Field Manual on AGROECOLOGY

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PREFACE

Our current food systems rely heavily on non-renewable resources, consume and waste too much water, threaten biodiversity, damage ecosystems and put undue strain on ecosystem services, and contribute significantly to climate change. Should this state of affairs continue, we may end up with food systems that not only fail to respond to our needs, but may also become irreversibly broken.

This manual was developed in the midst of the COVID-19 pandemic. With the lockdowns and restrictions in mobility came the opportunity to reflect on our experiences; it also compelled us to identify the restorative techniques and practices in agroecology that can contribute in transforming, sustaining, and securing our food production systems. While agroecology is a broad concept, this manual focuses only on the technical aspects of the subject.

Agroecology is the course of action that we need to take if we want sustainable food systems and be able to feed the world's growing population. The critical state of agriculture has spawned the rise of various approaches that aim toward sustainable agricultural production, e.g., organic agriculture, low external input sustainable agriculture (LEISA), permaculture, eco-farming, biodynamic agriculture, nature farming, agroecology, and the like. The first chapter of this manual explains the basic concepts and principles of agroecology and establishes the urgent need to transform agriculture. We cannot continue producing and consuming food the way we are doing now. Agriculture should be part of the solution instead of contributing to the worsening climate crisis and its attendant problems if we want to achieve sustainable food systems and enjoy genuine food security.

This manual is an immediate response to our partners' request for an easy-to-follow guide on agroecology that will help them transform their farms into sustainable and resilient systems. It is our hope that this material will serve as an impetus for us and our partners to develop and produce more educational materials to cover the other aspects of agroecology.

ACKNOWLEDGEMENTS

The inspiration to develop this manual came from our farmer-partners who are at the forefront of producing adequate, fresh, and nutritious food for their families and to members of their respective communities. Much of its contents are informed by their tested practices and experiences.

The unwavering support of SwedBio, our long-time partner in helping smallholder farmers in Southeast Asia made the production of this manual possible. Moreover, SwedBio has consistently advocated for farmers to discover their inner potentials and encouraged them to innovate.

Our deepest appreciation and heartfelt gratitude.

Chapter 1
Basic Concepts and Principles in Agroecology

What is agroecology and why we need it

The industrial food production system that has been practiced and is continuously being promoted across the globe has failed and is failing miserably. The narrow focus of agricultural development on increased productivity rather than on a more holistic integration of natural resources management (NRM) with food and nutritional security has resulted in high external input and resource-intensive agricultural systems.[1] Such an approach for producing our food according to FAO has caused massive deforestation, water scarcities, biodiversity loss, soil depletion, and high levels of greenhouse gas emissions.[2] This destructive trend has to stop.

Agroecology has a huge potential not only to bring back the health of our ecosystems but to help improve household food, nutrition, and livelihood security. It is an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems. It seeks to optimize the interactions between plants, animals, humans, and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system.[3] Agroecology is not just a package of technologies but a philosophy and a way of life. It is based on sound science and married with proven age-old practices of farmers, especially smallholder farmers – practices that are rooted in their traditional knowledge of finding solutions to their problems, grounded on their local context, and built on locally available resources and internal capacities.

1 IAASTD report
2 FAO. The Ten Elements of Agroecology: Guiding the transition to sustainable food and agricultural systems.
3 Ibid

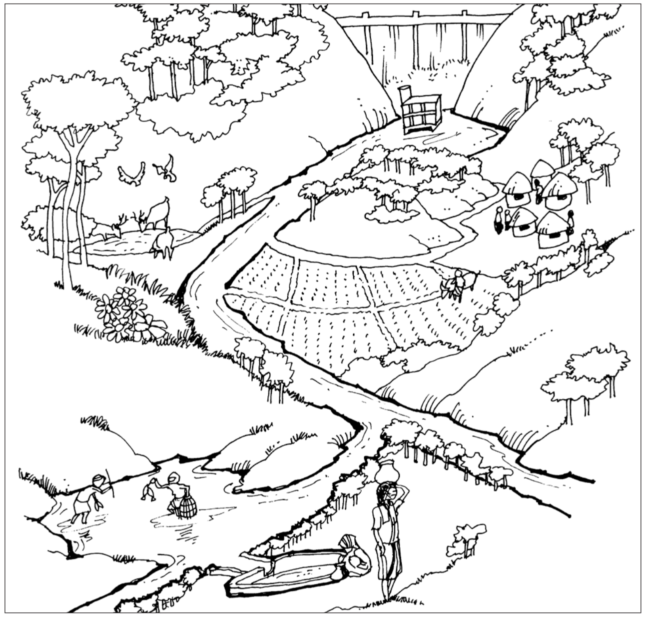


Figure 1. Agroecology attempting to mimic a rich natural ecosystem

Agroecology underscores the complex nature of agricultural systems and the intricate relationships among its various components. The key is not to treat each component of the agricultural system as an isolated entity but rather as an integral part of a holistic system that closely mimics nature as much as possible. In a natural ecosystem, like a natural forest, the various components support each other in a symbiotic relationship. Inherent in this ecosystem are the diversity of species and organisms within the system; the interdependency among these species and organisms; and the efficiency and self-sufficiency of the system as it does not require external inputs for it to continue to exist. This is the characteristic and strength of the natural ecosystem that agroecology attempts to simulate and apply in agriculture.

The food insecurity situation is exacerbated by the impacts of climate change. Extreme weather events are getting more frequent and more severe which negatively affect agricultural productivity.

Occurrence of super typhoons, changes in rainfall patterns, droughts and floods, and extreme high and low temperatures are all contributing to overall lower levels of food production. Inherent in agroecology are the principles of species diversity, nutrient cycling, integration and synergy of components – all of which make the agricultural system better able to mitigate and adapt, and therefore more resilient to the adverse effects of climate change.

Crucial decisions have to be made urgently to help address the multiple interrelated crises that stem from the practice of conventional agriculture – environmental degradation; food, nutrition, and livelihood insecurity; widespread malnutrition and hunger; among others. **In this context, agroecology is no longer just a choice but a necessity.**

Understanding the ecosystem

An **ecosystem** is a community of living organisms (biotic) in combination with the non-living components (abiotic) of their environment, interacting as a system.[4] In a natural ecosystem like a forest, the living and non-living things coexist in a certain balance and symbiotic relationship. The natural forest produces huge amounts of biomass using nutrients, water, and energy from the soil, air, and sunlight. It is self-sustaining and no external inputs are needed for the survival of the living organisms in the system. Conventional agriculture and even agroecosystems in contrast, produce less biomass and require external inputs to sustain them; the amounts will vary depending on the volume of needed inputs and how much of these are already being produced on-farm. The artificial nature of agriculture can create problems in the system like soil degradation, pest outbreaks, genetic erosion – causing an imbalance and exposes the vulnerability of the system, which consequently results in low productivity. To help minimize these problems, it is important to understand the ecosystem and how to keep its balance.

4 *https://en.wikipedia.org/wiki/Ecosystem*

The ecological pyramid

An **ecological pyramid** is a graphical representation of the relationship between different organisms in an ecosystem, shown in the accompanying figure. Each of the bars that make up the pyramid constitutes a different trophic level which is the position that an organism occupies within a food chain. The levels signify the order of the organisms, which is based on who eats whom, representing the flow of energy (food). Energy moves up the pyramid, starting with the primary producers at the bottom, followed by the primary consumers which feed on the producers, then secondary consumers which feed on the primary consumers, and so on.[5]

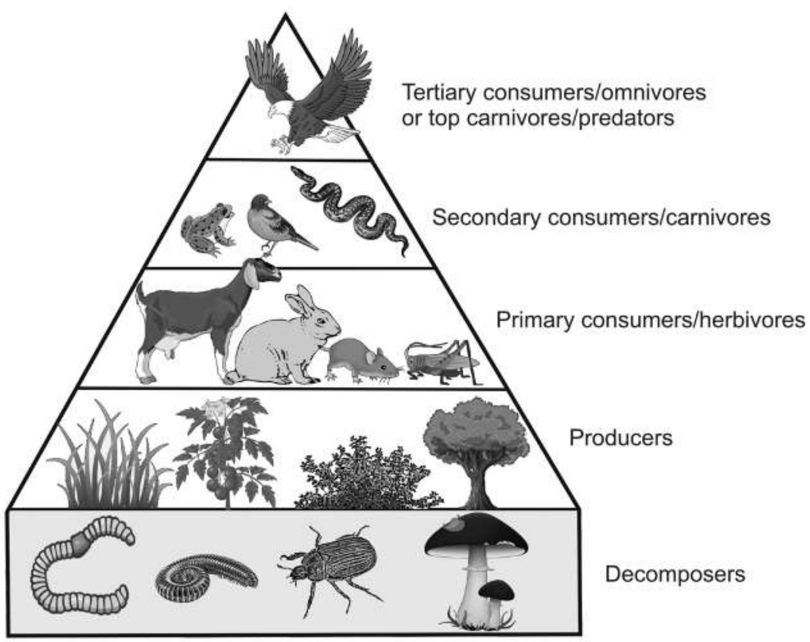


Figure 2. The ecological pyramid

5 https://biologydictionary.net/ecological-pyramid/

Primary producers (often referred to simply as producers) manufacture food for themselves and for other living things in the ecosystem using energy from the sun, carbon dioxide from the air, and nutrients from the soil. Plants are the only organisms that can produce food through the process called photosynthesis, hence they are called producers. They are at the bottom of the ecological pyramid.

Consumers feed on other organisms like plants or other animals. There are three types of consumers, represented by the three bars above the primary producers: the plant-eaters (herbivores), the meat-eaters (carnivores), and those that feed on both animals and plants (omnivores).

- The plant-eaters/herbivores or primary consumers only eat plants (e.g., some insects, ruminants such as goats, carabaos, and cattle) for their food.
- The meat-eaters/carnivores or secondary consumers only eat meat (e.g., snakes, some birds, spiders).
- The tertiary consumers can either be fully meat-eaters (e.g., eagles, snakes, lions) or they can eat both plants and animals/omnivores (e.g., pigs, some insects like flies, humans).

Many animals feed at several different trophic levels. Both carnivores and omnivores can be predators. They depend on the sufficiency of other organisms or their prey in the ecosystem for their food or source of energy.

Decomposers are organisms that feed on organic matter such as dead organisms or waste of producers and consumers such as fallen leaves and animal manure. Decomposers (e.g., bacteria, fungi, earthworms, and some insects) break down organic matter into humus and minerals which are important for both plant nutrition and soil health.

The ecological pyramid illustrates the flow of energy from the bottom (producers) to the top (different orders of consumers).

It also shows the decreasing amount of biomass and numbers of organisms from the base to the top of the pyramid, clearly indicating the need for a broad base of primary producers to sustain the different levels of consumers above it. Therefore, we have to maximize the use of available space for growing a diverse range and species of producers – trees, shrubs, grasses, vegetables, herbs, etc. It is important to appreciate that all these plants (producers) provide food for most organisms in the ecosystem: humans, livestock and other animals, and many of the other consumers (including decomposers) that are all equally important in maintaining the ecological balance.

Moreover, the ecological pyramid highlights the need to maintain the various levels of consumers at a certain balance so as to keep each type of organism at a certain limit. For instance, if the population of secondary consumers such as frogs and spiders (that feed on insect pests) significantly decline due to excessive pesticide application, this may lead to over-population of insects which are feeding on plants, resulting to decrease in crop yield.

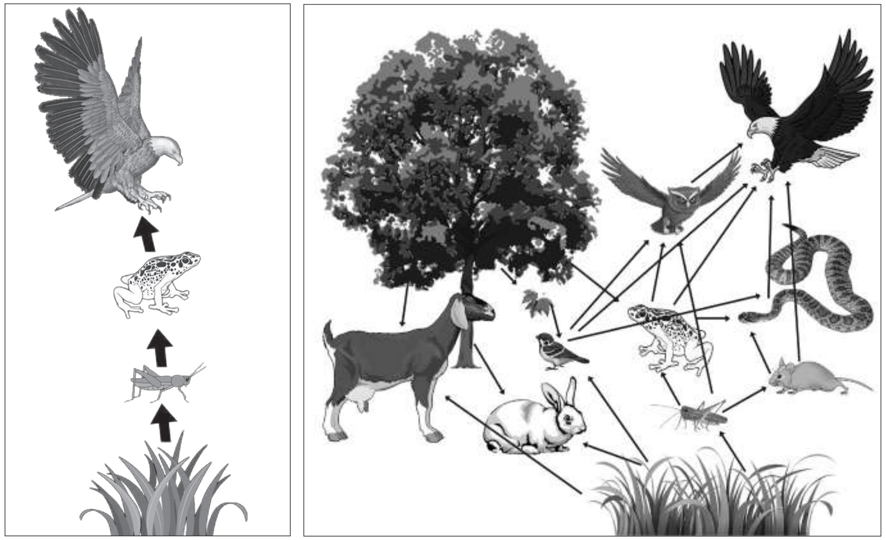
Box 1. Golden snails: the bane of rice farmers

In the Philippines, one classic example of upsetting the ecological balance in rice fields is the importation of the golden apple snail (GAS) from Latin America in the 1980s.[6] GAS was meant to provide an additional protein source especially for farm families. However, the golden snail did not become a significant addition to the diets of Filipinos who still preferred to eat the native *kuhol*. The foreign snail species instead became invasive since they were introduced without the predators from their country of origin; such predators naturally keep the population of their prey in check. GAS has become a major pest in rice fields, causing as much as more than 50% reduction in yields if not properly managed.

6 http://www.knowledgebank.irri.org/step-by-step-production/growth/pests-and-diseases/golden-apple-snails

The food chain and food web

The linear relationship between producers and consumers is known as the **food chain** (i.e., plants are eaten by insects which are eaten by birds, which are eaten by snakes). On the other hand, the interconnectedness of the food chains in the ecosystem which shows the more complex relationships of the different organisms is known as the **food web.** For example, birds eat plants and worms, aside from insects; they are in turn eaten by snakes which are eaten by predator birds like eagles (which also prey on other birds), and even humans. Every living thing interacts with one another and all of them have a role to play in nature. The food chain and the food web demonstrate the need to maintain the balance in the ecosystem.



Food chain **Food web**

Figure 3. The food chain and food web

Ecosystem balance (as exhibited in natural forests) depends on the presence of every type of the organisms in the food web. If one type of the organism becomes abundant or scarce, the entire balance of the ecosystem will be affected. The more biomass the plants (producers) produce, the more animals (consumers) survive, and the more organic matter is supplied to the soil. The more organic matter in the soil, the more soil organisms (decomposers) can live and make nutrients available to the plants which then can produce more biomass. This very important process is known as the nutrient cycle.

The nutrient cycle

The nutrient cycle is very important in the ecosystem as it allows for the movement of nutrients from the physical environment into the living organisms and ideally back again to the physical environment. This underscores the importance of nutrient recycling as an element of agroecology. Without recycling of nutrients back to the environment, there will be nutrient depletion, poor soil health, and poor plant growth, eventually leading to low crop yield.

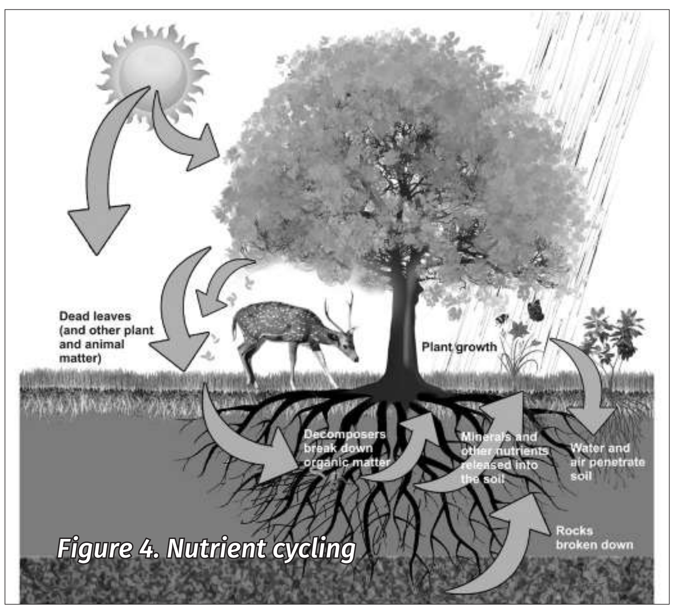


Figure 4. Nutrient cycling

To some degree, the nutrient cycling that occurs in a balanced ecosystem can be attained through integrated farming, depending on how it is designed and on how mature or sophisticated the system has become. By including different components where each one yields a product, by-product, or “waste” product that can be “consumed” by another component, a complete nutrient cycling (or recycling) is possible. This concept is explained in more detail in a later section of this manual.

Biodiversity: Basic foundation of agroecology

There is no way agroecology can be practiced without agricultural biodiversity. Also widely referred to as agrobiodiversity, agricultural biodiversity is broadly defined as the variety and variability of animals, plants and microorganisms that are used directly or indirectly for food and agriculture. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fiber, fuel, and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil microorganisms, predators, pollinators) and those in the wider environment that support agroecosystems (whether these are predominantly crops, livestock, fisheries, or forests), as well as the diversity of the agroecosystems themselves.[7]

We need agrobiodiversity for a variety of reasons: to maintain soil health; to promote growth and development of crops, livestock and fisheries (while at the same time strengthen their defense against pests, diseases, and adverse soil and environmental conditions); and to sustain micro-organisms, predators, and pollinators. Agricultural productivity relies on sustaining a wide range of species that live both above and below the ground. Largely unseen and often forgotten, we need diverse soil organisms to facilitate decomposition of organic matter, which aside from providing nutrients to crops, help rehabilitate degraded soils.

7 FAO, 1999. http://www.fao.org/3/y5609e/y5609e01.htm

Agrobiodiversity provides a wide range of essential services to the ecosystem such as pollination, pest and disease management, soil water retention and regulation, and many more. Moreover, a broad-based genetic diversity on-farm contributes to the stability and resilience of the agroecosystem. Biodiversity also strengthens the system's adaptive capacities as the different species evolve with the changing climate and other environmental stresses.

Monocropping or growing a single crop makes for a fragile system. Pest infestation or an unfavorable weather or climate can be enough to wipe out the crop stand; this is something that rarely happens when one has a great variety of crops growing at any one time in a particular area. This crucial role of biodiversity in agriculture calls for its conservation and management for the system to be stable, sustainable, and resilient – especially in the face of any adverse condition (See Box 2 below).

Box 2. Biodiversity at work in an agricultural system

Farmer A decided to plant sweet corn on his half hectare of land since he had a bumper crop the same season in the previous year. The corn plants started out well; with about 90% germination of the seeds planted, there was an even crop stand across the field. When the plants started flowering, a dry spell occurred that lasted for a month. Stress from the high temperature and low moisture caused the silk to dry up so the corn did not properly pollinate. As a result, the farmer got only half of the yield he was expecting to harvest.

Farmer B also owns half a hectare of land adjacent to Farmer A's but devotes only half of it (¼ hectare) to a seasonal 'major crop'. Like his neighbor, he also planted corn; he likewise got only half of the expected yield from his crop stand. But the similarity ends there. Within the area planted to corn are several alternating strips of

leguminous tree species that he regularly prunes to feed his livestock – a work buffalo and several heads of goats that he keeps in partial confinement. Along the perimeter which he used as a fenceline, he also planted some horseradish tree *(Moringa oleifera),* dwarf *katurai* or vegetable hummingbird *(Sesbania grandiflora),* and gliricidia *(Gliricidia sepium)* that served as "mother plants" for his black pepper *(Piper nigrum)* that have started to become productive. He also pruned the gliricidia regularly and used the leaf trimmings not only as additional feed for his livestock but also as green leaf manure for his garden.

With the exception of a patch which Farmer B permanently devoted to several forage grass species, the rest of the ¼ hectare is planted to an assortment of vegetables (leafy, fruit-bearing, legumes, rhizome/root vegetables) of varying growing periods. He makes sure to have at least three or more varieties of each vegetable currently being planted. And going back to the 'failed' corn crop... two weeks before harvest, it rained for three days. Farmer B observed that there was enough moisture in the soil to start a legume crop so he dibbled in a climbing variety of string beans *(Phaseolus vulgaris)* at the base of the corn plants. Instead of cutting down the corn stalks during harvest, he decided to leave them alone for the beans – this saved him time, effort, and resources as he did not have to prepare poles/trellises for the beans to climb on.

Chapter 2
Managing Soil Health and Nutrition

Soil plays a vital role in agriculture. It provides anchorage for plant roots; holds water and nutrients that are essential for plant growth; serves as habitat for myriad microorganisms that fix nitrogen and decompose organic matter; and is home to armies of microscopic animals as well as earthworms and termites that are essential as decomposers.[1]

Getting to know your soil

Soil is made up mainly of **water, air,** and **solid matter,** which is primarily composed of minerals and humus. A good soil has a well-balanced combination of these three components. Too much solid matter makes the soil hard, making it difficult for plant roots to penetrate. Too much water on the other hand reduces the amount of air in the soil, resulting in oxygen deficiency for plant roots. Too much air makes water drain very quickly, reducing the amount of available water needed for plant growth.

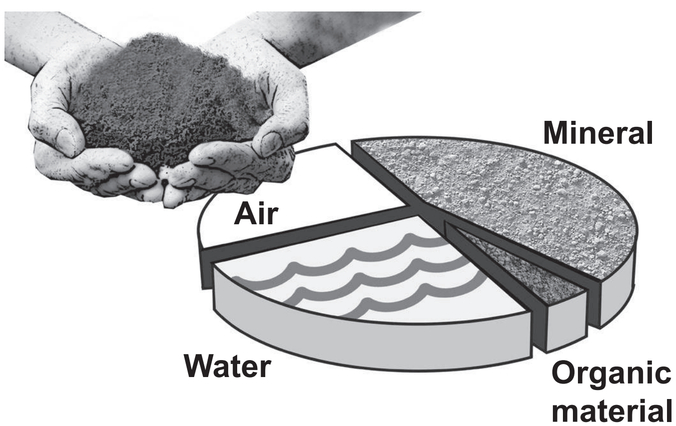


Figure 5. Ideal soil structure

1 *Adapted from World Soil Information (ISRIC). https://www.isric.org/discover/about_soils/why-are-soils-important*

The type of soil is determined by the proportion of these three basic components. Sandy soil has bigger particles and big pore spaces which makes it well aerated but renders it poor at holding nutrients and water. Clay soil has fine particles which are tightly packed together, so it does not drain easily and has very little or no airspace. The combination of sand and clay can produce an optimum size of pore spaces that can sufficiently hold water and nutrients, and at the same time provide adequate air circulation.

What makes a good soil?

Soil structure can be substantially improved by adding humus. **Humus** is the dark, organic material in the soil from decayed plant and animal matter produced from the action of decomposers such as termites, earthworms, and various beneficial soil microorganisms. Adding humus to clay soils helps in aggregating the small soil particles into larger clumps, creating larger pore spaces. On the other hand, adding humus to sandy soils helps bind the soil particles together, making them less porous. Humus therefore can improve the structure of both sandy and clay soils.

Humus holds soil nutrients strongly enough to prevent them from leaching into the surface and groundwater, but will also gradually release the nutrients, making these available for the plants' use. To reiterate, a good soil has enough minerals and humus, can adequately hold nutrients and water, but also has good drainage and aeration.

Aside from improving the physical properties of soil, humus also helps enhance the soil's chemical properties. As the decomposers get to work, the chemical compounds in the decaying organic matter are converted into a form that can be absorbed by plants; this process is called **mineralization.** Moreover, humus can regulate soil pH such that it acts as buffer, absorbing shocks from either alkaline and acidic soil conditions. If the soil is too acidic or alkaline, many of the soil nutrients or minerals become unavailable to plants; this is called **immobilization,** which is the opposite of mineralization.

