PEACE CORPS TRAINING MANUAL ON SOIL HEALTH AND FOOD SECURITY

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by

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ABSTRACT

This capstone is the first draft of a project, which will become a manual for training purposes for the Peace Corps post in Ecuador. The body text of this paper will be converted into the main body text of the manual. In comparison, the appendix will be transformed into the sidebars, case studies, and pictures that will accompany the text. The first chapter outlines the nutrition issues facing Ecuador, stating that the best soil management practices include agroforestry as solutions to the problem. Chapter two outlines new concepts about natural soil cycles of fertility and aims to give a basic understanding of how soil is formed and why it is essential for life as we know it. The last chapter presents different agroforestry schemes that are already in widespread use throughout Ecuador. This section provides basics into selection, physical arrangements, and the benefits of an agroforestry system.

BIOGRAPHICAL SKETCH

Paul Rule received his bachelor's degree from Gettysburg College. He served in the Peace Corps for 37 months, from 2014 to 2017 in the rural town of Colimes in the coastal region of Ecuador. As a semi-tropical region, Colimes has two seasons. The rains start in January and continue until June, reaching their peak in February and April. From July until December there is little to no rain. The rains come again in January, and the cycle continues providing Colimes with an average rainfall of 1,200mm per year. Rice is planted all year round. During the rainy season, corn, squash, pigeon pea, yard-long beans, melons, and a variety of herbs are grown. Towards the end of the rainy season farmers also plant yucca, platano, camote (sweet potato), or peanuts all of which can withstand the dry summer conditions or are harvested before the peak dryness in July.

In the 1980s, the current area where the community Puerto Rico is now located, was a large hacienda named "La Leopoldina." By the year 2000, the area was split and given to different groups of famers who formed associations to cooperatively administer and cultivate the land. The farmers worked together to petition the government to secure their land rights, and have named their association the Association of Montubias Agricolas en Colimes (ASOMAC). ASOMAC is comprised of about 100 farmers and their families each living and/or working on a two to three-hectare plot given to them by the association. Often more than half the allotted land is dedicated to rice. Most farmers in ASOMAC commercially grow rice as well as work as "obreros,"(farm hands), with local ranch owners to make their living.

Thanks to the Peace Corps training staff, Association of Muntubio farmers, indigenous taitas and yachacks who taught me and continue to teach me about healthy diets, healthy life, and the importance of focusing on natural, ecological farming so the earth and the people will grow and prosper. To all my professors in the past at Gettysburg, presently at Cornell, and those of the future: thank you for helping me along my journey. A special thanks to Dr.'s Terry Tucker, Marvin Pritts, and Janice Thies.

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A series of thanks for the farmers, community members, teachers, school directors, and officials from the health center combined with informal observations and official surveys with school children which contributed to Community and Participatory Analysis Tools for Action; This identified an essential area for improvement was nutrition and more consumption of fruits and vegetables. A special thanks to the Carpio Cedeño family of Puerto Rico who housed me for the entirety of my service and were the first of many families who adopted me. Me enseñaron el orgullo de ser montubio y campesino. We are all family now, for better or for worse.

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PREFACE

On November 11th, 2015, by order of the Minister of Agriculture, 44 families were forced from their landin the locality known as Leopoldina in Colimes County of the province Guayas. The land was seized by national police and given to another group of farmers. The warrant was executed early in the morning and without warning. The forced eviction was a problematic case that highlighted territorial disputes and competition for limited resources. The relocation of the families presented problems. All families lost land, and three families needed to be relocated. This relocation led families to withdraw from international? projects that were benefiting them and their community. The other two families had to create new garden spaces and recollect seeds. Some families were able to harvest and sell the crop on their old land, but after the evictions, many families did not have money to buy fruits. New houses needed to be built, and some property lines were redrawn to accommodate the newly located families. .

This manual was conceived and written in response to the challenges posed by this relocation. Such disruptions are not uncommon throughout the developing world. I hope this manual provides guidance to others who may find themselves in a similar situation with little background or training in community-centered farming systems. The contents of this manual are intended to provide fundamental information about soils, plants and farming systems for those intending to contribute to development efforts in tropical areas.

Chapter One: The Role of the Volunteer in Promoting Food Security

Framing the challenge

In 2018, the FAO reported there were 820 million people who suffer from hunger (FAO et al., 2019). According to the United Nations Hunger Report, this includes going for days without eating due to lack of money, lack of access to food, or lack of other resources (FAO, 2019). Eating less than 1,800 calories in a day, on average, signifies deficiencies in energy and likely deficiencies in protein, and/or essential vitamins and minerals. Individuals who are malnourished may be consuming adequate calories, but their diet is not balanced. A broad spectrum of health complications can result from unbalanced diets, including over-nutrition and undernutrition. Over-nutrition leads to chronic health issues like diabetes and heart disease. In contrast, undernutrition, especially in children, can lead to stunting, compromised immune systems, and host of long term health/developmental complications (UNICEF, 2014).

Promoting proper nutrition in many countries is complicated because there are many interconnected components that influence food security. In general, poor communities tend to suffer from undernourishment, while urban areas and wealthier individuals tend to be over-nourished. Many adults have poor eating habits consuming "empty calorie foods," or products high in sugar, which can cause obesity and simultaneously lead to a deficiency of vitamins and minerals, known as micronutrient malnutrition or *hidden hunger*.

Ecuadorians suffer from poor eating habits and food insecurity, and each requires different approaches and interventions. In Ecuador, 25% of all children under age five are chronically malnourished. Rates change among demographic groups, with 42% of indigenous children suffering from chronic malnourishment. In the poorest economic quintile, chronic malnutrition is 36.5%, while in the wealthiest quintile, it is 13.8% (UNICEF, 2013). In Ecuadorhowever, more people die from Ischemic heart disease than from another other natural cause (IHME, 2017), and this morbidity is associated with malnourishment rather than hunger. Ecuador has health problems associated with excess caloric and fat intake juxtaposed with communities suffering from hunger and other forms of malnutrition.

In Ecuador, one-quarter of the total land is used for agriculture in the form of cropland and pastures (FAO, 2019). Degradation of tropical soils has severe implications for the biodiversity it supports, the nutritional value of the food, and food security for the country (Piminetel, 2006). Soil best management practices are particularly urgent for Ecuador as it is already struggling to produce enough food for its people.

Peace Corp Goals Involving Food Security

As a Peace Corps volunteer, the primary goals of service are to promote world peace and friendship: by 1) helping the people of interested countries in meeting their need for trained men and women; 2) helping promote a better understanding of Americans on the part of the peoples served; and 3) helping promote a better understanding of other peoples on the part of Americans. The food security volunteer has additional program goals to ensure that families have sustainable, continuous access to healthy food and proper information about nutrition and diet, often through the promotion of home gardens and agroforestry. The word "sustainability" has various meanings, but generally, a sustainable farming endeavor provides healthy food to our generation without hindering future generations' ability to do the same.

History - On March 1st, 1961, President John F. Kennedy signed an executive order later authorized by the Congressional Peace Corps Act in September of that year, creating the Peace Corps. Sergeant Shriver was named the first director of the Peace Corps and would build the institution from an obscure government agency to the world-renowned organization it is today. Shriver felt that if we were to live in harmony in a conflict-ridden world, we must ask ourselves: How will this come about? Shriver postulated the best answer to the following question would lie with the youth and volunteers of America based on their willingness to meet international counterparts as equals in development projects for the betterment of human dignity and cooperation. With this began a decade's long journey into development practice and theory, which continues to this very day. As Peace Corps developed its program and training their developmental and theoretical trajectory would mirror the evolution of frameworks used by development professionals from the Transfer of Technology models of development to the models of Participatory Learning and Action models of today. As changes in development methodologies came about, Peace Corps adapted its training and program to meet the changing dynamics and theories of global development.

Shriver knew that linguistic, cultural, and social differences can block mutual understanding and that people project incomplete or erroneous understandings onto each other if not integrated. During the early years of the Corps, Shriver traveled to meet with congressional representatives from all 50 states. His mission was to prove that the Peace Corps could be an effective tool for peacemaking and peacebuilding. During these speeches, he would say:

> Guns won't change the world, dollar bills won't change the world, but the most powerful idea of all that free and committed citizens can transcend boundaries of culture, language, wealth disparities, old hostilities, and new nationalisms to meet with other men and women on the common ground of human service and dignity. (Price, 2012)

Shriver called this marriage of noble purposes with pragmatism and realistic administration' practical idealism', and Peace Corps training would prepare volunteers to enact practical idealism as the building block for peace.

Peace Corps training in the 1960s reflected the dominant social paradigm of assumptions that the perceived superiority of experts and their ability to solve the problems faced by host country nationals would be the best way to construct peace. This model often did not address broader social and economic structures that affected volunteers and the communities they served. Notable development theorists Robert Chambers and Janice Jiggins remark that Transfer of Technology (TOT) models, although the dominant model in research and extension, fail to change habits of most farmers because scientists retain all the power in the relationship (Chambers & Jiggins, 1987). Chambers refers to TOT as a one-way model of communication where scientists determine research priorities, develop technologies in controlled conditions that do not reflect the heterogeneity of growing conditions farmers face, and then charge extension services with disseminating the technology (Chambers & Jiggins, 1987). Information is obtained from the farmers and processed/analyzed to identify what might be useful for themselves as research scientists, not taking into account the enthusiasm of farmers nor enabling resource-poor farmers to meet their own needs and work out what they want. Chambers asserts this model is a poor fit because cultural and social differences between scientists and poor rural citizenry are vast, with neither being able to communicate effectively with the other. The result is a system that does not fit with the needs of resource-poor farmers who produce most of the food worldwide.

Early Peace Corps training models reflect this model of TOT and share the same shortcomings as pointed out by Chambers and Jiggins. Peace Corps shared assumptions about modernization theory that stated Western forms of knowledge and technology would help "develop" countries along the same lines as the western world. Campus training for volunteers before they began service focused on bringing in professors and experts to educate students so they could share this "know-how" around the world. In Peace Corps Ecuador, volunteer Moritz Thomsen chronicles his journey working in Esmeraldas, trying to get farmers to adopt modern methods of row monoculture and utilization of agricultural inputs to improve production. In this model, volunteers act as extension agents/skilled workers bringing the ideas, theories, and practices of the experts/professors to their field sites; however, just as TOT faced criticism, so did this early version of Peace Corps training. Volunteers returning from the field argued that the assumptions about modern theory clashed with what they saw as a necessary emphasis on community development. Returned volunteers claimed that modernist assumptions' emphasis on objectivity, rationality, and judgment were counterproductive and did not reflect the humanistic and experiential forms of inquiry they were presented during their service abroad. "The problem was not the lack of theory to apply to action but rather the knowledge content they were taught during training was wholly inaccurate with the realities they experienced" (Busch, 2018). Chambers and Jiggins would not be surprised by this critique. In another book by Chambers titled *Whose Reality Counts?* (1997), Chambers explains the myriad of social, cultural, and economic activities the rural poor engage in to meet their livelihood needs, sustain their family/kinship networks, and survive. These realities are not apparent to the expert who is removed from the rural context and does not associate with poor farmers since experts are usually from a higher class than their farming counterparts. The same is true about the professors and "experts" who prepared volunteers for service. During exit interviews, which almost all volunteers participate before they end service, volunteers stated the lectures provided by their professors did not prepare them for the emotional and practical challenges they faced abroad. Many wrote that the professors' understanding of countries was outdated or based solely on their anecdotal experience working or living abroad. Many volunteers cited their professors' view as a "complex misunderstanding" about the world of development frustrated with oversimplifications of language and culture and broader inadequacies of content. One volunteer went as far as to say he was more stimulated learning outside of the classroom, claiming he was more intellectually alive during service than during his undergrad years at Swarthmore College (Busch, 2018).

Chambers refers to this as a "Farmers-first perspective." Among the previously stated criticisms, a lack of accountability to farmers and local communities underlies problems in development programs. Development theorists Ian Scoones and John Thompson wrote about moving beyond the "Farmers-first perspective," which still extracts knowledge from rural communities in the hopes of improving research aims and goals—only involving farmers by incorporating farmer feedback of products/technologies (Scoones and Thompson, 1994). Even research programs aimed at learning what the farmer wanted to gain insight into program adaptations to meet their needs do not change the larger institutional mechanisms that marginalize the populations they are intended to help.

Just as TOT models shifted to more farmers-first/participatory views, the Peace Corps had to revise its training model. Faced with volunteer feedback stating that instructors were removed from the experience of the people the volunteers encountered the training shifted to include more experiential learning; however, although encouraging volunteers to learn from their host communities, and providing them with cultural immersions during training as a complement to their formal training improved volunteer experience in the field, it did not meet the criticisms of unequal development voiced by volunteers. David Bragin, who served in Ecuador for three years setting up rural agricultural cooperatives in 1965, stated that it was impossible to set up a non-exploitative organization in a society based on exploitation.

"What this comes down to is a naïve concept that volunteer service can be apolitical while, in reality, it is always in support of the status quo, of the oligarchy, or political party that is in power" (Busch, 2018). Improved experiential training focused on bridging the gap between practical and intellectual knowledge through experiential learning led to improvements in language training but did not respond to critiques of inherent unequal development and accountability to communities.

Peace Corps training changed its model depending on the contemporary critiques and discussions in the larger subject of international development, changing the task of the volunteer to provide objective observations and expert advice for the problems of a particular community to the experiential learning and participatory approaches championed today. In the 1980s, new development ideas from Europe focused on learning circles, and experiential learning introduced the idea of Participatory Action Learningusing methods of community appraisal like seasonal calendars, community mapping, appraisal walks, among others. Researchers could engage with a community to learn how to identify and address community needs together. This framework is evident in the Market Systems Development approach used to include small farmers by helping them promote their farmers' vision of changes they would like to enact. This is where a Peace Corps Volunteer can be beneficial.

A volunteer does not need to be an expert organic grower nor marketing strategist but rather act as a facilitator to promote community participation. In the Market System Development Approach, the role of the volunteer is temporary and catalytic, so volunteers can support projects by coordinating among the community in helping them identify their vision and limiting factors. Then can help with communication between the community and stakeholders or donors. Educating community groups to understand that markets are a confluence of factors and actors, including suppliers, traders, buyers, and consumers promotes a holistic understanding for farmers and producers of their important role in market chains. Volunteers can teach their communities to see patterns in markets, not just isolated events, or identify infrastructure and institutions underlying changes in the market. Volunteers can teach farmers that understanding market systems can help farmers differentiate their product or add value to it based on particular market preferences. Keep in mind that long term sustainability will mean becoming less dependent on outside aide as the project advances. As a volunteer, utilize the Community Analysis Tools to find gaps in knowledge, identify constraints, and define the roles of individuals in the system. Also, identify communities made vulnerable by external influences. The constraints and gaps in knowledge can be the center for coming up with interventions. While the identified communities will be the intended beneficiaries of the project, the role of the volunteer is to connect their community to networks of resources and professionals who can help them advance their project goals.

