Permagarden

Technical Manual *Second Edition*

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The Technical and Operational Performance Support (TOPS) Program is the U.S. Agency for International Development (USAID) Office of Food for Peace-funded learning mechanism that generates, captures, disseminates, and applies the highest-quality information, knowledge, and promising practices in development food assistance programming, to ensure that more communities and households benefit from the U.S. Government's investment in fighting global hunger. Through technical capacity building; a small grants program to fund research, documentation, and innovation; and an in-person and online community of practice (the Food Security and Nutrition [FSN] Network).

The TOPS Program empowers food security implementers and the donor community to make lasting impact for millions of the world's most vulnerable people.

Led by Save the Children, The TOPS Program draws on the expertise of its consortium partners: CORE Group (knowledge management), Food for the Hungry (social and behavioral change), Mercy Corps (agriculture and natural resource management), and TANGO International (monitoring and evaluation). Save the Children brings its experience and expertise in commodity management, gender, and nutrition and food technology, as well as the management of this 7-year (2010–2017) US$30 million award.

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Thomas Cole

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The TOPS *Permagarden Technical Manual Second Edition* resulted from an identified need for a practical resource that outlines the purpose and science of permagardens and provides detailed guidance on the implementation of permagarden components in a development context. This manual forms part of a larger toolkit that includes training guidelines and teaching tools. The contents of this manual, and the broader toolkit, were adapted and developed under the Agriculture and Natural Resource Management component of The Technical and Operational Performance Support (TOPS) Program. Many of the practices and key principles used in the permagarden methodology originate from Bio-Intensive Agriculture (developed by John Jeavons) and Permaculture (developed by Bill Mollison and David Holmgren). Additional content for the TOPS Permagarden Toolkit was developed from the methodology and trainings implemented by Thomas Cole and Peter Jensen.

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Abbreviations and acronyms

CEC Cation Exchange Capacity

cm centimeter(s)

FFP USAID Office of Food for Peace

IDP internally displaced person

IPM integrated pest management

kg kilogram(s)

m meter(s)

mm millimeter(s)

L liter(s)

SOM soil organic matter

TOPS Technical and Operational Performance Support (as in The TOPS Program)

TOT training of trainers

USAID U.S. Agency for International Development

Contents

Introduction

Throughout the world, households struggle to produce enough food and nutrients because of low yields that result from poor soil fertility, little access to water, and a lack of access to inputs. In addition, climate change, poverty, illness, poor governance, and inefficient markets all contribute to the difficulty of households becoming food and nutrition secure. Food security development programs continually seek solutions to increase the availability, access, and utilization of safe, nutritious food for the millions of household members who suffer from malnutrition. Often, programs propose the promotion of home gardens as a part of the solution to this problem. However, gardens can be successful in the longer term only if they focus on key agronomic and ecological issues.

The permagarden method combines components of permaculture,[1] an agricultural approach using design principles to utilize natural systems for production, and bio-intensive agriculture,[2] an agricultural approach to maximize production on a small amount of land through sustainable practices that increase biodiversity, to create a highly productive garden using a small amount of land. It is designed to work in both the rainy and dry seasons, and is an approach to home gardens that improves soil fertility and water management to produce nutritious crops. The method shows how farmers around the world with only a small amount of land can produce food throughout the year by learning principles behind proper gardening and resource management, and matching those principles to basic practices. The permagarden method is designed to empower gardeners to use local resources to overcome challenges in the garden; it is a simple solution that can help bring resilience to each household, one small adjustment at a time.

This manual serves as a key resource for development practitioners working with farmers to help them incorporate permagardens into their farming systems. The manual explains key concepts in creating a permagarden and matches them with appropriate practices, such as double digging, making botanical fertilizers, bio-intensive seed spacing, multicropping, and succession planting. It is intended to be paired with The TOPS Program training materials to enable project staff, together with farmers, to successfully implement a thoughtful, strategic approach to home gardens.

The permagarden method is related to The TOPS Program's Resilience Design in Smallholder Farming Systems Approach. Resilience Design is a principle-based

1 Additional permaculture resources are included in the resource list. These resources allow a more in-depth analysis of the permaculture practices integrated into this method.

2 Additional bio-intensive agriculture resources are included in the resource list. These resources allow a more in-depth analysis of the bio-intensive agriculture practices integrated into this method.

approach to design a farming system to efficiently use the resources and natural influences[3] found in a community, allowing for a more resilient production system. Agricultural resilience is about equipping farmers (and the living systems they depend on) to adapt and recover from shocks and stresses to their agricultural production and livelihoods.

How to use this manual

The TOPS *Permagarden Technical Manual* is a resource for agriculture project staff implementing home garden projects with farmers. The manual explains how the permagarden method addresses soil health, water management, and crop protection to create a year-round productive home garden. It includes an explanation of the purpose and reasoning behind the method, as well as instructions on how to implement the different practices. It is designed to provide agriculture staff with both the theory of the permagarden method and the practical activities needed to work with farmers to implement a permagarden.

This manual specifically focuses on permagarden production. It is recognized that some produce from permagardens may be sold for income, and certain plants can be incorporated into the permagarden design specifically with markets in mind. However, market demand and access challenges are location-specific, and methods for linking and integrating very poor producers into markets are covered in other resources and are therefore not covered in this manual.

This manual is part of a larger permagarden toolkit that includes guidelines for a 3-day training for agriculture staff and for a 5-day training of trainers (ToT). The guidelines for the 3-day training provide instructions for teaching development program participants; the ToT guidelines provide instructions for teaching agriculture staff from development programs. The toolkit also includes other teaching tools for agriculture staff, including pictorial sheets, a productive behavior checklist, a set of 'Walk and Talk' questions, the Permagarden Adult Training Resources, and barrier analysis questionnaires on permagarden practices.

It is important to note that any transfer of knowledge regarding new technologies, including testing and adapting permagarden practices, requires a significant amount of time. Therefore, 3-day trainings should be reinforced by continued technical support through extension methods, such as farmer field schools. It is important that farmers fully understand how to implement all permagarden management practices and their importance.[4]

Thus, the learning process should continue over multiple cropping seasons.

3 Influences are patterns that may have a positive or negative impact on the garden (e.g., sun, wind, slope, trash pits).

4 It is important to conduct some formative research to better understand the target population. The Barrier Analysis methodology is a type of formative research that can help identify the most influential determinants of behavior adoption and increase the impact on program participants.

By following guidance on landscape resource assessment, soil health, water control, and plant management, families learn that they have all the resources they need to attain food and income security. Gardens can be successful without large areas, pristine soil, large amounts of water, or expensive synthetic fertilizers. With proper management, permagardens can be successful in the wet and dry seasons and in different environments, including dryland or arid regions. By learning to manage small spaces, high yields of nutrient-dense, seasonal fruits and vegetables can be available year-round using only local tools, plants, and materials. By focusing on basic agronomic principles and proper soil and water management, the permagarden method helps families see this new paradigm of 'Small is Bountiful'.

Large yields of nutritious vegetables from small spaces.