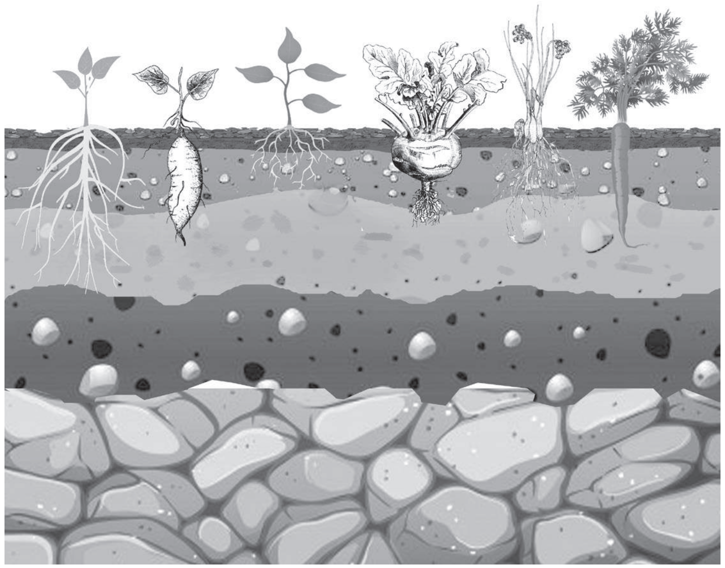


Figure 6. Layers of the soil

Soil organisms

A healthy soil is a living, dynamic ecosystem, teeming with microscopic and larger organisms that perform many vital functions. Such functions include converting dead and decaying matter as well as minerals to plant nutrients (nutrient cycling); controlling plant diseases and insect pests; improving soil structure to enhance its water- and nutrient-holding capacity; and ultimately improving crop production.[2]

The biological characteristics of the soil depends on the activities of the organisms living in it. The more active these organisms are, the more humus are produced through decomposition of organic matter, and the more nutrients that become available to plants. To keep these organisms active, they should be constantly "fed" with organic matter. This can be done several ways: by adding compost to the soil; by burying kitchen waste or incorporating green or dead leaves into the soil (instead of burning or throwing them away); or by simply using all sorts of farm "wastes" and by-products as mulch – the decomposers will eventually get to work on them. Continuous and excessive use of chemical fertilizers on the other hand kills these organisms and hastens the mineralization process, causing the faster disappearance of humus, and destroying the soil structure.

The soil organisms are also responsible for controlling the population of harmful soil-borne microorganisms that cause plant diseases (called pathogens) such as nematodes and fungi. In a balanced soil ecosystem, the numbers of these pathogens are usually very few compared to the beneficial or otherwise harmless soil organisms. Hence, disease-causing organisms are usually kept at levels that cannot harm or cause serious damage to the plants.

Practical techniques for improving soil health and nutrition

A healthy soil is fundamental in producing healthy plants. Studies have also found that the nutritional value of crops is greatly affected by the condition of the soil. The carbohydrate, vitamin, protein, and mineral contents of crops are linked to the soil's minerals and trace elements. Therefore, the soil has to be healthy in order for it to produce healthy and nutritious crops.

It is important to understand that the soil is home to a multitude of living organisms which need to be fed and cared for, to enable them to decompose and process organic matter (OM) so that nutrients become available to plants. Our mindset therefore should be to **feed the soil** and keep it healthy instead of fertilizing the plant. As long as we keep the soil healthy and full of nutrients, it will in turn take care of our plants. Applying OM – both from plant and animal sources – is important not only to provide the plants with essential nutrients for them to produce more, but also to help them grow stronger (stronger roots, stems, leaves,

2 FAO. 2015. Healthy soils for a healthy life. http://www.fao.org/soils-2015/news/news-detail/en/c/277682/

etc.). Stronger plants are better able to withstand insect attacks, plant diseases, and environmental stresses.

Moreover, OM greatly helps to improve and maintain good soil structure. As mentioned in the preceding topic, soil with good structure has good drainage and aeration, in addition to having adequate nutrient- and water-holding capacity. Organic matter acts like a **sponge** in this regard; it holds and stores water, making it available for the plant's use. Conserving moisture is especially crucial in the hot tropics where soils can quickly dry up.

While applying chemical or inorganic fertilizers may result in immediate plant growth and increase in yield, it can also contribute to soil degradation. Continuous application of chemical fertilizers leads to acidity and decreasing amounts of organic matter in the soil; this makes the microorganisms less active, and eventually leads to less production of humus. With less humus, soil structure degrades – it becomes hard and unable to adequately hold water and nutrients. With insufficient water and nutrients, the soil organisms will find it difficult to thrive. With less soil organisms, less OM is processed into nutrients available to the plants, and there will be less oxygen and less water as well. This cycle is repeated until more and more fertilizers are required to sustain plant growth because the soil is no longer capable of feeding the plant and sustaining its growth.

Organic matter is key to soil health and nutrition and therefore it is essential to ensure that the soil has sufficient amount of OM at all times. Organic materials must be returned to the soil that helped build it. As much as possible, all materials that are produced at the soil's "expense" (e.g., plant residues including weeds, wood ash, even animal wastes, etc.) should be returned to the soil to help replenish what were taken from it. A list of common organic materials and their nutrient compositions (nitrogen/phosphorus/potassium or NPK) is found in Appendix A.

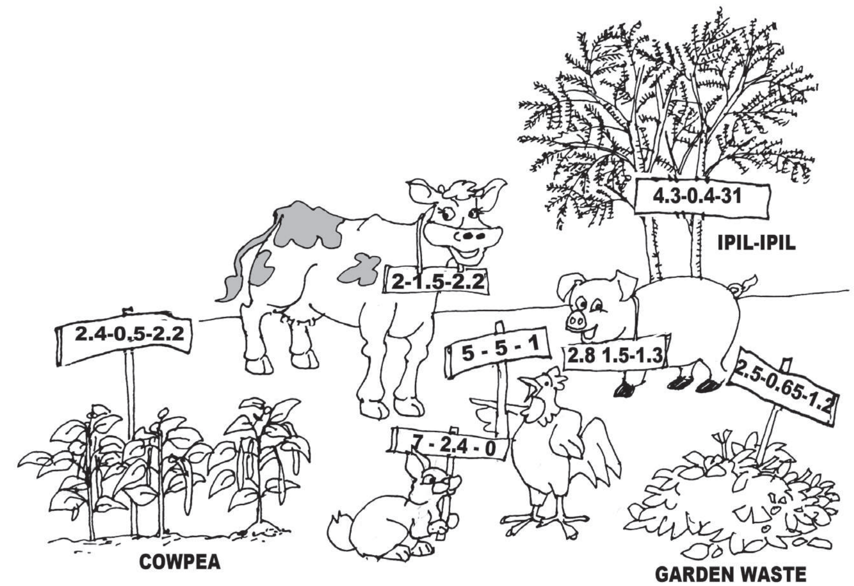


Figure 7. Average NPK content of select organic materials

We can maximize the benefits of OM as soil enhancer if it is properly processed and used. Discussed below are several ways in which this can be done, depending on available materials and labor and the obtaining conditions in one's farm or garden. These methods include composting, green manuring, use of organic liquid fertilizers, use of other soil amendments, and other cultural techniques.

1. *Composting*

Composting is the process of speeding up the decomposition of organic matter into humus-like material called compost by providing ideal condition for decomposers such as worms, beneficial bacteria, fungi, etc. to do their work. The ideal condition means that aside from the right amount and proportion of organic waste to be decomposed, sufficient air (oxygen) and moisture must be present for proper decomposition to take place.

Box 3. "Green" and "brown" ingredients in making compost

Good quality compost needs a good balance of "green" and "brown" organic materials. Green materials are fresh organic matter such as animal manure, fresh leaves and plant trimmings, grass clippings, including kitchen refuse and food scraps; **greens are rich in nitrogen.** On the other hand, **brown materials contain large amounts of carbon.** Examples of browns are dry leaves, straw and hay, twigs, wood chips, and sawdust. Generally, a ratio of 3-4 parts browns: 1 part greens is recommended for faster decomposition. If this proportion is not achieved, the compost pile may not properly decompose.

It is important to chop the compostable materials into small pieces (ideally 1cm-5cm) to have more surface area for the microorganisms to "attack". The smaller the size of the materials used, the faster the decomposition process. If the compost pile is not heating up, decomposition may take a long time; add more green materials to help activate the microorganisms. If the compost starts to smell, this indicates that a lot of nitrogen is converted to ammonia (which is lost through volatilization). In such case, more brown materials may be added.

The pile should also be turned to enhance aeration. Air is essential for the survival of organisms in the compost pile and for flushing out the carbon dioxide that is produced during decomposition. Lack of air also causes bad odor, hence it is important to turn the compost pile regularly, i.e., once a week.

Sprinkle the compost pile with water to keep it moist but not too wet. Decomposers need water to survive but too much of it will make oxygen unavailable, which will result in less activity of the decomposers. To find out if the composting materials have the right amount of moisture, they should feel as damp as a squeezed-out sponge.

To sum up, a good quality compost should be ready in three months (instead of the usual six) if the materials used are chopped in small pieces; are in sufficient amount and in the right proportion; the pile is kept moist; and is turned regularly. But even by just piling the organic materials without any of the above interventions, decomposition happens as a natural process and in time, these materials can still be used as compost. At the very least, composting is a great way of reducing organic waste and avoiding environmental pollution. Described below are several composting methods.

Open air composting. This is the most common method of composting because it is easier to do and requires less labor. It is done by simply putting together compostable materials either directly on the ground or in a bin. **Ideally, two to three bins or piles are necessary** to allow the composting process to proceed in one or two of the piles or bins while the compost in the other one is being used. However, the compost pile may attract pests like rats and flies; snakes may even find it a good nesting and breeding place. Keep the piles or bins covered when it rains to prevent them from getting too wet.

Pit composting. Another commonly used method is pit or trench composting. It is probably the oldest but quite an effective composting technique. Pit composting however requires additional labor for digging the pit(s). It is also more difficult to turn the materials. On the other hand, this method produces an abundance of earthworms and other decomposers that naturally live in the soil.

In situ composting techniques for home gardens.[3] The two examples below require less labor as hauling compost from the bin or pit and incorporating them in the garden bed is no longer needed. Composting is done right on the beds where the crops are to be grown.

3 Adapted from "The bio-intensive approach to small-scale household food production." IIRR. 1992. pp 47, 49-50.

Deep bed composting. Deep bed or trench composting is done by digging a trench in the middle of the raised bed about 30cm deep and at least a third of the bed's width. Place the mixture of carbon- and nitrogen-rich organic materials in the trench (3-4: 1 ratio as previously recommended), then cover them with a layer of soil – this should be about 15 cm thick of compostable materials and 2.5-5cm of soil layer. Then pile another 15cm layer of compostable materials and likewise cover this with soil.

Plant the crops about 15cm from and around the compost trench. The nutrients from the compost are absorbed by the plant roots as the organic materials decompose. The decomposition process however will take a while, thus additional organic fertilizers are needed initially to sustain plant growth. Unless the compost trench was prepared way in advance, it is expected that the succeeding crops are the ones that will fully benefit from the compost.

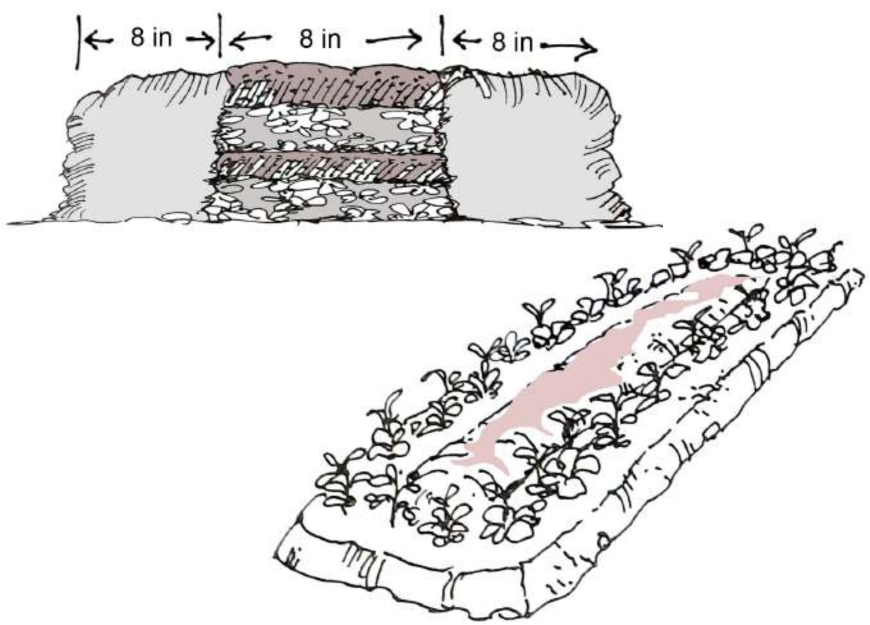


Figure 8. Preparing the compost trench and planting around it

Basket composting.[4] "Baskets" of about 30cm in diameter and 30cm in height (or even a bit taller) are half-buried in the garden plots. These are placed along the length of the raised beds, spaced about 1 meter apart. Place the recommended mixture and ratio of brown and green compostable materials and soil in the basket(s); do this in layers similar to the process described in trench composting.

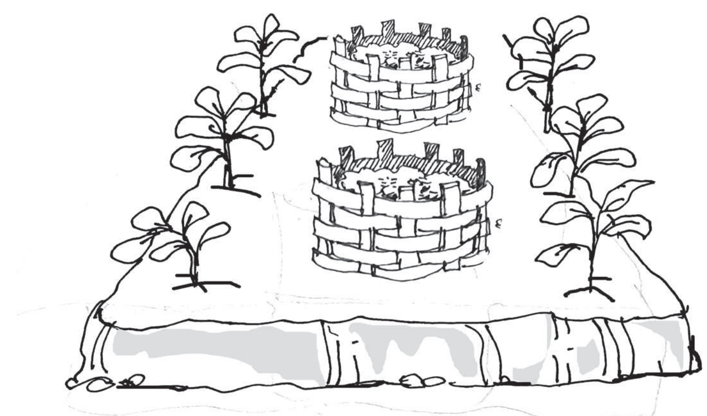


Figure 9. Planting crops around the compost basket

Similarly, plant the crops around and 15cm away from the baskets to prevent the plants from getting burned by the heat produced by the decomposing materials. Water the seedlings while young. As explained by the developers of the technology, they eventually simply water the (contents of the) basket; water carrying the nutrients flow naturally to the plants around it. On the other hand, the plant roots tend to move toward the baskets since they are drawn to the source of water. As the volume of the baskets' contents decrease with time, organic materials (and soil) can be added to provide a steady supply of nutrients to the plants around them.

4 Modified from the technique developed by the Mindanao Baptist Rural Life Center (MBRLC) from Bansalan, Davao del Sur in Southern Philippines.

Vermicomposting.[5] Vermicomposting is a process of decomposing organic wastes using various species of earthworms. The resulting compost contains worm castings plus undigested organic matter and various beneficial microorganisms. Compared to conventional compost, vermicompost has higher levels of nutrients, particularly nitrogen and phosphorus. When we consider that earthworms produce twice their weight in castings every day, that's a lot of nutrients added to the soil.[6] The most popular species being grown in the tropics are African night crawlers (ANCs or *Eudrilus eugeniae*) because they are observed to be voracious eaters and therefore also produce a lot of castings. However, any locally available earthworm species may also be grown.

Vermicast or pure earthworm castings is considered one of the best natural soil conditioners. Some studies indicate that the material is five times richer in nitrogen, seven times richer in phosphorus, and 11 times richer in potassium than the soil where the earthworms live. It is important to note that the quality of vermicompost also depends largely on the condition of the medium where the earthworms live, the kind of materials that they eat, and how the vermicompost is harvested and stored.

Described below are key ideas and recommendations to consider in vermicomposting. Specific steps in worm bin/bed preparation and maintenance, worm food preparation, and harvesting are not discussed in detail since the processes would slightly vary depending on the operation (for home use or commercial scale) and purpose for raising earthworms (production of vermicompost, vermicast, or worms for sale). Many resources can be found in the internet on nearly any subject area on vermicomposting, including do-it-yourself videos where one can get useful tips from experts and practitioners. However, despite the plethora of information available, a large part of adopting the technology will be trial and error – learning by doing, including making mistakes.

5 Adapted from Vermicomposting 101: https://urbanwormcompany.com/what-to-use-for-worm-bedding/

6 IIRR. 1992. The bio-intensive approach to small-scale household food production.

Worm bedding. Worm bedding, sometimes referred to as vermibed, is the medium where the worms are raised. Part of the worms' diet comes from their bedding; it should be prepared well to provide nutrients and maximum comfort to its inhabitants. Basically, any organic waste that is moisture absorbent, pH-neutral, carbon-rich, and is free from any sharp or abrasive surface that can harm the worms' sensitive skin can be used. **Fresh materials must be composted first** however, since heating associated with decomposition will make the worms leave the bed. A variety of materials that can be used in combination as worm bedding include:

- dry leaves and wood chips; farm or garden by-products/ wastes (cut into small pieces), coconut coir, etc.;
- aged manure from ruminants or grass-eating animals (carabao, cow, goat, horse, rabbit, etc.);
- any locally available organic material, including shredded paper and corrugated cardboard (plain, not laminated since the worms cannot digest the plastic coating); it is important to strip them of any adhesive tapes which are also undigestible and to remove staples that can injure the worms

Commercial vermiculturists have found that a mixture of finely chopped banana trunk (75% by volume), which is rich in potassium, and aged animal manure (25%) makes an ideal bedding material. The vermibed should be ready to "receive" the worms 30-45 days after preparing the mixture. A 1m x 2m x 30cm bed can accommodate 1kg of ANCs.[7] Compost can also be added to the worm bedding, as it can serve as a ready-made nutritious food for the worms. As a bonus, it is already colonized by beneficial fungi and other microorganisms. Moreover, compost has a friable texture which allows for good aeration and moisture absorption – two requirements for a good vermibed. Finally, note the following about worm beddings:

7 **Vermiculture sa Pilipinas,** *an online chat group of vermiculture enthusiasts*

- There is no one "best" bedding material. Some are inherently better than others, but even these better ones may not always be available. The key is to aim for **combination of a variety of materials.**
- Since the worms partly feed off their bedding, the materials should be shredded or chopped up into small pieces so that the worms can eat them more easily.
- Whatever bedding materials are used, they should be damp but not sopping wet.
- Occasionally mix and turn the bedding to keep it from compacting and matting up.
- During the dry months or hot weather, lightly sprinkle the bed with water to keep it moist and a little cooler.
- Remember that worms like the cool darkness of the soil, so the vermibed should be ideally placed in a shady spot. If using a bin, put a lid on it during daylight hours.

Food for the worms. Food can be introduced once the vermibed or bin has become **stable.** This means the earthworms are already acclimatized to their environment, evidenced by the presence of castings on the surface of the bedding. Usually, any organic kitchen waste and plant refuse can be given but it is easier for the worms to eat those from succulent or fleshy plants like cucurbits (e.g., squash, watermelon, cucumber, bottle and sponge gourd, etc.). These plants are high in sugar and break down easily so they are ideal as worm food.

Food is placed on top and to one side of the bedding and covered with a thin layer of soil (or the bedding material itself) so it does not unnecessarily attract flies and other insects. Moreover, worms go to the surface to feed but since they do not like the light, they are more inclined to swarm all over the food if covered rather than just access it from underneath.

It is important to observe how long it takes for the worms to finish off their food. Piling too much food all at once, especially those with high water content may make the bedding soggy; the food may also ferment if they are not eaten within a period of time.

Fresh manure can be given at this stage, by placing them a foot apart on top of the bed; they can be made into "patties" and coated with soil so they don't smell.

2. *Green Manuring*

Green manuring is the growing of plants in the field that are later incorporated into the soil. Examples of the practice are the use of leguminous cover crops and planting of fast-growing nitrogen-fixing trees (NFTs). This is especially useful in areas where animal manure is not abundant or readily available. Legumes have the ability to fix nitrogen from the atmosphere and store it in their root nodules, making nitrogen available to other crops. The thick foliage of cover crops also suppresses weed growth, thereby reducing or eliminating costly weeding operations. Depending on the types of green manures used, they can also serve as mulch and windbreaks; they can help suppress weeds; and control soil erosion and nutrient leaching.

Cover crops. Cover crops are fast-growing creeping or bushy crops, usually leguminous, with dense vegetative growth that are grown – as the term implies – specifically to cover and protect the soil. Their dense foliage provides shade to the soil and keeps its temperature low enough for microorganisms to remain active even during the dry season. Cover crops are usually grown in rotation with the main crop, in between cropping seasons during fallow periods, or even during the cropping season as intercrop or relay crop in between rows of the main crop.

Once incorporated into the soil, the rich biomass can substantially increase soil OM content to as much as **30 tons or more per hectare**;[8] it also enhances the soil's nitrogen content in the case of legume cover crops.

8 IIRR. 1992. The bio-intensive approach to small-scale household food production.

Cover crops with deep root systems even act as **nutrient pumps,** helping recover nutrients that have leached to the subsoil. This is especially true in case of sandy soils, wherein leaching of water and nutrients is a major problem. Additionally, as they later decompose, the matted roots of cover crops give the soil enough body to hold onto nutrients and water that would otherwise quickly drain below the reach of plants.

After collecting the harvestable parts (e.g., shoots and pods for human consumption, green leaves as high protein fodder for livestock), the cover crop can be turned under the soil. This should be done at least three weeks before planting the main crop to allow decomposition of the organic material. For those practicing zero tillage, it is best to use annual cover crops such as cowpea, which is allowed to grow until shortly before planting the main crop. The annual cover crop dies naturally after fruiting so the dried plants are just mowed or cut as short as possible, leaving the clippings on the field to serve as mulch and later as fertilizer. Some commonly used cover crops in the tropics are included in Annex A.

Nitrogen-fixing trees (NFTs). Like cover crops, NFTs can be used as green manure. Some practitioners prefer to call NFTs as **green leaf manures** since only their leaves are being used as fertilizer, unlike those of cover crops where the whole plant is incorporated into the soil. Fast growing leguminous tree species like *Gliricidia sepium* (madre de cacao), *Sesbania sesban* (sesbania), and *Leucocaena leucocephala* (ipil-ipil) are ideal because they can tolerate repeated coppicing or pruning. When using leguminous trees as green leaf manure, take note of the following points:

- These trees can be planted along the borders of the farm or garden to serve as live fence.
- When used as alley crops, it is important that the rows of NFTs are oriented in an east-west direction to keep them from shading the crops.
- Pruning can start when the trees are about 3 meters high. Subsequent pruning is done whenever leaves are needed or the trees begin to shade the crops. It is best to leave at least one branch per tree to ensure regrowth during very dry weather.
- The cut branches can be placed on top of the plots where crops will be grown to allow the leaves to wilt. After two days, simply shaking the branches is enough to remove the leaves, which are incorporated into the soil to a depth of about 15cm.
- Note that leaf decomposition usually takes from 3-4 weeks, so it is important to consider this vis-à-vis the planting schedule.
- If used as mulch, the cut branches are simply placed over the soil or in between the plant rows if there is a standing crop.

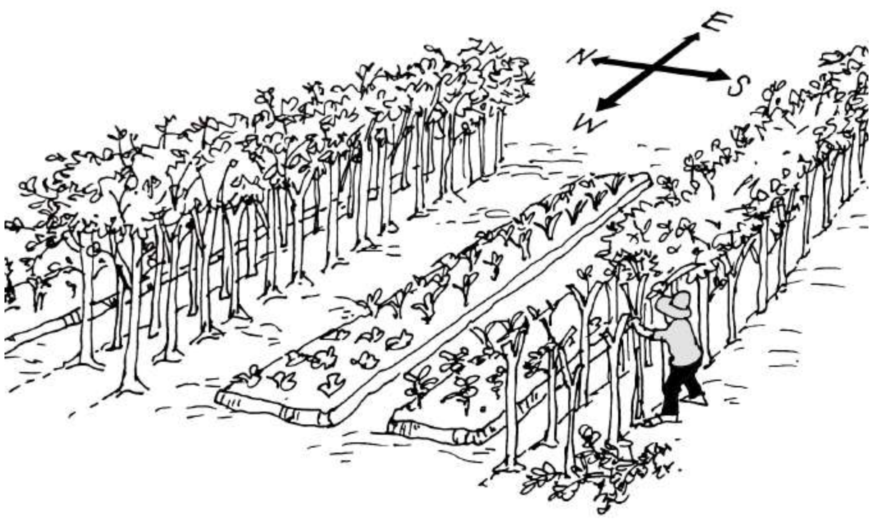


Figure 10. Integrating NFTs with home gardens

3. Use of organic liquid fertilizers

Organic liquid fertilizers are ideal plant boosters because they can be absorbed more quickly and are faster-acting compared to solid organic fertilizers. Their application can be timed during critical stages of crop growth when they are most needed. For instance, they can provide immediate relief as soon as seedlings have used up the reserve nutrients provided by the sprouted seeds, and they can give a nutrient boost during the flowering or fruiting stage of the plant. They are also ideal for rejuvenating fruit-bearing vegetables like tomatoes, eggplants, ladyfinger (okra), etc. However, over-application of organic liquid fertilizers can lead to excessive vegetative growth that prevents plants from flowering or fruiting.

