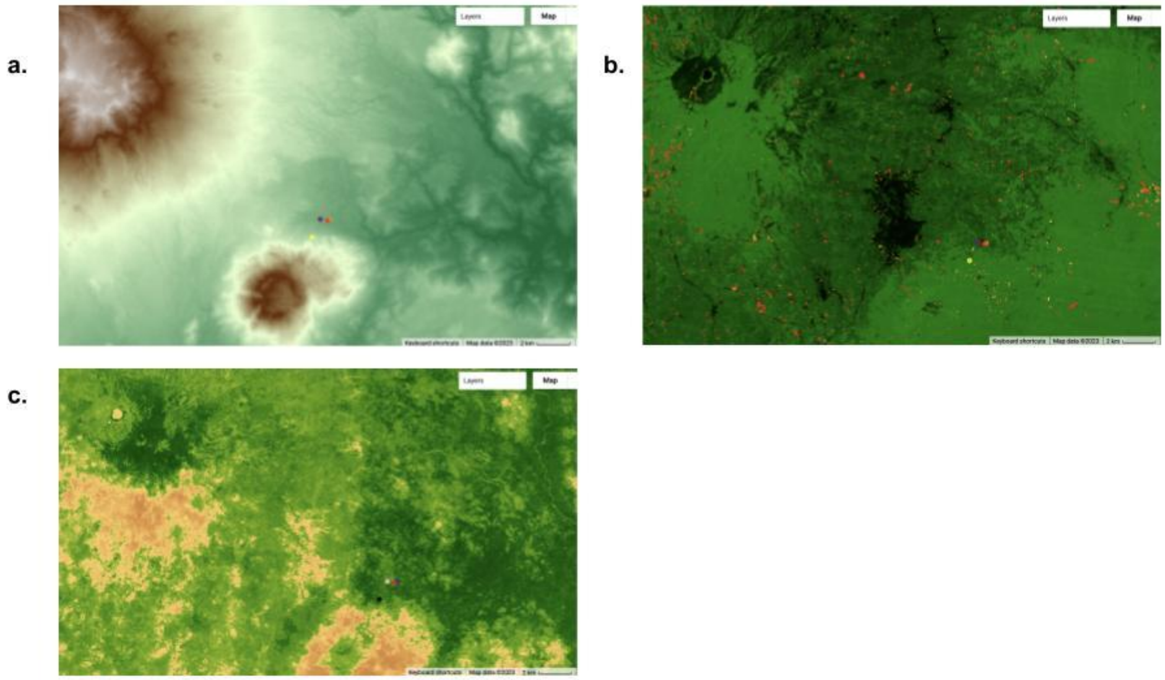
We used Google Earth Engine to make elevation, tree coverage, and vegetation maps without even visiting the site. Figure 4a shows the elevation in and around Nkongsamba. Elevation is depicted with white as the highest elevation, followed by brown, yellow, and light green as descending elevations, and dark green as the lowest elevation. The yellow dot is the location of the Melong II site, the red dot is the location of the Biosite, the orange dot is the location of the Reinsertion Camp site, and the purple dot is the location of the Agro-pastoral site.

Figure 4b shows the forest coverage in and around Nkongsamba. The orange-red scaled plots represent areas that have lost forest or the health of the forest has degraded in the past year. Red represents complete forest loss, orange represents degraded forest health, and colors in-between signify varying levels of forest degradation or loss. The lighter green represents greater forest density and black represents no forest cover at all. The colored dots represent the same sites as in the previous map.

Figure 4c shows the vegetation and greenness in and around Nkongsamba. The dark green represents high vegetation health and is scaled proportionally down to orange, which represents dying or dead vegetation. The black dot is the location of the Melong II site, the red dot is the location of the Biosite, the dark blue dot is the location of the Reinsertion Camp site, and the yellow dot is the location of the Agro-pastoral site. The code used to create each of these satellite maps on Google Earth Engine can be found in Appendices D-F.

Figure 4

Satellite Maps of A4A sites in Nkongsamba; 4a. Elevation map of Nkongsamba; 4b. Forest cover in Nkongsamba; 4c. Vegetation health in Nkongsamba.



We created elevation maps for each individual farm site from the coordinate and elevation data we recorded on the Garmin GPS device. Figure 5 shows the digital elevation models we made for each farm site in QGIS. The darker colors represent lower elevation and the lighter colors represent higher elevation. The raw coordinate points collected from the Garmin GPS at each farm site and uploaded to the BaseCamp application can be found in Appendix G.

Figure 5

Farm Site Digital Elevation Maps of A4A sites in Nkongsamba; 5a. Biosite DEM; 5b. Reinsertion site DEM; 5c. Agro-pastoral site DEM; 5d. Melong II site DEM.