Photograph: **Thomas Cole**

USAID Office of Food for Peace programs and participants

U.S. Agency for International Development (USAID) Office of Food for Peace (FFP) programs aim to increase food security for the most vulnerable populations. These populations often live and farm on small parcels of marginal land that are prone to droughts and/or floods. This farmland has generally been cultivated for many generations with little regard for soil health, resulting in long-term declines in soil fertility and widespread reduction in agricultural productivity. It is necessary for FFP programs to build the capacity of program participants to sustain or increase agricultural productivity by improving soil fertility and resilience to shocks and stresses.

Women with small children are often targeted for home garden initiatives in FFP programs. Regardless of the target audience, FFP programs need to take into account the time and labor requirements required to build a permagarden.

Strategies that make preparing the garden easier, like working in groups, digging after a rainfall, and soaking the hard, dry ground before digging, should be integrated into program work plans to increase the likelihood of successfully implementing a permagarden initiative.

Many of the concepts and practices in the permagarden method can be applied to other aspects of agricultural or natural resource management programs. The principles, such as designing the land for the greatest benefit and capturing the greatest amount of water, can be applied to a garden, farm, community, or watershed. Key permagarden messages, such as improved soil health and effective water management, and practices, such as digging swales, planting on contours, multicropping, adding soil amendments, and keeping the soil covered, are the same messages program staff can carry to farmers in their larger fields. Thus, the permagarden method is most impactful when integrated into a larger agriculture and natural resource management strategy. The Resilience Design in Smallholder Farming Approach is a good way to link home garden activities to larger field-based and natural resource management activities.[5]

5 See the TOPS Resilience Design for Smallholder Farming Systems Approach for more information regarding applying these techniques at a larger scale.

Overview of the permagarden method

The overall goal of a permagarden is to provide household members with an attainable, practical, and sustainable method to increase their own household food and nutrition security. By implementing the permagarden method, farmers can increase their household food production and income from small land areas. It is a sustainable method using local materials and building the environmental health of the garden. Additionally, with proper water management, this method works in the rainy and dry seasons, and is particularly useful in dryland or arid environments. Overall, the permagarden method has five aims:

1. **Ecological** – enhance natural resources and ecosystem services through:
   - improving soil and water health
   - increasing biodiversity, and
   - reducing erosion.
2. **Economic** – increase economic income by:
   - reducing input costs, and
   - diversifying and intensifying production.
3. **Energy** – increase energy efficiency through:
   - better garden design that works with natural influences to maximize the efficiencies of an integrated system and reduce time and energy expended tending crops and animals.
4. **Nutritional** – contribute to increased nutritional status by:
   - increasing access to a diverse diet, and
   - improving critical nutrient uptake.
5. **Social** – strengthen the skillset, capacity, and confidence of smallholder farmers by:
   - supporting local innovative farmers to become leaders
   - enabling them to understand how to maximize local resources and utilize influences improving their ability to adapt and test technologies.

The permagarden method is a combination of permaculture and bio-intensive agriculture.

'Permaculture', a combination of the words 'permanent' and 'agriculture', focuses on designing the garden to include permanent, soil-based structures. In essence, permaculture helps farmers to understand natural influences that affect the homestead, and results in a better garden location and design that optimizes the use of available resources. For example, swales are used to direct and capture rainwater. Specifically, swales are used around the edges of permagardens to control and manage water, for pest management, and to provide the potential for year-round supplemental food production on the berms.

Garden observation and dialogue.
Photograph: **Thomas Cole**

'Bio-intensive agriculture' refers to the efficient system of planting, deep healthy soil structure, diet design, composting, and management of annual crops in beds that are found within protective and productive berms.

The permagarden method teaches how to design and integrate multiple agricultural practices in order to increase production and create a more resilient garden. The success of a permagarden often depends on three things:

1. Understanding of key permagarden concepts (described in this manual),
2. How well the garden is designed to capture water and nutrients, and
3. Incorporating as many agricultural practices fulfilling each key concept as possible.

This permanent garden is a small-scale, high-yield, nutrition-focused instrument of food security that anyone can create close to home.

Empowering gardeners to make decisions

Building resilient households includes empowering people to make decisions together that can improve their livelihoods.

Building a permagarden can be a productive decision that can improve the availability of food, but it requires upfront time and labor commitment.

Program staff should encourage households to carefully consider what decisions to make to maximize their livelihoods.

Key concepts of a sustainable home garden:

- **Utilize local resources.**
- **Create an efficient garden design.**
- **Improve soil health.**
- **Increase water management.**
- **Plant for maximum benefit.**
- **Conduct proactive crop health and protection.**

A permagarden does not rely on expensive material from outside the community; it can be successfully created and maintained using only local tools and seeds. This productive space is not always used to produce the same crop. Rather, it is designed and managed in such a way that, like a house, once built, continues to provide both protection from the elements and production for the family for many years to come. With a permagarden, a family can have a diverse supply of fresh, nutritious fruits and vegetables on a year-round basis. The pathways in between the permanent growing beds allow easy access to the growing vegetables, fruits, and other useful crops. The protective berms around a permagarden's borders can hold local medicinal, herbal, and flowering plants that live from year to year and never need replanting, yet continue to provide useful products. The permagarden is intended to be located close to the home and therefore easy to manage, even for children, the ill, and the elderly.

Mercy Corps GHG group meeting under tree.

Photograph: **Thomas Cole**

Building resilient gardens and households

The permagarden method aims to build the capacity of farmers to withstand and adapt to environmental shocks and stresses, such as poor seasonal rainfall, droughts or floods, and still be able to produce nutritious crops throughout the year. This is achieved through applying the principles of creating a productive garden and by preventing dependence on outside or expensive resources. Materials needed for a permagarden are often available and accessible year-round within a farmer's community.

Enhancing resilience through permagardens means that programs must teach the basic agronomic principles and ideas behind the permagarden method instead of teaching how to replicate a particular practice. For example, at the end of the training, households should be able to manage rainfall runoff, not just build a swale, and to improve soil fertility, not just make compost. The fundamentals behind all of these practices are the keys to building resilient households.

Similarly, the design of the garden should not rely on only one agricultural practice to improve soil health or water management. Instead, the gardener should implement as many practices as possible to achieve these goals. For example, the gardener could use swales, berms, holes, and mulch to improve water management in the garden. As a general rule, the gardener should try to have at least three different agricultural practices for every function in the garden. Multiple practices are at the heart of the permagarden's success.

1 Identifying assets and resources

The permagarden method is based on using local resources to build and sustain the garden. A simple walk around a home, neighborhood, or village can highlight many assets and resources that can be useful in building, sustaining, and protecting these productive spaces.

Mapping local assets and resources.

Photograph: **Thomas Cole**

Assets Assets are useful items that we have in our possession (could be personal or communal), for example, land, seeds, bicycles, animals, unused organic matter, and tools.

Resources Resources are people, assets, materials, or capital that can be used to accomplish a goal.

Building local skills and confidence is a critical first step in creating sustainable gardens. It begins by taking a walk around the household and the community to determine what may be of use. Waste materials, such as charcoal, wood ash, manure, and green and brown organic material, contribute to the goal of soil health, but to simply tell people this fact is not enough.

Drawing out local knowledge via open conversation leads to local empowerment and ownership of the garden.