Today, Peace Corps training approaches still utilize community mapping, schedule analyses, and seasonal characters to gather information about the community. Then volunteers apply Community Analysis Tools to come up with a plan of action for the projects in their community. Although still grappling with assumptions about modernization and unequal development, trainings are specially adapted to each country, promoting the idea in education and development that one size does not fit all. Well-integrated volunteers can be expert advocates for the community, helping them voice their concerns, needs, and goals. Looking at the trajectory of development aims and goals, the key to successful projects is adaptability and resiliency. Planning projects for these two elements is one step towards a sustainable project.

Practical Challenges to Achieving Food Security and Sustainability

Nitrogen - Humans have doubled levels of reactive nitrogen in circulation, primarily as a result of fertilizer application and fossil fuel burning (Erisman et al., 2011). Increased pools of nitrates from applications of synthetic fertilizers lead to the release of greenhouse gasses (GHGs) during the process of nitrification in the soil. This massive alteration of the nitrogen cycle affects climate, food security, energy security, human health, and ecosystem services. Soils act as a carbon sink when planted with annuals or perennials; however, when soils are left bare, over-fertilized, or flooded, they can emit an especially dangerous nitrous oxide gas which has 298 times more warming potential than the same unit of carbon dioxide, $C0_2$ (Tian et al., 2015), worsening the effects of climate change. Flooded lands and paddy fields emit nitrous oxide, and farmers must be careful to manage their lands correctly to avoid the release of this gas. Since nitrous oxide is so much more potent than carbon dioxide, any fluctuation or spike in nitrous oxide emissions will offset years of carbon sequestration.

The industrial process used to make ammonia fertilizer, the Bosch Haberreaction, is reliant upon fossil fuels and emits tons of carbon into the atmosphere every year, contributing to the massive emissions from energy use in the private sector. At this point, the excess runoff pollution and total carbon emissions from the production of fertilizers are leading to an excess amount of C and N in water, and a deteriorating atmosphere is causing a host of health and environmental problems (Boerner, 2019). This means that synthetic fertilizers are not sustainable in the long term unless alternative energy sources like solar power can be used to fuel the process. The creation and use of N fertilizers can exacerbate drivers of climate change and their adverse effects on farmers. Utilizing natural forms of N fixation directly in the field while improving soil health using agroforestry offers a promising solution.

About two billion people rely on food produced from high energy, high synthetic input, and unsustainable form of production (Grindrod, 2017). Before the invention of the Bosch Haber process, almost all available plant N was fixed biologically. Advances in synthetic fertilizer packages and plant breeding genetics attributed to the Green Revolution led to increased food production preventing world hunger; however, since the 1950s, synthetic fertilizers are more heavily applied, and large agro-business companies have increased the total crop area planted to monocultures leading to environmental degradation (Aneja, 2012). Tropical soils generally contain low levels of latent N due to rainfall and leaching. The management practices presented in this manual, such as the use of green fertilizers, N-fixing tree species, animal manures, compost, and bed construction, will help volunteers, families, and farmers build fertility at no cost while regenerating soil health. The details behind soil ecology, nutrient cycling, agroforestry principles, and alternative farming management practices, including recipes to make natural fertilizer teas and repellants, will be discussed in later sections.

Phosphorus- Responsible for stimulating plant root growth, flower and fruit formation, and an essential part of ATP, the "energy unit" of plants, phosphorus is found in all living creatures and in soil organic matter.It is only made available to plants through P solubilizing bacteria and microorganisms that release P from the soil matrix. To maximize P availability for plants, there must be a healthy pyramid of soil flora and fauna to convert P from its organic and mineral form into phosphates that are available for plant uptake. Applied P is critical in certain soils, but over-application is a significant environmental problem. Runoff of phosphorus-rich soil or water leads to eutrophication of waterways (Ghosh & Lobo, 2017). This puts pressure on livlihoods of those who fish causing them to migrate and look for jobs elsewhere; further complicating the web of the climate crisis.

Other nutrients – There are 11 other nutrients essential for plant growth. The reader is referred to ________ for information on their characteristics and availability.

pH – The pH (acidity or alkalinity) of the soil is a major determinant of nutrient availability. If the pH is too low or too high, certain nutrients will not be available to the plant even though they are present in the soil. Many tropical soils are acidic and must be limed to achieve maximum productivity. The ideal soil pH for most crops is between 6.0 and 7.0 (see Chapter 2).

Heavy metals - Certain tropical soils contain high levels of certain metals that are not essential for the plant, but can be taken up by the plant and consumed by people. If the level of these metals is too high, toxicities can develop, particularly when plants are grown on acid soils. Examples of potentially toxic heavy metals are cadmium, arsenic and selenium. Lead can be toxic if it is present in soil that clings to certain crops on soils particles. Volunteers should be aware of the elemental status of the soils in their communities.

Soil Organic Matter- Maintaining high levels of soil organic matter (SOM) is essential for good soil health. SOM helps retain water, enhances soil structure and provides the primary food source for soil microbes. Decaying plant matter and manure are major sources of SOM (see Chapter 2). Warm temperatures and high rainfall accelerate the breakdown of organic matter and leaching of nutrients, rendering many tropical soils low in this component (see Chapter 2).

Water- Key for all life on earth, water is often one of many limiting factors affecting crop growth. Each region of Ecuador has its own rainfall patterns with the Amazon region receiving rain almost all year round, in contrast with the coastal region of Ecuador which has demarcated "wet" and "dry" seasons.

Climate change- Excessive amounts of greenhouse gases (GHGs), like carbon dioxide, methane, and nitrous oxide, are the primary drivers of climate change. Apart from changes in climate and erratic weather patterns, rising levels of $C0_2$ could be affecting crop growth. At first glance, rising $C0_2$ levels could be seen as a benefit because plants need $C0_2$ for photosynthesis; more $C0_2$ means more plant growth and, therefore, more crop production. Irakli Loladze is teaming up with an interdisciplinary research team to investigate what a rise in $C0_2$ is doing to plants and their fruit. Through his research, he has coined the idea of "nutrient collapse." He explains, "Rising $C0_2$ revs up photosynthesis, the process that helps plants transform sunlight to food. Elevated levels of $C0_2$ makes plants grow, but it also leads them to pack in more carbohydrates like glucose at the expense of other nutrients that we depend on, like protein, iron, and zinc" (Evich, 2017). If this thesis is proved correct, the results of rising GHG emissions would be disastrous for communities, like Colimes, around the world, which relies heavily on staple crops like rice for sustenance. Fewer nutrient-dense staple crops with higher levels of starches and sugars could exacerbate the prevalence of dietary caused illnesses like diabetes.

Labor- The promotion of home gardens limits the need for labor, but does not eliminate it entirely. Sowing, cultivating, harvesting, and storing are labor-intensive tasks, which is why many farmers turn to mechanization to save time and benefit from economies of scale. As a volunteer placed in a community, there may be individuals who come and go as transient laborers. When families work their own land, produce their own food, and reap the benefits of their labor, they are more likely to invest their time and effort into garden projects. Techniques presented in this manual, such as the use of mulch, polycultures, and closer plant spacing in raised beds, will reduce the time dedicated to weeding. For volunteers working with families, schools, or groups to help manage a garden or market products, the key is to find ways to reduce the need for labor while protecting soil health and natural resources.

Gender- The United Nations Food and Agriculture Organization estimates that women produce between 60 and 80 percent of the food in most developing countries and makeup about 40% of the total agricultural workforce worldwide (Doss, 2011). If women had the same access to productive resources as men, they could increase yields on their farms by 20-30%, which could, in turn, reduce world hunger by 12–17%, which equates to around 100-150 million people (Trufan, 2019).

Markets- Not all gardens will sell their produce. If families decide to sell their products, volunteers can help them determine prices and sales/marketing strategies. See **Item 1** *Ansoff Matrix* in the appendix for information about products and markets.

A new vision

Agriculture can take a new direction, which places small landholding farmers at the center of institutional support and policy. Hilal Elver, Special Rapporteur on Right to Food for the UN, states that "governments must shift subsidies and research funding from agro-industrial monoculture to small farmers using 'agroecological' methods" (Ahmed, 2014). This focus on improving the lives of resource-poor farmers is one point on a continuum of development theories aimed to promote participation.

Women play a pivotal role in natural resources management, and the inclusion of women in capacity development can strengthen resilience to climate change. By increasing female participation in climate change strategies, Peace Corps Volunteers promote economic development because of the productivity gains referenced above. When women are empowered as leaders, they can address barriers within their communities and mitigate climate change, and in doing so, will address the chronic underlying vulnerabilities, many demographics and communities face. "Improved gender equality is proven to make humanitarian response outcomes more effective, in particular when recognizing and promoting women's leadership" (Win, 2017). It is imperative that volunteers talk to the women and involve them throughout the program cycles when developing their projects.

Solutions: Agroforestry, Agroecology, and Climate Change the basics

Nutrient collapses, leading to undernourishment and the dangers of rising $C0_2$ levels, can all be addressed by promoting the use of agroforestry practices and agroecology. This field of applying ecological principles to food production examines the roles and interactions among all relevant biophysical, technical, and socioeconomic components of farming systems, and their surrounding landscapes to seek new ways of connecting agriculture, processing, distribution and consumption of food and its relationships with society and nature to make sure food is produced justly and sustainably. Before jumping into specific agroforestry models and examples, key terms and ideas need to be clarified and identified. Indigenous farming practices of seed saving, harvesting water, rotating crops, polyculture, and intercropping have been around for thousands of years and inform new areas of study such as Regenerative Agriculture and Permaculture. Many people use the terms agroforestry and agroecology interchangeably. Although these terms share ideas and concepts, using them interchangeably may lead to wrong assumptions and misunderstandings when working with nationals or other volunteers.

Agroecology is defined as "the science of applying ecological concepts and principles to the design and management of sustainable food systems" (Gliessman, 2007). Agroecology is knowledge-intensive, based on techniques that are not delivered top-down but developed based on farmers' knowledge and experimentation to maximize biodiversity and stimulate interactions between different plants and species, as part of holistic strategies to build long-term fertility, food production systems, and improve livelihoods. It also represents a social movement that started in

Brazil as a way to secure tenancy rights for poor, landless farmers and has now spread throughout the world, inspiring other groups to do the same (Schwendler & Thompson, 2017). "The core principles of agroecology include recycling nutrients and energy on the farm, rather than introducing external inputs; integrating crops and livestock; diversifying species and genetic resources in agroecosystems over time and space; and focusing on interactions and productivity across the agricultural system, rather than focusing on individual species" (Altieri, 2009).

The practices of agroforestry in South America have a long history dating back to the Incan Empire who managed and utilized the forests for their food, medicine, fiber, and cultural necessities. General classifications of agroforestry are defined as:

> The utilization of perennial trees, palms, bamboo, and woody shrubs in agricultural production schemes, combining annual crops and livestock in spatial and temporal arrangements on the same plot of land. Designed to promote ecological and economic interactions between the trees and agricultural components of the production system (Sinclair, 1999).

In Ecuador, a wide variety of agroforestry practices like multi-layered forest gardens, polyculture orchards, and ethnobotanical practices of the indigenous tribes like the Jivaro, Saraguro, and Woarani people of the Ecuadorian Amazon managing the biodiversity of forest resources are classified as one system of agroforestry named "Forest farming." Other systems include alley cropping with trees, silvopasture, hedgerows, windbreaks, and shelterbelts. All are effective ways to protect the soil environment while providing more substantial ecological and social benefits. For more information about these classifications and how farmers in the US utilize them, see the USDA website: (https://www.usda.gov/topics/forestry/agroforestry)

Both agroecology and agroforestry seek to integrate a balance of perennial and annual planting systems while integrating livestock for production. However, the difference is agroecology's commitment to coupling food production with beneficial biological interactions and synergies among the components of the ecosystem instead of external synthetic inputs.

Composting detritus from wood that contains lignin and has a high C:N ratio and annuals stabilizes soil carbon and feeds the soil flora and fauna. In this sense, we can feed ourselves and sequester carbon. Hundreds of pounds of food can be grown in small areas. Family gardens focused on producing food intensively using agroecological principles will sequester more carbon, feed more people, and build more soil fertility. Peace Corps volunteers can work with communities and families to combat rising health problems in Ecuador, such as malnourishment, the rising rate of heart disease, diabetes, and iron deficiencies. As a food security volunteer concerned about sustainability, our primary concern needs to be the recovery and usage of native or naturalized plants first, because these materials and seeds are more readily available and provide a suite of ecological services. Then, we look to adapt or develop new, varieties that perform well in the location.

Chapter Two: Soil and Health

Soil health basics

Soil is made up of particles, organic matter, microorganisms, atmospheric gases, and moisture working to feed the web of fungi, bacteria, enzymes, worms, and insects that convert organic matter into forms accessible for plants. Nitrogen, phosphorous, potassium along with other minerals such as magnesium, sulfur, calcium, zinc, iron, boron, copper, and cobalt make up a brief list of elements plants need to stay healthy; however, soil fertility is more than the chemical composition of the soil. Elements like phosphorous can be present in the soil but not in a form usable to plants. The living microorganisms, including soil microbes, bacteria, root enzymes, fungi, and worms, work to decompose nutrients into a form available for plants to utilize. The more diversity present in the soil leads to a better overall availability of nutrients for plants. Apart from the microorganisms, if we think of soil as the base of a food pyramid, a complex soil life will lead to more insects, bees, and lead to the attraction of other animals like birds and other fauna of the region. A healthier soil with more microorganisms present in the soil will support a greater diversity of flora and fauna.