There are several kinds of organic liquid fertilizers in popular use. Each formulation will have some variations but the general idea is to ferment fresh organic materials (plants, fruits, leaves, manures, etc.) to extract the liquid to break down their cells and eventually create various nutrients or enzymes needed by plants.

Note: Different sources cite varying proportions of the ingredients (e.g., plant material, sugar, and water), the dilution ratio, and dosages for application. Application rate may depend on the quality of the soil, the stage of plant growth, or the plants' general condition. One commercial vegetable grower who also makes, uses, and sells her own organic liquid fertilizers uniformly uses the proportion 1 part of any liquid fertilizer to 15 parts water to avoid confusion by having to remember varying dilution rates; she claims not to have encountered any problems by using this "formula".

Fermented liquid nitrogen. Fermented liquid nitrogen or FLN (sometimes referred to as liquid manure or manure tea) is used as an alternative to urea because of its high nitrogen content. The main ingredient of FLN is either **fresh animal manure** or **fresh leaves of leguminous plants** and is prepared as follows:

a. Fill a jute sack (sometimes called gunny or burlap bag) with fresh animal manure or leguminous leaves and tie its open end securely. A jute sack is ideal since it is relatively durable and can withstand repeated use. It is also porous – water can get inside the bag and drain from it just as easily.

b. Place the sackload of organic material inside a drum (55-gallon capacity) and add water until the sack is fully submerged. In the absence of a drum, other containers such as plastic pail or bucket can be used; adjust the amount of manure or leaves and water accordingly.
c. Put a rock or any heavy material over the sack to keep it from floating.
d. Keep the drum covered in a shaded area for about three weeks to allow the materials to ferment.

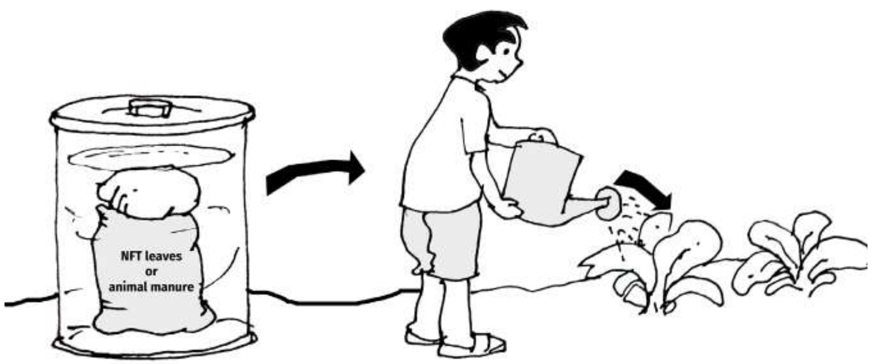


Figure 11. Fermented liquid nitrogen from animal manure or leguminous leaves

Once fermentation is completed, the spent leaves or manure can be thrown in a compost bin or directly incorporated into the soil. Dilute the FLN before application at a ratio of 1 part FLN: 5 parts water. The solution is applied around the base of the plants (avoid direct contact with the plants) at various stages of plant growth as nitrogen supplement.

Fermented plant juice and fermented fruit juice. Fermented plant juice (FPJ) and fermented fruit juice (FFJ) are rich enzyme solutions full of microorganisms such as bacteria and yeast that invigorate plants. Just as FPJ serves to enhance the growth of leafy plants (including fruiting plants before their flowering stage), FFJ is used to increase yield of fruiting plants. Described below are the steps for preparing them:

a. Finely chop fresh plant/weed clippings, kitchen vegetable scraps, or over-ripe/spoiled fruits and put these in a basin or bucket.
b. Thoroughly mix the chopped materials with molasses or brown sugar to aid in the fermentation process (2 parts chopped materials: 1 part molasses).
c. Top off the mixture with water.
d. Put the mixture in a clay, glass, or plastic jar up to 2/3 full, leaving the top third for air circulation.
e. Place a rock or any suitable heavy material on top of the mixture to compress the ingredients and push out extra air.
f. Cover the jar with a thin cloth or piece of paper. Secure the cover with a rubber band to keep out insects like fruit flies.
g. Place the jar in a cool and shaded area or dark corner.
h. After 1-2 days, open the jar to release some of the gas that has formed. At this point the rock can be removed already.
i. Cover the jar again to let the plant materials ferment for a few more days. Fermentation should be complete in 3 weeks.
j. Strain the fermented material; the slurry can be incorporated into the soil or put in a compost bin.
k. Transfer the FPJ or FFJ in an airtight container like a PET bottle. **Label the bottle** with the product name and date.

Sugar is food for the microorganisms that aid in the fermentation process. Brown sugar or molasses (industrial grade is cheaper which may be available at the local agri-vet store) is preferred over white sugar; the latter is already carbonated and has less minerals. Because of its molasses content, brown sugar contains certain minerals – most notably **calcium, potassium, iron, and magnesium** – white sugar contains none of these.

Carbon dioxide is produced as part of the fermentation process. Open or unscrew the container every couple of days or so while the mixture is still actively fermenting to release the gas and to keep the container from exploding.

A properly prepared fermented plant or fruit juice has a sweet or vinegary smell; discard it if it smells bad. Fermented juices stored at room temperature can be used for a month; they can last from 6-12 months if refrigerated. FPJ or FFJ should be diluted before application by using 1-2 tablespoons of fermented juice per liter of water.

Figure 12. Fermented fruit juice is rich in phosphorus and potassium

The solution may be used for watering plants or sprayed on their leaves (foliar spray). FPJ can be applied from seedling stage up to pre-flowering stage, once a week or depending on the plants' condition. For FFJ, spray it on flowers and fruits 1-2 times a week. However, it is more important to do this at the onset of flowering and fruit setting because the mixture is rich in phosphorus and potassium, which are necessary during these stages.[9]

9 https://www.agriculture.com.ph/2020/02/08/how-to-make-fermented-fruit-juice-for-fertilizer/

Fish emulsion or fish amino acid. Fish emulsion or fish amino acid (FAA) is made from fermenting fish scraps or "wastes", e.g., gills, entrails, scales. It is very high in nitrogen and also contains trace elements such as calcium, magnesium, sulfur, chlorine, and sodium which plants require in micro quantities. One can ask for these scraps from fish vendors in the local market. FAA is prepared by following these simple steps:

a. Wash and drain the unused fish parts or scraps to remove the blood; this is done to keep the mixture from getting smelly.[10]
b. Put the washed fish scraps in a jar.
c. Add water just enough to cover (submerge) the fish scraps.
d. Cover the jar with paper or thin cloth to keep out insects. Secure the cover with a rubber band or piece of twine.
e. Store the jar in a cool, dark corner or shaded area for about 2-3 months to allow fermentation. The process can be shortened to about a month by adding molasses or brown sugar at 1 part per 10 parts of fish scraps.

Properly fermented FAA smells similar to that of soy sauce. After fermentation, the liquid part (fish emulsion or FAA) will rise to the upper portion of the solution, while the solid parts will settle at the bottom. Strain to separate the emulsion and store this in an airtight container. Airdry the remaining sludge and mix this into the soil. The fresh sludge can also be mixed with hog feeds.

FAA should be diluted in water at 1 cup emulsion per 5 gallons of water; it can be used as a soil drench or foliar spray. This can be applied once or twice a week to improve plant growth during the vegetative phase.

10 https://www.agriculture.com.ph/2020/05/26/nutrients-found-in-fish-waste-can-improve-plant-growth/

4. Use of other soil amendments

Animal manure. One common method of augmenting the OM content in the soil is through addition of animal manure, as most of them have good amounts of NPK; a list of commonly used animal manures is also included in Appendix A. Being an organic material, animal manure is good for the soil not only because it provides nutrients, but also helps improve the soil structure.

As a general rule, we can simply age manure from grass-eating animals before using them; those from pigs and poultry (chicken, duck, turkey) need to be decomposed first through composting (mixed with straw at 1:1 ratio).[11] Chicken manure is considered to be particularly "hot" and can burn plants if not composted first or is used in large amounts.

Note that animal manure is generally rich in nitrogen so if too much of it is applied, it can cause excessive vegetative growth, nitrate leaching, and nutrient runoff. However, the more grass an animal has in its diet, the lower is the nitrogen content – with the exception of those that like to eat woody plants (goats) or vegetables (rabbits) which have more concentrated nutrients in their droppings.

Biochar. When used in soil improvement, charcoal is often referred to as biochar. Biochar increases the soil's ability to hold onto nutrients and beneficial soil organisms by slowing down or decreasing nutrient leaching (from rain and watering). The low density of charcoal lightens heavy or clay soils which allows for better root growth; this also improves drainage and soil aeration.[12] As charcoal is one of the most potent ways of killing mycotoxins from molds, adding it to the soil is also found to be effective in managing or reducing fungal infections in plants.[13] It can also be used for addressing soil acidity.

11 https://modernfarmer.com/2015/05/get-a-load-of-our-manure-guide/
12 https://www.capegazette.com/article/add-charcoal-create-rich-quality-garden-soil/25068
13 https://balconygardenweb.com/uses-of-charcoal-in-the-garden-is-good-for-soil/

Pre-treatment of biochar before using it has been found to be enhance its quality; it can be added to the compost pile or soaked in liquid fertilizer prior to incorporating it into the soil. Households that don't use a woodstove (that produces charcoal as a by-product) or a charcoal stove where spent charcoal can be collected can ask from neighbors that do. Vendors also sell their broken charcoal at a cheap price or may even give them away for free as they will no longer be able to sell them anyway.

Note: This material is not promoting the production of charcoal to be used as biochar, but rather encourages the use of "waste" charcoal for the purpose.

Agricultural lime. Inorganic N fertilizers (e.g., urea) have been applied in large quantities to increase crop yields; this has resulted in achieving self-sufficiency in food production in many developing countries. But long-term and excessive use of such ammonium-based fertilizers has had negative results – soil acidification being one of them. Acid soils render certain nutrients unavailable for plant use (nutrient immobilization) wherein crops no longer respond to further application of N fertilizers.

Lime, which is alkaline, is conventionally applied to decrease soil acidity, especially if the problem area is a bit wide. However, it is important to have soil analysis done first to determine the level of acidity and the correct amount of lime to use, including other management practices to help correct the condition.[14]

Wood ash. Most wood ash contain a good percentage of calcium carbonate (about 25%), an ingredient in garden lime. Because it is alkaline, ash can be added directly to the soil to neutralize its acidity. The material is quite versatile and has many other uses not commonly known by farmers and gardeners.[15] Although the amount of nutrients in ash is not particularly high, it contains

14 https://www.intechopen.com/books/nitrogen-fixation/nitrogen-fertilization-i-impact-on-crop-soil-and-environment
15 https://www.burlington.ca › Community-Gardens

trace elements and can be added to the compost pile to enrich it. Plants that love a little bit of wood ash mixed with the soil include garlic, spring onions and leeks, lettuces, and asparagus.

Wood ash can also be used to repel insects, slugs and snails, because like salt, it draws water from invertebrates' bodies, dessicating them. It can also be dusted onto plants infested with aphids, smothering these pesky pests.

Eggshells. The **calcium** in eggshells – while providing nutrient for plants, also moderates soil acidity. Similarly, shells from mollusks (clams, snails) and crustaceans (crabs, lobsters, prawns/shrimps) can also be used for the same purpose. Since these materials take time to break down, they should be ground or powdered first before mixing them into the soil so that the plants can absorb them more readily. Calcium- packed vegetables like broccoli, cauliflower, spinach, and amaranth will benefit from eggshells. The added calcium will also help prevent blossom-end rot in tomatoes, peppers, and eggplants.[16]

Spent coffee grounds.[17] Instead of throwing it away, one may simply put used or spent coffee grounds together with the rest of the kitchen waste for adding to the compost bin or pile. While spent coffee has lost most of its acidity, it can be incorporated into the soil around acid-loving vegetables such as carrots and radishes. However, even after brewing, the remaining caffeine in the coffee grounds can still negatively affect seed germination and early plant growth, as the substance can cause stunting in seedlings. Therefore, avoid using the material around young plants.

16 https://www.growveg.com › guides › using-eggshells-in-the garden/...
17 https://www.thespruce.com/using-coffee-grounds-in-your-garden-2539864

5. Use of other techniques to help conserve and improve soil quality

Minimum tillage. Tillage is used for seedbed/land preparation, weed removal, soil aeration, turning over cover or green manure crops, burying heavy crop residues, leveling the soil, or incorporating manure and compost into the root zone. However, excessive tilling of the soil is also known to contribute negatively to soil quality. It fractures the soil, damaging its structure and thereby accelerating surface runoff and erosion when it is exposed to water and wind. As a general rule, practice tillage only as necessary.

Tillage can be reduced by reducing soil compaction (from rain and exposure to the elements) by doing any of the following:

- growing viny cover crops in the dry season so the soil is not left bare;
- mulching the soil surface (with or without a standing crop);
- adding green leaf manure regularly;
- growing plants closer together (advisable if soil is originally dug to at least 30cm so the roots can go deep in the soil for water and nutrients); and
- leaving the plant roots in the soil at harvest time (i.e., cut the old plants at ground level, leaving root biomass in the soil profile).

In addition, raised garden beds should be of a width that will make it possible to work from either side to avoid having to step on them.

Mulching. The soil surface should **always** be covered either with vegetation or organic matter. When the soil is left bare, it is easily degraded and eroded by rain, wind, and the sun's heat. Apart from physically protecting the soil from exposure, mulch provides other benefits. For instance, it helps conserve soil moisture and

regulate soil temperature which favor the growth of earthworms and beneficial soil (micro)organisms. It also suppresses weed growth.

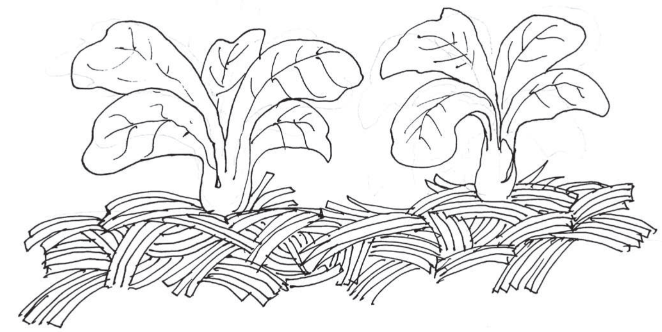


Figure 13. Mulch protects and enriches the soil

Many farm by-products can be used as mulch, e.g., rice straw, corn husks and cobs, and sugarcane leaves and bagasse. Grass clippings, cut up twigs, and other fibrous materials are also ideal for the purpose since they do not decompose easily and thus can stay longer on the ground. With time, these materials will disintegrate and partially decompose. They can be incorporated into the soil to add to its OM content and a fresh layer of mulch can be laid on the ground.

Planting trees and grasses in boundary areas (live fences). The boundaries of the farm may also be planted with multipurpose trees or shrubs and forage or grass species which serve as wind break to help hold the soil in place, preventing soil erosion. They likewise protect the more fragile crops from wind damage. In addition, grasses and especially the trees can serve as source of fertilizer, fodder, fuel, food, etc. They have the added advantage of being able to survive long dry spells or droughts, when no crops can be grown. In sloping areas, these can be planted along the contours of the land to serve as live terraces; this shall be the subject in a later section of this manual.

Chapter 3
Diverse and Integrated Cropping Systems

Applying agroecological principles in crop management requires understanding of the specific needs of the crops to be grown such as water, light, and nutrient requirements. This will guide farmers how to plan their cropping system(s) and assemble the different crops together with the other farm components such as livestock, forestry and fisheries – ensuring spatial and temporal diversity, optimum use of resources, and high productivity without damaging the ecosystem.

Crop planning

The objective of crop planning is to optimize the use of available resources in the farm in a way that encourages mutual support of diverse species of plants, farm animals, fish, and a range of beneficials (e.g., birds, frogs, insects/pollinators, microorganisms, etc.). This requires careful planning. For the crops component of the farm, this can be achieved through various strategies such as intercropping, crop rotation, multi-storied cropping, and the like. Other relevant practices such as use of cover crops and planting live fences were discussed in Chapter 2. Managing soil health and nutrition.

Important considerations in crop planning

Diversity

Crop diversification entails growing of as many species and varieties of crops as possible at any given time. For household food, nutrition and livelihood security, it will help to divide the area allocated for crops into sections. Each section should be planted to a specific category of crops (e.g., cereals/grains, legumes, fruit-bearing vegetables, leafy vegetables, and tubers/root crops), ensuring that all these categories are represented in

the farm at any given time. This way, the nutritional needs of the household can be met. A bigger area is allocated for crops that can be marketed for additional source of household income. Fruit trees, leguminous trees, forage grasses and shrubs, medicinal plants, insect (pest) repellants, and other useful plants such as attractants of pollinators can be grown within the farm or along its perimeter.

For smaller areas, mixed cropping can be practiced for growing a complete set of crops meant for household consumption in one plot.

The diversity of crops also helps in preventing pest outbreaks as different crops have different pests. For instance, a gardener might observe that the leaves of his/her *pechay* are riddled with small holes (indicating insect damage), but all the other vegetables do not have the same problem. If *pechay* were the only crop in the garden, the whole crop stand may be lost if an insecticide is not applied. The presence of many other crops serves as buffer which minimizes the possibility of a pest outbreak or a total crop loss.

Spacing

To optimize the use of a particular area, close spacing should be practiced, taking into consideration the crops' light and space requirements for optimum growth. In general, plants are correctly spaced when the leaves of fully grown plants barely overlap with the adjacent ones. A given area can accommodate more plants by sowing the seeds or seedlings in a triangular fashion compared to the conventional method of square or row planting.

Aside from achieving higher yields per unit area, the canopies of closely spaced crops will shade out the soil surface, largely discouraging weed growth. More importantly, it reduces the soil's direct exposure to sunlight, thereby minimizing moisture evaporation.[1]

1 IIRR. 1992. The bio-intensive approach to small-scale household food production

Nutrient requirements of crops

Different crops require different types and quantities of soil nutrients – e.g., leafy crops are heavy consumers of nitrogen; tubers and root crops require more phosphorus; fruit-bearing crops need more of potassium; while legumes can in fact add nitrogen to the soil. Cereal crops are also known as heavy feeders, that's why planting legumes after rice or corn is a good practice to replenish the soil nutrients that have been used up – especially nitrogen.

The rooting depth of crops is also important to consider. Shallow-rooted crops will absorb nutrients from the top layer of the soil while deeper rooted ones will utilize nutrients from the lower level(s) of the soil profile. Hence if shallow-rooted crops are planted together with other shallow-rooted ones, there will be competition for nutrients and the same is true if different deep-rooted crops are grown together. It is therefore crucial to mix crops of varying rooting depths. This is also important to consider in crop rotation. Shallow-rooted crops should be followed by deep-rooted crops (or vice versa) so as to optimize the use of soil nutrients in a given area.

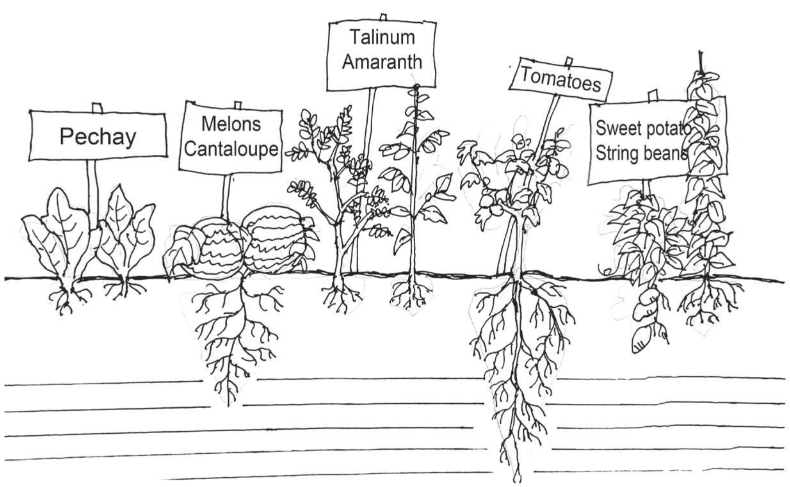


Figure 14. Planting crops of varying rooting depths

Light requirements of crops

Different crops have varying light requirements; they grow better and produce optimally if they receive their corresponding requirements for light. There are those that need full sunlight, others that can tolerate partial shade, and some that are shade-loving. Sun-loving crops require at least 6 hours of sunlight; examples are corn and vegetables that fruit heavily, like tomatoes, peppers, eggplants, beans, and okra. The same is generally true for vegetables of the cucurbit family such as squash, bottle gourd, sponge gourd, bitter gourd, and cucumbers. Leafy vegetables like spinach and lettuce and root crops such as sweet potato and carrots can usually tolerate partial shade or can do well with at least 2 hours of full sunlight and then are lightly shaded (or receive filtered sunlight) for the remainder of the day. Leafy greens such as kale and tubers like taro including ginger are most tolerant to shade and can survive with just filtered sunlight.

By planting shade-tolerant or shade-loving plants under or near taller crops, they are protected from sun damage. A related concept, multi-storied cropping, is explained at the end of this chapter.

Cropping systems

As previously mentioned, several strategies or cropping systems can be used to ensure farm diversity, optimize resource use, and attain higher productivity. Some cropping systems commonly practiced by farmers include the following:

Intercropping

Intercropping involves growing of two or more crops on the same land within the same growing season. This is usually done not only to optimize resources but also for other purposes: to suppress weeds (especially when cover crops are used as intercrop); to control pests; to maintain soil fertility (when legumes are used as intercrop); or to avert soil runoff by increasing soil cover.

When intercropping, it is important not to have the crops unduly competing with each other for space, nutrients, water, or sunlight. As previously mentioned, a good strategy is planting shallow-rooted and deep-rooted crops together to avoid soil nutrient competition. One other example is choosing a combination where one crop provides the needed shade or support to another. Some of the common types of intercropping based on the arrangement of crops are:

Row cropping entails the growing of two (or more) crops in separate rows. A popular combination in row cropping are cereals with legumes, e.g., corn with beans.

In ***alley cropping,*** crops are grown in between rows of trees, bushes, or hedges (usually leguminous or multipurpose trees) – forming alleys. This is usually practiced to protect the lower plants from winds and prevent soil erosion with the strong root system of the alley crops. The leaves from the leguminous trees also provide nitrogen when incorporated into the soil.

Relay cropping is the planting of two or more crops on the same piece of land but these are planted at different times. This reduces temporal overlap in harvesting. However, the second crop must be tolerant to the shade from the first one. A classic example is relay cropping string beans with corn. Corn is sown in the field first; when the crop is at flowering stage, the string beans are planted near the base of the corn hills. Instead of clear-cutting the corn plants during harvest, only the ears are picked. Their stalks are left standing in the field, serving as stakes to support the climbing string beans.

Crop rotation

Crop rotation is an important practice in agroecology as it allows the land to “rest” without keeping it idle or fallow. Planting the same crop(s) in the same area from season to season overburdens the soil. By changing the crop being planted in an area every season, the land is allowed to rest from one kind of plant and the

soil can get richer from the next plant that was put in its place. A good example is to follow corn, which is a “heavy feeder”, with a “giver” such as mungbean (which is a legume and therefore is a nitrogen-fixer), and then a “light feeder” such as *pechay*. As much as possible, avoid planting the same kind of crops in the same area within the same cropping year.