After walking around and determining potentially valuable resources and assets in the home and throughout the community, the next step is to map suitable potential garden areas in the homestead. There could be unused spaces or waste areas that could be converted into a bounty of produce by clearing the land, controlling the water flow, and managing new plants. Empowering families to make their own decisions about what areas are better than others, as opposed to imposing these decisions from the outside, results in greater buy-in from gardeners. Several key elements should be assessed for use:

Available space The space available to a household for a permagarden can be as little as a few square meters or as large as 100 m^2. Locate the garden within, or close-by, the compound, preferably next to the kitchen. Look for areas next to buildings or fences that are currently not well used but still receive at least 4 hours of sunlight a day. Walls, trellises, and fences allow for vertical planting, increasing production potential from a small piece of land.

Waste materials Animal manures have nutrients and organic matter that are critical to soil health. Wood ash, biochar, and charcoal dust provide key minerals and micronutrients and help hold soil moisture. Kitchen waste, green and brown leaves, and water can be collected and used to create valuable compost. Coffee

grounds provide organic nitrogen. Bones and egg shells are good sources of calcium and phosphates. Dried cow bones can be burned and then crushed to provide an important phosphorus-rich powder to improve the soil or to add to compost.

Water sources Underutilized runoff water from roofs, hillsides, roads, and pathways can be controlled, redirected, and stored within the homestead (especially in the soil). Homestead wells or municipal taps nearby can also be used. Household wastewater from the kitchen and bathing can become the primary irrigation source in the dry season.

Livestock Livestock are sources of useful materials or labor, but also need to be controlled by fencing or other means.

People Neighbors or other farmers in the community may have valuable knowledge that can be used, especially in areas of water or soil management.

Plants and seeds Many indigenous varieties are important to food security and are already readily available within the informal seed markets. Neighbors, friends, and extended family may have seeds or plants they are willing to share. Many perennial herbs, such as lemongrass and aloe, can be divided and replanted.

Fodder plants and grasses can similarly be planted strategically to provide food for animals.

Tools The only tools required to create a vibrant garden are a hoe, bucket, pick, and machete. Survey the household and neighborhood for additional tools that could be useful, such as rakes, watering cans, empty grain sacks, and twine.

Abundance of local materials available (above).

Discussing uses of local plants (right).

Photographs: **Thomas Cole**

2 Site design

Long-term planning and mapping of the garden will help lead to improved soil health and water management, limiting nutrient loss and building resources for the future. One of the first steps in site design is to understand the natural flow of rainwater and nutrients across the landscape, determining where and how runoff water enters the land and where it exits. The runoff from upstream is often full of nutrients, including animal manures, organic material and topsoil. Managing water flow is an important way of capturing and delivering these nutrients to a garden and preventing them from leaving it.

The aim is to effectively control water during the wet season and to access it during the dry season. Once water flow is understood, basic agronomic practices can be employed to capture the water. In this way the gardener can build a garden that slows the water on the land, allowing it to spread and sink into the soil.

Size and location

Site assesment.
Photograph: **Thomas Cole**

A permagarden can be located anywhere near the home. The size should be related to the amount of water available and the level of energy the gardener is willing to commit. Permagardens can be as small as 2 m^2 (e.g., 1 m by 2 m) or as large as 100 m^2 (e.g., 10 m by 10 m). In land-constrained areas, such as urban and peri-urban plots, or in refugee or internally displaced person (IDP) settings, the permagarden approach can provide an important source of food production when traditional vegetable growing is extremely difficult. In the dry season, garden beds can be scaled down to accommodate reduced water availability.

A good starting size for a typical household garden in a FFP program is 16 m^2 (e.g., 4 m by 4 m). More space can be added later, depending on family commitment and desire to expand, but it is important to start small. Beginning with a large space can quickly become too labor intensive and discourage farmers from continuing. Starting small provides the possibility for further expansion to meet family needs, and more effectively utilizes scarce resources, such as water. Once a farmer has the understanding and skills to manage an effective garden, then he or she can explore increasing the size of the garden to produce more vegetables than the household can consume to be sold in the market.

Choosing the best location for the garden at the homestead is important. The garden should be close to the home to allow for easy management.

Key characteristics of an ideal permagarden site:

- Receives full sunlight at least 4 hours a day.
- Accessible to all family members.

- Protected from extreme winds, livestock, or other damaging elements.
- Contains soil that is relatively free of rocks.

In addition, there are many natural influences that may affect the garden, such as the sun's movement across the land or the slope of the land. A few natural influence considerations when choosing the garden site include:

- In hot locations with a strong sun exposure, choose a site with shade or partial sun for part of the day.
- Place the garden downslope from a chicken coop or kraal (while still protecting the garden from animals) to allow gravity to bring manure and nutrients into the garden during a rain.
- Place the garden away from the trash pit or other hazardous materials.

Garden design and layout

After the garden site is chosen, it should be cleared of rocks, weeds, and other debris and then lightly cultivated—using a hoe to remove weed and grass roots that are just below the surface. As long as they have not gone to seed, these removed weeds and grasses can be used later in the composting process once the roots have completely dried out.

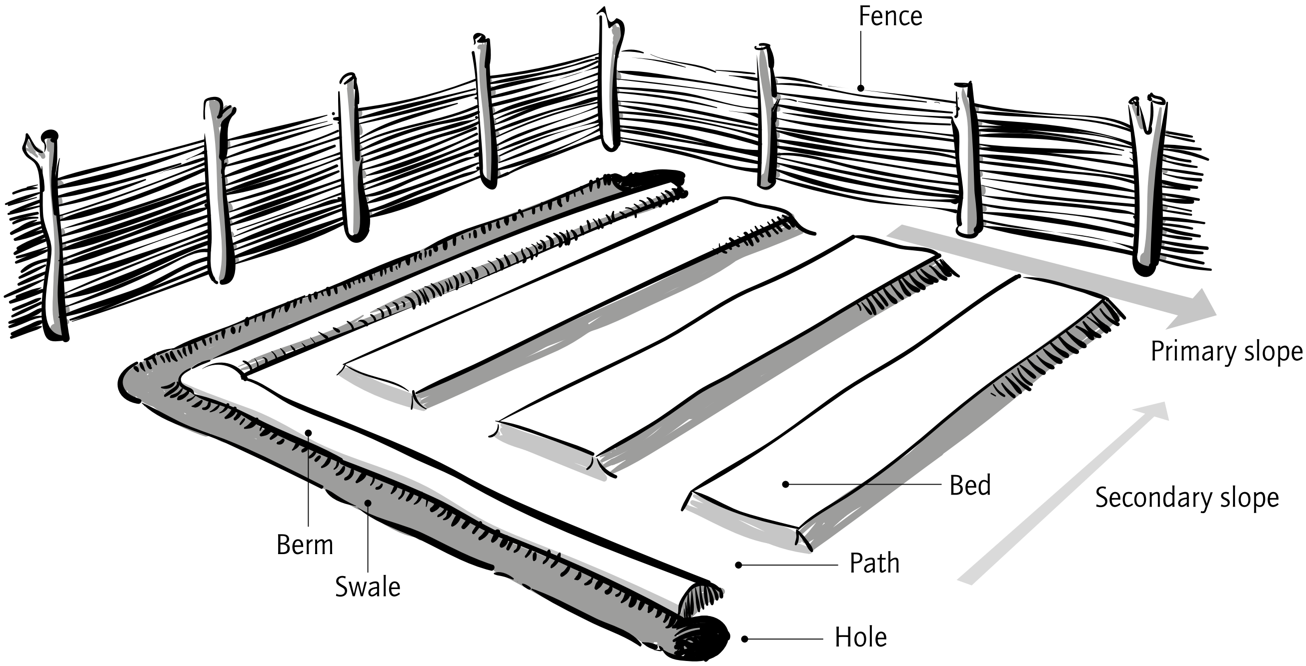
The gardener can control water flow into and through the garden for maximum use. It is therefore important to determine where rainfall will enter the garden and how water will flow through the garden. As water flows down slope across the land, it carries nutrients from other areas, including manure and biomass. The aim of the garden design in dry regions is to encourage these nutrients to flow into the garden and to sink into the soil, especially for use in the dry season or during dry periods in the growing season. Likewise, good design can help mitigate flooding in wet regions by diverting excess water away from the garden, preventing crops from getting waterlogged.