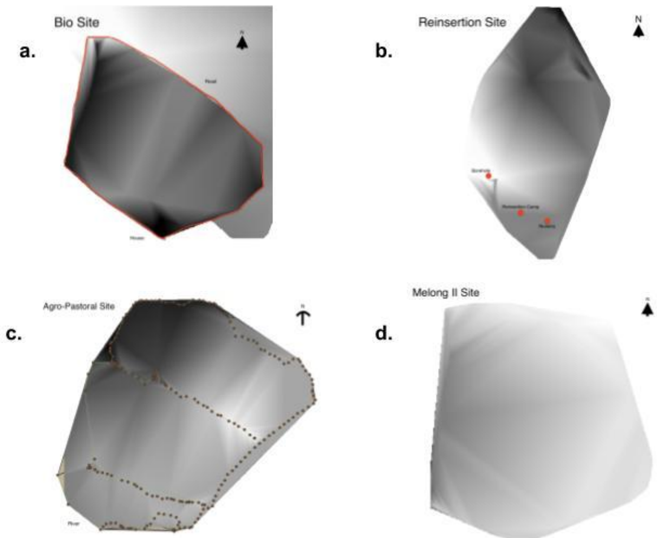
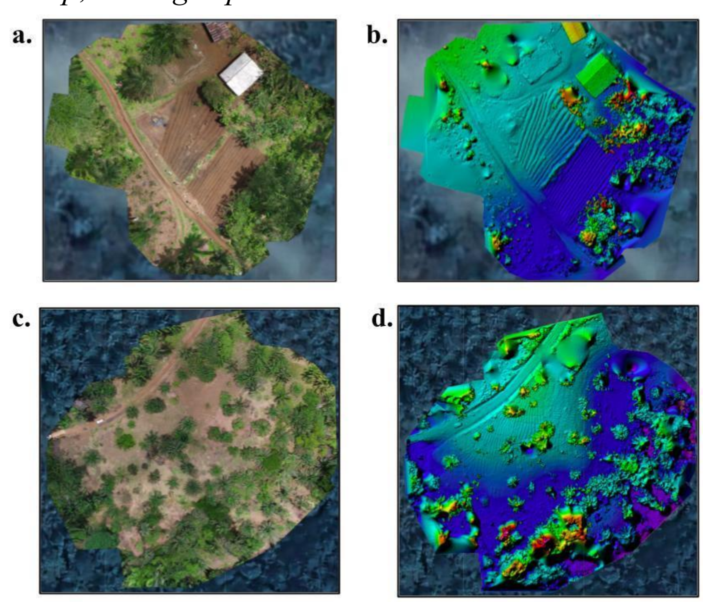


Figure 6 displays both the DEM and image maps created for the Biosite and Agro-pastoral Site. Each associated website contains the tools for measuring and altering aspects of each site. The scale of elevation for the DEM is only visible on the website version. The download capability on the site expires after 30 days.

Figure 6

A4A Farm Site Drone Maps (Image and DEM Maps); 6a. Biosite Image Map; 6b. Biosite DEM; 6c. Agro-pastoral Image Map; 6d. Agro-pastoral DEM.



Soil Testing

The preliminary tests by MINADER found the pH levels on the biosite were 4.91. The team also took pH tests across the biosite using the soil pH meter they brought to give to A4A.

Table 2

Soil pH test results at the A4A biosite before fertilizers are applied.

A4A Biosite pH Guide									
plant	optimal	loc 1	loc 2	loc 3	loc 4	loc 5		key	
Celery	5.8-6.8	6.7	6.3	5.7	6.0	5.6			optimal
Lettuce	6.0-7.0	6.7	6.3	5.7	6.0	5.6			nearly optimal
Leek	6.2-6.8	6.7	6.3	5.7	6.0	5.6			far from optimal
Tomato	5.8-7.0	6.7	6.3	5.7	6.0	5.6			
Black Nightshade	5.0-8.0	6.7	6.3	5.7	6.0	5.6			
Cabbage	6.0-6.5	6.7	6.3	5.7	6.0	5.6			

The A4A team in Nkongsamba took soil tests on May 26, 2023 and sent the updated results.

Table 3

Soil pH test results at the A4A biosite after fertilizers were applied.

A4A Biosite pH Guide									
plant	optimal	loc 1	loc 2	loc 3	loc 4	loc 5		key	
Celery	5.8-6.8	5	5.4	5.9	6.0	6.1			optimal
Lettuce	6.0-7.0	5	5.4	5.9	6.0	6.1			nearly optimal
Leek	6.2-6.8	5	5.4	5.9	6.0	6.1			far from optimal
Tomato	5.8-7.0	5	5.4	5.9	6.0	6.1			
Black Nightshade	5.0-8.0	5	5.4	5.9	6.0	6.1			
Cabbage	6.0-6.5	5	5.4	5.9	6.0	6.1			

Figure 7

Agripreneur using soil pH meter.

Agricultural Techniques to Promote Ecosystem Health

Figure 8

Nursery established in Ekangbeng next to the agripreneur's house.

Figure 9

Tillage progress of Biosite; 9a. Site upon arrival; 9b. Site after tilling and row formation; 9c. Site update 1.5 months post-trip.