Multi-storied cropping[2]

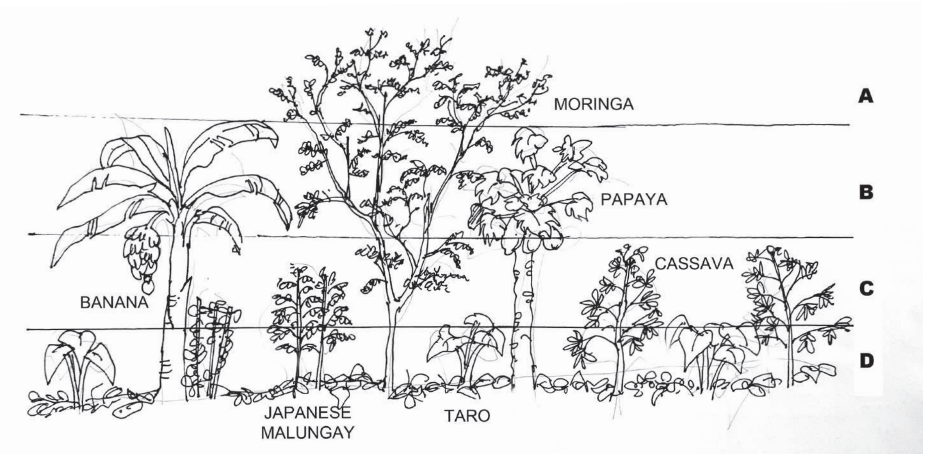


Figure 15. Crop combinations in a multi-storied cropping system

Upper canopy species (A): fruit trees and multi-purpose trees which can provide food, fodder, fuel and nitrogen fertilizers, and form a protective canopy against intense tropical sun and torrential rains (e.g., moringa, avocado, etc.)

Middle canopy species (B): smaller trees like papaya, banana, etc., including trailing plants (e.g., purple yam or ube which can be allowed to climb the trees

Lower canopy species (C): bush-level crops which can be grown to provide partial screen or sun protection for other crops (e.g.,

2 A farmer-developed multi-storied cropping system is commonly practiced in the uplands of Cavite province in the Philippines. The system includes any combination of perennial crops such as coconuts, coffee, lanzones*, papayas, and other suitable and preferred tree crops. During the initial years while waiting for the perennial crops to establish, a variety of annual and other short-term crops are also grown in the same area.*

Multi-storied cropping system involves growing plants of different heights on the same piece of land. It is usually practiced to optimize the resources especially the maximum use of sunlight under higher planting density.

In this system, crops with different light requirements are planted in such a way that a layered or multi-storied pattern is achieved. Thus, various crops can be grown together in a limited space without them competing with each other for light. An example of crop combinations that may be used in a multi-storied cropping system as illustrated in Fig. 14.

Chapter 4
Plant Health and Crop Protection

Ecological balance: The first defense against pests and diseases

Ecological balance describes the state of equilibrium between living organisms (humans, plants, and animals) and their environment. It allows for the continued survival and existence of organisms as well as their harmonious relationships with a stable environment that benefits and protects both.

Ecological balance is the natural tendency of plant and animal populations to neither decline in numbers to extinction nor increase to indefinite density; this results from natural regulative processes in an undisturbed ecosystem. In such ecosystems, a state of balance exists or will be reached – that is, species interact with each other and with their physical environment in such a way that on average, individuals are able only to replace themselves. Each species in the community achieves a certain status that becomes fixed for a period of time and is relatively resistant to change.[1]

When people begin to develop agricultural ecosystems (agroecosystems) where natural ecosystems previously existed, the balance is altered. The situation now warrants the development of agroecosystems that are self-regulating, self-sufficient, and require minimal "reactive" interventions; they should be resistant to various stresses and are resilient (i.e., able to bounce back from significant stresses). It necessitates an agroecosystem that mimics nature, or a farm that resembles a complex ecosystem.

Pest management is an ecological matter. The size of a pest population and the damage it inflicts will depend on the design and management of the agroecosystem. Ecological pest management

1 http://eagri.org/eagri50/ENTO232/lec08.pdf sees pests as a symptom of ecological imbalance. Each element in the environment – including pests – has a specific role or function to ensure the balance of the entire system. The idea is to maintain ecological balance by increasing the environmental pressure against pests, to ensure that their number is kept at manageable levels. This approach seeks to reduce the pest population while still protecting the environment and its inhabitants.

The vicious cycle of chemical pest control

Why is it impossible to control the so-called harmful insects and diseases by using synthetic pesticides?

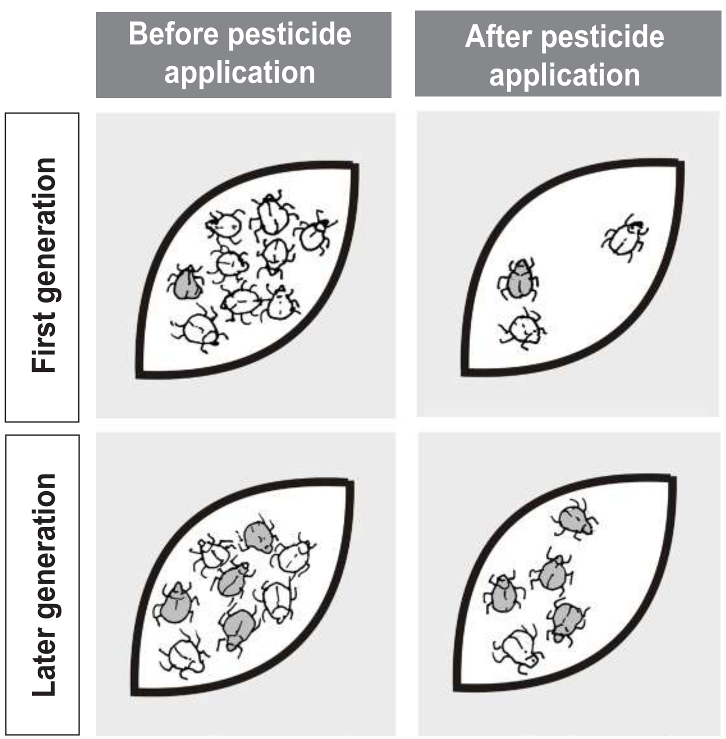


Figure 16. Pests develop resistance with continued use of chemical pesticides
https://en.wikipedia.org/wiki/Pesticide_resistance#/media/File:Pest_resistance_labelled_light.svg

A short life cycle coupled with the production of huge numbers of eggs at once is a characteristic of insects. This very characteristic enables insect pests to develop resistance to chemical insecticides quickly. As a result, farmers tend to use more or (other) stronger pesticides to control them. But again, the new insect generations become resistant to the higher dose or stronger type of pesticide. Another factor is the disappearance of natural enemies (e.g., spiders, frogs, birds, etc.) which feed on the insects. These natural enemies are fewer in number and have longer life cycles and thus reproduce much slower than the insect pests. They cannot develop the same resistance against chemical pesticides, are consequently killed, and in time eventually disappear from the agroecosystem. The result is the creation of an imbalanced ecosystem wherein only the insect pest population can break out.

Diseases follow more or less the same pattern. Use of chemical pesticides to control plant diseases causes the same vicious cycle in the following ways:

- Specific microorganisms which cause plant diseases (bacteria, fungi, virus, etc.) are very flexible in changing their character to adjust to increased dosage or intensity of pesticide application. Also called pathogens, many of these disease-causing microorganisms can easily develop resistance to pesticides.
- Beneficial microorganisms which control the pathogens are also killed by the pesticide. An imbalance in microorganisms occurs (pathogens vis-à-vis beneficials).
- The resurgence of new and resistant diseases creates a further imbalance of microorganisms.

Although chemical pest control temporarily demonstrates quick action, it cannot solve the problem in a sustainable way. The only ecologically viable solutions are those that consider the root causes and address the problems based on the rules of nature.

Ecological pest management

The basic guiding principle in ecological pest management (EPM) is that there is no such thing as a pest problem. If the ecological balance is not disturbed, then the appearance of a pest is not considered a problem but rather as a symptom. Once the symptoms show up, the causes (disruptive factors) should be discovered and addressed to restore the ecological balance.

EPM helps strengthen the natural systems to support the natural processes in regulating pests while enhancing agricultural production. It denotes working with nature, and not against it. It entails growing plants in the right soil, at the right time, including nourishing the soil and relying on the system's properties as a natural means to safeguard the health of the whole system.

Many factors can affect the vulnerability of crops to pest infestations. These can be related to the plant itself (such as its age or its adaptation to the local climate); to the environment (climate, light, temperature, humidity, wind); or to the different cultural management practices being used.

EPM puts emphasis on three basic principles to strengthen natural processes in enhancing the agroecosystem's capacity to keep pest populations in check: cultivating healthy soils, growing healthy plants, and knowing the pests.

Cultivating healthy soils. Healthy plants grow from healthy soils. A healthy soil is one that is relatively free of pathogens, contains sufficient nutrients, and with acidity or alkalinity levels (pH) that make the nutrients more readily available to crops. It also has a physical structure that is suited to the requirements of the different plants. Moreover, it hosts a microbial community that facilitates decomposition of organic materials, regulates release of nutrients and water movement, and improves soil aeration.

Growing healthy plants. Healthy plants have firm leaves, well-formed flowers and fruits, and well-developed root systems – making them more capable of withstanding pests (insects, weeds, and diseases), including extreme weather and climatic conditions. Growing healthy plants involves selection of appropriate crops and cultivars suitable to the local climate and soil conditions as well as the use of cultural management practices that promote good plant growth and development.

Knowing the pests. Pests have to be identified in order for them to be managed. The management strategies will also be more appropriate if the pests are known and understood. Knowledge about their life cycle, feeding habits, destructive stages, signs and symptoms of infestation, etc. will allow the farmer to find ways to control their population and manage them properly.

EPM practices

EPM focuses on preventive rather than reactive approaches to pest management. If proper preventive measures are taken, control measures will often not be necessary. Substantial knowledge and vigilant monitoring of the combined components of the agroecosystem are required for pest management to be effective. The following table lists the various practices associated with the key components of an EPM approach.[2]

2 https://www.ctc-n.org/sites/www.ctc-n.org/files/UNFCCC_docs/ref09x09_35.pdf

Box 4. Common techniques in the practice of EPM

Soil management

- Maintaining soil nutrient and pH levels to provide the best possible chemical, physical, and biological habitat for crops and soil organisms;
- Practicing crop rotation to enhance soil microbial populations and break disease, insect, and weed cycles;
- Applying organic manures to help maintain balanced nutrient and pH levels; adding soil conditioners (biochar, coconut coir, sawdust, lime, vermiculite) and microbial inoculants (rhizobia, mycorrhiza, effective microorganisms/EM), indigenous microorganisms/IMO) as supplements;
- Preventing or reducing soil compaction to improve soil structure and make nutrients more available; and
- Keeping soil covered either with crop residues or living plants

Crop management

- Selection of pest-resistant, local, or native varieties and well-adapted cultivars;
- Use of legume-based crop rotations to improve soil fertility and create favorable conditions for healthy plants, making them more pest- and disease-resistant;
- Use of cover crops such as green manure to reduce weed infestation and disease or pest attacks;
- Use of multiple cropping and agroforestry systems; and
- Use of crop spacing and patterns including tending practices to create conditions that are unfavorable to the pests.

Pest management

- Providing a favorable habitat to attract beneficial insects and other natural enemies;
- Managing plant density and structure so as to deter the onset of diseases;
- Cultivating for weed control based on knowledge of the critical competition period;
- Adopting intercropping (to "confuse" insect pests) and crop rotation (to break the pest cycle); growing pest-repellant plants; employing pest-trapping devices that use light, color, scents, and pheromones;
- Using of integrated pest management (IPM) strategies at various levels of integration;
- Using of synthetic agricultural chemicals to control pests **only as a last resort.**

Chapter 5
Water Conservation and Management

The water cycle

Water cycle describes the **continuous** movement of water in different forms – on, above, and below the surface of the earth. Water is lost as vapor into the atmosphere when the sun causes it to evaporate from the surface of oceans, rivers, lakes, and reservoirs; from the surface of the soil; or from plants when they transpire during photosynthesis. The water vapor then forms clouds in the atmosphere. Clouds build up until they become heavy and let the water fall back to the earth as rain. Rainwater runs off the land into rivers, lakes, reservoirs, and oceans. Some of the water is absorbed by the soil and over time, it percolates into the groundwater. It enters the soil through infiltration and then again evaporates from the soil surface or transpires through plant leaves before it returns to the atmosphere. And thus, the cycle starts again.

Box 5. Climate change and the water cycle

Global warming is speeding up the water cycle. Higher temperatures are increasing the rate of evaporation from water bodies and wetlands; the rate of melting snow from glaciers and snow-covered areas; and the rate of transpiration from vegetation. This loss of water to the atmosphere means that the warmer air contains more moisture. Increased atmospheric moisture will result in changes such as more frequent cycles of floods and droughts, or more severe storms such as cyclones and hurricanes. Water that evaporates cannot be used again until it falls as precipitation, and this process will now happen more rapidly.

With climate change, storms will come more often with heavier rains, and dry periods or droughts will likewise happen more often or last longer (La Niña and El Niño episodes). Generally wet areas will also become wetter, and dry areas drier. With increased storm events, water will move through the landscape more quickly and may become more destructive, causing flooding – resulting in mudslides and severe soil erosion. More flooding will damage crops and farms or croplands, grazing areas, and harm or even kill livestock. Flooding, sea level rise, and saltwater intrusion to freshwater wells and aquifers in coastal areas are already beginning to contaminate household and irrigation water sources.

Agricultural water management

Agricultural water management (AWM) seeks to use water in a way that provides crops and animals the amount of water they need, enhances farm productivity, and conserves natural resources for the benefit of users and provision of ecosystem services. AWM is concerned not only about irrigation and drainage but also of improved utilization of rainfall, use of recycled water, soil and water conservation, and watershed management.

One of the challenges confronting water management in agriculture is how to improve water use efficiency and ensure the sustainability of this resource. This can be achieved by increasing water storage at farm and catchment levels, decreasing water losses through evaporation, and increasing crop water productivity through irrigation. The following table lists some of the AWM practices that adhere to these principles.[1]

1 http://www-naweb.iaea.org/nafa/swmn/topic-water-management.html

Table 1. Efficient and sustainable AWM practices

Improved rainwater harvesting and storage	Decreased evaporation	Enhanced irrigation efficiency
▪ circular and semi-circular bunds ▪ planting pits (e.g., zai holes) ▪ small farm reservoirs ▪ small water impounding structures ▪ catchment strips ▪ contour ditches (contour trenches, infiltration ditches) ▪ contour ditches with live or stone barriers ▪ drainage and diversion ditches ▪ furrow dikes ▪ conservation bench terraces ▪ conservation tillage	▪ mulching ▪ cover cropping ▪ application of organic materials ▪ multiple cropping ▪ higher planting densities (triangular planting, multi-storied cropping)	▪ matching crops and cropping systems with rainfall patterns ▪ adjustment in crop establishment practices ▪ supplementary irrigation ▪ drip irrigation ▪ gravity-fed irrigation

Harvest and store rainwater

Rainwater is often wasted or underutilized; several techniques can be practiced to make more rainwater available to crops when most needed. These techniques include rainwater harvesting and storage (impounding), soil and water conservation, and using impounded rainwater for supplementary irrigation and for other purposes in the farm. These practices help to optimize rainwater use by minimizing water runoff, increasing water infiltration into the soil, and improving the soil's water holding capacity.

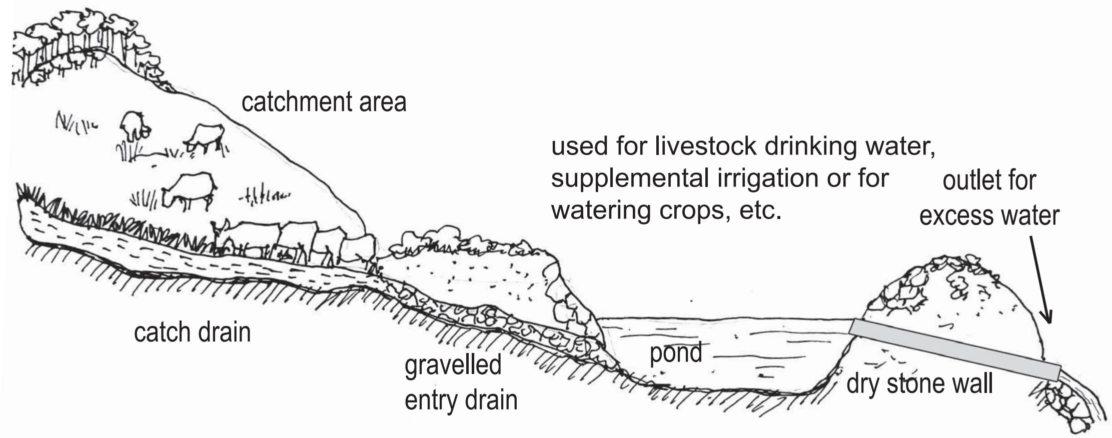


Figure 17. Multi-purpose pond for impounding rainwater

Rainwater harvesting starts with managing surface water and preventing runoff. The less water runs off the soil surface, the more water sinks into the soil. During strong rains, only a part of the water usually infiltrates into the soil; most of it flows away as surface runoff, thus being lost for the use of crops. In order to better conserve rainwater, its infiltration into the soil needs to be improved.

The soil's ability to absorb and store water largely depends on its composition and structure. Although soils rich in clay can store up to three times more water than sandy soils, infiltration is also much slower because the soil particles are finer and more compact.

Adding crop residues or growing a cover crop also protects the soil, prevents crusting on the surface, and slows runoff. Roots, earthworms, and other soil life maintain cracks and pores in the soil – which further enhances infiltration.

Decrease evaporation

A thin layer of mulch can considerably reduce the evaporation of water from the soil. It protects the soil from direct sunlight and prevents it from getting too hot. Mulching not only prevents the soil from being washed away by rain, it also absorbs and therefore conserves rainwater in the first place. Moreover, it keeps the soil humid and thus also enhances its biological activity.

Cover crops blanket the soil rapidly and densely without competing too much with the main crop. Conservation tillage minimizes soil disturbance, maintains a protective cover on the soil surface, and allows for early land preparation before the strong rains.

Cropping systems consisting of plants of different heights (multi-storied cropping systems) creates a micro-climate that reduces evaporation and protects the soil and the crops from the drying effects of sun and wind. Diversified agricultural systems can make more productive use of water. For example, agroforestry systems close their canopies earlier, which reduces soil water evaporation and run-off. Aside from their ability to effectively store water, the deep-rooted tree crops can also act as water pumps by tapping water from the deeper soil horizons.

Vegetation should be conserved or, where it was removed earlier, soil cover should be maintained by doing any of the following: incorporating crop or plant residues into the soil or leaving them on the surface as mulch; preparing the soil for the next set of crops; or otherwise planting cover crops. Moreover, it is good practice to leave roots of the previous crop or vegetation in the soil (with the exception of rhizomes of persistent weeds); they help control soil erosion and add to the organic matter upon decomposition.

Improve irrigation efficiency

Irrigation is the artificial application of water to the soil through various systems of tubes, pumps, and sprays. Irrigation water can come from groundwater, through springs or wells, surface water, through rivers, lakes, reservoirs, or even other sources such as treated wastewater.

Lack of water reduces the ability of the soil to supply nutrients to growing plants (i.e., it renders some nutrients/micro-nutrients unavailable for plant use), however fertile the soil may be. Supplemental irrigation or irrigating only during critical crop growth and development periods can result in greater water use efficiency and higher crop productivity. Coupling supplemental irrigation with rainwater harvesting can increase yields by up to 2-3 times more compared to conventional rainfed agriculture. Innovative practices such as drip irrigation, use of small affordable pumps, and small-scale water harvesting and storage can dramatically boost the productivity of small-scale farmers.

Farmers should select an irrigation system that does not overexploit the water source, does not harm the soil, and has no negative impact on plant health. In addition to the practices previously outlined, the re-use of wastewater and recycled water can reduce the demand for additional freshwater withdrawals and energy consumption.[2]

Good water management essentially improves the availability of rainwater and irrigation water, reduces surface runoff, and cuts down the amount of water demand; it also protects water resources from being polluted or wasted. Moreover, it involves selecting best suited crops and cropping systems, using crops of high water use efficiency, and includes making use of structures, practices and technologies that are efficient in water capture and soil moisture retention.[3]

2 https://www.cdc.gov/healthywater/other/agricultural/types.html
3 http://nelsap.nilebasin.org/index.php/en/information-hub/technical-documents/63-m4-agronomic-practices-for-water-management-under-smallholder-agriculture-manual-nelsap-nbi-2020/fil

Chapter 6
Postharvest Handling of Crops

Postharvest management

Postharvest loss is one of the key concerns in agricultural production. Substantial losses of up to 50% have been recorded from the time produce is harvested until it is consumed. These losses are expressed in quantity (measured in weight) and quality (measured in appearance, taste/flavor, texture, nutritional content, and economic value). The quantity and quality of loss is affected by practices at all stages from the harvest of produce to their consumption. To reduce such losses, it is essential to encourage farmers, traders, transporters and other actors to improve associated practices during and after harvest.

Post-harvest management is the system of handling, storing and transporting agricultural commodities after harvest. At the farm level, postharvest handling includes hauling, sorting, packing, weighing, and loading for transport to the market. Good postharvest management is key to maintaining quality of produce, minimize losses, and helps ensure that farmers get a premium price for them at the market. It is therefore important to understand the range of possible causes of postharvest loss (Box 5) so the farmers can address them as appropriate.

Box 6. Causes of postharvest losses [1]

- Metabolic. Fresh produce is “alive”. It breathes, loses moisture, releases heat, can get “sick” and even “die”. The natural process of respiration involves the breakdown of food reserves and the aging of these organs – thus leading to food losses.
- Developmental. These include sprouting, rooting, and seed germination – which all lead to deterioration in quality and nutritional value.

1https://www.researchgate.net/publication/277816312_Training_manual_on_postharvest_handling_and_marketing_of_horticultural_commodities

- Mechanical. Major losses are due to damage from rough handling, e.g., cuts and bruises on the produce. Overfilling (compaction) and use of inappropriate containers increase mechanical damage.
- Diseases. Many pathogens and decay organisms can attack crops/produce, leading to damage and deterioration.
- Insects. Many insects can infest crops, especially before harvest. Some larvae and insects that stay in the harvested produce, if not removed, can still continue to inflict physical damage.
- Temperature. High temperatures lead to significant deterioration, as exposure of produce to sun hastens wilting and decay.
- Relative humidity. Low relative humidity promotes water loss and shriveling.
- Atmospheric composition. High oxygen content in the atmosphere increases respiration and ethylene production. Ethylene induces ripening, resulting to change in texture (softening), color (yellowing), and further deterioration of the produce. The decrease in oxygen and increase in carbon dioxide concentration in the atmosphere reduce metabolic activity and promote deterioration.

Good harvesting practices

Some of the postharvest losses can be attributed to improper timing and manner of harvesting. Following are simple measures to minimize such losses during harvest:

Harvest at proper maturity. Product quality cannot be improved after harvest; it can only be maintained. It is therefore important to harvest at the right stage and size when the produce is at peak quality. Readiness of specific crops for harvest is commonly defined by maturity indices. These indices include the amount of time or number of days from planting, shape, size, color, texture, and sugar content of the produce; these are determined by the crop variety and the local context.

Harvest at the right time. Harvest early in the day when the air is cooler and the temperature in the field is still low. This simple and basic technique is very effective at reducing internal crop temperatures or the product heat load by several degrees.

Harvesting during or just after the rain is not recommended as wet condition (rainwater on the leaves or fruits) favors microbial growth and enhances tissue breakdown. Wet produce will also overheat when not ventilated and could cause growth of molds, premature rotting, or germination. Harvesting produce that are still wet with dew is also not recommended for the same reasons mentioned.

Harvest carefully. Harvest produce with care to minimize physical injury and preserve quality. Use appropriate harvesting aids and tools to reduce labor cost, improve harvest efficiency, maintain produce quality, and speed up the harvesting process and field handling.

Proper postharvest handling

Postharvest handling is the stage immediately following harvest. Depending on the produce, this may include some or all of the practices outlined below.[2] Farmers can take simple, no-cost (or low-cost) appropriate measures to avoid damage to harvested produce and greatly minimize postharvest losses.

- Hauling is moving produce from the field into a makeshift shed in the farm, field sorting table, packing house, or into a transport vehicle or shipping container as the case may be.

2 https://horticulture.ucdavis.edu/information/training-manual-postharvest-handling-horticultural-crops-rwanda

- Cooling is the process of lowering the core temperature (removing the “field heat”) of produce immediately after harvesting.
- Trimming involves removing leaves, stems and other plant parts, whether damaged or not, that are not required by the market and that may reduce their value.
- Cleaning or washing is done to remove dirt, dust, insects (or visible damage by insects) prior to being marketed.
- Sorting is done to remove and separate damaged, bruised, diseased, pest-infested and deformed produce from good produce to increase the value of the produce delivered to the market.
- Grading involves sorting produce into uniform size, length, color, shape, and firmness for better market price.