The flow of water is controlled through effective design and integration of technical practices, such as double digging, composting, close plant spacing, and mulching, combined with the appropriate use of swales, berms, holes, beds, pathways, and fencing. Using these techniques can significantly increase the amount of water infiltrated into and stored in the soil.[6] All of these components should be planned out on the cleared site. Each one of these components is discussed in greater depth later in this manual.

6 For more information, Creating Drought Resistant Soil http://www.fao.org/docrep/009/a0100e/a0100e08.htm

Since permagardens are designed to obtain the greatest benefit for the farmer and the garden, each garden design will look different depending on the context. Example instructions for planning and designing a permagarden are listed below. When drawing the lines in these instructions, it might be helpful to have string and stakes to plot the design. Make sure that the garden plan allows for enough space for a fence to surround the garden.

Basic garden design or layout



One example of how to plan and layout a permagarden

(see Appendix 1)

1. Step back from the cleared garden area and look for the steepest change in elevation from top to bottom. This change in elevation is called the ‘slope’. A swale(s) or ditch(es) should be placed to capture water as it flows into the garden. It is best to place the swales on the upslope side, at the highest point, to stop the water before it reaches the garden beds. This helps to protect the garden as it captures the main flow of water and nutrients from upslope, and allows the water to seep into the soil and move slowly towards the garden beds below the surface.
2. Draw a line along the side of the garden where the swale is planned. Keep the points of the line at the same elevation by using the A-Frame (explained in Water Management section (page 31). This line forms the border of the upper part of the top swale.

Another permagarden design.
Photograph: **Thomas Cole**

3 Draw a second line parallel to the first line down the slope. These two lines mark the entire upper swale. The swale should be large enough to hold all the rainfall that will flow into it during a rain (approximately 50-100 cm wide). Note: Often the swale will not be in a straight line because the contour of the land is not straight.

4 At one end of these two lines draw a 75 cm wide circle. This marks the receiving hole that will capture water coming into the garden that overflows from the swale.

5 Envision this hole filling with water. As the water slowly overflows out of the hole, it should be directed along the side of the garden so that it does not flow into the garden beds. Draw an outline of a swale along the side of the garden that will carry this water down the slope eventually into another hole (i.e., an overflow) that will be part of the side swale.

6 Draw a line parallel to the swale, approximately 50 cm toward the outside of the garden. This is the side berm.

7 Draw a lower swale, along with an approximately 50 cm wide berm on the outside of the garden and hole, the same as the swale at the top of the garden.

8 Draw a parallel line approximately 40 cm down the slope from the upper berm. The area between the berm and this line form the upper permanent pathway.

9 Draw another parallel line approximately 1 m down from this line. These two lines (the line at the bottom of the upper permanent pathway and the line drawn in this step) outline the first garden bed.

10 Below the first bed, repeat Steps 8 and 9 to create the outline of as many 1 m wide beds as the space allows. In dryer regions, the garden beds should not be raised in order to conserve soil moisture.

There are no exact measurements for the swales, holes, and berms. Some are straight and some may be curved, depending on the contour of the land. The size of these water harvesting structures also depends on how much water enters the garden site. If the garden is downslope from a large catchment area, or if the area tends to have heavier rainfalls, then the swales may need to be big. If the garden is in a refugee or IDP camp with limited space, the water harvesting structures may be small. The most important point is to place the water harvesting structures on contour. If they are not on contour, then water can flow out of the garden and be lost due to poor design. This is covered in more depth later in the manual.

The design of the garden can be continually adjusted. A gardener should gather feedback from the garden and make adjustments as necessarily. For example, if the gardener notices a swale fills up when it rains then the swale can be enlarged or an overflow added.

Permagardens are designed based on the specific garden site.
Photograph: **Eric Carlberg**

3 Soil health

Healthy soil is the basis of a productive garden. Increasing the amount and improving the quality of the air, water, and organic material in the soil leads to increased water infiltration and retention, nutrient cycling, and soil biological diversity in the soil, resulting in healthier, more nutritious crops and higher yields.

With a sound, long-term approach, healthy soil can be achieved regardless of initial soil quality. It is important to understand soil basics:

- Soil is a living substance that must be nourished, managed, and protected.
- Soil organisms help break down crop residues and plant matter into soil organic matter (SOM).
- SOM improves the structure of the soil, increases microbial activity, increases water infiltration, enables water retention, and increases nutrient availability for plants.
- Soil fertility management is achieved through conserving soil, water, and SOM; increasing SOM content; and supplementing nutrients through soil amendments.
- Deep soil quality is necessary for plant roots to maximize nutrient and water uptake and to maximize production. Double digging can improve deep soil quality when combined with compost and other amendments (see page 18).

The 'ideal' soil is 25% air, 25% water, 45% mineral particles, and 5% organic matter. Analyzing the existing soil helps unlock its potential to grow more crops. The critical elements of healthy soil are its physical properties, nutrient availability, biological activity, and deep soil quality.

Soil physical properties

Soil physical properties are broken down into soil texture and structure.

Soil texture

Soil texture refers to the size of the soil particles. The soil textural classes, from the largest to smallest soil particle size, are sand, silt, and clay. Knowing the textural class of the soil gives clues to the farmer about its current nutrient and water-holding capacity, and opportunities for improving the soil.

- Sandy soils (soils with a higher percentage of sand than clay and silt) drain well but do not hold nutrients for long periods of time. As water moves through sandy soils, plant nutrients are washed away. Sandy soils are very susceptible to wind erosion but are less vulnerable to water erosion.
- Silt soils (soils with a higher percentage of silt than sand and clay) are relatively fertile compared to clay and sandy soils, but are most at risk to water erosion.

Compost.
Photograph: **Thomas Cole**

- Clay soils (soils with a higher percentage of clay than sand and silt) hold onto plant nutrients, but are easily waterlogged and compacted.
- Loam soils are made up of a percentage of the three types of soil textures. The different percentages of sand, silt, and clay in the loam soil varies. They drain well, but also hold water better than sandy soils. They have high soil fertility and are best suited for agriculture.

Organic matter, incorporated into the soil in the form of compost, crop residue, manure, and biochar, can be used to improve soil quality if it is too sandy or clayey.

Soil structure

Water- and air-holding ability

How gardeners manage the soil, however, can create (or destroy) soil structure and the resulting soil quality and soil health. Soil structure refers to the way soil particles are put together. Some of this is natural arrangements, or groupings of particles into clumps based on the way the parent rock has degraded into soil, and the rest is influenced by soil and crop management.