Soil combines lithosphere (rock), atmosphere (air), hydrosphere (water), and biosphere (living things) in one area, providing habitat, nutrients, and moisture necessary for all life. Soil is not just the physical parts that make it up; it is also the active interactions between its various physical, biological, and chemical components. Stable soil provides conditions for plant growth that produces food, medicine, and fiber for humans. Protecting soil structure and biodiversity from unsustainable management practices is a key challenge of the 21st Century (Brussaard et al., 2007). Thinking of soil health only in terms of fertilization needs is neglecting the other parts of soil, which are equally crucial for food production. Soil quality is essential for providing humans with food and water. Thus it is crucial to understand how healthy soil functions to know how to implement changes to improve soil health, and ultimately human well-being. Soil health is defined as, "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans, and the capacity of a soil to function, within ecosystem and land-use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health" (Moebius-Clune et al., 2017). Soil provides a wide range of ecosystem services, and as a result, fertile soil is an essential natural resource for maintaining the health and well-being of the world population. When soil structure and ecology are healthy, soil supports the filtration of water into aquifers and other freshwater sources. Optimum soil structure also mediates water drainage and retention. During a saturating rain, pores retain water in smaller pores while filtering water downward through larger pores. An ideal soil structure retains more water for plant uptake during dry times, and will also allow air to rapidly move back in after rainfall so that organisms can continue to thrive (Moebius-Clune et al., 2017). The soil food web and ecology of microbial organisms, insects, and mammals act as stores for mineral nutrients used by plants to grow. Soil retains other minerals, including carbon, and is a medium in which plants grow to access nutrients in the soil, making them bioavailable for mammals (Parker, 2010). However, current agricultural practices degrade the soil.

Ecuador has a diverse soil profile, which is different from other tropical countries because its geography includes high elevation soils of the paramo that experience a different climate compared to lowland tropical/semi-tropical forests. In general, tropical soils are classified as clay soils with low nutrient reserves. High year-round temperatures and increased humidity in the coastal region and Amazon basin lead to an increase in the decomposition of organic matter compared to temperate climates, where cold weather slows the decomposition process (Lal, 2000). The paramo of the Andean highland does not have high temperatures year-round. Paramo soil is thick, dark, has high levels of organic matter (Córdova, Hogarth, & Kanninen, 2018). The high level of organic matter acts as a sponge, absorbing water, and slowly seeping the water down into the low lands. The soil of the paramo is paramount to the hydrology cycle of the Andes and the Amazon (Buytaert et al., 2005).

In the Amazon basin and coastal lowlands, the clay soils support the biodiversity of trees and plant life that provides us with clean air, food, and medicine derived from plants. Since decomposition happens at a higher rate in these tropical zones, maintaining appropriate levels of organic matter in the soil is crucial for fertility management. When there is no organic matter, the soil organisms cannot function, natural cycles cease to work, and plant nutrient availability decreases (Lal, 2000). Managing soils based on their unique profile and characteristics, including best cultural management practices, is essential to provide a tailored intervention to a community, increasing the rate of success and adoption. Understanding what soil is and the organisms, animals, and cycles that drive soil creation will provide insight into reversing degradation.

The Soil Food Web

Soil is made up of mineral particles, organic matter, microorganisms, atmospheric gases, and moisture working to feed the web of fungi, bacteria, enzymes, worms, and insects that convert organic matter into forms accessible for plants. Plants acquire the nutrients they need for growth and reproduction via pools of inorganic nutrients found in the soil; however, these pools are constantly acted upon by soil microbes that, through their lives and deaths, immobilize and then return soluble nutrients to the soil matrix. Soil is categorized and layered, generally speaking as horizon layers that lie deeper in the earth, subsoil, and topsoil. Soil is formed when parent material, known as regolith, is weathered and exposed to the atmosphere. Through this exposure, living organisms thrive, like bacteria, which through their generations, accumulate organic matter and begin creating soil. To understand how plants obtain nutrients from the soil, the entire wood web must be analyzed as a series of trophic levels that act upon plant cellulose and detritus into inorganic nutrient pools for plants. As more organic matter piles up, more bacteria go through life cycles, and various microorganisms come to thrive. Plants add to the system, and through the cycles of nitrogen, carbon, phosphorus, and photosynthesis, nutrients accumulate. Organic material is dropped on top of the soil, decomposes, and is cycled constantly (Bronick & Lal, 2005).

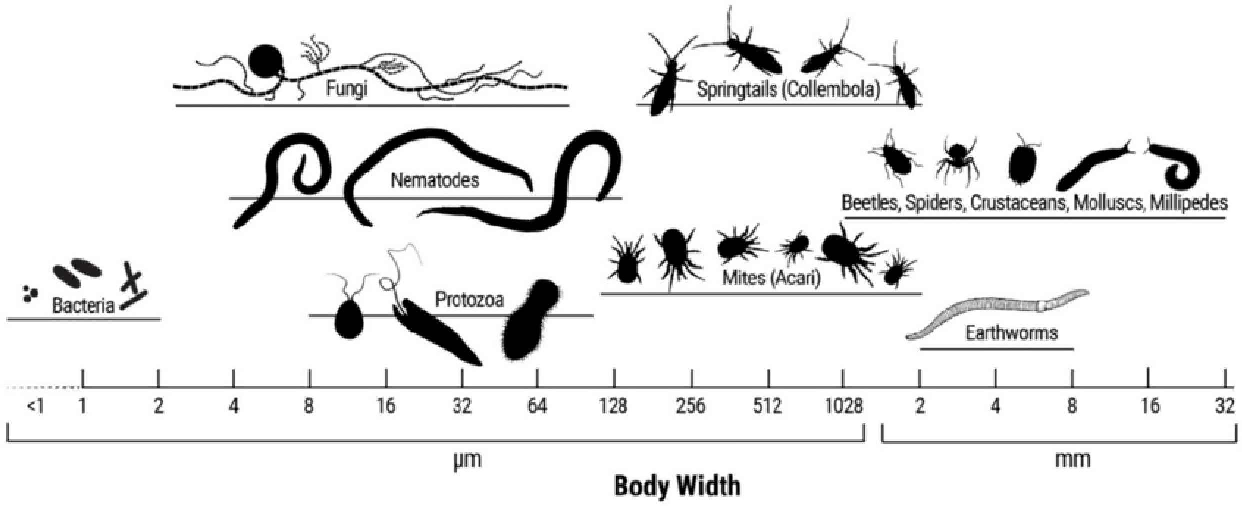


Fig. 2.1 -Soil organisms grouped by class, showing the size of body width. Bacteria in the diagram represent all prokaryotes, bacteria, and Archaea. Image from (Brackin et al., 2017).

Bacteria and Archaea

For this manual, both the animal kingdoms of Archaea and Bacteria will be referred to as Bacteria, and they constitute the largest demographic of population density in the soil. Bacteria are the primary actors in driving the cycling of minerals in the soil, converting mineral pools of nitrogen, iron, phosphorus, and carbon elements into available forms for plants. In the topsoil, the area surrounding plant roots referred to as the *rhizosphere* is an area that hosts a variety of microorganisms that interact with plant roots to:

1.) Supplement nitrogen to the plant via endophytic nitrogen-fixation
2.) Suppress parasitic organisms to reduce crop damage
3.) Outcompete pathogens for nutrients, essentially starving the harmful bacteria, and suppressing disease outbreaks. (Parker, 2010)
4.) Bind together soil particles in a process known as aggregation through the secretion of enzymes and polysaccharides during metabolic processes.

Fungi

Fungi and the rest of the organisms listed after are members of the Eukaryote domain. Mycelial networks of hyphae bind soil particles together and act as a capture net and transport system for critical nutrients like phosphorus. At the same time, they perform vital functions like decomposition of recalcitrant organic material, like lignin in wood, and contribute to carbon sequestration in the soil. As the hyphae move through the soil, they create micro-pores allowing for aeration and infiltration of water and roots. In addition to nutrient acquisition and creating optimum soil structure fungi benefit plants by:

1.) Producing antibiotics, parasitizing other fungi, and competing with harmful plant microorganisms.
2.) Forming symbiotic relationships with a host plant via the root system to provide a range of beneficial services such as enhanced nutrient uptake, drought tolerance, and disease resistance.

Nematodes and Protozoa

When many gardeners think of nematodes, they think of a parasitical worm that feeds on living plants causing tissue damage and, ultimately, crop loss; however, some nematodes are predatory, which means they feed on lower-order organisms like other nematodes, bacteria, and fungi. Through their predation, they lower populations of plant-harmful nematodes. Their excretions are sources of nutrients and energy for other organisms. Nematodes can even be a food source for fungal predators. Protists are divided into three categories: Ciliates, Flagellates, and Amoebas. Ciliates tend to be the lowest in population and move in a locomotive fashion using exterior hair-like structures called cilia. They eat bacteria and smaller protists. Flagellates move using a single or dual motor-like Flagella to propel movement. In addition to consuming lower orders of life, some flagellates are saprophytic, meaning they can feed on dead or decaying organic matter. Amoebas are the classic microorganism that looks like a blob and moves in a slinky fashion named *pseudopodia*, or "fake foot."

Nematodes and protozoa are important:

1.) Cyclers of nutrients, their excretions are sources of carbon and nitrogen for other organisms
2.) Control of bacterial populations and soil structure while feeding on and suppressing pathogenic bacterial populations, as well.
3.) Bioindicators of soil food web health, because the diversity of species and quantities present in a particular soil is a sign of healthy soil function.

Arthropods and Earthworms

For this manual, insects that can be seen without a microscope, known as soil meso/macrofauna like mites (Acarids), springtails (Collembolan), termites (Isopteran), ants (Hymenopteran), and beetles (Coleopteran), will be grouped together with millipedes/centipedes (Myriapoda), spiders (Arachinae), snails/mollusks (Gastropoda), and earthworms (Annelids) because they share similar ecological functions in the soil:

1.) Begin to tear, rip, chew, and fragment organic residue. Through their consumption of detritus, they inoculate the smaller particles with microbes from their saliva. A process termed comminution.

2.) Graze on microbial populations when they reach too high of a population density; therefore, cycling nutrients back into the soil substrate and regulating microbial growth.
3.) Act as ‘ecosystem engineers’ due to their ability to maintain soil structure and improve aeration and water infiltration through the creation of pores while burrowing.

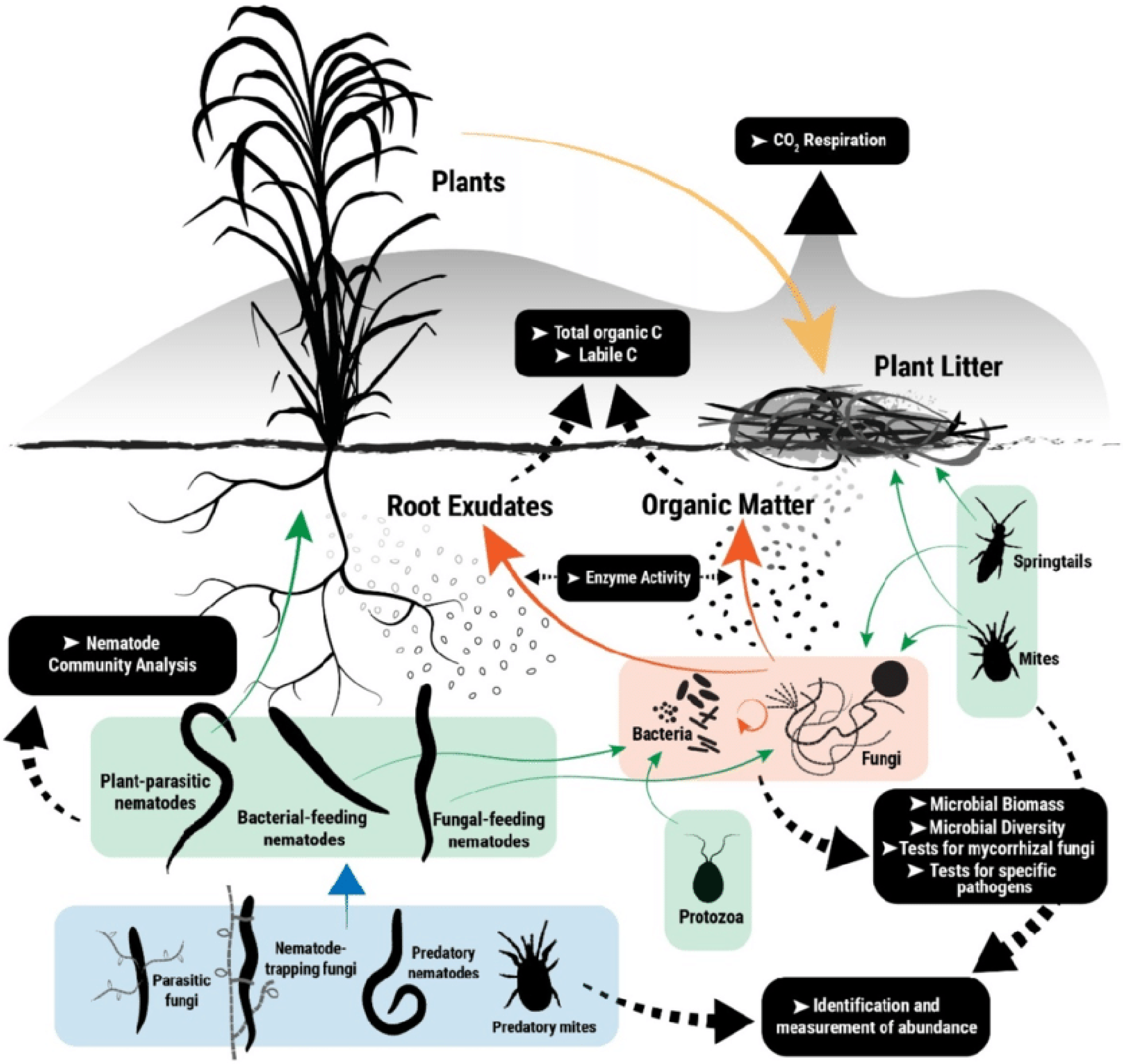
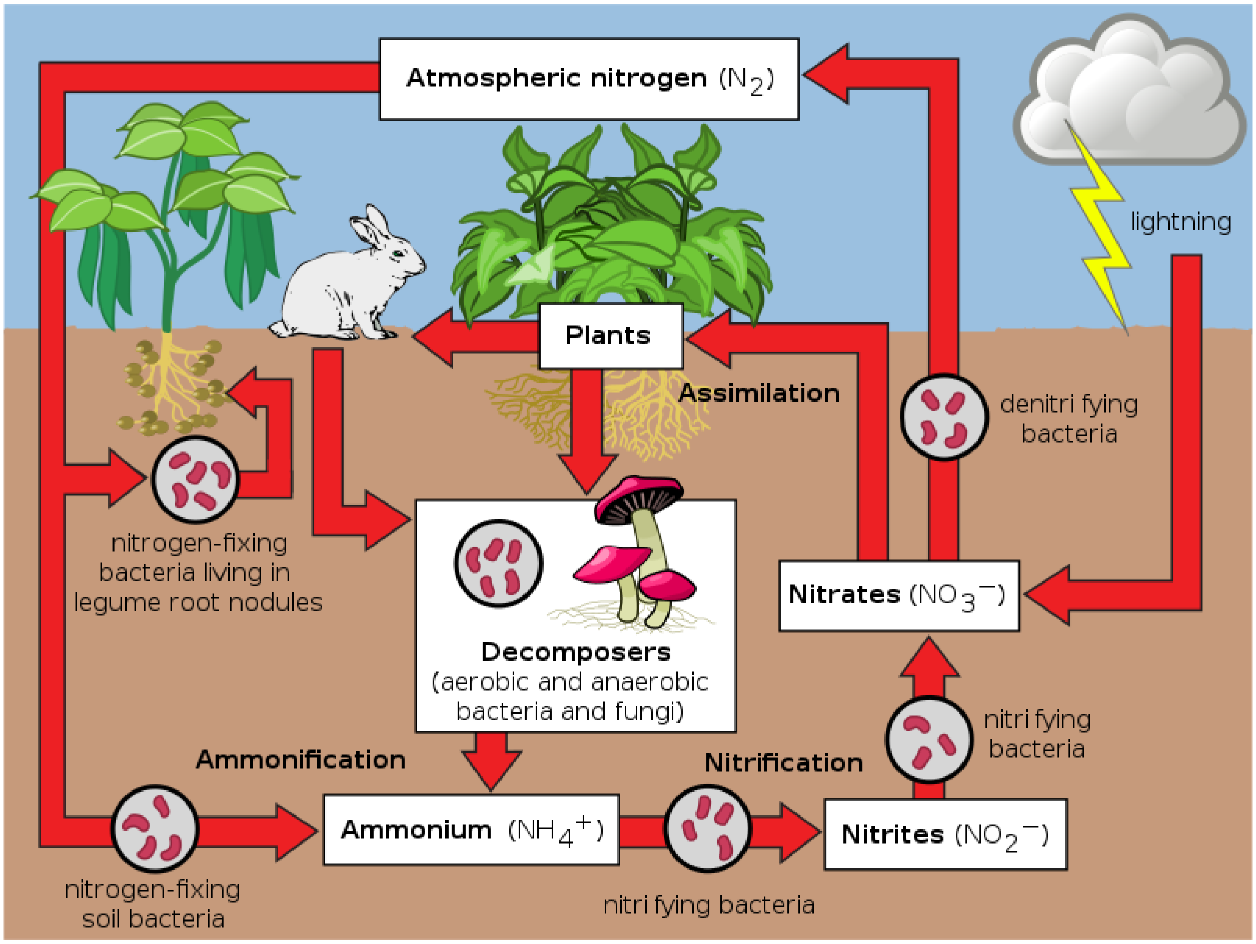