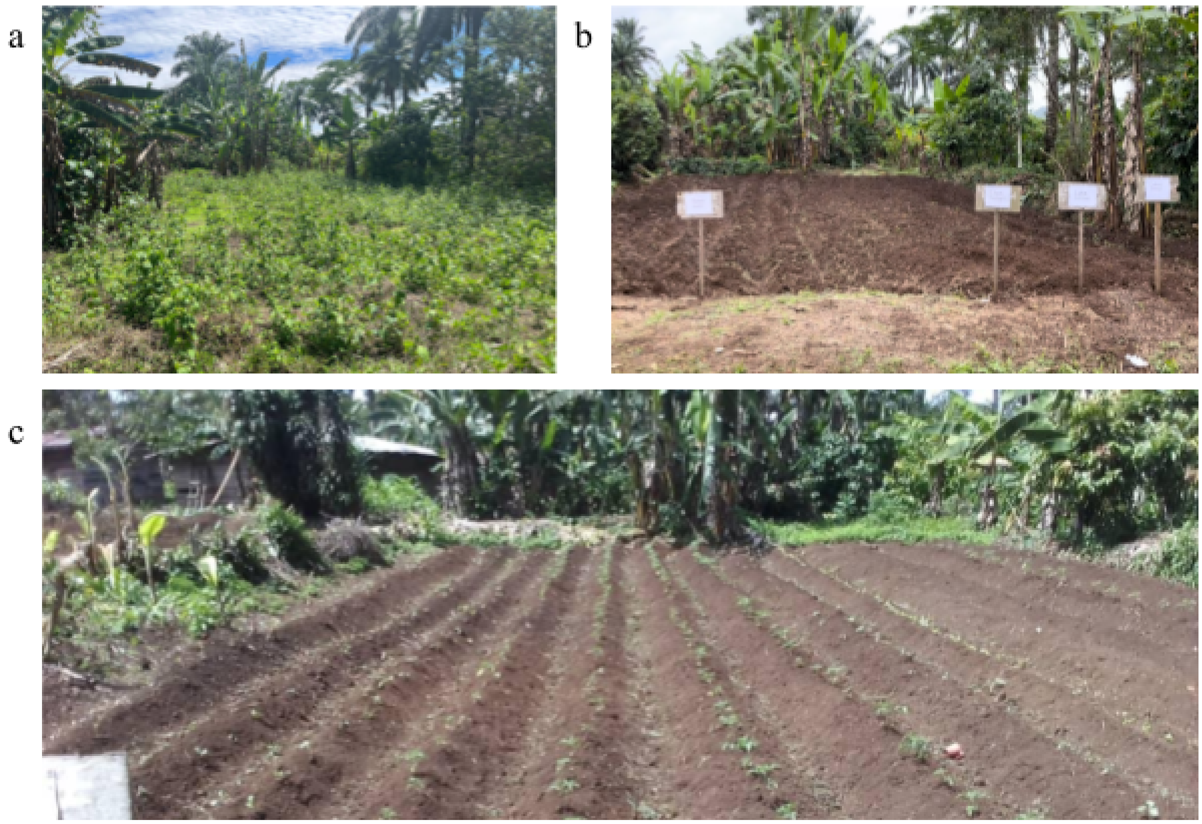


Figure 10

Crops at the biosite two months after planting; 10a. Tomatoes; 10b. Cabbage.

The tomatoes have established successfully and are currently flowering and bearing fruit. The lettuce, cabbage, and nightshade are also growing to completion and have been partially harvested, mainly for agripreneur consumption. The final nightshade production quantity was six packs of 100 grams. A4A recommended that the agripreneurs use it for their own consumption. Lettuce yield was too small for measurement or sale, but has also been consumed by the agripreneurs. The quantity produced is equal to what has previously been produced by conventional methods. They report excellent flavor.

Figure 11

Compost pile at the reinsertion camp.

Hydroponics Systems

Figure 12

Two Liter Hydroponic System 12a; Completed hydroponic grow cup 12b .

a.  b. 

Figure 12a is a hydroponics system made out of styrofoam with orange grow cups in position. The bottom half of the grow cups are inserted into the top of the system. Figure 12b is a prepared grow cup that features holes for roots and blue pool noodle to hold the crop in place.A

Hydroponic guide was created to aid with the construction and maintenance of the hydroponics system (Appendix J). Figure 13 illustrates what the system will look like in the designated area approved by MINADER.

Figure 13

Location and proposed design of hydroponics system.

Sustainable Technology for Farm Site Innovation

Figure 14

Solar panel installation.

With help from Taku Energy and funding from TGIF, four solar panels were installed on the Reinsertion Camp site(Figure 14), providing electricity and lighting to agripreneurs. The solar water pump system remains in progress.

Using Neem Oil as an Organic Pesticide

The first application neem oil on the biosite was successful in protecting the cabbage from insect attacks. The tomatoes and lettuce suffered a significant loss. In response, we advised a second spray or soak which had fully successful results, and no further insect or fungal attacks have been reported.

Discussion

Creating Site Maps Using GPS and Drones

Mapping supports agriculture projects by informing users of trends in yields, vegetation and soil health, and damage from pests and disease. Maps also provide simple spatial context and inform land management decisions, especially in the face of climate change (Backes, 2003, Bulletin, 2009).

Google Earth Engine is a premier application for visualizing environmental features using satellite imagery (Tamiminia, 2020). Google Earth Engine has been used across many disciplines to analyze trends in environmental data at small and large scales (Zhao, 2021), so it was a key tool for creating a holistic understanding of various environmental factors in and around Nkongsamba. Using satellite imagery to see large-scale deforestation (Figure 3b) can help the Ministry of Agriculture and A4A determine soil health, water availability, and soil nutrient uptake (Ryan, 2011). Vegetative health (Figure 3c) can be used as an indicator for areas that are ideal for future agricultural use. Poor vegetative health might suggest pest or disease vulnerability, and can be used to estimate crop yield (Mutanga, 2019). A4A plots suffering from the presence of diseases or insects might use the vegetative health maps alongside the elevation maps to make informed decisions about how to tackle these problems. It can be difficult to understand how large scale environmental patterns are affecting small scale agricultural plots, but Google Earth Engine provides easily accessible datasets and a platform to visualize them.

The Garmin GPS gathers precise field information and can store large amounts of coordinate and elevation information (Pandey, 2021). The A4A team now has the GPS device and can create more maps as new sites are acquired. Although the drone mapping outputs are easier to create, the on-site reliability provided by the Garmin GPS is vital for A4A's purposes. The GPS can immediately determine simple direction, coordinate, and elevation data wherever the team is. Soil and vegetation are a direct reflection of topographic features including slope and elevation (Bishop, 2002). Many connections have been made between soil health and topography (Haneklaus, 1996).