There are many benefits to good soil structure, such as good water infiltration and root growth, reduced erosion, enhanced nutrient cycling, and increased biological activity in the soil, all leading to better crop production.

Soil structure can be protected or improved through good soil and crop management practices, such as:

- Using permanent planting beds and pathways to avoid walking on and compacting the soil.
- Practicing close plant spacing and mulching to create a protective plant canopy to decrease raindrop impact on the soil.
- Tilling the soil when it is dry or slightly wet.
- Having plants on the beds, which increases the soil biology and the resulting actions that form individual aggregates that improve soil structure.
- Adding organic matter (especially from compost), crushed charcoal and/or lime to the soil.

Nutrient availability

Soil acidity

Too much acid in the soil limits plant roots' ability to absorb beneficial minerals due to the presence of too many hydronium ions. These ions are removed from the root zone once the acidity is removed, which can be done through the addition of liming agents, such as calcium carbonate. Most minerals are available to plants in soils that are just slightly acidic (pH 6.0–6.8).[7] Soil acidity on either side of this range prevents nutrient retention in soil and limits uptake in the roots. Soil acidity can be changed by adding numerous amendments. For example, wood ash, which contains calcium carbonate, decreases acidity, while coffee grounds increase acidity. Farmers need to connect with local agencies to test the acidity of the soil in their gardens, but, in the meantime, they can increase a plant's ability to grow in either acidic or basic soils by adding large amounts of compost, manure, wood ash, and charcoal dust.[8]

Nutrients needed for healthy soil

While soil can appear inactive, there is actually a whole world of activity that supports agriculture going on every day under the surface. Plant roots search for water and critical nutrients. Soil microorganisms break down dead material and compete with each other for resources. All this activity means that there is a constant exchange of energy and nutrients between the soil, the air, and living and dead things. These exchanges are called cycles, and by following them step by step, we can see that soil is constantly being formed and reformed by the surrounding environment. By understanding these cycles, practitioners can better understand how to build long-term soil health.

Carbon cycle

Carbon is a basic element of living things, but it does not exist in just one form. It can be found in many things, from sugar to soil particles to gases. The movement of carbon from one form to another is called the carbon cycle, and all stages of life, from birth to death, are involved in this cycle. Without the carbon cycle, life would not be possible.

The carbon cycle plays an important role in agriculture. When a young plant grows, it takes in carbon from the air to make its food. When a dead plant decays, most of its carbon is released back into the air, but some carbon remains in the soil and becomes SOM. Over time, as more and more plants decompose in the soil, the level of SOM increases, along with the levels of soil microorganisms.

7 pH (which stands for 'power of hydrogen') is a measure of the amount of these acidifying ions found in the soil. Although pH can sometimes extend past 14, the typical range for soil pH is from 5.5 to 7.5. Acidic soils have a pH less than 7. The lower the number, the more acidic the soil. Basic soils have a pH greater than 7. The higher the number, the more basic the soil.

8 More information can be found in Test of your soil with plants 2nd edition by John Beeby.

As organic matter increases, the soil is able to support more plant life, which then returns more carbon to the soil. This cycle is the foundation for fertile soils.

Gardeners can use the carbon cycle to their benefit. Composting, crop residue management, and the addition of other organic matter all encourage the creation and utilization of SOM. These techniques are key to ensuring long-term soil health.

Nitrogen cycle

Nitrogen is another basic element of life. Without nitrogen, plants are not able to convert sunlight into food. The nitrogen cycle follows the movement of nitrogen from one form to another, just like the carbon cycle.

The air is mostly made of nitrogen gas, but plants cannot use nitrogen in this form. Nitrogen gas must be converted to other forms before plants can use it. This important conversion is carried out by certain soil microbes. These microbes live inside the roots of legumes (groundnuts, peas, beans). These microbes live inside the roots of legumes (groundnuts, peas, beans), where they have access to food created by the plants from sunlight.

By including legumes in crop rotations, gardeners can increase the level of nitrogen in the soil. Crops planted where legumes have been previously planted can then use the nitrogen stored in the soil for their own growth.

Applying woodash increases the soil's pH level.
Photograph: **Thomas Cole**

Local soil amendments

Many local resources exist around the home or the community that can help grow healthy plants and sustain productive activities. Animal manures, ash, charcoal dust, burned crop residue, and organic plant material are all valuable assets available locally that can be used to improve the long-term quality of the soil. These local soil amendments contain the same benefits as inorganic fertilizer: nitrogen (to improve leaf growth and help leaf formation), phosphorous (to improve root development and flowering), and potassium (to improve seed formation). Many of these resources can be added directly to the soil when tilling or preparing the permagarden (see page 26). They can also be used to help amend the soil when planting berms or other areas around the homestead with useful trees or shrubs. Other waste materials may need further decomposition, burning, or crushing before adding to the garden.

Wood ash is a primary source of calcium carbonate, which can increase the soil pH level (i.e., reduce the soil's acidity). A soil with a low pH (i.e., high soil acidity) blocks the uptake of beneficial minerals by the plant. Wood ash from cooking fires, found almost everywhere, counteracts this pH imbalance. Wood

ash is also an important source of potassium and supplies trace amounts of phosphorous and magnesium. Wood ash can be applied directly to the soil and mixed in before planting. The application rate should be no more than 1kg per 10 m^2. Wood ash works best when it is in contact with as much soil as possible. Broadcasting ash on the surface without mixing it into the soil does not raise the pH effectively.

Charcoal is an important soil amendment, especially the small chips and dust no longer useful as fuel. The addition of charcoal dust helps increase water retention, creates habitat for microorganisms, and permanently improves the soil's ability to hold nutrients by increasing its Cation Exchange Capacity (CEC). This becomes even more important in sandy soils, which have a difficult time holding nutrients, and in gardens in subtropical or humid areas where compost or SOM breaks down rapidly in the soil. Charcoal dust helps keep these nutrients from leaching out and makes them more available for crops in a permagarden.

Charcoal dust can be added annually to the garden, 1–2 cm spread over the top of the bed and then mixed into the top 10 cm of the soil. In most communities, charcoal dust is readily available where vendors sell bags of charcoal.

Biochar is charcoal made specifically for soil improvement using whatever abundant and underused crop residue, such as maize or sorghum stalks, rice husks, and sugarcane bagasse, is available. If not made on purpose, it can often be found in large burn piles within crop fields. In areas with high levels of usable crop residue, making biochar is a good way to provide this amendment for both the permagarden and the field crop garden. Instructions to make biochar can be found in Appendix 3.

Making biochar (above).

Gathering soil amendments (right).

Photographs: **Thomas Cole**

Coffee grounds are an excellent and, depending on location, abundant source of organic nitrogen. It is already in a stabilized form and is slowly released into the water in the soil for uptake. Coffee grounds can be added to the compost pile, mixed directly into the soil during the double digging process, or added as a soil amendment when planting trees or other plants around the homestead.

Egg and oyster shells are an excellent source of calcium, important for healthy flowers. Both must be dried and, in the case of oyster shells, slowly burned, before being crushed into powder. For the calcium to become available for plant uptake, however, it must first be digested by soil microbes, one more reason to make sure the garden soil has ample organic matter and compost.