Fig. 2.2—The soil food web with various indicators of soil health overlaid (black boxes). Image from (Brackin et al., 2017).

Nitrogen, Carbon, and Phosphorus Cycles

In an ecosystem, nutrients are cycled continuously in processes mediated by soil microbes. Nitrogen is often a limiting factor for plant growth and net production. Organic debris like leaves, manure, and wood will stimulate microbial responses known as N mineralization or immobilization. Bacteria and fungi need specific C: N ratios to function and develop biomass. Carbon is the primary energy source used to support growth, while N is used to assemble proteins, nucleic acid, and produce enzymes. When organic material that is high in nitrogen, like manure or green manure debris, is incorporated into the soil, microbes will obtain the C and N they need for cellular function. The excess is released into the soil solution. This is known as mineralization and increases plant-available N. The opposite of mineralization is immobilization. This occurs when organic materials that are low in nitrogen like sawdust, straw, or corn debris used as soil amendments. The C is consumed, but the N needed for nucleic acid and enzyme production must be obtained from the soil solution, which decreases plant-available N.

The nitrogen cycle



The nitrogen cycle consists of the following steps – Nitrogen fixation, Ammonification and Nitrification, Assimilation, and Denitrification. The diagram above shows all the transformations N undergoes during the cycle. Nitrogen fixation starts with N_2 deposition through precipitation, which is then transformed by symbiotic bacteria known as Diazotrophs, Azotobacter, and Rhizobium. These bacteria consist of a nitrogenase enzyme which has the capability to combine gaseous nitrogen with hydrogen to form ammonium. The nitrogen undergoes a set of changes, in which two nitrogen atoms get separated and combines with hydrogen to form ammonium (NH_4). Mineralization of ammonium, NH_4, from decomposed detritus and the atmosphere mark the entrance of N into the soil ecosystem. Atmospheric N enters the cycle through the process of biological nitrogen fixation stimulated by bacteria living in the soil or within root nodules that use the enzyme nitrogenase. Only prokaryotic bacteria and archaea have the gene sequencing to produce these enzymes; therefore, eukaryotes cannot fix nitrogen for plants. Another form of N fixation can occur either by the atmospheric fixation- which involves lightening, or industrial fixation by manufacturing ammonium under high temperature and pressure condition. (see appendix **Item** 2. *Ammonium and nitrate*).

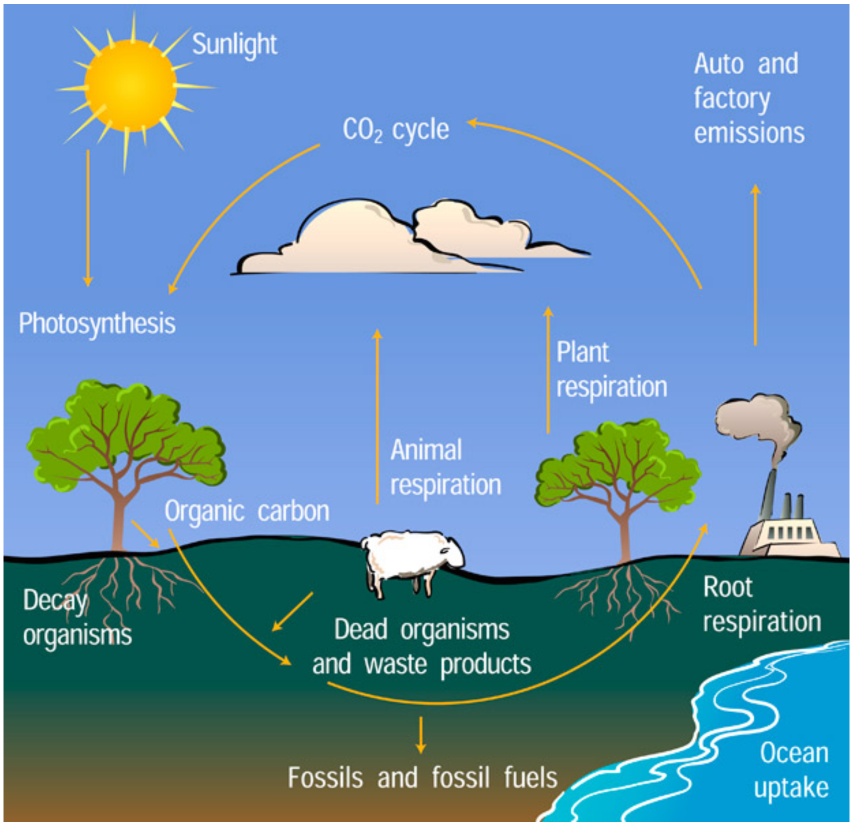
The next steps are ammonification and nitrification, both of which are mediated by microbes. Nitrogen fixation and the decomposition of organic matter create pools of ammonium, NH_4, in the soil. This ion can be taken up by trees and other woody perennials or undergoes another transformation known as nitrification. Nitrification refers to the oxidation of ammonium into nitrites, NO_2, by Nitrosoma bacteria and then nitrates, NO_3, by Nitrobacter species. Because electrons are added to the substance during oxidation, nitrification results in more acidic soil, nitrates are more mobile in the soil and can be leached out if they are not assimilated into plant biomass.

Assimilation refers to the N uptake by plants who use it to grow or store it in their biomass, preventing the leaching of these soluble forms of N. Plants use the N to create chlorophyll and photosynthesize. Nitrogen is also used to create plant proteins, which marks the entrance into the food web when the primary consumers eat the plants.

Denitrification is the process in which the nitrogen compounds return to the atmosphere by reducing nitrate (NO_3) into atmospheric nitrogen (N_2). This process of the nitrogen cycle is the final stage and occurs in the absence of oxygen. Denitrification is carried out by the denitrifying bacterial species- Clostridium and Pseudomonas, which will process nitrate to gain oxygen for themselves and give out nitrogen gas as a byproduct. Sometimes during this process, nitrous oxide, N_2O, is released into the atmosphere. The release of nitrous oxide happens primarily in monoculture, flooded rice paddies. Nitrogen is also cycled by human activities such as the combustion of fuels and the use of nitrogen fertilizers. These processes increase the levels of nitrogen-containing compounds in the atmosphere.

These sets of processes repeat continuously and thus maintain the percentage of nitrogen in the atmosphere. The nitrogen cycle is important because all living organisms need N to live and function. Without the nitrifying and denitrifying bacteria, N would remain in the atmosphere or in other forms unavailable to plants since the plants absorb the usable nitrogen compounds from the soil through their roots. Then, these nitrogen compounds are used for the production of proteins and other compounds in the cell. Animals assimilate nitrogen by consuming these plants or other animals that contain nitrogen. Humans consume proteins from these plants and animals. Then, the nitrogen assimilates into our system used as building blocks that make up various components of the human body, such as hair, tissues, and muscles.

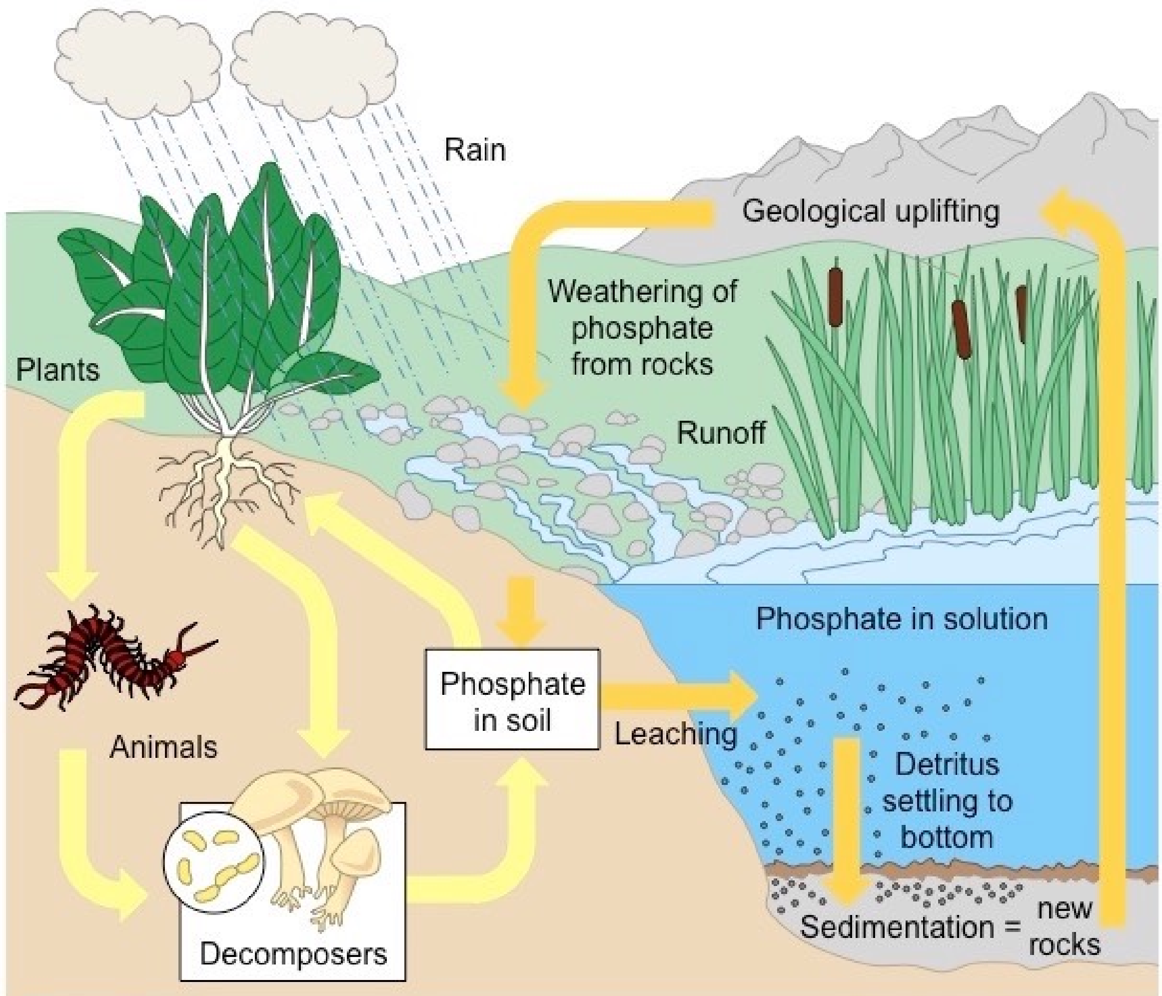
The Carbon cycle



Most of the earth's carbon is stored in rocks and sediments. The weathering of these rocks through rain led to the creation of dissolved carbonates, which would become the start of soil [see appendix figure 3. *A brief history of soil creation*]. The rest of the carbon is located in the ocean, atmosphere, and living organisms. These are the reservoirs through which carbon cycles. Carbon is transformed via photosynthesis, decomposition, respiration, and combustion. Carbon is an abundant element found in every living organism. The gaseous forms, carbon dioxide, CO_2, and methane, CH_4, are primary drivers of climate change and the biological carbon cycle. Plants move carbon from the atmosphere into the biosphere through photosynthesis. They use energy from the sun to chemically combine carbon dioxide with hydrogen and oxygen from water to create sugar molecules. As plants photosynthesize, they store carbon in their roots and above-ground biomass as starches, cellulose, and lignin. Primary consumers then eat plants. The sugars and nutrients present are metabolized by the consumer and used for energy. Animal respiration, excretion, and decomposition release CO_2 back into the atmosphere. Rocks like limestone and fossil fuels, like coal and oil, act as storage reservoirs that contain carbon from plants and animals that lived millions of years ago. When these organisms died, slow geologic processes trapped their carbon and transformed it into these natural resources. Natural processes such as erosion release this carbon back into the atmosphere very slowly. In contrast, volcanic activity can release it very quickly. Anthropogenic processes like the combustion of fossil fuels in cars or power plants is another way this carbon can be released into the atmospheric reservoir quickly.