1. Avoid rough handling of produce

Damaged produce tends to have a shorter shelf life, be more prone to disease and decay, and appeal less to consumers. Therefore, one should handle the produce gently and no more than necessary. Avoid unnecessary wounding, bruising, crushing, or damage (from humans, equipment, or harvest containers). Damaging a produce can reduce its quality and storage life. Any punctures or bruising, especially on soft fruits and vegetables, will decrease their water content and increase their susceptibility to disease. Bruises, spots, and cuts will also decrease the shelf life of the produce. The use of proper harvesting implements not only helps ensure quality, but also reduces damage to the part being harvested (leaves, flowers, or fruits), and also to the plant itself.

2. Keep produce away from the sun

Keep harvested produce away from direct sunlight whenever possible by creating or finding a shady spot in the field or a makeshift shed to temporarily store them. They must be put under shade to keep them as cool as possible; this also serves to protect them from excessive water loss that could lead to wilting and shriveling and other spoilage processes. Crops should be allowed to dissipate heat under shade before packing.

3. Avoid contamination

Avoid infestation with diseases and insects, and use adequate control measures as needed. Faulty postharvest practices such as poor hygiene and use of contaminated wash water provide opportunities for contamination by toxin-producing and pathogenic microorganisms. The soil is also a rich source of pathogenic and spoilage microorganisms. The use of appropriate ground cover/liner, or sorting table in the farm is important so that harvested produce is not in direct contact with the soil. The same is true with using only cleaned and, as necessary, sanitized handling tools, equipment and containers. Do not compromise high quality product by mingling it with damaged, decayed, or decay-prone product in a bulk or packed unit.

4. Use appropriate packing and packaging systems

Different kinds of fresh produce need different types of packaging depending on their physical, anatomical, and physiological nature (mainly transpiration, respiration, and ethylene production rates) and susceptibility to microbial decay. The packaging practices also need to consider temperature, relative humidity, and ventilation as they also play a key role in determining shelf life of the fresh produce.

Proper packing protects the produce from damage during handling and transport. Choosing the right packing materials and methods depends on the type of produce, distance and mode of transport, and market destination, e.g., community market, supermarket, processing plant, etc.

The use of liners and cushions (newspaper, banana leaves), individual wraps, vents in carton box to minimize heat buildup, proper strapping, and other protective packing techniques should be considered. Packing the right quantity in containers to prevent mechanical damage is important. If produce is packed loosely, excessive shaking or vibration may cause bruises. If produce is packed too tightly, bruising can also occur due to compression. The following table outlines some packaging solutions for minimizing losses during post-harvest handling[3].

Table 2. Causes of and potential solutions to postharvest losses

Reasons for postharvest losses	Potential packaging solutions
Bruising due to compression of overfilled packages/ containers	Use of shallow and smooth surface containers Reduce the quantity of produce in the containers
Puncturing injury	Use of rigid containers with proper grips Use of smooth containers and handling equipment
Water loss or wilting	Use of precooling and evaporative cooling techniques, e.g., use of wet cloth, banana sheath to cover produce
Microbial growth	Cleaning and sanitation practices
Inadequate ventilation	Use of packaging materials that allow for air circulation
Impact or vibration injury during transport	Use of restrainers, individual wrapping and cushioning Use of rigid containers with cushioning for each product Restrain packages by bracing them inside vehicle or strapping them on racks

3 https://avrdc.org/download/publications/from_the_field/postharvest/vegetable-pht-training-manual-english.pdf

Store produce properly

There are times when farmers need to store their produce. These are commonly stored for domestic consumption, or for selling them at a later date. During storage, the produce can be damaged by mold, insects, bacteria, disease, and over-ripening.

Proper storage aims to keep the quality of agricultural produce and prevent them from deteriorating for a specific period of time. In order to achieve this, farmers need to keep their produce in a place that can slow down respiration, moisture loss, and decay. The following table lists the specific purposes of appropriate storage conditions and the strategies that can help achieve them.

Table 3. Strategies for different storage purposes

Purpose	Strategy
Slow down respiration rate of the produce	Choose a place in the building, house, or shed that does not receive direct sunlight or heat Keep the place cool or at the lowest temperature possible
Minimize moisture loss from the produce	Increase humidity in the storage area by misting or putting a wet cloth over the produce
Reduce risk of microbial growth	Keep the place cool (at the lowest temperature possible) Separate storage area from the work area. Maintain cleanliness using good housekeeping practices. Allow for cleaning and air circulation by putting storage racks away from walls.

Fig. 18. Simple low-cost practices can greatly minimize farmers' postharves losses

5. Transport produce appropriately

During transport, the produce must be stacked in ways that minimize damage, then braced or secured. The use of an open-air vehicle is preferable as it allows air to pass through the load and provides some cooling of the produce as the vehicle moves. Transporting produce during the night or early morning can reduce the heat load on the vehicle. Transition time between loading and unloading should also be as short as possible.

Drivers of vehicles used for shipping must also be trained in proper loading and unloading and general handling of produce. They should also follow good hygiene and sanitation practices to prevent contamination of their cargo by pathogens and other microorganisms.

Final note. Recorded postharvest losses of up to 50% – which can be significantly reduced – is lamentable, especially in light of food and nutrition insecurity and widespread hunger being common in many countries. Good harvesting practices and improvements in postharvest handling are vital to maintaining the quality of fresh produce; minimizing postharvest losses (and the associated income losses to producers); and to ensuring that safe and more nutritious foods are made available to consumers.

Chapter 7
Seed Conservation and Management

Seed quality as key determinant of agricultural productivity

Seed is a basic input in agriculture. It is critical determinant of agricultural production on which depends the performance and efficacy of other inputs.[1] Seed contains the genetic information and is one of the least expensive but most important factors influencing a crop's yield potential, adaptation to environmental conditions, and resistance to insect pests and diseases. **Yield potential** is the yield obtained when a crop is grown in environments to which it is adapted, without limits on water or nutrients and in the absence of any pests, diseases, and weeds.

The quality of seed alone is known to account for at least 10-15% increase in productivity. Quality seeds appropriate to different agro-climatic conditions and in sufficient quantity at affordable prices are crucial to raising productivity. It is therefore important to use the seed conforming to the prescribed standards in terms of high genetic purity, physical purity, physiological quality, and health quality as defined below:

- **Genetic purity** is the true to type nature of the seed such that the resulting seedling or plant should resemble its mother in all aspects.
- **Physical or analytical purity** refers to the cleanliness of seed from other seeds, debris, inert matter, and insect-damaged and diseased seed; seed with physical purity should have uniform size, weight, and color.
- **Physiological quality** pertains to the ability of the seed to germinate which is in turn related to germination capacity, viability, vigor, and dormancy.
- **Health or sanitary quality** is the health status of seed or the absence of insect infestation and fungal and other disease infections, in or on the seed.

1 http://eagri.org/eagri50/GPBR112/lec01.html

Fig 19. Select only well-filled, undamaged, and uniformly-sized seeds for planting

Box 7. What makes a good seed?[2]

- A good seed grows into and produces something consumers want to eat (nutritional quality, taste/flavor, aroma, texture).
- A good seed not only produces good food, but also more good seeds that farmers can save, share and replant.
- A good seed is one that farmers can afford and have access to.
- A good seed is ecofriendly. It works with nature, instead of against it (e.g., resistance to pests and diseases, adaptability/tolerance to other environmental stresses).
- A good seed has a good or high yield potential, i.e., makes the most of the soil, water, and light that are available in its environment, while resisting local pests and diseases.
- A good seed contains diverse traits that enable the crop to adapt and evolve with the changing environment.
- A good seed has potential traits might not be immediately visible (or even useful), but they could come in handy down the line, especially with our changing climate.

2 https://weseedchange.org/what-makes-a-good-seed/

Seed conservation and management

As farmers worldwide were encouraged to trade their (bio)diverse traditional or indigenous crop varieties with genetically uniform and high-yielding modern cultivars, significant amounts of the genetic diversity of agricultural crops had been lost. **This loss of genetic diversity is called genetic erosion.**

Seed conservation and management aims to address genetic erosion and farmers' limited access to locally adapted crop varieties. Such initiatives help communities to learn concepts and skills that allow for the conservation, development, rehabilitation and continued use of local and traditional varieties, as well as their reintegration into the farming systems. These initiatives contribute to improving farmers' access to locally adapted seeds and lessen their dependence on commercial seed sources.

Having access to an abundant variety of crop seeds that are locally adapted is central to a community's ability to feed itself. Such diversity allows a community to withstand or survive and bounce back from pest infestations or extreme climate events that often result in total crop failure.

On-farm conservation of seeds or plant genetic resources is defined as "the continuous cultivation and management of a diverse set of plant populations by farmers in the agroecosystems where a crop has evolved." On-farm conservation concerns entire agroecosystems, including immediately useful species (such as cultivated crops, forages and agroforestry species), as well as their wild and weed-like relatives that may be growing in nearby areas. The following Box 8 lists some of the objectives of seed conservation and management.

Box 8. Objectives of seed conservation and management[3]

- To conserve the processes of evolution and adaptation of crops to their environments
- To conserve diversity at different levels – ecosystem, species, or within (intra) species
- To integrate farmers into a national plant genetic resources system
- To conserve ecosystem services critical to the functioning of the earth's life support system[4]
- To improve the livelihood of resource-poor farmers by providing seeds that they can sell or cultivate as crops
- To maintain or increase farmers' access to and control over crop genetic resources

Seed conservation and management encompasses germplasm collection, varietal evaluation, line selection, seed rehabilitation, and plant breeding with and by local farmers and communities. It supports community-based initiatives such as seed exchange networks, community seed banks, and participatory plant breeding.

Genetic diversity of crops can be increased by empowering farmers – providing them access to varieties and equipping them with the knowledge and skills in undertaking varietal trials, selection, and breeding. They are also encouraged to pursue and strengthen linkages with other farmers and institutions engaged in similar activities.

3 https://www.cbd.int/doc/case-studies/tttc/InSituTraining.pdf

4 A life-support system provides all or some of the elements and functions essential for maintaining life on earth, e.g., oxygen, nutrients, water, disposal of body wastes, control of temperature and pressure, and the likes.

Seed production and handling

Seed production is a special type of crop production wherein cultural management practices are more diligently applied to ensure the quality of the crops and their seeds. Adequate care is given from the acquisition of seeds up to harvest, adopting proper crop and seed management techniques. Seed quality depends partly on the health and vigor of the mother plant, as well as the care used in picking or harvesting, drying, and sorting the seed. Farmers produce seed to have access to high quality planting material of their preferred varieties for the next sowing period. This also presents potential for gaining higher income either from getting better yields or from the sale of seeds.

High quality seed is achieved if the appropriate agronomic practices are strictly followed. The way each of these practices are handled will affect all seed quality aspects: genetic, analytical (physical), physiological and sanitary, as well as the amounts produced. Table 4 lists the essential steps in producing and processing seeds.

Table 4. Steps in seed production and handling

Seed production	Seed handling or processing
• selecting varieties to be multiplied • selecting seed for planting • selecting the site where the seed will be grown • preparing the land or seedbed • planting the seed • weeding • controlling diseases and insect pests • harvesting the seeds	• drying • cleaning • sorting • measuring moisture content • testing for germination • treatment • storing

In addition to the practices mentioned above, two key measures also need to be observed in seed production – field isolation and roguing or the removal of off-types. These practices help ensure genetic purity of the variety. It means that the particular seeds possess genotype that will guarantee the developing plants to have distinctive, uniform, and stable verifiable characteristics.

Isolation is the separation of a seed crop from all possible sources of contamination to prevent natural cross-pollination from undesirable pollen (e.g., different variety). Adequate isolation can be achieved through space (distance between crops) and/or time (separation through periods of fertilization). The choice of isolation technique depends on the farmers' systems used in a given community and the likelihood of unwanted cross-pollination.

Box 9. Growing good seeds[5]

- Select the right site for seed production, e.g., a fertile field that conforms with isolation requirements.
- Grow only one variety of high-quality seed in each field.
- Keep the crop free of weeds, insect pests, and diseases.
- Do not allow any intercrops (no mixed cropping).
- Harvest seed at the best time for the best seed quality.
- Sort, clean, dry, grade, and label the harvested seeds; remove debris, off-seed, and damaged seeds.
- Check for seed quality, percent germination, and purity.
- Store clean and dry seed in sealed storage container.
- Store containers in a cool, dry, and clean area away from pests and moisture.

5 https://cgspace.cgiar.org/bitstream/handle/10568/93422/spg_malawi.pdf?sequence=1

Plants with deviating characteristics in a variety are called **off-types.** The presence of off-types results in varieties becoming less uniform and less distinct and therefore impure, which reduces the value of the seed, as well as general performance of the variety. Any off-types should be removed from the crop stand or field before pollen shed.

It is best to harvest fully mature crops and dry them well before storage. Harvesting seed crops at the onset of physiological maturity is not recommended. Seeds at this stage have just completed their development and they still have high moisture content; they cannot be used as seed even if they are dried.

The seeds should be kept on the plant until moisture content goes down to the desired level.[6] Moisture content is best measured by using purpose-designed moisture meters. Where a meter is not available, most farmers use indicative methods to find out if the seed is sufficiently dry, such as biting the grain, pinching it between the fingers, or shaking it with salt – following the simple steps below:

1. Fill one third of a bottle with grain (250-300 grams, depending upon receptacle size).
2. Add 20-30 grams of dry salt (about 2-3 tablespoons).
3. Put a lid on the bottle and shake vigorously for 1 minute. Let it rest for 15 minutes and then shake it again.
4. If the salt sticks to the sides of the bottle, forming layers, the grain moisture content is higher than the permissible 14-15%.

Seed storage

Seed storage aims to prolong the viability of the seed until planting time. Deterioration (especially physiological aging) largely depends on environmental conditions under which the seeds are stored and not the duration of storage per se. The intended period of seed storage depends on end-use of the seed.[7]

6https://vtechworks.lib.vt.edu/bitstream/handle/10919/66734/2232_Neuendorf_Small_Scale_Seed_Prod.pdf?sequence=
7 https://fscluster.org/south-sudan-rep/document/good-quality-seed-production-guide-ssd

Table 5. Purposes of storage and their respective storage duration

Storage period	No. of months	Purpose of storage
short term	1-9	To ensure supply of seeds for the next cropping season
medium term	9-18	To guard against disasters such as droughts or floods which may result in seed production failures
long term	>18	To ensure supply of seeds of pure genotypes to replace contaminated varieties

Three critical factors affect seeds in storage: temperature, relative humidity (RH), and seed moisture content (MC). As a general rule, lower levels of these three factors can better ensure the quality and viability of seeds.

- Every 1% reduction in seed moisture content doubles its storage life. Below 9% MC, insects struggle to establish; above 17%, molds would proliferate.
- A 5-degree Celsius drop in temperature doubles the life of dry seed. Insects flourish at optimum temperature of 25-34 degrees C, while molds thrive between 15-30 degrees C.[8]
- Optimum RH is between 40%-80%.

Seeds can be placed in metal silos or bags. Bags or sacks have to be stacked properly and stored in well-ventilated places. In addition, they have to be placed on platforms raised at least 20cm from the ground and away from walls to avoid seepage of moisture from damp areas. For short-term storage, paper bags or any material that allows for the maintenance of adequate seed moisture content are recommended.

8 https://cgspace.cgiar.org/bitstream/handle/10568/93422/spg_malawi.pdf?sequence=1

Ordinary plastic bags should never be used as they act as mini greenhouses, retaining heat and moisture. If the seed is not completely dried before sealing, the heat and moisture trapped inside the bag will facilitate the growth of mold and subsequent deterioration of the seed. Direct exposure to sunlight for even a short period can also raise temperature rapidly and injure or kill the seed.

Hermetically sealed containers offer an alternative to traditional storage. They work on the principle that seeds release carbon dioxide which rapidly replaces the oxygen in the sealed container. Once oxygen is depleted, the pests die and fungi cannot thrive – thus retaining seed viability. A number of examples can be used for the purpose. Community seed banks (CSBs) can use purpose-built metal silos/cans (35kg or 70kg) or custom-made plastic bags (PICS or GrainPro bags). Small farm households can also use jerry cans and soft drink/soda/mineral water bottles, jars, and other sealed airtight plastic, metal, or glass containers.

Fig 20. Store seeds in appropriate containers, properly labelled

Community seed banks

Most small- scale farmers in developing countries routinely save their seed from one harvest to the next, and would share and exchange these with their fellow farmers. This is how they have developed the widely diverse crops that farm communities enjoy today. In many developing countries, small farmers still source some 70%-80% of their seeds from those that were saved on-farm.

Appreciating CSBs

Community Seed Banks (CSBs) are collections of seeds that are administered by communities and play a significant role in ensuring seed security and conserving agricultural biodiversity, along with the traditional knowledge associated with their cultivation.

CSBs store seed from a wide range of individuals, informal groups and even nongovernment organizations that share seeds among themselves. The seeds are primarily obtained from farmers' own production, sometimes in partnership with research institutes and the formal seed sector (e.g., production of certified seeds).

CSBs have three common underlying principles: 1) farmers require steady and reliable access to a wide variety of appropriate planting materials; 2) farmers are the stewards of agricultural biodiversity; and 3) optimal crop biodiversity requires sustainable use through on-farm conservation, e.g., the recovery and maintenance of viable populations or crops with potential of being widely propagated, cultivated, and used.[9] The following table lists the multiple roles of community seed banks.[10]

9 http://www.fao.org/3/ca8198en/ca8198en.pdf
10 https://www.bioversityinternational.org/e-library/publications/detail/the-multiple-functions-and-services-of-community-seed-banks

Table 6. Functions and services of community seed banks

Function	Services
Conservation	• short-term conservation of mostly local varieties • longer-term conservation of heirloom and rare varieties • restoration of “lost” and neglected varieties • development of protocols for conservation of healthy seed and training of local communities
Access and availability	• platform offering multiple channels of access and availability of seeds at the community level • maintenance of seed supply of locally adapted species and varieties at a low cost • fostering of seed exchanges at local levels • access to crop varieties with unique traits that are not grown or conserved locally • provision of adapted seed to marginal communities not served by government or commercial seed dissemination efforts • when quantities suffice, capacity to respond to acute seed shortages at the local level • seed multiplication that includes varieties bred through participatory activities
Seed and food sovereignty	• maintenance of local control over seed conservation, exchange, and production activities (community-based biodiversity management) • income generation through the sale of seeds • sharing of agricultural biodiversity knowledge and expertise • links between in situ and ex situ conservation • support of traditional and ethnic food culture and cultural uses • contribution to ecological agriculture and food sovereignty movements

Community seed banks provide easy access of preferred seeds to farmers in a specific community. CSB materials are part of the pool of plant varieties continually being planted, multiplied, evaluated, selected, and bred by local farmers over time. These collections can include traditional and farmer-developed varieties, modern or formal varieties, and even exotic ones coming from other countries.

The local crop varieties – being conserved *in situ* – continue to evolve and adapt to their local environments. CSBs address all concerns of a healthy seed system which provides diversity and stability. They have the capacity to enable vibrant seed distribution within and across communities of quality seeds that can adapt to the challenges of changing climate and is a promising mitigation measure in times of natural disasters or pest and disease outbreaks.

Healthy seed systems emphasize the use of clean, disease-resistant seeds of locally adapted varieties. This measure is key to avoiding the spread of pathogens and pests, and in helping farmers adapt to local and global challenges while complying with national seed regulations.

Managing CSBs

The decision to set up a seedbank has to be based on a felt need of the communities. CSBs will become more useful and relevant to the community if these are managed by local farmers' groups that have clear goals and basic capacities towards conservation and sustainable use of seeds.

The support of government institutions is also important in raising their awareness on local situations and seeking their support for CSBs. This support includes allowing farmers to save, use, exchange, and sell their seeds using a quality control system which they themselves developed.

CSBs and household seed storage

Even while a common seedbank may exist for use by the community, individual farmers also save and store seeds for their own particular use. Although household seed storage is usually for short-term purposes only, this system helps ensure that diverse materials are available even outside of the CSB. This also serves to complement the seedbank and as a backup when materials stored there are damaged or rendered non-viable for some reason. As such, part of CSB initiative should be to encourage farmers to undertake their own household level seed saving and storage.

Connecting CSBs

CSBs need a continued infusion of genetic materials to increase crop diversity and to meet changes in farmers' preferences and environmental challenges, especially with worsening climate change. In this regard, it is important for CSBs to be linked to each other for exchange and diffusion of materials. This helps make seeds of diverse varieties available to farmers across areas of equally diverse agroecological and climatic conditions. Linkages among CSBs will strengthen solidarity, facilitate mutual learning, and generate support for seed conservation and use among communities. Whenever possible, CSBs should also be linked to and supported by institutional or NGO-managed seed banks that can provide access to more seed materials and serve as back-up to the accessions in the communities.

Modern agricultural practices have led to the loss of biodiversity in agroecosystems, resulting in the decrease of these ecosystems' abilities to provide food and other related ecosystem services. Seed conservation and management aims to restore biodiversity to improve agricultural productivity – by sustaining farmers' abilities to preserve and utilize seeds, enhance plant genetic and species diversity, and increase community resilience against environmental challenges brought about by climate change.

Chapter 8
Livestock Production and Management

Integrating animal raising with crop production

Livestock are an integral part of rural farmers' operations, contributing to household income, food security, and family nutrition.

In smallholder farming systems, crop and livestock production are closely interlinked. Generally, different livestock species are produced on such farms, with crops and crop by-products providing some of the feed; the animals on the other hand provide manure (fertilizer) for the crops, aside from contributing draft power for farm operations. Milk, meat and eggs are often produced simultaneously, but these are unlikely to be the main source of farm income.

In addition to providing benefits for the farm household, adding livestock to the farming system can benefit the community and local economy. There is a renewed and growing demand for food products grown by small local farmers but in many places, finding them is often difficult. Raising native animals can help diversify the food choices available to consumers. The clamor for healthier and safer food also motivates consumers to avoid animal products that are commercially produced with the attendant high amounts of antibiotics and growth hormones.

The following are some of the reasons for rural households to raise farm animals:[1]

- Animals provide nutritious food in form of meat, milk, and eggs and therefore contribute to improved nutrition (especially protein uptake) of farm families.

1 https://www.organic-africa.net/fileadmin/organic-africa/documents/training-manual/chapter-05/Africa_Manual_M05.pdf

- They provide other products that can be sold such as horns, bones, hides and skins – giving the farmer extra income.
- Animals are a source of financial security; in urgent cases, the farmer can sell some of the animals to get instant cash (which cannot be done with crops not yet ready for harvest).
- Carabaos (water buffaloes), cattle/oxen, horses, and other large animals can provide draft power for soil cultivation and transport.
- Ruminants or grass-eating animals can graze on range lands that are not suitable for soil cultivation, hence increasing land utilization.
- Animals provide manure that is rich in nutrients and makes a highly valuable form of fertilizer or raw material for making compost.
- On a farm that produces crops, animals (especially ruminants) can feed on crop residues and other waste products from harvesting and processing, and thus contribute to recycling nutrients within the farm.

Livestock care and management

Efficient and sustainable livestock production relies on good basic animal care and management practices. It requires carefully selecting locally adapted animal species and breeds, using adequate locally sourced materials for feeding, providing good animal care and housing, and protecting the animals against parasites and diseases.

It also means dealing with challenges of sustainable livestock production such as limited amount of locally available feeds especially during the dry season, pest and disease outbreaks, and unfavorable or inclement weather. The situation is aggravated by inadequate knowledge on proper animal breeding. Successful livestock production depends on three basic requirements: proper selection of animals, appropriate feeding, and keeping the animals generally healthy.

1. *Select animals appropriate to the farming system and the environment*

Under ordinary farmers' conditions, local breeds and crossbreeds of local with improved strains have been shown to have comparative advantage over imported or newly introduced breeds.

Being products of a long process of natural selection, local breeds have developed unique physical characteristics and behaviors that enable them to survive and reproduce under natural environments, even with minimal intervention. Hence, they require lower production inputs in terms of housing, feeding, and general management. They also produce products with desirable attributes that are paid a premium price by consumers[2]

Slow growth rate and inconsistent or erratic production performance are some of the challenges of raising local breeds. These could be addressed through proper selection of the best genetic resource for reproduction. The process involves selecting the animals possessing the desirable traits which are then used as breeders. Choosing breeders vary depending on the animal species and the purpose for raising them. Nevertheless, following are some general guidelines to keep in mind:

- Keep good performance records of male and female animas with good quality potential for breeding.
- Select breeding stock emphasizing several desirable traits.
- Select animals/breeds carefully to avoid birthing difficulties. Avoid crossing large breed males with small breed females.
- Grade up native animals with improved pure breeds to acquire superior traits of the improved breed.
- Aim to improve production performance and product quality while conserving the adaptability traits and maintaining genetic diversity.