Kitchen scraps are a tremendous source of macro- and micronutrients, as well as organic material for the compost pile. These include Irish and sweet potato peelings; the tops of beets and carrots; the stems from kale, chard, and other greens; and the rinds or peels of fruit, such as melons or bananas. In addition to composting, kitchen scraps can be converted into nutrient- and microbe-dense 'tea' for irrigation and leaf application to garden crops following the method described in the plant health section. Collecting kitchen scraps in rubbish pits around the compound is an effective way to store these materials and help them decompose before putting into a compost pile.

Manures are good sources of organic material for the garden, and they provide small amounts of nutrients in the form of nitrogen, phosphorus, and potassium. Manure can be sourced from cows, pigs, chickens, goats, rabbits, horses, sheep, ducks and other fowl. It is important to use well-aged (dry) manures in the garden, after they have decomposed or composted for several months, as fresh manure can contain harmful pathogens and may harm plants if applied directly to crops. In addition, manure from dogs should not be used in the garden, because it is more likely to contain pathogens. Fresh manure, as well as a slurry of fresh manure and cow urine, can be used to make a liquid manure tea. This tea can then be applied through leaf feeding or through drenching the roots of the crops.

Applying well-aged (dry) manure to the garden:

- Locate a source of well-aged manure (poultry or cow manure may be the most available in the community).
- Gather enough to apply 2–5 cm over the area where crops will be planted.
- Mix into the top 20 cm of the soil.
- Repeat before every planting cycle.

Mixing manure into the soil.
Photograph: **Thomas Cole**

Biological activity

Microbes

Although invisible to the naked eye, the fungi and bacteria (collectively known as microbes) in soil play a critical role in the carbon and nitrogen cycles. Without them, dead plants would not decay; they would simply remain on the soil surface for years. With them, dead plant material is incorporated back into the soil as organic matter and nitrogen is cycled into forms that plant roots can absorb.

By conserving soil moisture, rotating crops, and increasing SOM, bio-intensive agriculture provides the conditions that allow soil microbes to thrive. In doing so, a gardener can reap the benefits through healthier crops and higher yields.

Soil organic matter

SOM is a critical component of healthy soil. The most productive agricultural lands in the world are areas with high SOM. SOM consists of plant, animal, and microbial residues at various stages of decomposition. SOM can range in age from a few months to thousands or even millions of years. It can be a maize plant that has partially decayed over the last 6 months or tiny particles that have been formed over centuries. The final product of decomposition, humus, is a dark and crumbly material that has stabilized over time.

Without SOM, soils would be much less hospitable to plant growth. SOM increases a soil's ability to retain nutrients, improves soil structure, increases air flow, and provides a rich environment for soil microbes active in nutrient cycling and disease suppression. All these factors work together to provide ideal conditions for healthy root growth.

In a general sense, SOM can be seen as a buffer against extreme conditions. It protects the soil against sudden changes in acidity. It improves water drainage of clay soils and water retention of sandy soils. Soils with low SOM do not have these benefits, and crops grown in soils with low SOM more quickly succumb to environmental stresses. Managing SOM in this respect is a building block of a resilient household. Decreasing the amount of tillage, adding organic matter to the soil, and keeping plant cover on the garden are all ways to maintain or increase SOM.

Compost

Compost is a key way to add SOM to the garden. Organic matter, best applied as compost or rotted manure, is the most important ingredient that can be added to improve garden soil. In addition, it combines with other processes to ensure superior levels of air, water, microorganisms, and minerals essential for vigorous root health and corresponding growth and crop yield. Just a single tablespoon of finished compost contains over 7 billion beneficial microbes that work to ensure long-term soil and plant health. As discussed below, compost plays many roles in the soil. It is also easy to make if enough materials are available. Over the course of just a few months, locally gathered waste materials can be converted into a soft, nutrient-dense asset (Appendix 2).

Decomposition is a natural process of nutrient cycling. When dead plants or animal manures are left in the field, their nutrients eventually return to the soil as they decompose. Composting is just a managed process of decomposition that maximizes the benefits for the gardener. With the right materials and proper maintenance, a compost pile produces nutrient-rich material that can help improve soil over the long term.

Composting relies on soil microbes to break down material. Therefore, it is important to provide the right materials in the right amounts for the microbes to work efficiently. The basic ingredients for good compost are brown, carbon-rich materials; green, nitrogen-rich materials; air and water. Composting works best when the pile has one-third 'green material' and two-thirds 'brown material'. Up to 10% of the composting material can be soil as well. As a general rule of thumb, green material is moist, flexible, and high in nitrogen, while brown material is dry, brittle, and high in carbon. A variety of greens and browns can be used. The green material can include vegetable scraps, fresh crop residues, manure, and weeds that have not gone to seed. The brown material can include corn cobs, straw, and dry leaves. Too much of either green or brown material slows the decomposition process and lengthens the time until the compost is ready. Supplying sufficient water for the microbes to live is important. Too much

Effective compost requires a good mixture of plant materials.
Photograph: **Peter Jensen**

water and they will drown with little access to air. Too little water and they cannot function as well. A simple method to gauge the right amount is to hold the early compost materials in your hand and squeeze it hard. If water runs out, it is too wet. If your hand does not glisten when you open it up, it is too dry.

A well-made compost pile heats to 120–140° Fahrenheit (49–60° Celsius) after just 2 days. One 1m^3 pile, after 2 or 3 months (turned over once every 1–2 weeks, adding water as needed), provides ten 20 L buckets of finished compost for use in the garden. This is enough for three 5 m garden beds. During garden bed renovation, following the removal of the previous crop, one 20 L bucket of finished compost should be added per two square meters.

When blended and managed over the course of 2–3 months, a compost pile creates a material that improves the health of the soil and the plants that grow in it.

A well-made compost heap provides nutrients to enrich garden soil.
Photograph: **Thomas Cole**

Compost provides many benefits to the garden:

Improved soil structure Compost is an important soil conditioner. It breaks up heavy clay soils and binds together sandy soils. This improved structure allows a sandy soil to hold water and a clay soil to drain water, promoting proper root growth and health.

Soil moisture retention The organic matter in compost allows it to hold six times its weight in water. A soil with good organic matter content soaks up rain like a sponge and regulates the supply of water to the plants. A soil stripped of its organic matter resists water penetration, leading to crusting, erosion, and flooding.

Aeration A well-aerated soil assists in the diffusion of air and moisture into the soil and in the exchange of nutrients. Carbon dioxide released by organic matter decomposition diffuses within and above the soil.

Fertilization Compost contains many elements that are essential to plant growth, including nitrogen, phosphorous, potassium, magnesium, and sulfur, and is especially important as a source of trace elements, such as molybdenum, zinc, and iodide. In addition, compost increases a soil's CEC, which increases its ability to hold nutrients.

Nutrient release Related to fertilization, organic acids released by decomposing organic matter dissolve soil minerals, making them available to plants as food. As organic matter breaks down, it slowly releases key nutrients for plant uptake and a healthy soil microbe population. Nitrogen, one of the most important plant nutrients, is also the most easily lost to leaching and gasification.