Carbon is the chemical backbone of life on earth. Carbon compounds regulate the earth's temperature, make up the food that sustains us and provide energy that fuels our global economy. Trees and plants fix carbon in their biomass and through the secretion of polysaccharides in the soil surrounding the root zone that provide energy for microbes living in the rhizosphere. The ocean sequesters carbon dioxide and methane by combining them with hydrogen ions to form carbonates that sink into the ocean (Gligorovski et al., 2015). The excess C in the oceans is causing acidification causing rippling effects for marine organisms. Fixing carbon in plants and trees while providing fruit, starch, and other staple food crops are one of the best ways Food Security Volunteers can mitigate climate change and food insecurity. Longer-term solutions to climate change will include the reduction of emissions of methane from ruminants and rice production along with the reduction of nitrous oxide emissions from the over-application of chemical fertilizers.

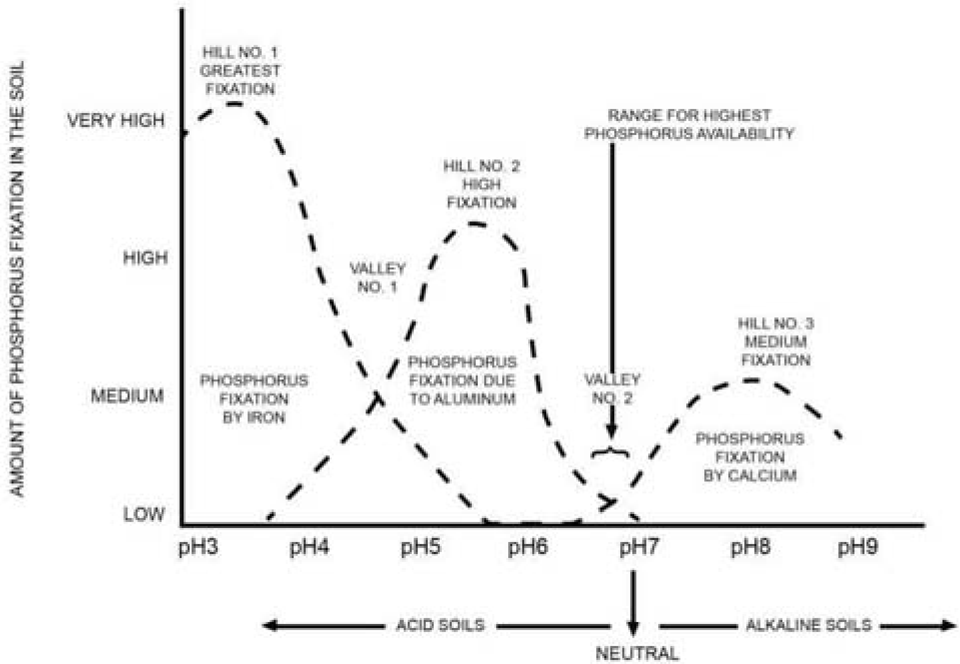
The phosphorus cycle



Phosphorus is another essential element for life on earth. Phosphates make up the links in chains of DNA and plants utilize Adenosine triphosphate, ATP, which is comprised of three different phosphorus-based molecules that are broken to derive energy for metabolic reactions in living organisms. Phosphorus is different from nitrogen and carbon because although it does have a gaseous form, it is primarily found in sedimentary form as phosphate-rich rocks. Unlike nitrogen, phosphorus does not change the oxidation state. P is weathered from rocks and enters the soil solution where it can be absorbed into living biomass. When P is not absorbed by living organisms, P is fixed or adsorbed when bound to soil particles, or P precipitates if plant-available inorganic P reacts with dissolved iron, aluminum, manganese (in acid soils), or calcium (in alkaline soils) to form phosphate minerals which are unavailable for plant uptake. Like nitrogen, P is mineralized by microbes that convert organic P to $H2PO_4^-$ or $HPO4^{2-}$, forms of plant-available P known as orthophosphates. Immobilization is when these phosphates are consumed by microbes, turning the P into organic P forms that are not available to plants. The microbial P will recycle into the soil over time as the microbes die.

P is often a limiting nutrient in crop growth, leading to stunting in plant growth and reduced production. Returning crop residues to the soil, incorporating animal manure, and using compost in beds will maintain sufficient levels for gardening. Net mineralization of phosphorus occurs during additions of ground limestone or wood ash as soil amendments. Since much of P added from fertilizers is fixed to calcium in more alkalai soils and iron and aluminum at lower pH levels. See appendix **Item** 3.

Soil pH: acidity and alkalinity



Since most of the P is fixed in soil bacteria that can produce acids capable of converting this bound P into a soluble form are crucial for the cycle to continue. When P is freed up by bacteria, it enters the soil solution where it is absorbed into plant biomass or is uptaken by endophytic mycorrhizal fungi and delivered to plants. If neither of these happens then, P becomes insoluble again.

Conventional agriculture and contributions to soil degradation

Conventional agriculture practices contribute to soil degradation by destroying soil aggregation and optimum structure, leading to leaching and erosion (Fierer et al., 2009). Planting and fertilization regimes disrupt the soil environment by altering abiotic factors like soil pH, which impact the microbial communities and populations present in the soil. Excess nitrogen (N) and phosphorus (P) from over-fertilization combined with reduced soil nutrient retention because of poor soil aggregate structure are causing excessive algae blooms and hypoxic zones in seas and ocean areas worldwide, furthering the importance of widespread restoration efforts (Hart et al., 2004).

The cause of soil structure degradation varies based on geography like site latitude, elevation, and slope combined with the biophysical production system, such as tilling or slash and burn for cattle overgrazing but serves the same purpose: disrupting the delicate pore structure of aggregates in the soil. Often, tilling combined with bare-soil fields accelerates soil depletion because soil without ground cover is exposed to wind and water erosion. In Ecuador, repeated mechanical tilling regimes lead to soil dispersion and slaking in the more humid lowlands of the coastal region and the Amazon, which leads to rapid loss of soil nutrients to wind and water erosion. The massive clearing and burning of an entire forested landscape means a drastic decrease in vegetative cover. Without aggregation in tropical clay soils like those found in the Coast or the Amazon, the small particle size of clay means pore sizes are smaller. When clay soils are wet, the particles can bond together if they are compacted, forming an impenetrable layer for water and nutrients. Once compacted, soil quality declines quickly, leading to dispersion. Tilling breaks up soil macroaggregates but not microaggregates. As soil degrades, heavy rains cause smaller particles to settle into smaller pores where they clog and seal the top layer of soil. Dispersed soils form a crust and cracks on the top layer, which prevents seeds from germinating, referred to as slaking. Slaking prevents water from filtrating into the subsoil. Dispersed soils move water laterally, and cause pooling of surface water, suspended soil causes water turbidity while nutrients are increasingly washed away from the land.

Mechanical tilling breaks up soil structure, exposing soil carbon to mineralization, creating microaggregates that are more vulnerable to erosion and nutrient leaching. [Item 4. Soil aggregation and structure] Earthworm numbers and fungi populations are generally higher in abandoned or reforested sugarcane fields compared with managed fields (Zou and Bashkin, 1998), and numbers tend to decrease in fields after tilling due to soil disruption and drying (Kibblewhite et al., 2008; Stork and Eggleton, 1992).

In addition to damaging soil structure, conventional practices of synthetic input use and crop homogenization restrict the species diversity of bacteria, archaea, and fungi in the soil creating a soil environment that favors certain groups and taxa over others. Inputs make the soil more acidic which is not a conducive environment for many types of beneficial bacteria. Studies show that increased applications of ammonium can be toxic to specific taxa of bacteria (Fierer et al., 2009). Synthetic fertilizers not only alter bacteria populations, but they also reduce the diversity of mycorrhizal fungi species present in the soil (de Graaff, Kardol, et al., 2019). One practice of modern conventional agriculture that decreases soil biodiversity worldwide is the continuous use of monocultures. Monocropping alters species variety present in the soil because plants select for specific taxonomic groups of bacteria, which will benefit their growth and development (Vorholt, 2012 and Aleklett et al., 2015). The same is true for fungi populations, some plants more readily form associations with mycorrhizal fungi and share the mycelium network with plants in proximity. Studies show that intensive monocultures of crops, even trees, impedes these connections and mutualistic relationships from forming by homogenizing the microbial population because plant genotype has a strong influence on microbial composition in the rhizosphere (Marques et al., 2014). Tilling and homogenization of vegetation cover through monocropping reduce the complexity of soil food webs and alter species richness creating environments that favor some species while destroying habitat for others. Researchers are concerned that fewer functional groups of biota with less diversity of taxonomical groups will threaten the ability of soil function in agricultural production systems (Tsiafouli, et al., 2015). Limiting microbial phylogeny can eliminate redundancies in functional traits that drive nutrient cycles, making them vulnerable to complete collapse.

Soil, Tilling, and Bed making

Soil structure, soil water content, pH and soil temperature play roles in the structure of the food web, the primary driver of activity within the soil food web is organic matter, in which carbon is an energy source for the remainder of the food web. To avoid the pitfalls of most bare soil, monocrop styles of agriculture volunteers can promote the incorporation of compost, manure, woodchips, or other locally available organic residues to stimulate the base of the soil food pyramid: the microorganisms. By incorporating soil amendments like woodchips, researchers have seen an increase in yields of wheat and other staple food crops (Beeby et al., 2020 and Li et al., 2018). For these reasons, the making of beds should include: 1) incorporation of organic material into the first 25cm of soil to improve soil structure and jumpstart the base of the soil food pyramid, the microorganisms. 2) mulching on top of beds to reduce plant stress related to water and elevated temperatures, and 3) creation of bed areas with adjacent pathways so weeding, harvesting, and other fieldwork can be done without stepping into the bed and damaging the structure. [**Item 5.** bed-making process]

Summary

Organic matter like leaves, woody debris, animal wastes, and plant roots mark the entrance of nutrients into the soil formation cycle. Soils also act as a carbon sink and is a medium for plants that take atmospheric CO_2 and transfer it to their biomass, returning it to the soil when decomposed and used by microbes as nutrients and energy for the cycles that drive soil fertility. From the soil surface, organic material and debris are “processed” by micro to macro-level soil biota. Different groups of biota exist; there are microorganisms, microfauna, mesofauna, and macrofauna. Each provides a unique function in the service of recycling nutrients and making them bioavailable for plants. The primary services of the organisms present in the soil are the decomposition of organic matter, nutrient cycling, along with the creation of channels, aggregates, and pores through burrowing and movement called “bioturbation”, which improves water storage in the soil. Finally, beneficial bacteria and microorganisms can suppress disease when they outcompete pathogens for nutrients, essentially starving the harmful bacteria (Parker, 2010).

Microorganisms such as bacteria and fungi are the primary decomposers and drivers who govern biogeochemical cycling of carbon (C), phosphorus (P), and nitrogen (N), mineralizing the compounds, making them available for plant uptake. Beneficial fungi, known as mycorrhizal fungi, form ecto- or endo- phytic mutual relationships with plant roots, siphoning water, and nutrients from their network of hyphae to the plant and making it available to the plant. In exchange, the plant root exudates feed the fungi (Brussaard, 1997). Microfauna, like protozoa and nematodes, help circulate nutrients in the system and predate pests and diseases that antagonize plants (Brussaard, 1997). Mesofauna and microfauna including earthworms, ants, termites, and arthropods like mites, springtails, and small arachnids shred, tear and eat organic matter, thus converting it into smaller pieces that can be inoculated by microorganisms (Moebius-Clune et al., 2017). Earthworms, ants, termites, and insects exist across soil horizons, so they draw organic matter from the top layers of soil and bring them deeper into the subsoil or horizon layer and vice versa. They manage the web as they graze; their excrement is a source of nutrients for bacteria that drive soil function.

Volunteers can promote soil health and fertility through regular additions of organic matter. The next portion of the manual will discuss the basics of tree crop physiology and agroforestry schemes, which can be adapted to sites. Not every project run by a Food Security Volunteer will involve an agroforestry component. A tightly spaced home garden can provide the micronutrients lacking in many rural family diets while augmenting staple food crops or providing extra income. Understanding how to promote natural fertility cycles will allow Volunteers and their community to build fertility without using industrially produced fertilizers and chemical products—thus promoting the biological health of the soil and well-being of those who live off the land.

Chapter Three: Agroforestry for Sustainable Production

The promise of agroforestry

Around the globe, farmers find ways to integrate tree species into productive niches on their farms. This practice, agroforestry, addresses societal concerns because agroforestry desires to couple human and ecological well-being. As a study, agroforestry promotes productivity along with stability and equity of land use through advocacy of secure land tenure to promote long term sustainable production using perennials (Wilkinson, 2009). Agroforestry addresses biophysical concerns of degradation and social concerns of access, land tenancy, and marginalization. Studies in Vietnam have shown that after the third year traditional agroforestry systems increase the livelihood of farmers more than annual rice production without causing soil and environmental degradation (Thang et al., 2015) The indigenous communities that protected this knowledge are the most vulnerable to exploitation and marginalization. Learning from the indigenous communities and empowering natives to share their knowledge requires the cultivation of productive relationships and coordination between indigenous and larger institutions.

The replacement of forest cover with monocultures simplifies the landscape, and creates concerns among researchers who indicate loss of crop diversity can make the food systems vulnerable to shocks like loss of fertility, pest predation, and disease outbreak (Tscharntke et al., 2005). Plant biodiversity often leads to fewer pests because the food source for pests is distributed and natural enemies often can find habitation in the diverse canopy (Altieri, 1999)

Advantages of trees in an agricultural context

The inclusion of leguminous trees has proven to reduce soil erosion and increase soil productivity allowing resource-poor farmers to increase their yields without the harmful effects of synthetic fertilizers (Bronick & Lal, 2005). The nutrients drawn up from deeper in the soil profile are then deposited on the soil surface as a mulch via leaves, sticks, and organic litter through the pruning and incorporating leaf cuttings into the soil, which is commonly practiced, with *Acacia* species and *Tamarindus indica* (Jambulingam & Fernandes, 1986). Tree roots stabilize the soil, and increased root density is correlated with less soil erosion. Studies show significantly less erosion in soil roots zones compared to bare soils or solely annuals (Bronick & Lal, 2005). Through root carbon composition or root exudates of sugars and amino acids into the soil, roots provide the carbon needed to metabolize energy for microorganisms to carry out their nutrient cycling duties (Brussaard, de Ruiter, & Brown, 2007). Trees also store carbon in their wooden structures, which is released back into the atmosphere as it decays. Trees partition water and mineral nutrients by exploiting reserves deeper in the soil than shallower roots system of annual and some perennial plants, promoting the complementary sharing of nutrients and water. Resources near the surface are captured by shallow-rooted plants, while tree roots tap deeper into the soil and reduce competition for reserves closer to the surface (Kreilein, 2010).