Drone mapping has grown in popularity and quality over the last decade. Large scale sites can be mapped far faster with drones versus conventional methods, and drone maps offer more detailed visualization of soil and vegetation (Puri, 2017). Drones used for these purposes belong to a category of "precision agriculture." These drones contain LiDar sensors, RGB cameras, thermal imagery, NDVI, and a number of other sensors. For large scale farms, these measurements are critical, especially in an increasingly difficult agricultural landscape (Deponte, 2019). However, these drones are far too expensive and complicated for small rural farm sites like those operated by A4A. On small rural farms, there is no need for – let alone access to – precision agriculture drone mapping. The DJI mini 2 drone costs $450 and does not require technical skill to operate and generate outputs. It is an accessible and user-friendly mapping tool that does not sacrifice quality. The accuracy of the drone map measurements is comparable to those of the GPS–collected data.

Even with Google Earth Engine, there is a scarcity of satellite imagery in rural Cameroon that is precise enough to inform A4A's operations. Prior to our visit, we lacked a clear vision of how the sites looked. Upon arrival, tree and brush coverage made it difficult to infer shape and area from the ground. The drone images contributed to an orthomosaic map that brought much-needed clarity on the shape and landscape of the sites. The associated Digital Elevation Model (DEM) provides a significant amount of detail, but the accuracy is somewhat questionable. The sensor capabilities of the DJI mini are mainly infrared, combined with a GPS . These are merged through MapPilotPro to generate the DEM based on inferences of general slope.

In the field, there were complications and glitches leading to incomplete or unusable maps. Of the five attempts, we had two failures for different reasons. For the Melong II site, the software canceled the path and returned back halfway through the flight. It was the last flight of the day, and we did not have enough battery power or time to do another run. The software was able to create a map of the half it did complete. The flight of the reinsertion camp site went according to our outline, but when we input the images, the output became messy and overlapping. We have attempted to adjust the images and processing to generate a usable map, but the final product is incomplete. We could complete these maps if we had had time on site for more trials.

Soil Testing

Preliminary tests by MINADER found the pH levels on the biosite were 4.91, which were lower than the average plant prefers. pH would ideally range from 5.5-7.0. Also, maximum availability of phosphorus occurs in the pH range of 6.0-7.0 (Griffith, 2023). So, we pursued methods to increase the soil pH, such as compost application. The pH results from the soil pH meter were all within or slightly outside the optimal pH ranges. Those that were below optimal helped support our explanation of the importance of building a compost pile, because the compost pile will create a natural fertilizer that helps neutralize soil pH. The follow-up soil tests found that the average pH had decreased overall.

Agricultural Techniques to Promote Ecosystem Health

Agriculture is a long, holistic process, so our results for compost and biochar application, intercropping, and neem oil usage are not cut-and-dry. For example, the long term impacts of biochar occur six months post-application (Joseph et al., 2021). Even quantitative factors like yield cannot yet be analyzed because we planted the crops in March, and they will be harvested towards the end of the summer. Other metrics, such as soil organic matter and water retention are more difficult to measure at all.

We are able to discuss how relevant and easy the methods were to implement. For example, it was free and fast to create the compost pile. It didn't require much new action by the agripreneurs, and they have enthusiastically been adding to the pile even after our departure. We were even informed that after our presentation, the community members in attendance wanted to implement compost piles on their own farms. Previously, most community members threw their food scraps around their farms randomly. The A4A team mentioned that applying more compost would have helped even further improve soil quality, so this compost pile will hopefully help contribute to fertilization efforts. After our team left Cameroon, the A4A agripreneurs have provided technical training to teach the community members how to replicate the compost pile.

The lettuce and cabbage blossoming have been hindered by lack of rainfall. The entrepreneur's greatest challenge has been the limited rainfall and the malfunctions with the solar water pump. Fortunately, pests were not a large obstacle this season because the neem oil was successful at deterring insects and fungal disease.

Hydroponics Systems

We found resourcefulness to be a major asset to the construction of the hydroponics system. Our initial prototype was built using one 2 liter styrofoam box we found in a store's chocolate display and a plastic bin previously used for cooking. In this way, hydroponics can provide opportunities to repurpose materials otherwise seen as "trash" into vessels for growing food. A challenge we encountered was soldering iron failure due to the difference in electrical currents. We were still able to use it by heating it over an open flame. Any long, pointed metal object can be used this way. We are grateful for MINADER's support and adoption of the hydroponic systems, and for the interns who expressed interest in maintaining the crops. It was difficult to determine a location prior to our visit, so we could only identify a suitable spot when physically in Nkongsamba.

Assembly of the final hydroponics system will take place shortly after completion of this report. We are hopeful that it will be successful with the guides we created, and we will be keeping in touch with A4A and the team at MINADER to track its progress. Hydroponics is designed to be a "set it and forget it" system. With more experience, A4A will be able to run many systems with less overall maintenance. We look forward to receiving updates and seeing the completed hydroponics set-up.

Sustainable Technology for Farm Site Innovation

The solar drip irrigation system is an ongoing project, and will not be finished until the pump and irrigation are successfully installed. Currently, the only functional component is the solar panels. They are providing electricity to agripreneurs living at the Reinsertion Camp. However, the energy produced is insufficient to power the pump. We will need either additional panels or a different pump that is compatible with the existing panels. A4A is working with Tako Energy to resolve this issue. Furthermore, the weight of the solar panels has damaged the roof, causing leaks in the bedroom of the Reinsertion Camp. This is a significant consequence, and we advise similar future endeavors to be mindful of the structural capacity of farm sites receiving solar technology.