2 https://agris.fao.org/agris-search/search.do?recordID=PH2011000198

2. *Make the best use of local feed resources*

A good feed supply and feeding system are essential to successful livestock farming. Feed resources include fodder from natural grasslands or pastures, local "weeds" that provide green and succulent feed, and field wastes such as straw, chaffs and tops of roots and tubers. Other feed sources include byproducts of milling, vegetable oil extraction, sugar refining, brewing and alcohol distilling, starch and molasses production, fish and meat processing, dairying, etc. Commercially manufactured feeds such as mixed feeds and mineral feeds are available in agri-veterinary stores but are often more costly.[3]

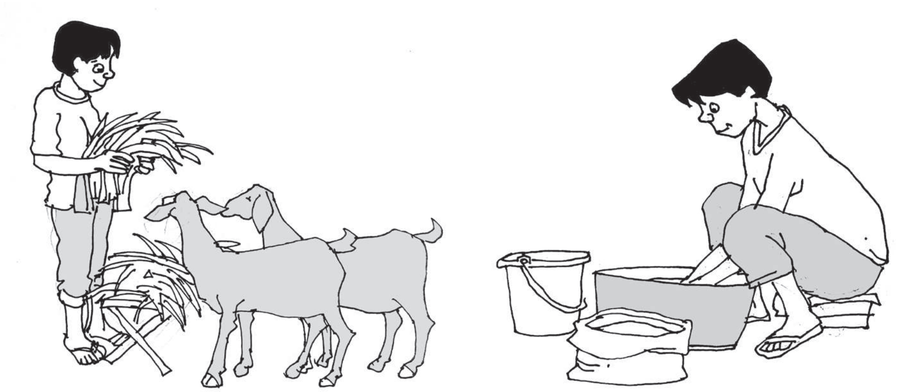


Figure 20. Locally sourced and self-formulated feeds

Livestock have different feed requirements based on their species, age, and purpose of production (e.g., for dairy, meat, eggs or as breeders). They depend on different types of foods to grow and produce well. As a general guideline, the daily ration for any farm animal should contain an average composition of 7 parts carbohydrates, 2 and half parts proteins, and half a part of vitamins, minerals, and oils.[4]

3 https://encyclopedia2.thefreedictionary.com/Feed+Resources
4 https://www.organic-africa.net/fileadmin/organic-africa/documents/training-manual/chapter-05/Africa_Manual_M05.pdf

Nutrient requirements

Carbohydrates provide animals with energy for their daily activities and production purposes. Protein is needed for the animals' growth and repair of tissues. Lack of protein in the diet leads to poor growth rates or slow weight gain, reduced yield of animal products, loss of weight, and late maturity for growing animals. Vitamins are needed only in small amounts, mainly for boosting the animals' immunity.

Minerals are essential in the animal body for different functions. Calcium and phosphorus are necessary for bone and eggshell formation, muscle contractions, and synthesis of hormones and enzymes. Lack of minerals results in slow growth, soft or brittle bones that fracture easily, difficult births, low egg and milk production, retained afterbirth, etc. Fats and oils provide a layer of insulation below the animals' skin for protection against the cold. They also facilitate the absorption of vitamins in the body.

While **water** is not considered as a true nutrient, it is essential for the absorption of other nutrients in the body. It is also responsible for giving shape and turgidity to most body tissues. Clean water, which is free from contamination with chemicals and disease-causing agents, should be provided to the animals at all times. Table 7 lists the sources of different nutrients required by different species of livestock.

Conventional and alternative sources of nutrients

If local feeds are used, they must have comparable nutritional contents as those from conventional sources. They should also be highly palatable and digestible, and without any harmful physiological effects (no toxins, etc.). If commercial or conventional feedstuff is preferred, they must be available whenever they are needed, and must be cheap enough to make their use economical.[5] Table 8 is a list outlining some feedstuffs and the ranges of inclusion rates (in terms of dry matter content or DM) as livestock feeds.[6]

5 https://businessdiary.com.ph/410/indigenous-feed-resources-for-livestock/
6 https://www.intechopen.com/books/animal-husbandry-and-nutrition/current-and-future-improvements-in-livestock-nutrition-and-feed-resources

Table 7. Nutrient sources for different animal species

Species	Carbohydrates	Proteins	Fats	Vitamins	Minerals
chicken	cereal grains, roots and tubers and their industrial byproducts	insects, worms, leguminous plants and seeds, fishmeal	byproducts of oil processing (coconut, sunflower, sesame, peanut, etc.)	leafy greens, fruit and vegetable wastes,	ground or powdered eggshells or shells of snails, clams, crustaceans, etc., grit/ stones, bone meal
pig	same as above	leguminous fodder and seeds, kitchen food waste, fishmeal	same as above	fruit peels, kitchen food waste	mineral or salt licks
goat/ sheep, cattle, carabao, other ruminants	forages, pastures, crop residues	leguminous fodder, young grass	not necessary	green pasture, fresh or dried leaves	mineral or salt licks, herbage, shrubs, crop residues

Small scale livestock producers will benefit from these feeding regimens that complement the practice of farming systems where there is a close integration of raising crops and livestock.

Table 8. Conventional and alternative sources of different nutrients

	Conventional or commercial feedstuffs	Alternative or local feedstuffs	Inclusion rates (% of DM)
Energy sources	corn, vegetable oils	locally available grains, cassava root or peel meal, yam peels, potato root or peel meal, by-products of oil processing, forage plants	50–60
Fiber sources	wheat bran, corn bran	rice bran, corn stovers (stems and leaves) and husks	10–15
Plant protein sources	soybean meal, peanut cake, palm kernel cake	by-products of oil processing (cottonseed cake, pigeon pea meal, etc.), cowpea vines, peanut and soybean stems and leaves, sweet potato vines and leaves	10–20
Animal protein sources	fish meal, blood meal, poultry offal meal, hydrolyzed feather meal, crystalline amino acid sources	dried poultry manure meal, snail meat meal, insect fly, pupal and larval meals, earthworms,	5–10
Mineral sources	oyster shells	ground or powdered eggshells or shells of snails, clams, crustaceans, etc.,	2–5
	bone meal	Limestone	2–3
	dicalcium phosphate		1–2
		Common salt	0.25–0.50

3. *Raise healthy animals*

Farmers need to consider the following principles of raising healthy animals and ensuring successful livestock production.[7]

Prevent the introduction and multiplication of infections through proper selection of suitable animal breeds, close monitoring and observation, and implementation of quarantine measures as appropriate. Vaccination is recommended especially for certain diseases which cause great losses due to high mortality rates.

Provide good growing conditions for animals to enhance their natural immunity and resistance to infections. These include provision of balanced animal feed, appropriate housing, and proper animal handling practices. It also involves observing proper hygiene and sanitation (e.g., regular cleaning of animal pens and feeding/watering troughs). Moreover, avoid stressful conditions that weaken the bodies of animals that make them more susceptible to diseases and infections.

Apply direct treatment(s) to kill parasites and disease-causing organisms if infections still occur despite the above-mentioned preventive measures. Consider the use of chemical drugs and antibiotics if proven herbal and other traditional medicines are found inadequate to treat the infection.

Furthermore, farmers need to ensure that suitable types of livestock and appropriate numbers are raised depending on the size of the farm, type and amount of feed available, availability of labor, and the market for the animal products. It is also essential to avoid pollution of the environment by ensuring appropriate collection, storage, and use or disposal of animal manures and other waste products.

7 https://www.organic-africa.net/fileadmin/organic-africa/documents/training-manual/chapter-05/Africa_Manual_M05.pdf

Chapter 9
Fish Rearing and Management

Sustainable fish farming

Fish farming or fish culture is the raising of fish in tanks, ponds, or other enclosures. Fish farming involves a set of interventions in the rearing process to enhance production such as regular stocking, feeding, protecting the stock from predators, and the like. A farmer planning to raise fish needs to consider a number of factors: the suitability of the soil, topography of the land, availability of good quality water, good market demand, proximity to market(s), and availability of needed inputs such as fish fry or fingerlings, feeds, and fertilizers.

Although fish can also be raised in elevated concrete water tanks, fixed or flexible plastic containers, or by fencing-off or using net-cages in swamps or lakes, the most efficient way to grow most fish in rural areas is the use of earthen pond systems. Such systems are defined by the following characteristics:

- require only basic or simple technical know-how
- have zero or minimum negative impact on the environment
- allows for fast and low-cost fish production
- requires a minimum of intervention from farmer- fish raisers, who are engaged in other major activities
- can keep external inputs to a minimum
- should have a good potential to generate income

Productive and sustainable fish farming also requires a good fish breeding program or a reliable and reputable source of fingerlings, a feeding system, and fish and pond management systems.

Fish farm management

Fish rearing involves several activities to ensure successful operation in a cost-effective manner.

Box 10. Good pond management practices[1]

- Stock healthy and disease-free fish fry or fingerlings that are obtained from reputable fish hatcheries.
- Stock according to the recommended number of fingerlings per unit area.
- Always maintain good water level (1.0m-1.5m) and quality.
- Watch out for fish enemies or predators (including human poachers) and eliminate or control undesirable and unwanted organisms inside and around the pond area
- Feed fish regularly (twice or thrice daily) from the same feeding spot by gradual broadcast. Avoid excessive feeding in order to prevent pond fouling and pollution.
- Maintain a normal green pond water color. Replenish the water when it turns deep green or when fish begin to gather at the surface to gulp for air.
- Watch out for abnormal fish behavior such as lack of appetite, easily visible slow tail movement, difficulty in swimming, etc. Immediately remove diseased, dead or dying fish or any other dead animal found in or around the pond.
- Maintain pond structures. Routinely check for damage and repair pond walls, pond bottom screens, and water supply structures.
- Keep accurate records of all fish farming activities.

Selecting fish to raise

The type of fish to farm depends on several factors such as environment, location, and the technical and financial capacity of the farmer. The key biological characteristics of the fish (growth rate, reproduction, size and age at maturity, feeding habits, hardiness and susceptibility to diseases) determine the suitability of a species for culture in the locality. The match between available fish feeds and the food preference of the selected fish species as well as the demand and market value also need to be considered.

The species chosen should ideally be easy to manage, popular for consumption, available as stock in the region, and should grow well under local conditions. It is better to rear fish that reach marketable size before they attain maturity, as this means that most of the feed is used for muscle growth instead of reproduction. Early maturity also ensures earlier availability of fry for the next stocking cycle.

Tilapia, carp, and catfish are the most common types of fish farmed by smallholder farmers. Tilapia is particularly suitable as it can grow fast even with food containing little protein. It tolerates a broad range of environmental conditions (oxygenation, water salinity, etc.). It also reproduces easily in captivity, is not very sensitive to handling, and is very resistant to parasitic diseases and infections. Moreover, tilapia is popularly consumed and is therefore widely marketable.

Carp also presents a number of comparative advantages. Just like tilapia, this fish can eat food with limited protein and fish meal content. It can be raised as part of a polyculture system (e.g., can be grown with other species such as tilapia and milkfish as well as with other types of its own species), allowing optimal use of the natural productivity of ponds.

Catfish is also suitable because it is robust and grows rapidly. It has an omnivorous diet (mixture of animal- and plant-based feed) and high fertility, with quasi-continuous reproduction. It has a remarkable growth potential (weight gain of10g/day) and an air breathing apparatus that allows it to survive out of the water for longer periods. However, it is not recommended for polyculture because it is known to be cannibalistic – even eating smaller ones of its own kind.

1 http://www.deltastatejobcreation.ng/training%20modules/compiled%20fishery%20manual.pdf

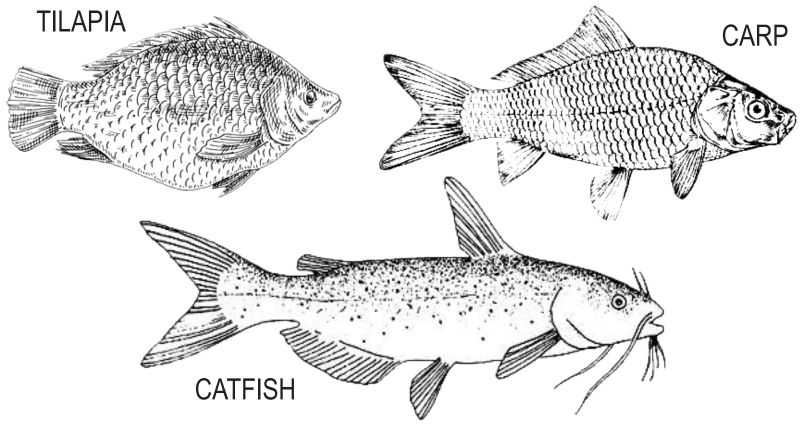


Fig 21. Popular fish species for raising in ponds

Fish fries for rearing are procured either from the wild or from commercial sources. The number of fish per pond (stocking density) depends on water conditions, size of fish seed, culture system, and management. Healthy fingerlings of 5-7cm can be stocked, but using juveniles of 7-10cm is more advisable because they have a higher survival rate.

Stocking is preferably done early morning or late evening when it is relatively cooler and when the fish are less active. To minimize shock, put the sealed plastic bag (where the fingerlings are contained) into the pond; when the temperature in the bag has "equalized" with that of the pond, gently release the fingerlings into the water. Wait for 6-12 hours after stocking before feeding the new stock. The fingerlings should be sorted 15 days or 2 weeks after stocking to remove shooters or jumpers (fast growers) to be placed in a separate pond. This would help ensure the even growth of fish; this practice also reduces cannibalism in catfish.[2]

2 http://ceadese.unaab.edu.ng/beta/wp-content/uploads/2019/03/Course-material-on-FISH-TRAINING-WORKSHOP-FOR-UNEMPLOYED-YOUTH-@CEADESE-Capacity-Building.pdf

Feeding

Feed is a key component of fish production and therefore must be given priority. Feeds alone can constitute 70%-80% of production cost. Some farmers rely on the natural productivity of the environment or of the ponds/structures built for fish production. This means that food for the growing fish is provided by organisms that are naturally living or reproducing in the water. However, the farmer should be ready to provide additional feed if s/he wants the fish to attain their ideal weight gain, especially if they are primarily for sale.

Nutritious feeds will have proteins, fats, carbohydrates, as well as substances present in relatively low amounts (e.g., vitamins and minerals). Nutritional requirements and diets vary by age and species. Young fish need rations rich in protein, while growers and breeders require optimum energy from carbohydrates to maintain growth and performance. Feed can be given all at once or divided into two equal portions and given in the morning and in the evening.[3]

Table 8. Recommended ration for different fish stages

Age of fish	Carbohydrate	Plant protein	Animal protein	Minerals
Fry-fingerling	5 parts	2 parts	3 parts	0.3 part
Grower	6 parts	2 parts	2 parts	0.3 part
Breeder	7 parts	2 parts	1 part	0.50 part

3https://www.nari.org.pg/sites/default/files/pdf_files/6.%20Fish%20Farming%20Training%20manual%20for%20TOT_MS051218%2011%20Dec.pdf

Some farmers are successfully using feeds they have mixed themselves using locally available ingredients. Starchy ingredients such as cassava and sweet potato tubers may be produced on-farm. Protein ingredient by-products are purchased and mixed with either cassava or sweet potato to make fish feed that are nutritionally balanced. The following materials may provide supplementary food for fish:[4]

- Terrestrial plants: grasses, legumes, leaves and seeds of leguminous shrubs and trees, fruits, vegetables
- Aquatic plants: water hyacinth, water lettuce, duckweed
- Small terrestrial animals: earthworms, termites, snails, silkworm pupae
- Aquatic animals: worms, tadpoles, frogs, reject fish or fish waste from the market
- Cereals: rice (broken, bran, hulls, polishings), wheat (middlings, bran), corn (gluten meal, gluten feed)
- Oil/cakes left after oil is extracted (from mustard, coconut, peanut, African palm, cottonseed, sunflower, soybeans, etc.), sugar cane by-products (molasses, filter-press cake, bagasse), coffee pulp
- Other food wastes and processing by-products: brewery wastes and yeast, kitchen wastes, slaughterhouse wastes (offals, blood, rumen contents)
- Manure: chicken droppings, pig manure

Box 11. Feeding habits of fishes[5]

Catfish are carnivorous so their feed is 90 % meat or other animal-based protein sources. These can be ground fresh trash fish, worms, insects, slaughterhouse by-products, chicken entrails, dried or fresh water shrimp, fish offal, and by-products of canning factories. The remaining 10 % is composed of boiled broken rice mixed with vegetables or rice bran.

Tilapia on the other hand are omnivorous and feed on both plant and animal material such as algae and microalgae as well as zooplankton, small crustaceans, and insects.

Carps just like tilapia are omnivorous, with a high tendency towards the consumption of animal food such as water insects, insect larvae, worms, molluscs, and zooplankton. Zooplankton consumption is dominant in fish ponds where the stocking density is high. Carp also consumes the stalks, leaves, and seeds of aquatic and terrestrial plants, decayed aquatic plants, etc.

To augment food supply, install strong light over the pond at night to attract insects which can serve as additional food for the fish.

Managing fish health

The main causes of disease in fishes are inadequate feeding, exposure to an extreme or toxic condition, and attack by pathogenic or disease-causing organisms. Nutritional diseases become more frequent as the cultivation system becomes more intensive and the fish are obtaining smaller proportions of their nutrients from natural food organisms. Pathogenic organisms will either attack externally (on the skin, gills or fins), or internally (in the blood, digestive tract, or the nervous system). The risk of disease is even greater when fishes are exposed to extreme or toxic conditions such as the following:[6]

- Rough or excessive handling, such as during sorting/grading or harvest

4https://www.actioncontrelafaim.org/wpcontent/uploads/2012/07/acf_fish_farming_manual_2011_en.pdf
5https://www.nari.org.pg/sites/default/files/pdf_files/6.%20Fish%20Farming%20Training%20manual%20for%20TOT_MS051218%2011%20Dec.pdf

6https://www.actioncontrelafaim.org/wpcontent/uploads/2012/07/acf_fish_farming_manual_2011_en.pdf

- Overcrowding or situations causing behavioral stresses, such as in storage or during transport
- Unsuitable water temperature (too cold or too warm/hot)
- Lack of dissolved oxygen in the water, usually due to increased oxygen demands of fish, warmer water that holds less oxygen, and increased bacterial decomposition of dead plant and algal material
- Changes in water pH toward extreme values, e.g., too alkaline or too acidic. Pond water ranging from pH 6.5-8.5 at sunrise is generally the most suitable for pond fish production. Most cultured fish will die in waters with pH below 4.5 and 10 or above.
- Presence of toxic gases such as ammonia or hydrogen sulphide from decaying organic matter and wastes of fish and other animals in the pond, easily detected by their pungent smell
- Water pollution by agricultural or industrial chemicals, sewage effluents, heavy silt loads

Disease control in fish farms focuses on preventive measures related to good management practices that include the following:

- Ensuring good water quality. There should always be a sufficient supply of water, adequate concentrations of dissolved oxygen, and no pollution.
- Keeping the pond environment healthy. Control silt and unwanted plants, maintain a healthy balance of phytoplankton and zooplankton, and change the water if necessary.
- Maintaining recommended stocking density. If necessary, keep different sizes or sexes separate to control fighting. Care for your fish during storage and transport.
- Preventing the introduction of disease organisms from outside your farm.
- Preventing the spread of disease organisms. If a disease breaks out, remove dead or dying fish from the ponds as quickly as possible (at least once a day), and do not disturb or stress the remaining fish more than necessary.

Harvesting and marketing fish

Harvesting is catching fish either for home consumption or for sale. In order for the venture to be profitable, fish should be harvested at the correct time and using the appropriate method(s). Feeding is discontinued 24 hours prior to harvest; this is to lessen the “unfavorable” smell of the fish especially attributed to the feeds given. Partial or complete harvesting of the fish stock can be done.

Partial harvesting is recommended if some large fish can be harvested already so that the rest of the fish can continue to grow – especially those that have not reached marketable size. Complete harvesting entails draining all the water in the pond to catch all fish using seine fish nets. Fish should be caught during cool and clear weather especially in the early morning and at the time it is to be marketed.

Primary consideration in marketing is maintaining the quality of the fish, especially its freshness. One should ensure sufficient ice supply, clean containers, proper transport, etc.[7] Clean water and adequate oxygenation, on the other hand, are critical if live fish are moved for marketing. The temperature difference between the transport water and the water from which the fish was harvested should be less than 10°F. Delivery schedules must be worked out carefully to minimize transportation time and quality loss.

Establishing and maintaining fish ponds

Fish ponds are designed and constructed for maximum water control, where it is possible for the water to be easily and completely drained and replenished. Earthen fish ponds are more commonly used in places where there are nearby natural bodies of water such as rivers, creeks, springs and swamps. Farmers dig and construct earthen fish ponds and divert or channel water into the pond for raising fish. If fish production is meant to only serve household needs and the fingerlings will be purchased from a hatchery, then only two ponds will be needed.

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7 *http://pubs.iclarm.net/resource_centre/CSISA-HH-manual.pdf*

If a fish farming activity is intended to be independent from hatcheries, the farmer will need several ponds: 1) hatchery or spawning ponds for production of eggs and small fry; 2) nursery ponds for production of larger juveniles; and 3) some grow-out ponds and brood ponds for rearing brood stock. Some farms have fattening ponds for the production of fish that will soon be consumed; others even have storage ponds for holding fish temporarily, often before they are sold. One standby pond for special situations may also prove useful.

Designing and constructing the pond

Site selection for fish ponds should take into account the availability and quality of water, impermeability of the soil, and suitability of the topography. The slope should be shallow (not steep) and near the water source. The site should also be accessible for the farmer to have a daily control and supervision of the pond; preferably, it should be near the house to discourage poaching. A properly designed and constructed pond will be easily managed and will last longer, saving extra work and related expenses, and resulting in greater productivity.

Box 12. Design considerations in establishing fishponds[8]

- the source of water used to fill the pond
- how water will be brought to the pond
- the type of soil available for building the pond
- the size, shape, and depth of the pond
- the slope of the pond bottom (for good drainage)
- the height, width, and slope of the dikes
- the type of drainage system that will be used
- the layout (arrangement) of ponds used for different sizes of fish

8https://www.nari.org.pg/sites/default/files/pdf_files/6.%20Fish%20Farming%20Training%20manual%20for%20TOT_MS051218%2011%20Dec.pdf

Diversion ponds are recommended for small-scale fish farming as they are generally inexpensive, have a low flood risk, and drain well. They are also easy to manage because the water supply is well controlled. This facilitates fertilizing the water, feeding and harvesting the fish, and preparing and drying the pond bottom.