All trees can contribute to available N through the pruning and incorporating leaf cuttings. Tree roots create space for pores in the soil increasing soil aeration and water filtration deeper into the soil horizon and promote beneficial biological interactions between microorganisms and plant species. A key example is the symbiotic relationships formed by arbuscular mycorrhizal fungi and roots. Mycorrhizal fungi increase the soil volume explored by the roots and increase nutrient absorption by the plants (Carvalho, Tavares, Cardoso, & Kuyper, 2010). The improved soil structure not only optimizes water and P acquisition, but improved soil structure leads to an increase in carbon sequestration. Carbon sinks into the soil as root mass or as root secretions (Buck, Lassoie, & Fernandes, 1999). Tree roots create habitat for microorganisms by increasing soil porosity and adding carbon into the soil. As soil fauna restores soil function improves, for example, the return of root and soil organisms improves the filtration quality of the soil. Roots and organisms remove nitrates and minerals from water. As water seeps through the soil, it is purified and stored in aquifers or re-enters the water cycle (USDA, 2012). More water availability means more plants can grow, and the cycle builds on itself.

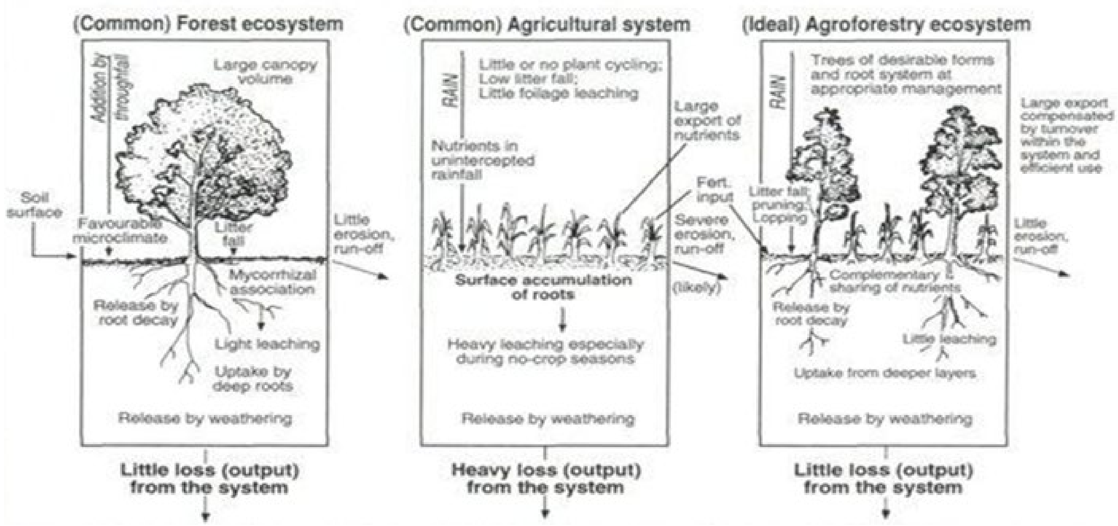


Figure 3.1 from Buck et al., 1998

Is agroforestry right for your site?

Before a volunteer decides that they want to implement an agroforestry food security production project, project information must be gathered, and questions answered.

1. *Do we own the land or have a long-term commitment to the land?*

   Agroforestry is all about trees. Many fruiting trees begin flowering and producing fruit after some years. An agroforestry system is about long-term welfare and nutrition. If the farmer owns the land, s/he has a vested interest in thinking about how the land can be maintained over long periods of time. If they do not own the land or worry about the risk of having their land taken from them, they will have less interest in the long-term benefits. For instance, after the evictions in my site, farmers may not make these types of improvements believing their work will only go to the benefit of someone else.

2. *Do we have sufficient land space to do an agroforestry project?* Container gardens and intensive vegetable beds can be done in small spaces but agroforestry requires at least 8 to 10 square meters to make it viable. Smaller project sizes can be done; however, tall layers will not be used. A 5 X 5 meter area could contain some cacao and coffee combined with vegetables for daily nutrition. However, planning is vital if space is limited.
3. *What trees, shrubs, and plant combinations do we want in the system?* Agroforestry relies heavily on multipurpose trees, perennials, and shrub plants. Ground layer annuals are included but are temporary and eventually get shaded out. Trees should be selected based on their nutritional value (do they provide nuts, fruit, etc.) as well as their ability to fix nitrogen, provide fuelwood, beautification value, and/or provide foliage/feed for livestock. Native or naturalized trees should be considered first because these materials and seeds are more readily available and provide a suite of ecological services. If no local tree variety is available to meet a need, then an exotic replacement species may be found.

Basic schemes

There is a wide array of tree species that fit into a sustainable agroforestry system based on their lumber value (forestales), fruit production (frutales) or contribution to ecosystem services (e.g. (legumbres leñosas). Once the woody components of the system are selected, the next step is to physically arrange them in a complementary and efficient design.

Multilayered managed forests

For the model presented below, citrics are the ¨frutales¨ with the Laurel tree species (Cordia alliodora) valued for its lumber as the ¨forestal¨. Bushes (Arbustos) and crops are then interplanted amongst these trees. Corn (Zea mays), Pineapple (Ananas comosus), Achiote (Bixa Orellana), Cacao (Theobroma cacao), and Coffee (Coffea arabica or Coffea canephora known as "Robusta") can be grown in the understory. In this model, fruiting trees (frutales) are planted every ten meters scaled in with a wood tree (forestal) every ten meters. Every five meters, there is a fruit or wood tree. The area in between the trees is free to cultivate or plant perennial shrubs like Achiote species or shade-tolerant trees like cacao. This model is general and provides room for variation depending on the site.

DISEÑO DEL SISTEMA AGROFORESTAL

A: Forestales
Instalado cada 10 m
B: Frutales
Instalado cada 10 m
C: Arbustos
Instalado cada 0.30 m

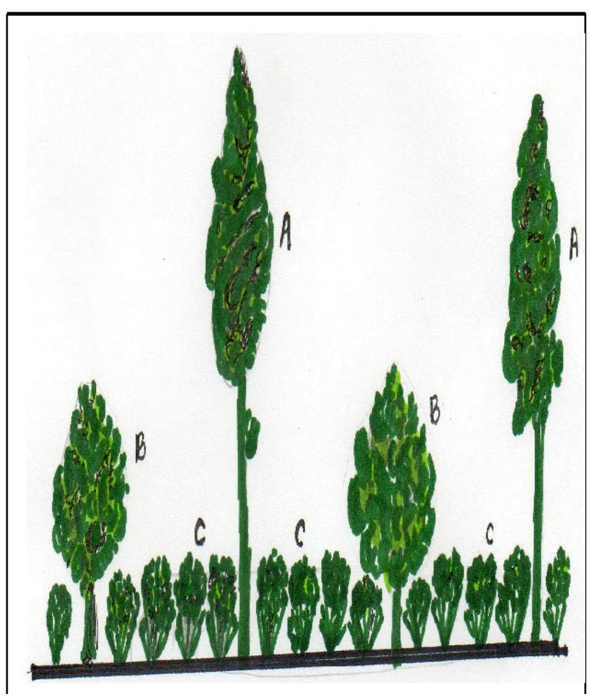


Figure 3.2 Basic planting scheme: the areas marked with C can also be filled by tomatoes (Solanum lycopersicum) and peppers (Capsicum annuum). Just be aware that with time sun-loving plants will be shaded out as the trees develop their canopy. For this reason, bushes or shade-tolerant trees may be better depending on what the individual project entails.

Multi-layered home gardens

In Ecuador, multi-layered home gardens have a strong tradition in all parts of the country. In these schemes, trees are planted in four to seven layers by planting trees, a long-term harvest crop, with short term harvest crops like corn, beans, peppers, tomatoes, and other vegetables so that farmers do not need to choose between feeding their families and making sound long term, ecological farming choices. The key is to ¨layer¨ crops together planning not only time of harvest but also size, shade, and canopy of the plants/trees one is planting.

Figure 3.3 A four-story agroforestry house garden in the coastal town of Olon, Ecuador.

Over time, the arrangement and species present will change, but the idea of planting up to seven layers applies to all agroforestry projects. The seven layers are as follows:

Layer one is comprised of temporary herbaceous or root crop plants responsible for covering the soil and protecting it from nutrient leaching due to rainfall. Example plantings include rice (Oryza sativa), watermelon (Citrullus lanatus), beans (Phaseolus vulgaris), cowpea (Vigna unguiculata), squash (Cucurbita moschata), sweet potato (Ipomoea batata), and groundnut (Arachis hypogaea),

Layer two serves the same ecological function as the first: productive ground cover responsible for the reduction of work spent on weeding and the production of crops for subsistence or commercialization. Species include various perennial grasses and forage crops or okra (Abelmoschus esculentus), black pepper (Piper sp.), pineapple (Ananas comosus), maize (Zea mays), cassava (Manihot esculenta), bell pepper (Capsicum anuum), sesame (Sesamum indicum), tomato (Lycopersicum esculentum).

Layer three acts like a bridge in the process of generating income between the harvest of annual crop species and the beginning of the productive phase of tree species. Formed by banana (Musa sp.), occasionally papaya (Carica papaya), and castor bean (Ricinus communis), the layer also protects the soil against nutrient leaching as its foliage reduces the impact of tropical raindrops. At the same time, leaves can be "chopped and dropped" to cover the soil serving as a mulch.

Layer four includes crops such as coffee (Coffea arabica), orange (Citrus sinensis), lemon (Citrus limon), acerola (Malpighia glabra), cacao (Theobroma cacao), cashew (Anarcadium occidentale), achiote/urucum (Bixa orellana), muruci (Byrsonima crassifolia), and guava (Psidium guajava). These perennial crops are fruit trees and bushes that grow up to six meters in height creating an understory microclimate.

Figure 3.4a
The photo displays a three-story agroforestry system. Pictured is a layer of yucca combined with an overstory of banana and cacao. The arrangement is a standard three-story system on the coast of Ecuador. More can be fit into this scheme. Compare the above picture to **Figure 3.4b,** which has a grass ground cover and various climbing vines on their palm tree species. Anamalai Plantations in Sethumadai, Pollachi Photo: Young, S. Jan 15, 2020.

Layer five forms a higher crown with a less dense shade cover than the lower layers. Species include various palms or lumber species like palm trees such as açai (Euterpe oleraceae), bacaba (Oenocarpus bacaba), peach palm (Guilielma speciosa), and the medicinal species Dragon's blood (Croton lechleri).

Layer six contains trees of heights between 15 and 20 meters mixed palm trees are characteristic for this layer. Example trees include rubber trees (Hevea brasiliensis), cupuaçu (Theobroma grandi florum), biribá (Rollinia mucosa), avocado (Persea americana), genipapo (Genipa americana), coconut (Cocus nucifera), buriti (Mauritia flexuosa) and oil palm (Elaeis guineensis).

Layer seven Trees have the same function as emergent species of the permanent forest species, absorb nutrients from deeper soil horizons and deposit them on the surface again after leaf drop while providing food, lumber, medicine, and/or habitat. The most common species in this layer are andiroba *(Carapa guianensis*), mango (M*angifera indica),* taperebá *(Spon diaslutea*), bacuri *(Platonia insiginis*), Brazil nut *(Bertholletia excelsa)*, and sapodilla (*Achras sapota).*

The option of working with different plant types regarding crown size and forms, trunks and root systems, and the individual ability of each species in recuperating areas offers enormous flexibility in forming the floristic composition of a multi-layered agriculture module mimicking the home garden. Farmers need to test the recently introduced system and make their own experiences. Subsequently, they are able define the appropriate combinations of species, reflecting their own needs, local market, climatic conditions, and site idiosyncracies.

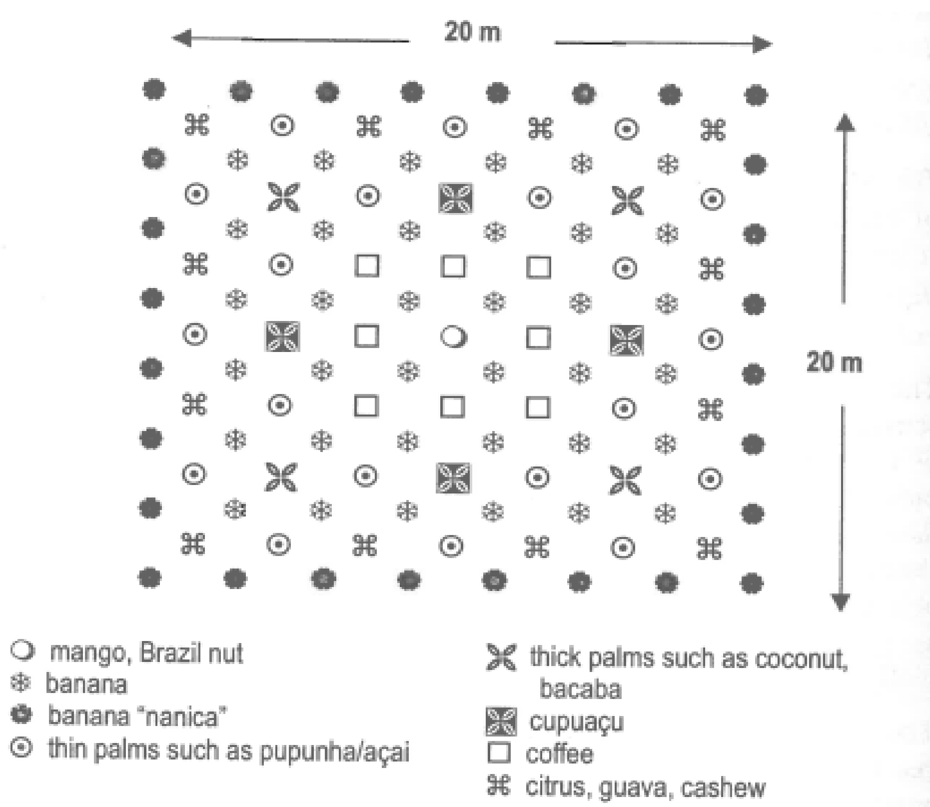


Figure 3.5 Demonstrates a geometric planting scheme of the seven-layered system within a 20m x 20m block from (Mitschein & Miranda, 1998).