Additionally, the initial estimation of the water table depth was wrong, so the solar pump could not reach sufficient water. The borehole must be made deeper. Currently, the agripreneurs have to carry watering cans to water the crops by hand. We hope that Tako Energy will remedy the issues, and we are eager to receive positive updates from A4A.

Future Recommendations

Creating Site Maps Using GPS and Drones

The elevation maps should be used to make future decisions about planting and watering schemes. Similarly, the satellite maps should be used to gain a better understanding of the surrounding area and guide decisions about new farm locations or existing farm needs. We recommend that A4A uses these maps to demonstrate their capabilities in generating geospatial information about their farm sites, particularly when talking with stakeholders and donors. For future, large scale sites, drone mapping would be more useful to determine full scale visuals on covered farm areas.

Agricultural Techniques to Promote Ecosystem Health

Many sustainable farming practices contradict conventional agriculture knowledge, which can be intimidating. Nonetheless, we recommend that A4A seriously considers both conservation tillage and cover cropping in the upcoming seasons, as there is a wealth of research supporting both interventions (Alexander, 2014; Davis, 1994; Fageria & Moreira, 201; Hillel & Hatfield, 2005; Petit et al., 2020).

We intended to purchase pure, unscented soap for use as a safe emulsifier for our neem oil insecticide. In Nkongsamba, we were unable to find any soaps that were 100% free of fragrance. It is unlikely that a small amount of fragrance will damage the plants, but we still recommend natural alternatives for future use such as African Black Soap or soap from the Shampoo Ginger Lily (scientific name "*Zingiber Zerumbet*") which is grown in the Littoral region of Cameroon, where Nkongsamba is located.

Intercropping was easy to implement, because it is a simple modification of their typical farming procedure. Going forward, we recommend a simultaneous larger scope intercropping strategy that rotates the rows such that each growing season, a given crop is not planted in the same row it was planted the previous season. Since every crop has a unique relationship to the soil ecosystem, annual rotation helps support a rich soil microbial diversity (Venter et al., 2016). We also recommend spacing the seedlings farther apart, as a large portion of the bed space on the Biosite was left untouched.

Moving forward, the team recommends for A4A to use the soil test pH meter to test the soil pH every few weeks. The soil pH measurements can be a simple guide, but we also recommend A4A to repeat the more complex MINADER lab tests annually, to confirm results. As the May soil test results were still low, we recommend A4A continues to apply compost and biochar.

We look forward to keeping in touch with the team on the Biosite and learning how their experiences with the compost pile, the intercropping layout, the biochar and the neem oil play out.

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Appendix

Appendix A: A Guide to Using the Garmin GPS 65S

This is a link to the Owner's Manual for the Garmin GPS 65S. The manual in French can be found in a pdf in the Follow Up/Recap folder that the UCLA team has shared with A4A. Important notes on how to use the Garmin:

- The device takes two AA batteries but the batteries can be recharged using the charging cable.
- The 'on/off' button is on the side of the device, and should be turned off after every use to conserve battery (work will be saved when device is powered off).
- To mark a point on the device, select the 'Waypoints' option from the main menu and then press the 'Mark' button on the device. You will be given the coordinate and elevation information immediately, and from there you have the option to save the point or to erase the point. Individual points can also be labeled from this screen. Each saved point comes with a timestamp so successive points / tracking your movement can be accessed later on.
- The charging cable is also used to link the Garmin to the computer where points/data can be uploaded.
- The Garmin data can be viewed easiest on any computer using the Garmin BaseCamp Application.

Appendix B: Garden Sprayer Guide

Appendix C: DJI Mini 2 Drone Guide

https://dl.djicdn.com/downloads/DJI_Mini_2/20210630/DJI_Mini_2_User_Manual-EN.pdf

Appendix D: Elevation Code

```
//Elevation Map Code - Google Earth Engine - JavaScript
var geometry = ee.Geometry.Rectangle(9.65, 4.83, 10.1, 5.19);

var collection = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR')
    .filterDate('2019-01-01', '2019-12-31')
```

```
    .filterBounds(geometry);

var elevation = ee.Image('CGIAR/SRTM90_V4');

var elevationPalette = ['006633', 'E5FFCC', '662A00', 'D8D8D8',
'F5F5F5'];

// Compute the NDVI using Landsat 8 imagery.
//function addNDVI(image) {
 // var ndvi =
collection.select('B4').subtract(collection.select('B3'))
 //
.divide(collection.select('B4').add(collection.select('B3')));
//  return image.addBands(ndvi);
//}

var addNDVI = function(image) {
  var NDVI = image.normalizedDifference(['B4', 'B3'])
  .rename('NDVI')
  .copyProperties(image,['system:time_start']);
  return image.addBands(NDVI);

};

var collectionNDVI = collection.map(addNDVI);

Map.addLayer(elevation, {min: 300, max: 3000, palette:
elevationPalette}, 'Elevation');

Map.addLayer(collectionNDVI.select('NDVI').mean(), {min: 0, max:
1, palette: ['red', 'yellow', 'green']}, 'NDVI');

var ndviElevation = ee.ImageCollection.fromImages([
  collectionNDVI.select('NDVI').mean().visualize({min: 0, max:
1, palette: ['red', 'yellow', 'green']}),
  elevation.visualize({min: 300, max: 3000, palette:
elevationPalette})
]).mosaic();

Map.addLayer(ndviElevation, {}, 'NDVI Elevation Map');
```

```
var geom = ee.Geometry.Point(9.986439, 4.943454);
var geom2 = ee.Geometry.Point(9.985597, 4.943053);
var geom3 = ee.Geometry.Point(9.981469, 4.943570);
var geom4 = ee.Geometry.Point(9.976971, 4.933620);

Map.centerObject(geom, 10);
Map.addLayer(geom, {color: 'orange'}, 'Googleplex');
Map.addLayer(geom2, {color: 'red'}, 'Googleplex');
Map.addLayer(geom3, {color: 'purple'}, 'Googleplex');
Map.addLayer(geom4, {color: 'yellow'}, 'Googleplex');

Export.image.toDrive({
  image: collection.mean(),
  description: 'elevation_nkongsamba',
  scale: 30,
  region: geometry
});
```