In these ponds where only part of the natural body of water diverges into a supply canal that brings water to the ponds, the entry and exit of water are controlled. The water supply flows to the ponds through gravity (i.e., the water source is higher than the location of the ponds). Furthermore, ponds that have a diversion canal can be built parallel to each other or in a series. Ponds with a regular shape and size are easier to manage and adapt to specific purposes.[9]

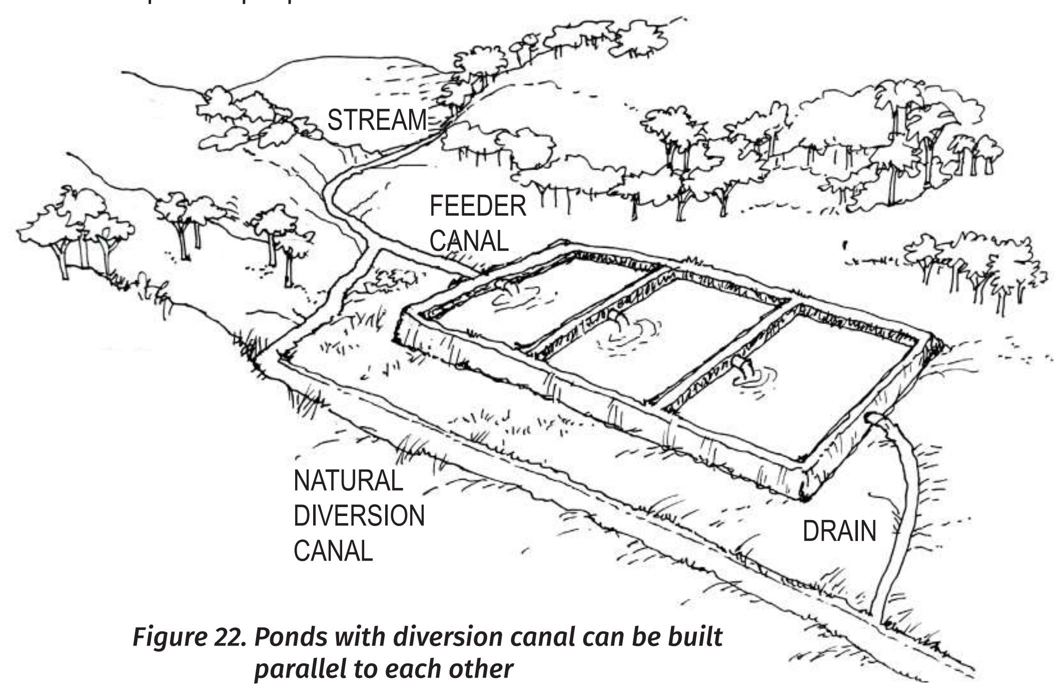

Figure 22. Ponds with diversion canal can be built parallel to each other

9https://www.actioncontrelafaim.org/wpcontent/uploads/2012/07/acf_fish_farming_manual_2011_en.pdf

Maintaining the pond

Ponds need to undergo maintenance after every fish farming cycle to ensure continuous and sustained productivity. Farmers should routinely carry out the following maintenance chores:[10]

- Remove silt, mud, detritus and clay (from dike erosions, turbid water, organic fertilizer, rainwater run-off, etc.) from pond bottom to maintain its depth.
- Completely plow and expose pond bottom to sun and air for a few days or until the soil cracks.
- Clear the bottom of twigs, branches, leaves, dead fish, etc. and remove all predators that feed on fish (snakes, frogs).
- Smoothen the plowed and cleared area.
- Check any fences for damage. Repair holes which let in fish-eating animals; clear weeds and unnecessary vegetation in and around the pond to keep pests and predators away.
- Check inlets, outlets, and screens for damage; remove clogs, or. replace them if necessary. Check the pond walls for cracks, leaks or weak points and repair them.
- Replant grass cover (regrassing) on pond walls or mow as needed.

Fish ponds are maintained to create a conducive environment for the wellbeing and growth of the fish. Maintenance also generally involves lime and fertilizer treatment of pond bottom (to reduce loss by seepage, improve pond fertility and stimulate plankton production), filling the pond and maintenance of optimum water depth, as well sanitation and disinfection of ponds.

Fish farming is a viable enterprise that can help improve the socioeconomic conditions of farm households. It does not only provide additional income but also ensure families' access to a protein source for better food and nutrition security. Agroecological fish farming entails producing fish to high standards of animal welfare and environmental protection, with less environmental impacts and improved ecological resilience. These are achieved through management practices that allows for polyculture, proper selection of fish species, use of alternative feeds, preventive fish health management, good pond management, waste recycling, etc. These practices allow fish farming to adhere to the principles of agroecology on diversity, synergy, and resource efficiency.

10 http://www.deltastatejobcreation.ng/training%20modules/compiled%20fishery%20manual.pdf

Figure 23. Regular maintenance of the pond is needed for better fish growth

Chapter 10
The Lowland Ecosystems

Characteristics of lowland agroecosystems

Lowlands are warm alluvial plains with slow-flowing rivers found in gently undulating or relatively flat areas at an altitude no higher than 200 meters above sea level (masl). They receive most of the water draining from the uplands, including the various particles and dissolved elements. Because of this, lowlands have mostly rich soils capable of supporting varied (agro)ecosystems that produce food crops for subsistence and for the market.

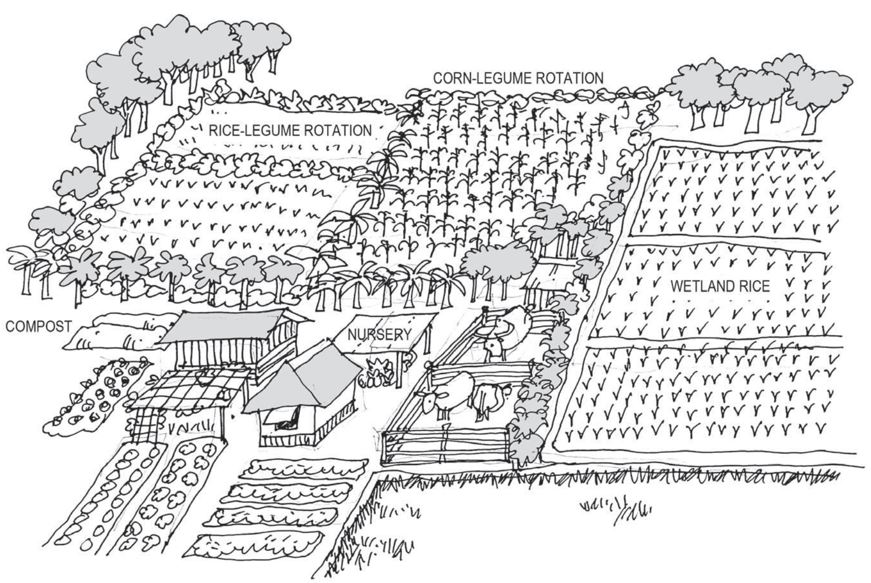

Figure 23. A typical irrigated lowland agroecosystem

Lowlands are divided into rainfed and irrigated agroecosystems, with the latter being generally more productive due to the availability of water throughout the year. Depending on the water source, these irrigated ecosystems allow for continuous farming

of rice and/or other crops such as corn, sweet potatoes, cowpea, peanuts, vegetables, etc. On the same area that rice is produced during the rainy season, vegetables and other crops are cultivated in the dry season. Rainfed dryland areas on the other hand are grown to other cereal, root, tuber and leguminous crops and also to suitable fruits and vegetables.

Rice remains the most important crop grown in the lowlands of Southeast Asia. The greatest levels of productivity are found in irrigated agroecosystems, where the main crop (rice) is usually grown twice a year. Farm productivity is much poorer in rainfed agroecosystems where yields are low and only one main crop is grown annually. Soil moisture deficit is the main factor that limits crop productivity in rainfed agroecosystems. The amount of rainfall is near negligible, whereas evaporation losses are much higher, resulting in scant soil moisture.

Lowland agroecosystems are associated with the significant but short-lived yield increases in rice production brought about by the Green Revolution from the late '60s to the mid '80s. Rice yields of 5tons/ha and above under a monoculture, high external input production system (especially the heavy use of inorganic fertilizers and pesticides) have led to significant yield increases. The system, however has also caused many unwanted side effects: increased pest incidence, environmental degradation, health problems, increased socio-economic differences, decrease in nutrient cycling, and loss of biodiversity.[1]

Agroecological farming ensures and enhances productivity of lowland farms by encouraging farmers to intensify, diversify, integrate their farming enterprises, while adapting to climate change. Intensification is associated with increase in production of a given crop per unit of resources used, while diversification pertains to the generation of genetic, species, and enterprise diversity in the farming systems. Integration further amplifies the

1 https://edepot.wur.nl/75446

outcomes of intensification and diversification by ensuring that the outputs (including the wastes and byproducts) of the diverse components of the systems are being used as inputs in the other components.

Systematizing Crop Intensification

Intensification of crop production is usually associated with adoption of seeds of high yielding varieties (HYVs), increased use of inorganic fertilizers and pesticides, improved irrigation facilities, and improved or mechanized farm implements. But with the unwanted social and environmental impacts associated with it – and with the lessons learned from the promotion and implementation of the System of Rice Intensification (SRI), a new approach to crop intensification is being considered. This takes into account agroecological principles that seek to make the most productive use of available natural resources and agrobiodiversity in crop production.

SCI has emerged in recent years in a number of countries. It was reported to have raised the productivity of land, water, seed, labor, and capital resources that farmers can invest for growing a wide range of crops. The ideas and practices that have given rise to SCI were derived from farmers' and others' experience with SRI. SCI and SRI share common elements that substantially raise the productivity and profitability of more 'intensively' managed crops.[2] These elements include:

- Establishment of young healthy plants and attentive care to conserve and nurture their potential for root system growth and for associated shoot growth
- Significant reductions in crop density, transplanting or sowing **individual** plants using wider spacing – giving each plant more room to grow both above and below ground

2 https://agricultureandfoodsecurity.biomedcentral.com/track/pdf/10.1186/2048-7010-3-4.pdf

- Enrichment of the soil with organic matter, and keeping the soil well-aerated to support better growth of roots and of beneficial soil organisms
- Application of water in ways that favor plant root and soil microbial growth, avoiding submerged soil conditions that adversely affect both roots and aerobic soil organisms.

Aside from rice, SCI has been applied to a range of other crops – finger millet, wheat, sugarcane, tef, oilseeds such as mustard, legumes such as soya and kidney beans, and various vegetables.

System of Rice Intensification[3]

The System of Rice Intensification (SRI) is an agroecological methodology for increasing the productivity of **irrigated rice** by changing the management of plants, soil, water, and nutrients. SRI originated in Madagascar in the 1980s and is based on the crop management principles of significantly reducing plant population, improving soil conditions and irrigation methods for root and plant development, and improving plant establishment methods.

The central principles of SRI include:

- Reduced and controlled water application. Rice field soils are kept moist rather than continuously saturated (minimizing anaerobic conditions); this improves root growth and supports the growth and diversity of aerobic soil organisms.
- Reduced plant density. Rice plants are planted singly and spaced widely to permit root and canopy growth in order to keep **all leaves** photosynthetically active.
- Early plant establishment. Healthy rice seedlings are transplanted when young (less than 15 days old with just two leaves) – quickly, shallowly, and carefully, to avoid trauma to roots and minimize transplant shock.
- Enrichment with organic matter to improve soil conditions

3 http://sri.ciifad.cornell.edu/

Based on the above principles, farmers adapt recommended SRI practices to respond to their own conditions. Adaptations are often undertaken to accommodate changing weather and climate patterns, soil conditions, water control, access to organic inputs, labor availability, etc. The following are the recommended SRI management practices:

Crop Management. Rice seedlings are transplanted very young at the 2-leaf stage, usually between 8-12 days old. They are transplanted carefully and quickly, protecting the seedlings' roots and minimizing the transplanting shock. The seedlings are planted singly (one plant per hill) instead of the traditional 3-4 together to avoid root competition. They are also more widely spaced (25cm x 25cm, or even wider in particularly rich soils). Adaptations for direct seeding and mechanical transplanting have been undertaken in a number of countries.

Soil Management. The soil is enriched with organic matter to improve soil structure, nutrient and water holding capacity, and favor soil microbial development. Organic matter (OM) constitutes the base fertilization and is complemented by inorganic fertilizer as needed. As soils are improved through cumulative OM additions, many nutrients (including micronutrients) become more available to the rice plants. Additionally, the soil is also able to hold more nutrients for release as the plants need them.

Water Management. Only a minimum of water is applied during the vegetative growth period. A 1-2cm layer of water is introduced into the paddy, followed by letting the plot dry until cracks become visible, at which time another thin layer (1-2cm) of water is introduced. The same water level is maintained during flowering stage, followed by alternate wetting and drying during the grain-filling period, and then draining the paddy 2-3 weeks before harvest. Some farmers irrigate their fields every evening; others leave them drying out over 3-8 days, depending on soil and climate conditions.

Weed Management. With the intermittent irrigation (or alternate wet-dry conditions previously described), weeds grow more vigorously, and need to be kept under control at an early stage. A rotary weeder – a simple, inexpensive mechanical implement – is most often used starting at 10 days after transplanting (10 DAT), repeated ideally every 7-10 days (for up to 4 times) until the canopy closes. The weeder has several benefits:

- It incorporates the weeds into the soil where they decompose and their nutrients can be recycled.
- It provides a light superficial tillage and therefore aerates the soil.
- It stimulates root growth by root pruning.
- It makes nutrients newly available to the plant by mixing water with OM-enriched topsoil (a re-greening effect of the rice plants can be observed 1-2 days after weeding).
- It redistributes water across the plot, helping eliminate water patches in lower lying areas that create anaerobic conditions for the plants.

The use of the rotary weeder contributes to homogeneous field conditions, creating a uniform crop stand and leading to increased yields. The benefits of SRI include an increased yield (50%-100% or more), a significant reduction in required seed (up to 90%), and water savings (50% or more). Many adopters of the system also report a reduction in pests and diseases, unfilled grains, grain shattering, and lodging. Lodging occurs when plant stems weaken to the point where they can no longer support the weight of the grain, causing the plant to fall over.

Additional environmental benefits stem from the reduction of agricultural chemicals, water use, and methane emissions that contribute to global warming. The system does not require the purchase of new seeds, the use of new HYVs, or the application of chemical inputs, although some farmers may opt to use them.

Facilitating farm diversification and integration

Monoculture has resulted in higher risks from climatic variations, insects and diseases, price fluctuations, and shifts in market demands. It has also led to reduced productivity due to improper farming practice, heavy use of external (especially chemical) inputs, degradation of land and water resources, low quality and unsafe produce, and insufficient utilization of natural resources.

Agricultural diversification

Agricultural diversification is the introduction of other crop varieties, species, and enterprises in crop production farms. Some farmers introduce other field crops, vegetables, fruit trees, livestock, and even fish into their farms.

Diversification in rice-based farms has long been encouraged primarily to maximize farm income, produce more varieties of food, and promote better nutrition for farm families. Rotating rice with other cereals like corn and other grain crops, high-value crops like potatoes, legumes, or planting of fodder crops are just some of the examples of how farmers can optimize their use of farm resources. Such crop diversification is very suitable especially in rainfed farms since available water cannot supply the requirement of another rice crop, particularly during the dry season.

Moreover, diversified farming systems minimize unpredictable risks such as the build-up of pest and diseases that is common in rice monoculture. With climate change, agricultural diversification has been proven as an effective strategy to promote resiliency to extreme climate and weather disturbances.[4]

4 https://kukr.lib.ku.ac.th/journal/KJSS/search_detail/result/307914

Farm integration

Integrated farming systems (IFS) have been traditionally practiced by farmers around the world. It has been advocated as a tool for the judicious use of inputs to make agriculture productive, profitable, and sustainable. IFS aims at an appropriate combination of farm enterprises like growing field crops, raising livestock, apiculture, fish raising, mushroom cultivation, and a host of others. The system interacts with the environment without disrupting the ecological and socio-economic balance on one hand while it aspires to meet the farmers' needs on the other.

Integrated farming systems are often less risky because if managed effectively, they benefit from complementarity and synergism among the enterprises. The integration of different components provides ways to recycle products, by-products, and even waste products of one component as input to another.

Soil types, amount of rainfall and its distribution, and length of the growing season are major considerations in the selection of suitable components of an IFS. However, the needs and resource base of farmers are also major deciding factors in the final choice of IFS components, of which there are three main ones:

- Crop component (grains/cereals, legumes, oilseeds, sugarcane, fiber crops, vegetables, fruit and timber trees, etc.) is usually grown in the main crop fields.
- Animal component (cattle, goat, sheep, chickens, ducks, fish, bees, etc.) is usually raised within or near the homestead.
- Homestead component (household wastes and by-products, value added products, post-harvest wastes, biogas, etc.) which includes other allied activities undertaken within the homestead

Growing fish with rice

Rice cultivation occurs in a range of agroecosystems. It grows in lowland areas that are seasonally inundated by rainfall and in floodplains or lands near the edges of rivers and lakes that are periodically flooded. These agroecosystems also provide habitats for a wide range of aquatic species for home consumption or for sale. They may include fish, crustaceans (crabs and shrimps), mollusks (snails), reptiles (frogs, monitor lizard), various insects, and a variety of aquatic plants.[5]

By growing rice and fish together, farmers can make more efficient use of increasingly scarce water and land resources. Aside from the reduced need for purchased inputs, such systems often generate more income per hectare than rice monoculture. There is evidence that these systems are more resilient to the impacts of extreme weather or climatic events (including pest and disease outbreaks), further enhancing their sustainability.[6]

Growing fish with rice is a good example of two farm enterprises that are mutually beneficial. While the fish thrive due to the dense (rice) vegetation protecting them from birds, the fish in turn provide a natural source of fertilizer with their droppings; they eat insect pests, and help circulate oxygen around the paddy field. Tilapia and carp are the most widely cultured fishes in rice fields and are stocked at a rate between 0.25 and 1 fish per m^2. Rice-fish systems make efficient use of scarce water and land resources, maintain biodiversity, regulate water flows and water quality, and reduce the need for agrochemicals in rice production.

Rice-fish farming as usually practiced is the growing of rice and fish together in the same field at the same time. However, it is also taken to include the growing of rice and fish serially (one after the other within the same field; it can also be the growing of rice and fish simultaneously, side by side but in separate compartments, using the same water.[7]

5 https://www.frontiersin.org/articles/10.3389/fsufs.2020.576179/full
6 https://www.agrilinks.org/post/back-future-rice-fish-agroecosystems?utm_source=USAID+Bureau+for+Food+Security
7 http://www.fao.org/3/a0823e/a0823e.pdf

Rice fields are modified in order to raise fish. All modifications have the basic goals of providing deeper areas for the fish to grow without inundating the rice plants. This is achieved either by making portions of the rice field deeper than the ground level (bottom of paddy field) for the fish, or by creating areas higher than the ground level for the rice or other crops.

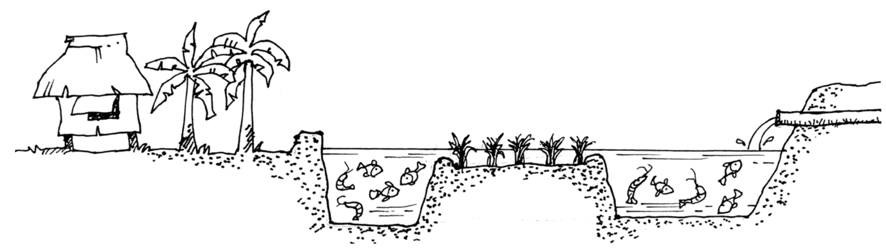

Figure 23. Modified rice field to accommodate fish rearing

Four physical modifications are commonly made to prepare rice fields for fish culture: 1) increasing the height of the dike or bund to allow deeper water inside the field and/or to minimize the risk of it being flooded; 2) provision of weirs or screens to prevent fish from escaping as well as keeping predatory fish from coming in with the irrigation water; 3) construction of proper drains, which is often recommended but not always practiced; and 4) establishment of deeper areas as refuge for the fish.

A fish refuge is a deeper area provided for the fish within the rice field. This can either be a trench or several trenches, a pond, or even just a sump or a pit. The refuge is meant to provide a place for the fish when water in the field dries up or is not deep enough. It also serves to facilitate fish harvest at the end of the rice season, or to otherwise contain fish for further culture while the rice is being harvested.

Table 9. Calendar of activities in a rice-fish system[1]

Activities	June				July				August				September				October				November			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
water entry	■	■																						
fertilization	■	■					■		■		■		■		■		■							
rice planting			■	■																				
fish stocking					■																			
fish feeding						■	■	■	■	■	■	■	■	■	■	■	■	■	■					
water quality control						■	■	■	■	■	■	■	■	■	■	■	■	■	■					
harvesting																				■	■	■		
restocking					■																			

1 *Manual for fish culture in rice paddy & earthen pond using Lao fishes https://www.jircas.go.jp/sites/default/files/publication/manual_guideline/manual_guideline3-9_-.pdf*

Management activities for fish culture in rice paddies is illustrated in Table 9. Organic manure is applied before preparing the rice field, and every 15 days thereafter during the main growing season. This provides nutrients for the rice and the added cultures of plankton or algae that are used to feed the fish. Supplementary feeds may be given as needed, once or twice a day.

Ducks can also be integrated to further improve the systems' productivity. The paddling movement of the ducks stimulates plant growth, while their manure naturally fertilizes the soil. The ducks also eat the harmful insects and weeds, thus reducing, if not eliminating the need for pesticides and herbicides. Duck integration has been reported to have increased rice production by 20% while reducing production cost by 30% in Zamboanga del Sur in the southern part of the Philippines.[8]

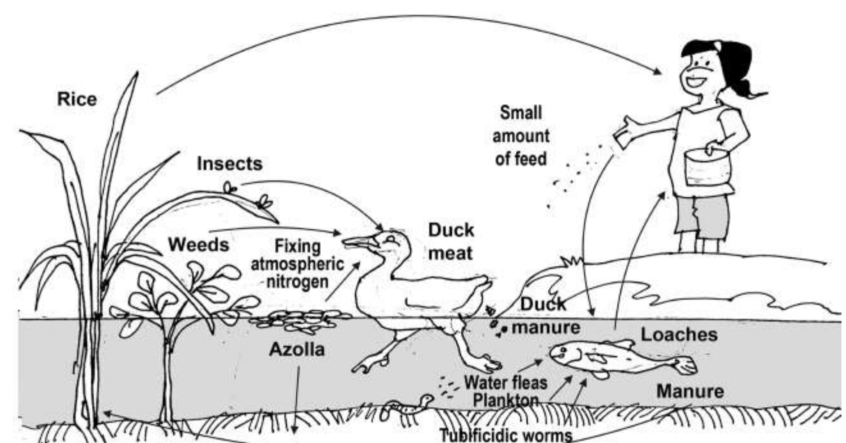

Figure 24. Ducks can be integrated into an existing rice-fish culture

8 https://www.equatorinitiative.org/2017/08/08/integrated-rice-duck-farming-and-value-chain/

Lowland agroecosystems are considered as the most productive and suitable for agricultural production. These advantages, however, are being increasingly compromised due to intense cultivation practices that these agroecosystems are being subjected to. Because of the high level use of modern varieties, farm machineries and excessive amounts of inorganic fertilizers and pesticides, lowland agricultural systems are beset by soil compaction, soil fertility decline, pest outbreaks, biodiversity losses and yield shortfalls. The systems' continuous dependence on external inputs makes them vulnerable to price shocks that lead to decreases in farm income as well as degradation of the environment.

Agroecological farming in the lowlands uses ecological processes and functions to increase productivity, strengthen ecosystem services, and minimize environmental impacts. It shifts the focus away from crop yields in monoculture systems to cultivation practices based on ecosystem and biodiversity management. Agroecological farming promotes diversification and integration to facilitate the interaction of different farm components with one another and with the physical environment. These practices enhance nutrient cycling, water flow regulation, pest suppression, etc. and thus, help sustain food and livelihood security of many rural households.

Chapter 11
The Upland Ecosystems

Characteristics of upland agroecosystems

The uplands are areas of land above flood level or alluvial plains along rivers and between hills. They constitute the mountain and foothill portions of the landscape that are somewhere around 200m- 500m above sea level (masl).[1] Uplands are very important landscapes because they affect other ecosystems in various ways. They present a great diversity of land uses and habitats that include patches, corridors, and matrices of secondary forests, open grasslands, tree plantations, swidden farms, and human settlements. Swidden farms or farms subjected to slash-and-burn farming and shifting cultivation are grown to rice, corn, cassava, sugarcane, coconut, fruit orchards, and a mix of upland crops.

Figure 26. A typical upland agroecosystem

1 http://erdb.denr.gov.ph/wp-content/uploads/2015/06/upland_compendium.pdf

Four problem areas have consistently been identified in the management of upland agroecosystems: 1) low productivity; 2) difficult product marketing; 3) problematic land tenure; and 4) limited access to financial and other basic services.[2]

Upland agroecosystems are often highly eroded and acidic steep slopes dominated by persistent grasses and are dependent on rainwater for crop production. Their low productivity leads to more land use conversions to expand the area for agricultural production; in addition, shorter fallow periods are being used for lands already under shifting cultivation. Decades of continuous slash-and-burn cultivation and other inappropriate agricultural practices have resulted in rapid land degradation that have made these upland farms even more barren and unproductive.

The unsustainability of land use systems in the uplands is associated with inequitable and insecure access to land resources by increasing populations of subsistence farm families. Many of these areas occupied are considered non-alienable and non-disposable and are owned by the State. The absence of security of tenure is a disincentive for farmers to invest in permanent crops and soil conservation measures. As a consequence, upland farmers tend to favor growing short-term cash crops over long-term crops like trees and perennials.