Alley cropping and hedgerows with trees

An example of agroforestry is alley cropping with trees. In alley crop agroforestry schemes, trees are planted in hedgerows, or in the field intercropped with annuals. This practice can achieve many of the beneficial soil functions provided by natural forests while also supporting food production, as long as the trees are planted to reduce competition, enhance profitability and not impede harvesting.

The scaling up of agroforestry schemes like alley cropping has been done on other continents such as Africa and Asia (Styger et al., 1999), and is the best way of addressing soil degradation while providing for human livelihoods. Through the planting, maintenance, harvesting, processing, and sale of agroforestry products, smallholder farms in Ecuador employed 57% of the agricultural sector and 77% of the rural employment sector (Córdova, Hogarth, & Kanninen, 2018). Alley cropping improves soil fertility and reduces leaching because perennial roots have larger mass compared to annuals and penetrate deeper into the soil, drawing up nutrients inaccessible to annuals.

In alley crop agroforestry schemes, trees are planted in hedgerows along a contour, or the field intercropped with annuals. The physical arrangement of trees maximizes light capture by plants and prevents soil erosion. First, trees planted on contour act as physical barriers to erosion. Not only do the roots stabilize the soil reducing the amount carried off in rains, but tree leaves of the canopy also reduce the raindrop impact directly on the soil, so when water hits the ground, it is less likely to dislodge soil particles on impact. Trees planted as windbreakers reduce wind velocity, which removes finer soil particles, organic matter, and nutrients, slowly degrading soil fertility and structure (Dosskey, Brandle, & Bentrup, n.d.). By manipulating the density and arrangement of the tree, canopy light use is maximized as the canopy layers intercept light ensuring higher total capture compared to monocultures. One study tested light use efficiency of 7 production systems to compare the performance of monocultures to agroforest alley cropping schemes: The treatments : were: (1) apricot (Prunus armeniaca) and millet (Setaria italica); (2) apricot and peanut (Arachis hypogaea); (3) apricot and sweet potato (Ipomoea batatas); and four monocultures (4) sole apricot; (5) sole millet; (6) sole peanut; and (7) sole sweet potato.

Figure 3.6 Arrangement of tree alley crop schemes from the above-mentioned study (Zhang et al., 2018)

By spatially layering the plot, upper story trees capture light first, followed by smaller, understory trees, and as light passes through each layer, it is captured and used by the plants effectively intercepting the energy before it hits the soil. Sunlight shining directly on soil causes evaporation from the soil surface limiting moisture content of the soil stressing both crops and the soil organisms as they compete for the limited supply of water. Shade from agroforestry practices reduce heat stress and improve growing conditions for crops such as cotton, *Gossypium hirsutum*, and soybean, *Glycine max*, that have higher rates of field emergence when grown under moderated temperatures" (Dosskey, Brandle, & Bentrup, n.d.). As each tree, shrub, and annual layer intercepts light before it hits the soil surface, they convert the sun's radiation into biomass via photosynthesis. By layering plants, evaporation from the soil is reduced, leaving more moisture for crop growth. The previously mentioned study modeled spatial light interception and use efficiency based on the plots they cultivated for the experiment. The authors concluded that the total light interception in agroforestry was 54% higher than in the sole tree stand and 23% higher than in sole crops. They also assert the photosynthetic efficiency is higher in crops grown under agroforestry canopies compared to monocultures of annuals (Zhang et al., 2018). Greater plant diversity and light interception have implications for carbon sequestration and increased plant biomass. When plant biomass has edible fruits, seeds, roots, and tubers, this means food is more efficiently produced for humans, and crops are buffered from large fluctuations in temperature.

Layered systems work best in high light environments. Light is dissipated as it penetrates the canopy and plants in the understory may not receive enough light to saturate the photosynthetic pathways. Agroforestry systems, especially multilayered systems, can be more difficult to harvest, particularly with mechanized devices that depend on long, straight rows without interference from other plants.

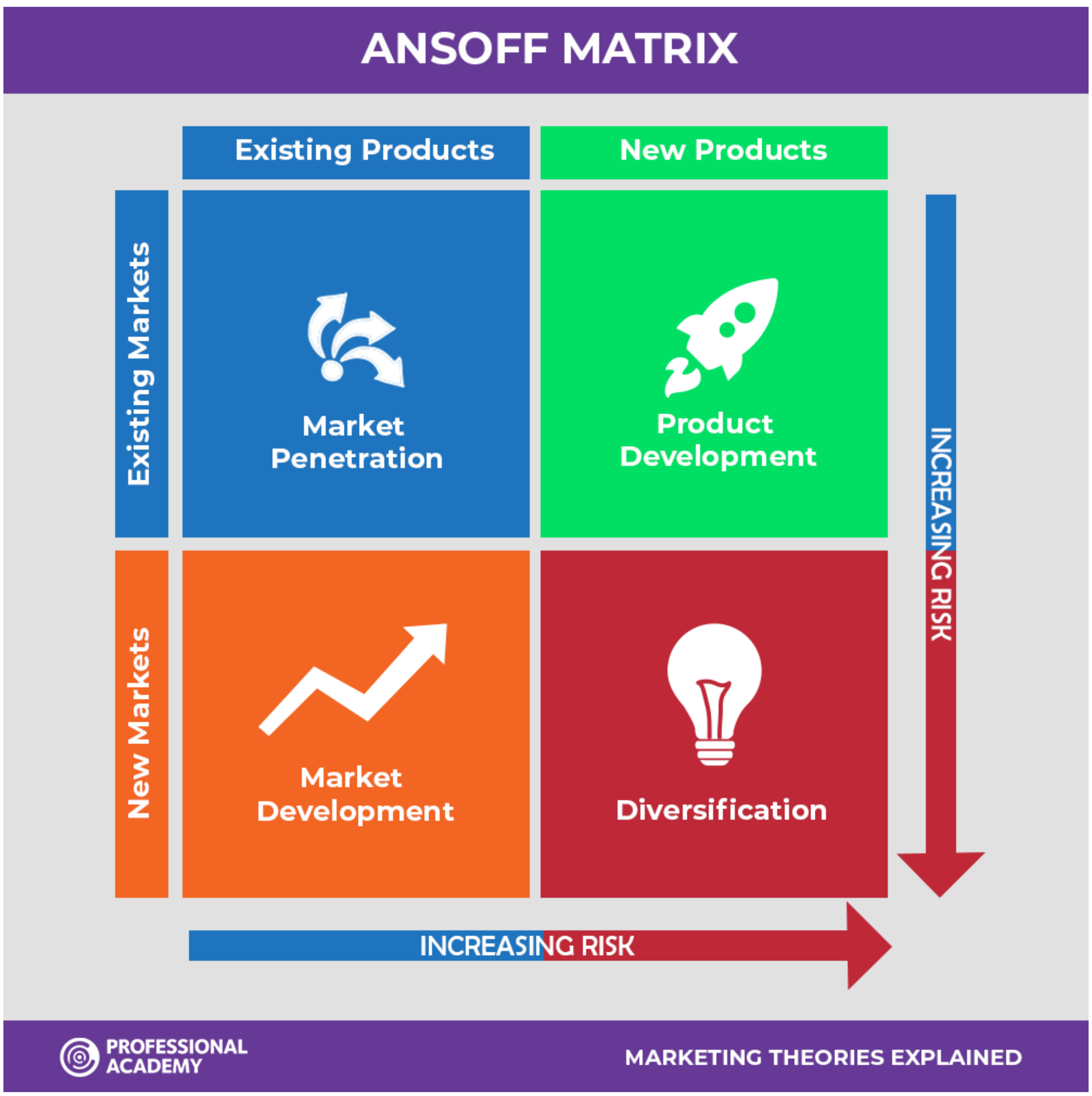
Conclusion

Soil integrity and health are a priority for maintaining crop productivity, and improving climate resiliency. Studies indicate that food production will have to increase in the next twenty years to feed the expected world population of eight billion people (FAO, 2019). If the current levels of degradation continue, we will likely be unable to meet future worldwide demand for food. Agricultural practices must, therefore, change to contend with the challenge of producing more food on an ever-shrinking supply of land (Floros et al., 2010). Agroforestry may contribute to solutions to these challenges. To be successful with an agroforestry project, consult with farmers and local experts on what species can be used and where to find propagation materials like seeds or cuttings. For examples of farms enacting these types of practices visit the *Third Millennium Alliance* website: (https://tmalliance.org/agroecology/community-agroforestry-initiative/). Their farm reserve is located between the mid-sized coastal towns of Jama and Pedernales in the province of Manabí. The regenerative farm projects aim to remove the pressure of deforestation by using regenerative agriculture principles to improve the livelihood of local farmers. Other notable regenerative agricultural farm areas include Maya Mountain North Forest Reserve in Belize. A Peace Corps Volunteer does not need to be the expert farmer, manager, or leader, making every decision and planning all the details but acts as an advocate to make sure nutritional and household concerns are represented when planning a model.

Appendix

Item 1 *Ansoff Matrix*

The Ansoff Matrix The Ansoff matrix was invented by Igor Ansoff in 1965 and is used to develop strategic options for businesses. The matrix represents four market scenarios and proposes strategies to navigate each scenario. As the diagram below depicts, the matrix contains four quadrants, with each one representing possible scenarios and strategies for future product and market activities.



The blue scenario section titled "Market Penetration" represents when you have an existing product which you would like to sell in an established market. An example of this is selling extra produce to a local market. This strategy focuses on increasing the volume of sales and asking questions like, "How can we grow our market or produce more on less overhead?"

The next scenario in green titled, "Product Development, is when one has a new product to sell in an existing market. An example is the introduction of an exotic fruit or the ability to produce a scarce commodity during the "off-season." Using irrigation during the dry season to grow corn means farmers get a higher price than during the rainy season when corn is in boon. Volunteers can engage farmers and counterparts to ask, "How can we expand our product portfolio by modifying or creating products?"

The third, orange quadrant titled "Market Development," focuses on reaching new markets with existing products. Developing a marketing strategy to differentiate products or reach new demographics is a classic strategy in this scenario. Volunteers should focus on questions of expansion, such as, "How can we extend our market? Do we extend it geographically or look to new demographics in our current market range?"

Finally, the red section titled "Diversification." focuses on the scenario trying to reach new markets with new products. Ansoff described two types of diversification *related* and *unrelated*. *Related* diversification means The organization stays within a market they have familiarity with while *unrelated* means moving into a market or industry where they have no experience. Diversification is the strategy associated with the highest levels of risk. Volunteers can help communities facing this scenario by helping them think in terms of innovation and pioneering new products, models, and scales of production.

Item 2. *Ammonium and nitrate*

Nitrogen takes many forms throughout the nitrogen cycle, but the two most important for plant nutrition are ammonium, NH_4+, and nitrate, NO_3-. Both forms are present in a well-functioning food web, and certain plants prefer ammonium over nitrate. Nitrate is negatively charged, so it combines with water readily where it can be absorbed by plant roots or leached out of the system when water drains out. Ammonium is positively charged, so it binds to negatively charged particles in the soil. Ammonium is acted upon by nitrifying bacteria to transform it into nitrates via the two-step nitrification (oxidation) process. Without those bacteria, annual plants like those used in most gardens will not produce as well as desired. To determine what form of nitrogen a plant prefers the best general solution is the following: If a plant will be in the ground for only one season like watermelon, corn, rice, tomatoes, peppers, and various salad greens, then their preferred form of nitrogen is most likely nitrate. Perennial shrubs and trees tend to prefer ammonium.

Item 3. *A brief history of how soil is created.*

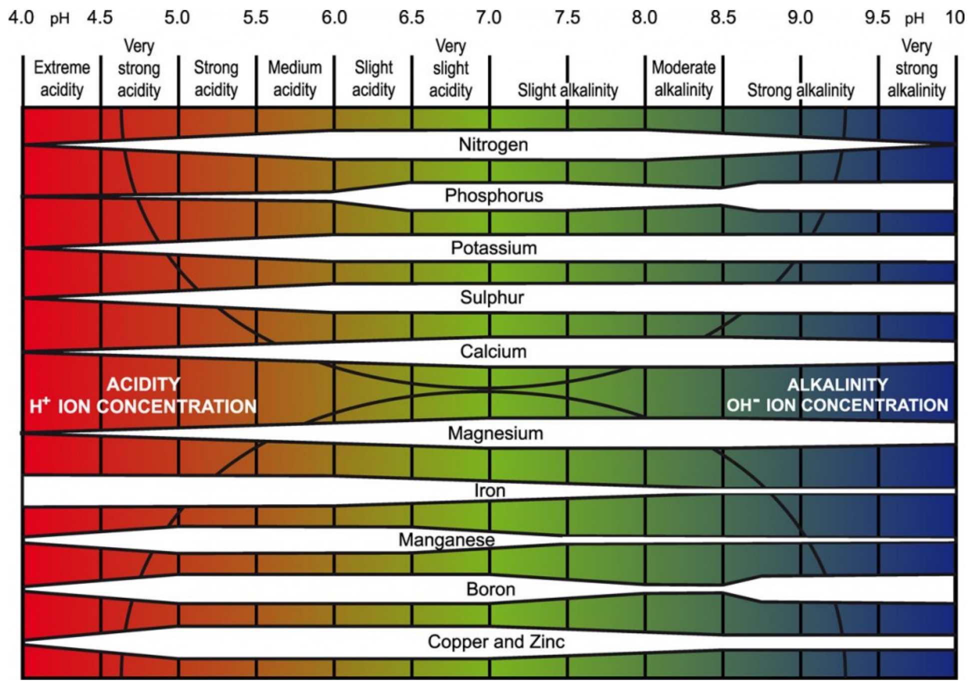
Regolith and pieces of bedrock (the parent material of soil) exposed to the atmosphere and weathered, accumulate living organisms, like bacteria which through their lives, and deaths accumulate organic matter and begin creating soil. As more organic matter piles up, more bacteria go through life cycles, and more microorganisms came to thrive. Plants added to the mix, and through this cycle of nitrogen, carbon, phosphorus, and photosynthesis, life grew as dead matter. It was returned to the earth and recycled into the soil. Organic material is dropped on top of the soil, decomposes, and cycles continuously. Adding layers is the natural way to build soil. When I was helping a fellow volunteer in the city of Puyo in the province of Pastaza, I was drying my clothes on his cement rooftop when I noticed the roof had pools of water that were collecting algae. The colony was small but had some green. Mostly there was a type of brown slimy moss, the start of a soil.

I returned to the roof almost year later and was surprised to find a tree growing out of the thin layer of dead, slimy moss/algae. Not only was there now a small tree, but the moss had greatly increased in surface area. What started as a small colony quickly spread in the favorable conditions of the Amazon. In very little soil, a great deal was growing.