Appendix E: Forest Coverage Code

```
// Forest Coverage 2020 - Google Earth Engine - JavaScript
var dataset =
ee.Image('UMD/hansen/global_forest_change_2020_v1_8')
  .select(['treecover2000', 'lossyear']);

var treeCoverVisParam = {
  bands: ['treecover2000'],
  min: 0,
  max: 100,
  palette: ['black', 'green']
};

Map.addLayer(dataset, treeCoverVisParam, 'tree cover');

var treeLossVisParam = {
  bands: ['lossyear'],
  min: 0,
  max: 20,
  palette: ['yellow', 'red']
};
```

```
Map.addLayer(dataset, treeLossVisParam, 'tree loss year');

var geometryA = ee.Geometry.Rectangle([9, 4, 12.3058, 7.9475]);
var geom = ee.Geometry.Point(9.986439, 4.943454);
var geom2 = ee.Geometry.Point(9.985597, 4.943053);
var geom3 = ee.Geometry.Point(9.981469, 4.943570);
var geom4 = ee.Geometry.Point(9.976971, 4.933620);

Map.centerObject(geom, 10);
Map.addLayer(geom, {color: 'orange'}, 'Googleplex');
Map.addLayer(geom2, {color: 'red'}, 'Googleplex');
Map.addLayer(geom3, {color: 'purple'}, 'Googleplex');
Map.addLayer(geom4, {color: 'yellow'}, 'Googleplex');

Export.image.toDrive({
  image: dataset,
  description: 'hansen_2020_nkongsamba',
  scale: 30,
  region: geometryA
});
```

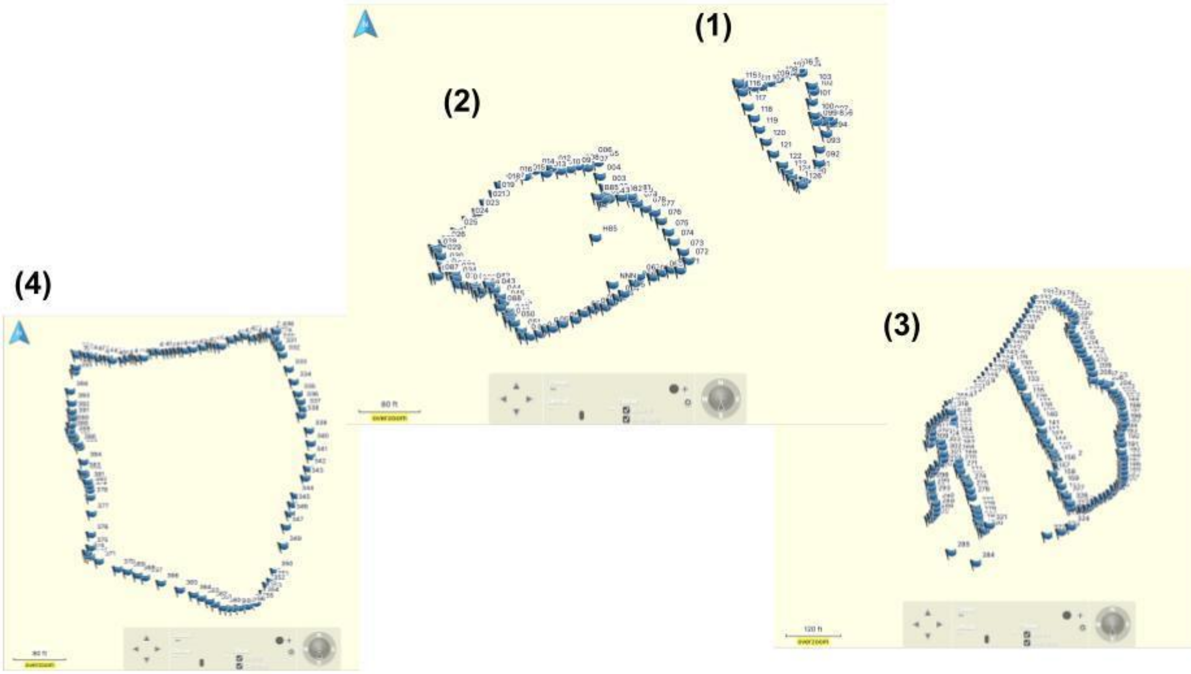
Appendix F: NDVI Code

```
// NDVI - Google Earth Engine - JavaScript
var collection = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR')
                  .filterDate('2021-01-01', '2021-12-31')
                  .filterBounds(ee.Geometry.Rectangle(9.72,
                    4.76, 10.08, 5.04));

var addNDVI = function(image) {
  var ndvi = image.normalizedDifference(['B5',
'B4']).rename('ndvi');
  return image.addBands(ndvi);
};

var collection_ndvi = collection.map(addNDVI);
var median_ndvi = collection_ndvi.select('ndvi').median();

var visParams = {
  min: 0,
  max: 1,
```

```
  palette: ['FFFFFF', 'CE7E45', 'DF923D', 'F1B555', 'FCD163',
'99B718', '74A901', '66A000', '529400', '3E8601', '207401',
'056201', '004C00', '023B01', '012E01', '011D01', '011301']
};
Map.addLayer(median_ndvi, visParams, 'NDVI Median');

var rectangle = ee.Geometry.Rectangle(9.72, 4.76, 10.08, 5.04);
Map.centerObject(rectangle);

var geom = ee.Geometry.Point(9.986439, 4.943454);
var geom2 = ee.Geometry.Point(9.985597, 4.943053);
var geom3 = ee.Geometry.Point(9.981469, 4.943570);
var geom4 = ee.Geometry.Point(9.976971, 4.933620);

Map.addLayer(geom, {color: 'blue'}, 'Googleplex');
Map.addLayer(geom2, {color: 'red'}, 'Googleplex');
Map.addLayer(geom3, {color: 'pink'}, 'Googleplex');
Map.addLayer(geom4, {color: 'black'}, 'Googleplex');

Export.image.toDrive({
  image: collection,
  description: 'hansen_2020_nkongsamba',
  scale: 30,
  region: rectangle,
});
```