Agroecological farming in the uplands necessitates farm management practices that are able to prevent soil erosion, improve soil fertility, conserve water, and maintain vegetative cover. They should also help ensure household food and nutrition and generate income. Development interventions should at the same time address issues of land tenure, product marketing, and access to financial and other basic services (e.g., development and extension programs) to alleviate poverty.

2 http://antonantonio.blogspot.com/2015/02/basic-upland-problems.html

Establishing Agroforestry Systems

Agroforestry is a general term for the system of combining trees with the production of crops and livestock. It is a dynamic, ecologically based, natural resource management system that diversifies and sustains smallholder production.[3]

Agroforestry systems are multifunctional; they can provide a wide range of economic, sociocultural, and environmental benefits. The three main components – crops, animals, and trees – can be combined in numerous spatial and temporal arrangements and for different functions, creating thus many different kinds of systems,[4] the more common of which are described below:

- **Agrisilvicultural** systems are a combination of crops and trees, such as alley cropping or home gardens.
- **Silvipastoral** systems combine forestry and grazing of domesticated animals on pastures, rangelands, or on-farm.
- **Agrosilvipastoral** systems are those where the three components (crops, trees, and animals) are integrated, e.g., home gardens involving animals as well as scattered trees on croplands that are used for grazing after harvest.

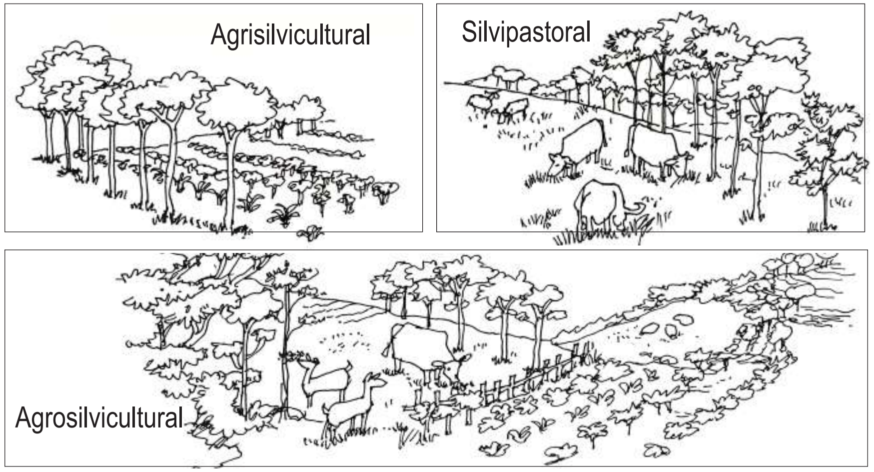

Figure 27. Common agroforestry systems

3 https://downloads.ctfassets.net/e09p19lzfrfe/65FcYX8OjlNm3JkFc2Zilc/ee54b825a8c8ec4ab6f69bbbddf0dc30/Agroecology-Guide_Final.pdf
4 http://www.fao.org/forestry/agroforestry/80338/en/

Many farmers do not want to practice agroforestry because they believe that trees will reduce productivity of the land and that they may physically interfere with farming operations. Some of them are afraid that adding trees into the farm could result in the increase in pest species. The area occupied by trees also represents an immediate loss from current production. However, subsistence farmers must be encouraged to weigh this certain short-term loss against potential longer-term benefits that they may gain from increased soil fertility and reduced soil erosion with agroforestry.

Agroforestry practices ensure that trees are compatible with the accompanying crops and that they allow the correct amount of sunlight for crops to grow and develop. By using trees to provide additional shade to the ground (discouraging weed growth), the farm is less likely to require spraying for weeds. Pruning and maintenance is also done to attain the desired level of sun and shade. Trees and crops in agroforestry systems interact in relation to total nutrient and water cycles as well as light capture. Tree roots act both as a "safety net" for nutrients that have leached down the soil profile below the crop roots, and as a "nutrient pump" for weathered minerals in the deeper soil layers.[5]

Agroforestry bridges the gap that often separates agriculture and forestry by building integrated systems that address both environmental and socio-economic objectives. It helps prevent environmental degradation, improve agricultural productivity, while at the same time provide more stable incomes and other benefits to farming households. It can also improve the resiliency of agricultural systems and mitigate the impacts of climate change.

5 https://www.commod.org/content/download/4241/31920/version/1/file/7_Magcale-Macandog_2005_BC.pdf

Sloping Agricultural Land Technology

Sloping agricultural land technology (SALT) is a system of farming sloping lands whereby alleys of commercial and food crops are grown in between rows of perennial trees and shrubs that are planted along the contours. The trees and shrubs are preferably nitrogen fixing but can also be fruit- or nut-bearing. Natural vegetative strips (e.g., fodder crops), rocks and stones, farm trashes or crop residues are piled along the contour lines to facilitate creation of terraces.

SALT was developed by the Mindanao Baptist Rural Life Centre (MBRLC) in the Southern Philippines to help control soil erosion and increase crop yields. It is a technology package of soil conservation and food production that integrates trees with crops and livestock. The rows of perennial trees and shrubs along the contours serve to slow down surface runoff and intercept eroded soils, thus minimizing soil erosion. It was specifically designed as a viable alternative to the destructive traditional farming practices (swidden cultivation) of upland farmers.

SALT is an agroforestry model where rows of perennials like coffee, cacao, citrus, and other fruit trees are interspersed throughout the farm plot. The strips not occupied by permanent crops, however, are planted alternately to cereals (corn, upland rice, sorghum, etc.), legumes (soybean, mung bean, peanut, etc.) and/or other annual crops (sweet potato, melon, pineapple, castor bean, etc.). SALT also includes the planting of trees for timber and firewood usually at the "head" of the farm and along its boundaries. Tree species for "boundary forest" of SALT farms include mahogany, casuarina, sesbania, cashew, etc. Contour lines are planted with nitrogen fixing hedgerow species such as flemingia, desmodium, calliandra, gliricidia, and leucaena.[6] Table 10 on the next page lists the different SALT practices that help achieve some of the agroecosystem management objectives:

6 https://tunza.eco-generation.org/resourcesView.jsp?boardID=worldReport&viewID=10043

Table 10. Agroecosystem management objectives and corresponding SALT practices

Agroecosystem management objectives	SALT practices
Soil and water conservation	establishing, cultivating, and planting contour lines; growing hedgerows, creating natural vegetative strips, piling rocks, stones, trashes etc. in the contour lines; establishing check dams, contour and drainage canals; mulching with hedgerow trimmings and crop residues
Nutrient management	trimming nitrogen fixing trees and shrubs and incorporating them in the soil or using them as mulch; application of crop residues and other organic materials
Pest management	crop rotation, intercropping, companion planting; "push and pull" technique (growing plants that either attract or repel insects)
Systems diversification	intercropping, crop rotation; growing perennials and annuals in separate strips; growing live fence/trees in farm boundaries; growing nitrogen fixing trees as hedge rows; creating natural vegetative strips; growing fruit and timber trees; raising livestock
Systems integration	Growing green manures (nitrogen fixing trees and shrubs) for soil quality improvement; growing forage and fodder for livestock; growing annual crops and using crop residues as feed and/or fertilizers; growing trees for food, fodder, timber and other wood products

Outlined below are the different SALT "models" MBRLC has developed that upland farmers can choose from, depending on which one is most appropriate for their situation e.g., resources, capabilities, and based on the steps needed to establish them:[7]

- SALT-1 (Sloping Agriculture Land Technology) uses 45% of the land for growing food crops, 30% for perennial crops, and 25% for fast growing nitrogen fixing trees/shrubs
- SALT-2 (Simple Agro-Livestock Technology) uses 40% of the land for agriculture, 20% for forestry, and 40% for livestock,
- SALT-3 (Sustainable Agroforestry Land Technology) uses 40% of the land for agriculture and 60% for forestry
- SALT-4 (Small Agro-fruit Livelihood Technology) uses 75% of the land for fruit trees and 25% for short term crops

Box 13. Steps in establishing a SALT farm

1. <u>Make an A-frame.</u> Nail or tie together three wooden or bamboo poles in the shape of a capital letter A. The base of the legs should be about 90 cm apart. Mount a level at the cross bar. *(An A-frame is a simple device for laying out contour lines across the slope.)*
2. <u>Locate the contour lines</u>. Locate the contour lines using the A-frame, starting from one side of the farm all the way to the other end. Mark with a stake each spot where the legs of the A-frame "land" as you go along. Space the contour lines 4-5 meters apart.
3. <u>Cultivate the contour lines.</u> Plow and harrow 1m wide strips along the contour lines to prepare them for planting. Use the stakes/markers in step 2 as guide during plowing.
4. <u>Plant seeds of nitrogen fixing trees.</u> Lay two furrows along each prepared contour line. Plant 2-3 seeds of the hedgerow species/hill (in double rows), with a distance of 12cm between hills.

7 https://qcat-demo.wocat.net/en/unccd/view/unccd_67/

5. Cultivate alternate strips. Cultivate only alternate strips (i.e., 2, 4, 6 and so on) to minimize erosion, as unplowed strips can better hold the soil in place. *(The space between rows of nitrogen-fixing trees on which the crops to be planted is called a strip or alley.)*
6. Plant permanent crops. Plant permanent crops every third strip. Plant tall crops at the bottom of the farm and put the short ones at the top. Permanent crops such as coffee, cacao, banana, and others of similar height may be planted at about the same time when the nitrogen fixing hedgerow species are sown in step 4.
7. Plant short-term crops. Plant short and medium-term cash crops (e.g., corn, sweet potato, pineapple, ginger, taro, peanut) between strips of the permanent crops.
8. Trim nitrogen fixing trees. Every 30-45 days, prune the growing hedgerows to a height of 1.0-1.5m from the ground. Pile the cut leaves and twigs on the soil around the crops.
9. Practice crop rotation. Plant legumes where cereals (e.g., corn and upland rice), tubers, and other crops were previously planted. Rotate crops every planting season; do not plant the same crop on the same area within the same year.
10. Build green terraces. Pile organic materials such as straw, stalks, twigs, branches and leaves at the base of the rows of nitrogen fixing trees.

Upland agroecosystems are characterized by excessive degradation of land, water, and other natural resources and unabated loss of biodiversity. Deforestation, high rates of soil erosion, low soil fertility, and unsuitable intensive farming practices have led to ecologically unstable and less productive agricultural systems. Uplands are generally designated as marginal lands due to these different combinations of challenges and constraints.

However, upland agroecosystems can be managed in ways that support the evolution of location-specific, ecologically stable and economically productive farming systems. This can be done by ensuring that the choice of farm enterprises and land management practices are determined by soil and climate conditions and socioeconomic constraints of the site. Agroforestry and other agroecological farming systems and practices are promoted to help address these production constraints.

Agroforestry systems generally had a positive impact on biodiversity and other ecosystem services. Aside from enhancing productivity, these systems and practices are also associated with improved erosion control, soil enrichment, biodiversity conservation and climate change mitigation through carbon sequestration.

Chapter 12
Agroecology for Sustainable and Resilient Food Systems

Understanding food systems

A food system comprises the activities, processes, and structures related to the production, processing, distribution, and consumption of food. It also takes into account all the elements and outputs of these activities, along with their socio-economic and environmental outcomes.[1] Food systems exist at local, regional, national, or international levels; many factors influence the different processes depending on which level the system is at. The following table lists the specific inputs and outputs of each food system process.[2]

Table 11. Food system processes and their respective inputs and outputs

Food system process	Inputs	Outputs
Production	knowledge and skills on how to raise crops and livestock; sun, soil, water, air, seeds, livestock; access to land, tools, farm equipment	food ready for processing
Processing	knowledge and skills in harvesting, packaging, storage, and processing; facilities and equipment	food ready for sale and distribution
Distribution	food ready for sale or distribution; sales outlets; marketing efforts	food ready for purchase and preparation
Consumption	food that is ready to prepare; knowledge and skills in food preparation; cooking appliances	food ready for consumption

1 http://www.fao.org/docrep/w0078e/w0078e04.htm#P1642_90314
2 https://sustainablefoodcenter.org/latest/blog/what-makes-up-a-food-system-breaking-it-down-into-4-parts

Climate and weather have always had a large impact on farming. Unpredictable weather patterns, extreme temperatures, floods, and droughts brought on by climate change add more uncertainty to the food system. Agricultural and food policies also shape how food systems are allowed to function.

Complex problems beset the current food systems – environmental degradation, climate change, continued world hunger, consolidation and industrialization of the food system, etc. The systems are also associated with enormous hidden costs. They have become unsustainable and incapable of dealing with growing population pressure, food and nutrition insecurity, dietary shifts, health disparities associated with poverty, and many other related issues. The food systems are also considered as fragmented – where consumers have lost relationship with the production of their food, while growers have lost contact with the consumers who eat the food that they grow.
Conventional thinking about food is also increasingly being challenged. From the idea that food is being regarded only as a commodity, it is now shifting towards food becoming acknowledged for its nourishment, social and cultural values, including its deep connectedness with ecosystems, ecosystem services, and natural resources. The transformation of current food systems is increasingly considered to minimize environmental impacts and sustain livelihoods on one hand, while also producing food of sufficient quantity and quality on the other.

Transforming food systems

Transforming food systems requires a number of key changes: 1) Food systems should enable all people to benefit from nutritious and healthy food; 2) They should reflect sustainable agricultural production and food value chains; 3) They should mitigate climate change and build resilience; and 4) They should encourage a revitalization of neglected rural territories.[3]

3 https://link.springer.com/article/10.1007/s13593-018-0519-1

Food systems, in order to be sustainable, need to contribute to a coherent and equitable production and exchange of food, build up human and social capitals, and cycle rather than transport resources through, from, or to disconnected parts of the systems.[4] Food is being moved from farm to table with the use of labor and energy and it also generates wastes as it moves through the system.

Sustainable food systems must be centered on people and based on rights; adopt an integrated approach; build capacities to manage changes and redress power disparities; involve a long-term policy commitment; and be adequately supported and resourced. They should also be able to meet challenges regarding issues surrounding farming and food, and address how they can contribute to re-connecting consumers and the food that they eat.[5]

Box 14. Attributes of a sustainable food system:

- supports family farming to enhance food security, livelihood, employment opportunities
- revitalizes local economies and brings back cultural identities
- recognizes and puts value on cultural identities
- conserves agrobiodiversity and genetic resources
- creates value-adding products and services from diversified agroecosystems
- empowers women and local communities

Creating agroecological food systems

Applying agroecological principles in sustaining food systems fosters better understanding of the three dimensions of agroecology – as a science, as a social movement, and as a set of farming practices. Agroecology applies ecological science and

4 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6417402/
5 https://www.slideshare.net/ExternalEvents/agroecology-and-sustainable-food-systems

concepts to the study, design and management of sustainable food systems. As a social movement, it promotes rural development, food sovereignty and other social dimensions that closely links farmers, consumers, governments, and all other actors in the food systems. It reconnects people to their food and producers to consumers – making healthy food accessible to all consumers, and available for their use in healthy and sustainable diets.

Agroecological farming practices are important in the package of solutions needed to transform food systems. Such practices are diverse but can be characterized by a generic set of agroecological principles, i.e., a preferential use of natural processes and a focus on local suitability, equity, and systems management. These principles help design holistic farming systems according to local socio-economic and agroecological contexts.

Table 12 lists agroecology principles and their applications in a food systems context.[6]

Agroecology, together with food sovereignty, offers a pathway for a more just and sustainable food systems and communities. The emphasis on institutions and the resilience dimension suggests stronger links between agroecology and basic environmental, ethical, political, and governance-related questions.

Agroecological food systems are widely diverse, shaped by context, and achieved through multi-actor planning. Social organization, community building, common learning, and knowledge creation as well as the support from appropriate governing and institutional structures are crucial for creating food systems that are based on the agroecological context of the area.

6 https://www.tandfonline.com/doi/full/10.1080/21683565.2017.1365321

Table 12. Agroecological principles and their applications in food systems

Agroecological principles	Food system applications
Minimal external inputs	use of local resources which enhance the environment; use of energy, human skills, capacities (internal inputs) in a food system that is in accordance with the natural and social environment
Recycling of internal resources and minimizing losses	use and re-use of farm and household resources, by-products, and wastes (e.g., food, water, and organic matter) in all the different levels of a food system, including minimizing losses of genetic resources
Contextualized farming	farming and food systems are developed in each context with and by the actors, who carry and constantly co-create relevant knowledge
Resilience	adaptive capacity, health and immunity in the food system at all levels (e.g., social and environmental; individuals and populations) in terms of ability to absorb shocks and disturbances over seasons and in times of change and challenges; this involves feedback loops of production and need for diverse food over seasons; diversification of enterprise and diverse genetic resources can enhance resilience
Multi-functionality	ability and capacity of the system to carry out multiple functions, often involving multiple actors and giving many different roles to each system element, as well as to the links between them
Complexity and integration	enhancing interaction and synergies in socio-ecological systems; building on resource efficiency at all levels of the food systems to meet the challenges of seasonality, storage, and production at scale
Equitable	emphasizing multi-actor involvement, the necessity of judicious use of human and other resources and mutuality within the system; valuing different capacities and knowledge types and no exploitation, as well as acting in ways that foster, nourish, and allow future generations to develop and prosper
Nourishing	use of benign inputs and resources which nourish the soil, organisms, the environment, and ecosystems at all levels; supporting healthy diets in resource-efficient food systems, and understanding health as resilience

Developing climate resiliency

Climate change and variability, in combination with non-climate drivers such as land degradation, forest encroachment, and/or deforestation have altered ecosystem functions and agroecological systems. They have effects on sea level rise or variation in the water regime, shifts in seasons, and the frequency and magnitude of extreme weather events. The effects can result in decline of agricultural productivity, species migration or displacement of ecosystems, worsening of health conditions, etc. Food availability will be greatly affected by low production and productivity.[7]

Climate-resilient food systems have the capacity to cope with hazardous events, threats, or disturbances by responding in ways that sustain their essential function, identity and structure, while also maintaining people's capacities for adaptation, learning, and transformation.

Risks created by weather variability and extremes are addressed by ecological design and management of agroecosystems. These practices emphasize the creation of production systems that are

7https://wedocs.unep.org/bitstream/handle/20.500.11822/35958/EbA_TZ_Handbook.pdf?sequence=2&isAllowed

well adapted to the local landscape and climate. Diversification and integration practices build soil health and spread climate risks throughout the growing season, reducing potential losses from any single extreme weather event. It also enhances ecosystem services that buffer production losses from weather-related disturbances. Diversified, high-value marketing spreads climate risks across multiple markets, improves profitability and produces social capital, all of which enhance capacity to respond to challenging climate conditions and to recover from climate-related damages.

Stimulating Community Food Systems

Local food systems can help communities become more resilient in the face of challenges like pandemics and climate change. Shorter supply chains, less transportation, less processing, and more traceable and transparent production are all advantages of a local food system. Local food systems have potential for improving resource recycling, raising collective awareness among different actors, and providing opportunities for mutual learning. A rich knowledge base of practical application and innovation can be used to guide the development of locally adapted, sustainable, and climate-resilient community food systems.

Localizing the food system means connecting local growers with local consumers. The types and degrees of contact between those who grow and produce food and those who receive and consume them are enhanced in local food systems. There is direct interaction and feedback, exchange of experiences and knowledge, and inherent local context and embeddedness.[8]

Efforts to promote local food systems include "buy local" initiatives, food hubs, farmers markets, community-supported agriculture, and farm- to-school initiatives (e.g., using locally produced and processed meals and snacks for school feeding programs). The efforts can range from food production to aggregation of produce from smaller-scale farms to larger volume buyers, to allowing local growers to sell to supportive institutional customers. There are also food policy councils which help institutions and individuals recognize the advantages of buying local foods, and facilitate interactions with farmers and other institutional efforts to help communities scale up local and regional food systems and strengthen their economies.

The emergence of the community food security movement upholds the notion that all people have a right to access local, nutritious, culturally appropriate, non-emergency food. It links anti-hunger efforts with sustainable agriculture, economic development, and social justice advocacy.

8 https://casfs.ucsc.edu/about/publications/Teaching-Organic-Farming/PDF-downloads/3.4-sustainable-ag.pdf

Appendix 1. Nutrient composition of various organic materials

Organic Matter	% Nutrient Content		
	N	P	K
Animal Wastes (Dried)			
Bat (Guano)	1.0-12.0	2.5-16.0	0
Cattle	2.0	1.5	2.2
Chicken	5.0	2.0	1.0
Duck	2.3	1.4	0.5
Goat	1.4	1.0	3.0
Horse	1.6	1.7	0.7
Rabbit	7	1.7-3.1	0
Sheep	1.5-3.1	1.0-2.5	0.3-2.3
Swine	2.8	1.4-1.6	1.2- 1.5
Water buffalo	1.1-1.2	0.6-0.8	0.7
Crop Residues			
Banana skin (ash)	0	3.3	41.8
Banana stalk (ash)	0	2.3	49.4
Coconut husk	1.8	0.3	2.1
Corn stover	0.6	0.7	3.0-3.2
Cotton stalks & leaves	0.9-1.6	0.2	1.4-2.8
Cowpea stems	0.5-1.1	0.1-1.1	0.4-2.5
Hulls	1.7	0.2	1.2
Peanut roots	1.1	0.1	1.3
Rice straw	0.6-1.0	0.1-0.3	0.9-1.4
Roots	1.1	0.1	1.5
Sugarcane (leaves)	1.0	1.5	3.2
Sugarcane trash	0.4	0.2	0.5-0.4

Organic Matter	% Nutrient Content		
	N	P	K
Tobacco stalks	3.7	0.7	4.5
Tomato stalks	0.4	0.1	0.5
Wheat straw	0.5	0.2	0.6
N-fixing trees (Leaves)			
Acacia arabica	2.6	0.4	2.8
Acacia ferruginea	3.00	0.1	0.9
Azadirachta indica	2.8	0.3	0.4
Gliricidia sepium	1.8-3.6	0.1-1.8	2.6-2.7
Leucaena leucocephala	4.3	0.4	3.1
Green Manures			
Crotolaria juncea (Sunn hemp)	2.0-2.3	0.5	1.8
Crotolaria usarmoensis	5.3	-	-
Desmodium trifolium	2.9	0.1	1.3
Melitotus indica	3.4	0.2	1.3
Pisum sativum (Pea)	2.0	-	-
Sesbania aculeata	2.2-3.5	0.6	1.2
Sesbania speciosa	2.5-2.7	0.5	2.2
Vigna unguiculata (cowpea)	1.7-3.1	0.5	2.2
Alfalfa	2.5	0.5	2.1
Algae	2.5	0.1	0.4
Azolla sp.	3.7-4.0	0.5-0.9	0.3
Calopogonium mucunoides	3.8	0.2	2.0
Vigna radiata (mungbean)	0.8	0.5	1.2
Water hyacinth	2.0	0.4	3.4

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Organic Matter	% Nutrient Content		
	N	P	K
Other Composting Materials			
Bloodmeal	12	0	0
Bonemeal	3.5	18	0
Eggshell (burned)	0	0.4	0.3
Feathers	15.3	0	0
Fish meal	6	6	6
Molasses	0.7	0	5.3
Wood ashes	0	1-1.5	1-3
Compost			
Food waste	0.4-1.6	0.1-0.4	0.2-0.6
Garbage	0.4-4.0	0.2-1.3	0.2-2.1
Garden waste	1.4-3.5	0.3-1.0	0.4-2.0

Source:

https://thenutrientcompany.com/blogs/horticulture/npk-value-of-everything-organic-database

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About the Publishers

The Southeast Asia Regional Initiatives for Community Empowerment (SEARICE) is a regional non-government organization that promotes sustainable and resilient food systems through ecological agriculture with emphasis on the conservation and development of agricultural biodiversity; and advocates for policies that support, strengthen, and institutionalize community initiatives on sustainable and resilient food systems. It works in partnership with farming communities, local and national government units, civil society organizations, and academic and research institutions in Southeast Asia.

SEARICE is registered with the Philippines' Securities and Exchange Commission (SEC) as a non-stock and non-profit organization.

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SwedBio is a development programme that works to advance sustainable and equitable governance of biodiversity knowledge and policy. It is a knowledge interface at Stockholm Resilience Centre contributing to poverty alleviation, equity, sustainable livelihoods and social-ecological systems rich in biodiversity. SwedBio enables knowledge generation, dialogue and exchange between practitioners, policy makers and scientists for development and implementation of policies and methods at multiple scales

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