This rooftop (representing regolith) offers a pictorial insight into the beginnings of the soil making process. Parent material accumulates algae, which begin the life cycle and builds soil. Many efficient plants are sometimes identified as weeds when, in reality, they are some of nature´s best soil builders. From the rooftop, I realized one thing. I would always add layers and minimize tilling in all of my garden sites.

Item 4. *Soil pH: acidity and alkali*

Soil pH is measured using a logarithmic scale that ranges from acidic, 0.0, to alkali, 14.0. Soil pH can affect plant growth in several ways. Plants uptake nutrients through their roots, and most operate best in the pH range of 6.5 to 7.5 because this provides the range where all plant nutrients are available.

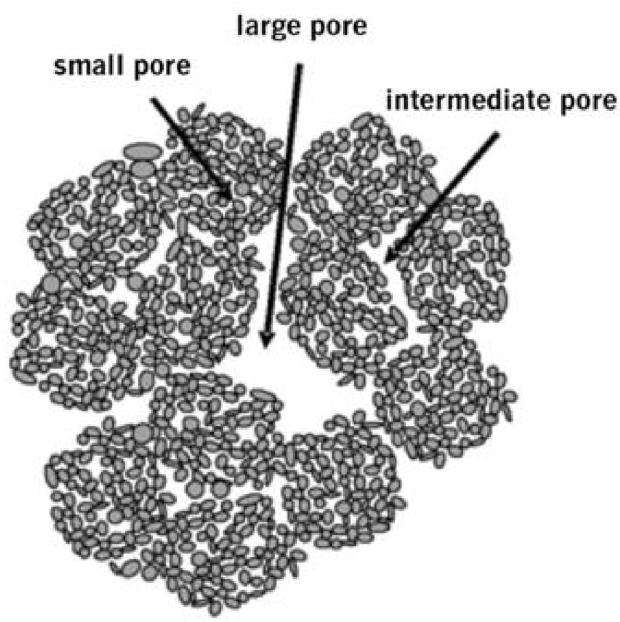


Most nutrients occur in the soil as positively charged ions attached to negatively charged soil particles. When the plants secrete liquids from their roots into the soil, these secretions are very acidic, and they raise the acidity of the soil near the root hairs. The plants' more positively charged solution secretions are picked up by the more negatively charged soil particles. In order for the soil particles to pick up this solution, they must let go of the positively charged nutrient ions, freeing them to be absorbed and used by the plant. The plants are exchanging with soil to get the nutrients they need. A soil's pH refers to the state of the soil in its relation to ion exchange and nutrients.

Soil ecology and microbes influence pH levels in the soil. Forest soils tend to be dominated bu fungi, meaning there is more biomass of fungi present compared to the numbers of bacteria present. Garden beds and agricultural soils tend to be dominated by bacterial populations. A fungal dominated soil tends to be acidic because fungi secrete organic acids when they decay organic matter. With enough fungal acids, the soil pH drops below 7, which is not suitable for nitrifying bacteria. Less nitrifying bacteria means less ammonium is converted to nitrates. Since most annuals do not prefer ammonium, they do not thrive and are replaced by woody perennials that utilize the ammonium. For volunteers who want to promote bacteria-dominated soils, look to incorporate fresh green plant residue and manures into the beds. Make sure to incorporate it into the soil between 10cm and 25cm deep. Additions of aged, brown organic matter like wood chips promote fungal populations in soil. Remember, vegetables and annuals tend to prefer nitrates and bacterial dominated soil; whereas, trees and perennials tend to prefer ammonium and fungal dominated soil.

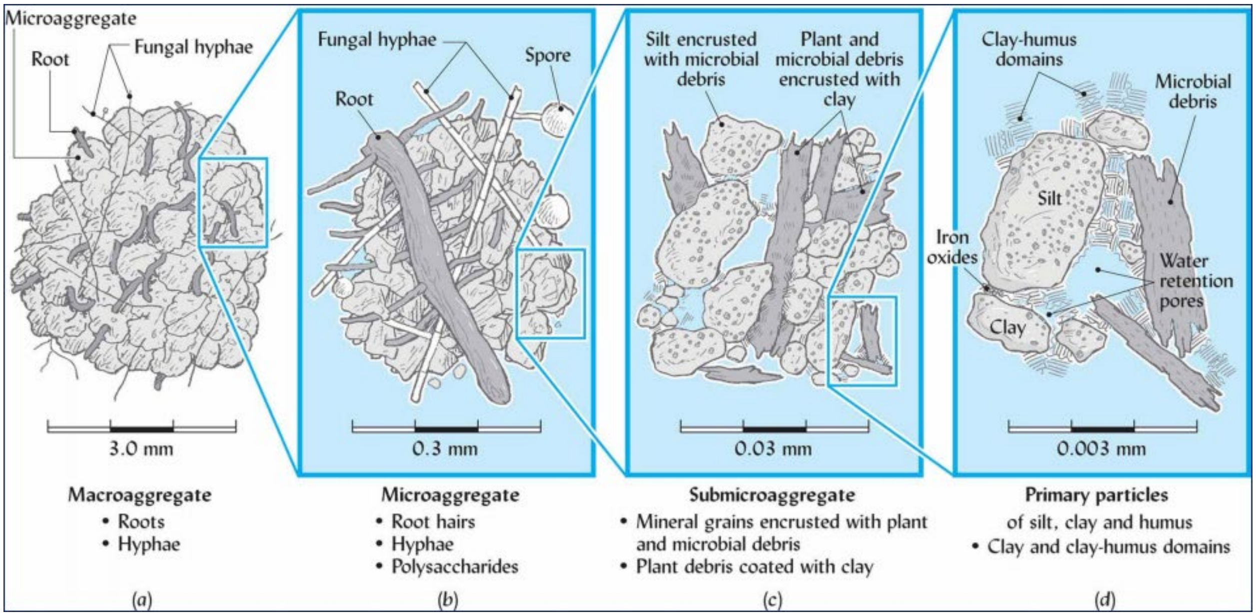
Item 5. *Soil aggregation and structure*

Soil aggregates, the crumbs of soil, are made up of smaller soil particles that bind together. The aggregates themselves are important, but so are the spaces (or pores) between them. A well-aggregated soil has a range of pore sizes. Each pore size plays a role in the physical functioning of the soil. Large pores drain rapidly and facilitate air exchange during wet periods. Large and intermediate pores contribute to functional drainage in the soil. As water moves through the larger pores, it is captured inside the small and micro-sized pores



Small pores retain water, which can help a crop get through dry periods with minimal yield loss. Sandy and gravelly soils are naturally deficient in small pores and are therefore drought-prone; whereas, loams and clays can retain and thus supply crops with more water.

Soil aggregates are also divided into categories of varying sizes.



Macroaggregates are larger than 250 μm and provide an area for colonization of microorganisms. Microaggregates are smaller than 250 μm, formed as the result of microbial decomposition of organic matter from macroaggregates. Microaggregates are relatively less labile than the macroaggregates, but once it is encapsulated within macroaggregates, microaggregates stabilize and resist further decomposition (Six et al., 1998) Another stabilizing compound in the soil are polysaccharides which are excreted by microorganisms, plant roots, and is found in plant residue. Polysaccharides bond micro-aggregates together. The combination of micro and macroaggregates produces pores of air and moisture as habitat for various soil biota. Different binding agents and mechanisms come into play at different spatial scales. Polysaccharides bond smaller aggregates together while fungal hyphae and plant roots bind together larger soil aggregates to immobilize and prevent erosion (Tisdall & Oades, 1982).

Item 6. *Bed construction*

Materials needed:

1. Well decomposed manure (estiercol) or leaves (tierra de sembrada). Compost would be more favorable, but if not available, these materials are sufficient.
2. Mulch material: We use rice husks because they are readily available. Wood chips, hay, or dried leaves will also work. It is best to use what is readily available.
3. Wood Ash (ceniza) or Dolomitic Lime (cal agrícola)
4. An optional fourth item is a set of string measuring a length of 10 to 15 meters attached to a stake on each end. This is used to mark a straight line for bed construction.

Start with a hoe and break up the land and form it into mounds. Once the whole bed is piled into the mound, we add the ash and manure. We take this and using the hoe mix it all together, and then cover the beds with the rice husks. These beds are then ready for direct plantings of corn, peanuts, yucca, sweet potato, cowpea, sweet peas or transplants of lettuce, cabbage, tomatoes, peppers, carrots, and other items for the kitchen garden.

These beds require one till. With the incorporation of ash, manure, and mulch layer, weeds are kept under control until we plant. Once the garden plants are big enough they act as a living mulch shading out smaller competitors. With each harvest we chop and drop, add on another layer of ash or manure, and cover with the rice husks again; layering to mimic how soil is naturally made.

Item 7 *Seed Germination and Transplanting*

A food security volunteer is faced with a great challenge ¨how can we grow enough food to feed a family at no, or little, cost?¨ Plants from nurseries must be bought, and having to buy seeds or small plants every year is not sustainable. Starting plants from seed is the cheapest way to start a garden. Many seeds can be taken from the foods you eat. Vegetables like carrots, lettuce, and spinach must bolt, create flowers which develop seeds, meaning these seeds cannot be harvested from the fruit. These seeds must be bought or acquired from an outside source. Starting plants from seed is not difficult but for those who have never done it the task can seem daunting; however, the pay off is worth the while as one seed will multiply into dozens or hundreds of seeds during its lifetime. Acquiring and starting seeds in nurseries is a necessary skill in order to make a garden.

In our gardens we submerged our seeds in water overnight and then wrapped them in newspaper, toilet paper, coffee filters, or banana leaves to keep them moist until they began to push out the first part of their root system (this could take days so make sure to keep the seeds moist until the roots show).

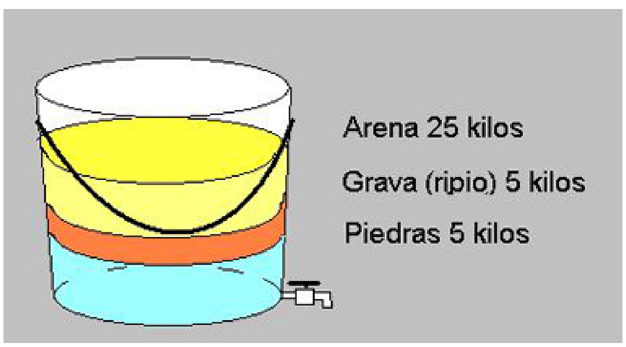
Once the roots are exposed they can be planted into cups, trays, or directly into the field. Plants like peppers and tomatoes are best if left to grow until they are an inch or two tall. Then they can be transplanted into beds. After the root system starts the next part of the plant we see develop are the germination leaves which jumpstart photosynthesis until the true leaves arrive. Below are the germination leaves of tomatoes followed by the true leaves of tomatoes.

Once the plants are taller and have their true leaves, they are ready to be transplanted. To transplant, remove the plants from their container as pictured above. Then separate the plants making sure not to break stems.

From here make a hole in the ground, or container, where the plant will be placed and insert it into the whole at a depth so that the germination leaves are just showing above the ground.

Item 8 *Charcoal, rock, and sand water filtration*

This water is Apart from water used for agriculture; however, one garden site was near the treatment station. The family had diverted some of their house water to a hose line, which was used to water plants. This allowed them to grow many ornamentals and some herbs throughout the whole year. One downside to this water was that it is treated with chlorine. Chlorine, as well as Iodine, is commonly used to kill harmful bacteria and organisms found in water. Chlorine is tolerated by plants but only in small amounts. Too much chlorine will lead to stunted growth and disease. The results of using chlorine in this garden were smaller fruits during harvest and stunted growth for plants like corn. Chlorine will eventually wash away during the rainy season, but the high levels of chlorine in the water made growing in the dry season a less fruitful endeavor. As a result, part of the grant was dedicated to creating a water filter using sand, gravel, rock, and charcoal, all of which were placed in a large, elevated plastic water tank that would feed water through a hose. The tank was elevated on a platform made of cinderblock. This system removes Chlorine and other debris, leaving clean water.



The following pages will detail what step, by step, how to set up one of these filters. The first step was to acquire the materials. All of these were easily found in Colimes at little or no cost. For example, the charcoal, sand, and rocks were collected from the surrounding areas at no cost. The gravel and cinderblocks had to be bought from a construction warehouse located in Colimes. If cinder blocks cannot be found, bricks are a good substitute, or if there is an area elevated (like a hill or berm) above the garden, the ground can be leveled, and the tank can be placed there. The water will flow downward naturally with gravity. The key is to do the project as inexpensively as possible. The most costly item was the sizeable 600-liter plastic tank. This was covered using money received from a food security project grant.

Next, locate the site where the tank will be placed. Remember to take into account the need for the downward flow of water if bricks or cinderblocks are not available. From there, the area must be leveled to begin the construction of the platform.

Once the leveling is completed, begin to lay down the cinder blocks. The platform for the tank does not need to be more than half a meter tall. Make sure to check with the leveler at every step. Any instability could cause the blocks, or tank, to topple or fall. Again, the goal was to keep costs down and make a simple system, so we did not use cement or mortar to make a base; however, for stability, this is worth considering. We decided to wet the ground and lay down some fine sand to make sure the first layer was as secure as possible.

After the ground is level, construct a cinder block platform large enough to rest the tank on top. We found that at least six squares using about 15 cinderblocks per square was sufficient and provided the needed stability. The stability of the platform is much more important than height. Use the level after laying the first layer to make sure the platform is level. If the first layer is level, all subsequent layers should be level as well. Once the platform is even, the next step is to take the tank, place it on top of the platform and begin filling it up with the filtration materials. The charcoal and rocks should be placed first. This is very important because if the sand or gravel are placed first, they can block the hole where the water comes out. Generally, the items should go in from coarsest to finest with the sand being the last to go in. After the large rocks and charcoal are the finer rocks and pebbles, then the gravel, and finally the sand.


The final step is attaching the hose to the tank. Once this is complete the water was fed into the tank from the top, filtered down, and flowed though the attached hose to the garden area.

After completion let the water run for about thirty seconds as some sand and debris will flow through. This is a simple model but very effective. An improvement to this model, for future volunteers to build upon, would be to add more hoslines and create a drip irrigation system. Drip irrigation is the most efficient way to deliver water to plants right at the root zone; where it is needed the most. This filtration system can also be adapted with water catchements to collect rainwater. All of these topics must be expanded upon in future projects by future volunteers. In a tropical desert climate any and all ways to maximize water harvests and more efficient use of water will lead to extended growth and better harvests into the dry season, sustaining year round harvests and ensuring families always have access to nutritious food.

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