Appendix G: Farm Site Coordinate Points in BaseCamp

Appendix G1 is the biosite, Appendix G2 is the reinsertion site, Appendix G3 is the agro-pastoral site, and Appendix G4 is the Melong II site.



Appendix H: Drone Mapping Associated Websites

Each sites accompanying website contains the tools for measuring, reshaping, and the DEM legend.

Biosite 1:https://www.mapsmadeeasy.com/maps/public/0ebcfe8160694d2fae49ca8768233c2d/
Biosite 2:https://www.mapsmadeeasy.com/maps/public/8e426f29c5604b428cd029c3b4480bc0/
Agro-pastoral:https://www.mapsmadeeasy.com/maps/public/679ea92186884f00886e5d0d53e5c8b9/
Each sites accompanying website contains the tools for measuring, reshaping, and the DEM legend.

Appendix I: Neem Oil Pesticide Guide

Guide for Using Neem Oil as a Pesticide

Step 1: Mix up the soap and water

Neem oil needs an emulsifying agent to effectively mix with water, like mild dish soap. Add 1 spoon of unscented dish soap to 1 gallon (3.75 liters) of warm water in a bowl and mix it thoroughly.

- Backpack Sprayer can hold 4 gallons (15 liters) of liquid.
- Unscented powdered soap can also be used if liquid soap is unavailable.

Step 2: Top it with the neem oil

After combining the soap with water, add 2 spoons of neem oil to the mixture and stir it thoroughly.

Step 3: Spray It

Once mixed properly, add the prepared solution to a garden sprayer. Spray the solution on **all** plant surfaces until the leaves are wet and dripping. Use gloves to avoid any contact.

OR

Step 3: Soak It

Pour 2 to 3 cups of your neem soil drench around the roots of each plant. To combat an existing infestation, repeat every two weeks. In the case you are fighting powdery mildew or root rot, watch the plant closely until any symptoms have disappeared.

Step 4: Reapply To Avoid Plant Diseases and Pests

Reapply the neem oil mixture regularly, approximately after every 7-14 days (spray every 14 days as a preventative measure, 7 days if you're trying to control an active pest infestation). Be sure to spray on both sides of the leaves.

Important Notes:

Make sure to use 100% cold pressed neem oil with azadirachtin.

Always Test First
Neem oil is powerful and contains natural chemical compounds that can leave burns on sensitive plants.
Always apply a tiny amount to the plant 24 hours before the main application to ensure your plant isn't sensitive or allergic to the neem. **Be sure to use unscented dish or unscented powdered soap as an emulsifying agent.**

Do not spray your neem oil in the middle of the day when the sun is a threat. Spraying neem oil under intense sunlight will put your plants at risk of burning. **Apply the mixture in the early morning or late evening.** All the insects are usually inactive during these times. If there are small or delicate areas you can't reach with the spray bottle, you can go over them gently with a Q-Tip or soft toothbrush. Also, ensure that neem oil is properly mixed with water to avoid a too potent mixture.

Neem oil should be applied when rain is not expected within 24 hours of application. Leaves should not be dripping from rain or watering before applying to ensure the product makes good contact and does not run off. Heavy rainfall (two inches or more) within 24 hours of application generally requires reapplication.

Do not use neem oil on newly transplanted or stressed plants.