Soil acidity and toxin buffer Plants have specific tolerances in terms of toxins and soil acidity. Organic matter, in particular the carbon molecule, draws these toxins and acidity out of the soil water, allowing plants to have a broader range of tolerances to these elements, which are common in the world's poorest soils.

Germination and early seedling growth Steady moisture levels are required for a seed's coat to crack and germinate. Compost in the soil acts as a sponge, absorbing water and keeping the seed moist. This increases the speed of germination and the likelihood of the fully developed young plants — called seedlings — to survive periods of dry weather that would otherwise destroy the tender stems, roots, and leaves.

How to make compost

Materials needed:

- Brown/dry leaves or grasses – about six large sacks.
- Green grass, leaves, or weeds from garden area (no seeds!) – about two large sacks.
- One 20 L bucket of manure or good topsoil (source of bacteria).
- Three or four 20 L buckets of water.
- A 1 m stick to use as an aerator and thermometer.
- A machete or hoe to chop the material into small pieces.

Materials that should NOT be added to a compost pile:

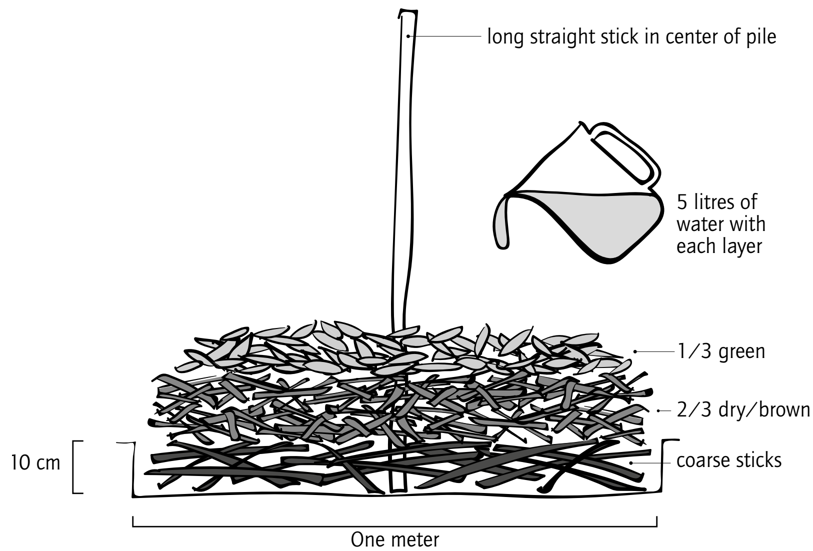
- Plants known to be diseased or under severe insect attack.
- Plants that are toxic to other plants and microbial life, such as hemlock, acacia, juniper, bamboo, gmelina, onion, citrus, castor bean, and eucalyptus.
- Plants or plant materials that may be too acidic, such as pine needles.
- Perennial, invasive weeds and their root systems, such as wild morning glory, and Kuch, Bermuda, Striga, or Kikuyu grass.
- Soap, oil, meat, or the manure from meat-eating animals, like cats and dogs, which may contain pathogens.
- Human excrement.

Compost instructions[9]

1. Select a place in the shade. Too much sun dries out the compost pile and slows down the decomposition process.
2. Gather brown and green materials. Large leaves should be chopped into small pieces to speed the decomposition process and release moisture and minerals. A properly made compost pile contains one-third green materials and two-thirds brown materials.

9 This is only one way to make compost. Another method is to have a high C:N ratio. This method can be learned from the additional resources listed at the end of the manual.

3 Put down an initial 5-15 cm layer of coarse sticks. This helps aerate the pile from below, enabling air movement through the pile during decomposition.
4 Begin to layer and mix the brown and green materials. Start with a 20 cm layer of brown.
5 Add a 10 cm layer of green.
6 Add 2 cm of topsoil, manure, or finished compost (approximately 4 large handfuls).
7 Blend all layers together while water is added to moisten well.
8 Repeat Steps 4 through 7 until the pile is 1 m wide by 1 m deep by 1 m high.



9 Cover with 2.5 cm of topsoil and a sheet of plastic to help hold the moisture in the pile. If plastic is not available, then cover with dry grass.
10 After 2 days, the pile becomes very hot. This means that the bacteria are working to break down the materials. DO NOT MIX. Measure the temperature only if desired.
11 WAIT 1 WEEK. Gently mix while adding more water to keep moist. Cover well.
12 WAIT 1 WEEK before mixing and applying water again. Cover well.
13 Allow pile to rest for at least 2 weeks before mixing again. Cover well.
14 Continue to mix every second week, watering and covering until the inside of the pile is brown, crumbly, and cool to the touch. At this point, the compost is ready to be used in the garden.

Deep soil quality

Deep soil quality (healthy soil in both the topsoil and subsoil) is important for good plant root growth. The average garden is tilled to the depth of the equipment normally used to work the land. At best, this means soils are aerated to about 20 cm, the length of the average hoe blade. Over time, with successive tillage to the same level, a nearly impermeable subsoil—a 'hard pan'—is created that blocks the movement of air and water through the soil profile, which in turn stunts the growth of the roots of plants. If plant roots are not able go deep into the soil (which they can do only if there is a good air-water dynamic in place), then they must be planted farther apart so as not to compete with neighboring plants for air, water, and nutrients. When planted farther apart, sunlight easily reaches the soil surface, causing weed germination, moisture loss, and overall weaker, underproducing plants. All these losses are avoided by having deep soil quality.

When the starting soil is unhealthy, there are some techniques the farmer can use to speed up the process of having deep soil quality, such as double digging. By preparing the soil deeply, i.e., breaking through and amending the compacted subsoil layer, ample air, water, and carbon allow healthy plant roots to go much deeper into the soil.

Double digging.
Photograph: **Thomas Cole**

Double digging

When starting your permagarden for the first time, or working with unhealthy soils, the permagarden method recommends practicing double digging.[10]

Double digging requires a lot of effort, but ultimately it creates a garden bed that is easier to manage.[11] Since double digging requires so much work, it is important for a gardener to work during the cool part of the day or to dig after a rain when the ground is soft. A gardener can also make the process easier by teaming up with neighbors and family members.

Often when a garden bed is prepared using double digging, the bed will increase in height due to increased aeration in the soil. However, in arid areas, the finished beds should not be raised; rather, they should be kept at soil level, or even slightly sunken, to help conserve moisture. The beds still need to be double-dug, but the finished height needs to be lower to avoid the soil drying out when hot winds blow.

Double digging allows for closer plant spacing, as the roots grow down rather than to the sides. Double-dug beds are permanent, which allows them to absorb and retain water more effectively. They can be amended with important nutrients and SOM that is sourced locally. Crops can then be rotated between beds or from one place in a bed to another place in the same bed from season to season to maximize pest control and achieve higher yields.