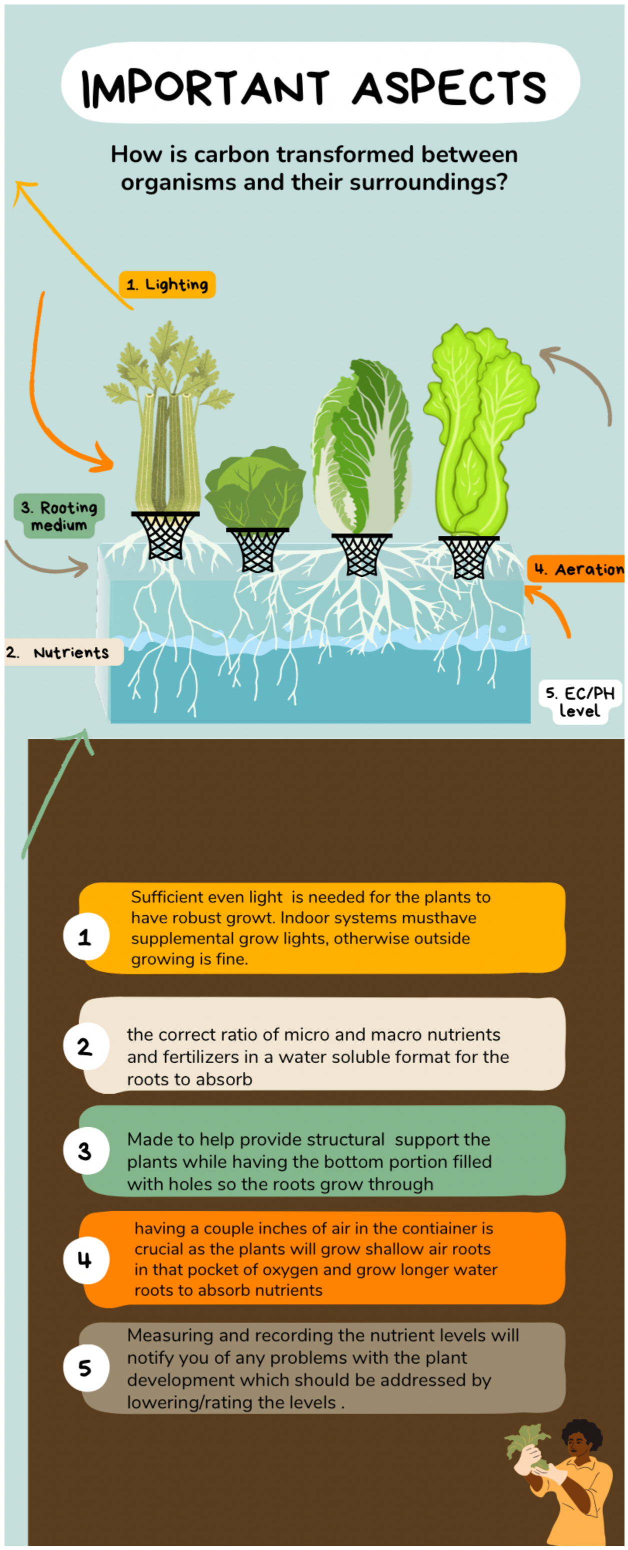
Note that pure neem oil may solidify at cooler temperatures.

Make no more than you'll use. Once diluted, neem oil doesn't keep long. Keep the batches of your mixture small, prepare it on the day you wish to use it or else the mixture will start separating with time.

Be sure to stir mixtures frequently to maintain strength.

You can add essential oils to your mixture, as certain pests are repellent to the smell of essential oils such as peppermint, lemon, etc!

Appendix J: Hydroponic Systems Guide


IMPORTANT ASPECTS
How is carbon transformed between organisms and their surroundings?
1. Lighting
3. Rooting medium
4. Aeration
2. Nutrients
5. EC/PH level
1
Sufficient even light is needed for the plants to have robust growt. Indoor systems musthave supplemental grow lights, otherwise outside growing is fine.
2
the correct ratio of micro and macro nutrients and fertilizers in a water soluble format for the roots to absorb
3
Made to help provide structural support the plants while having the bottom portion filled with holes so the roots grow through
4
having a couple inches of air in the contiainer is crucial as the plants will grow shallow air roots in that pocket of oxygen and grow longer water roots to absorb nutrients
5
Measuring and recording the nutrient levels will notify you of any problems with the plant development which should be addressed by lowering/rating the levels .

Growbox Assembly

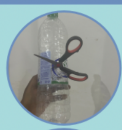
Gather all the materials required to create this system. You need to make the growing medium which will provide structural support to the seedlings, a grow cup that allows the roots to get access to air and water, as well as the grow box that will contain it all in addition to the nutrients

01 – [Growing medium] Cut pool Noodles

Take pool noodles and use scissors to cut one inch sections so You have rings. Cut a slit from top to bottom on one of the sides

02 –Fit pieces together

Take the rings, and widen the slit by cutting a piece less than a half inch big which will be fitted in the center opening of the ring, while the whole ring will be inserted into the top part of the grow cup.

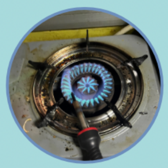


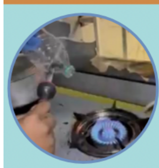
01 – [Grow cup] Collect/Cut bottles

Collect, sanitize, and dry the cups you will use. Cut plastic water bottles in half horizontally and remove the plastic covering from the middle.

02 – Heat up Soldering Iron

Use a soldering iron or any pointed metal object that can be heated on a stove to create uniform holes in the plastic.



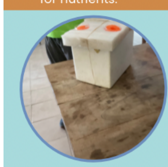


03 –puncture holes in bottles

Use the heated soldering Iron to puncture holes on the bottom 1/3rd portion of the bottle. You want to create holes alternating all around so there's an even distribution, the amount of holes can vary, but an excess number isn't necessary.

04 – Fit pieces together

Take the growing medium created earlier and fit it into the wide opening of the bottles. The width between the bottom of the growing medium and top of where the holes begin shouldn't be too far apart or close together as the roots will grow down and reach for nutrients.



01 – [Grow box] cut holes

Cut holes into the top of the container to fit the grow cups snugly in place. The amount of liters the container can carry and the sizing of mature plants should be factored into how many holes should be cut. Try to space the holes as far from each other as possible to maximize space while minimizing competition

02 – assemble box

Put the grow cups in the holes created. There should be adequate space between the middle portion of the bottle for oxygen while the bottom should be low enough to be submerged in the nutrients.