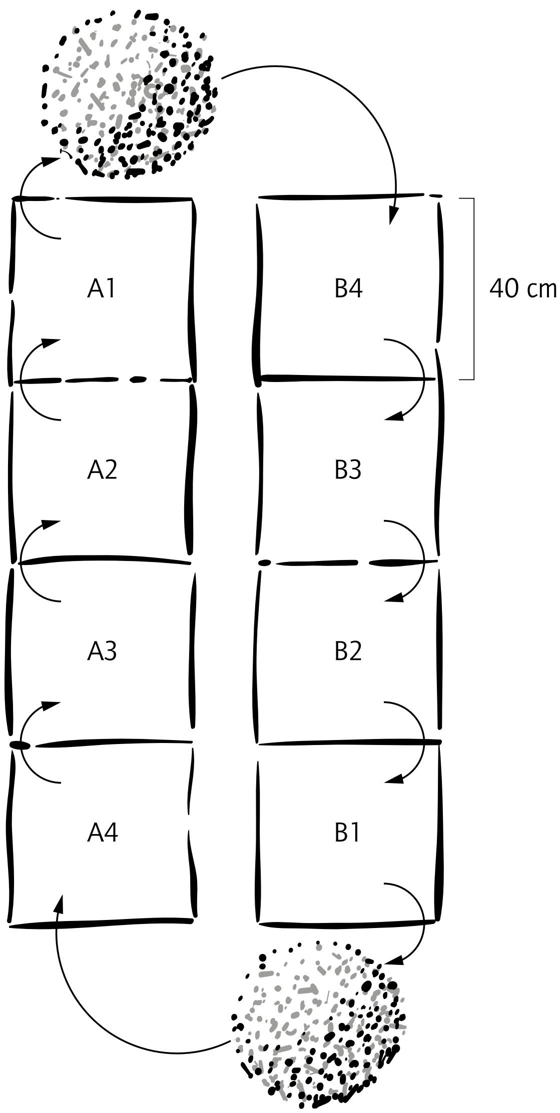
10 It is important to note, however, that once the farmer has obtained deep soil quality, benefits from double digging decrease, and increased oxidation and disruption can cause losses in SOM.

11 A double-dug garden bed does not need to be dug again once deep soil quality is obtained.

How to double-dig a permagarden bed (Appendix 4)

Begin by marking the edge of the permagarden beds using sticks and string or a hoe in the dirt. Make sure that all the beds, pathways, swales, berms, and holes are measured and marked before beginning to double dig.

1. Once a bed is marked, measure 40 cm segments along the bed lengthwise. Put small stakes at the 40 cm marks or simply mark with a hoe.
2. Remove 20–30 cm of topsoil from first 40 cm section (A1 in the diagram below), digging down until the hard pan is reached. The removed topsoil should be kept at the end of the bed.
3. When possible, have a partner dig the next 20–30 cm of subsoil from the same section, loosening and digging but not removing the soil. Keep loosening the whole section until most of the larger pieces have been broken up.
4. Add compost, manure, wood ash, charcoal dust, or any other soil amendments to the loosened subsoil. One shovel or several handfuls of each amendment is enough.
5. Using a shovel or a hoe, mix these amendments into the subsoil.
6. When possible, have a partner dig 20–30 cm of topsoil in the next 40 cm section. As it is dug up and loosened, place this topsoil on top of the subsoil section that was just amended. Make sure that all the topsoil gets removed.
7. When possible, have a new person loosen the subsoil as in Step 3. Repeat Step 3.
8. Amend the soil, following Steps 4–5.
9. Repeat Steps 3–6 until bed is complete. The saved topsoil from the start of the bed should be used to build up the bed in the last 40 cm section.
10. Once the double digging process has been completed, add more manure, compost, and soil amendments to the finished bed. Add one shovel full or several handfuls every 50 cm.
11. Smooth out the top with a rake or hoe or by hand, creating a flat planting space. The garden is now ready for planting or seeding.



Double-digging demonstration (top right).
Photograph **Thomas Cole**

Sequence for double digging a permagarden bed (bottom right).

4

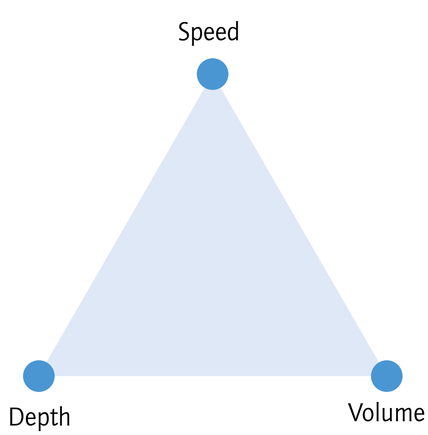
Water management

Water is the most critical element for plant growth. Without it crops cannot grow. It can also be the most limited and precious resource, especially with expected higher temperatures and irregular rainfall patterns made worse by global climate change.

Globally, rain-fed agriculture uses only 35–45% of the rain that falls; in some areas of sub-Saharan Africa, this amount drops to 15–20%. The question is not how to access more water, but rather how to improve water use efficiency, especially in areas where the amount of land available for planting crops is limited.

Even in dry locations, a lot of rain can fall on a small piece of land: 1 mm of rainfall converts to 1 L of water per m^2. This means that in a region that receives only 150 mm of rainfall each year, there are 150 L of water that fall per m^2. In other words, assuming a typical rainy season, 2,400 L of water fall directly on a 4 m by 6 m garden, which is more than enough to grow a wide variety of crops. And this does not include all the rainfall on the rest of the land upslope from the garden, which can be directed into the garden to increase moisture availability.

Effective water management also decreases soil erosion. Unmanaged rainfall hits the land and flows over and out of the garden, taking the soil with it. Over time, a lot of nutrients and soil are lost due to rain. By effectively managing rainfall, the impacts of erosion are minimized and the nutrients and organic matter built up in the soil can remain in the garden.



The level of soil erosion caused by water is represented on the soil erosion triangle. A farmer can reduce the amount of soil erosion by slowing the water's speed, by reducing the volume of water moving across the land, or by reducing the depth of water moving across the land. A garden design that manages the rainfall will not only capture the rain for the garden, but will also prevent the top soil – and its nutrients – from flowing off the site.

The permagarden design allows for the efficient capture and retention of even the most minimal rainfall through micro-catchments (small methods to capture water). At the same time, it allows for the safe and easy removal of excess water to minimize erosion or flooding. The design is also based on the efficient reuse of household wastewater and other practices that conserve water in the garden. The key is for a gardener to make the most out of the available water, which involves minimizing water runoff, evaporation, and waste, and allowing it to enter the soil. Water can be captured from several sources, including:

- Rainwater harvesting.
- Water retention.
- Household spare water management.

Swales help to conserve and store water in the soil (top).

Photograph **Thomas Cole**

The Soil Erosion Triangle (above).

Rainwater harvesting

Rainwater harvesting is the capturing of rain that falls on the land. It requires the gardener to design the land and implement a planting approach to prevent rainwater from leaving the garden site through a collection of practices, including swales, berms, half-moons and catchment holes. In dryland areas, the gardener's aim is to retain all the rainwater that falls or flows on his or her land.

The first step to effective rainwater harvesting in a permagarden is to understand the three key 'S' principles of water management: Slow, Spread, and Sink. Once these principles are understood, a gardener can identify his or her main sources of water and then implement the best range of practices to utilize those resources.

Slow, spread, sink

Effective water management in the garden begins with the three 'S' principles: Slow, Spread, Sink.

Slow the water down so it can infiltrate into the soil. Once the water falls on the land, the gardener needs to slow the movement of the water. Slower-moving water has a much better chance of providing crops the moisture that they need than water that flows over the surface of a garden and runs off. Mulch, swales, rainwater catchment holes, and half-moons are all practices to help slow the water.

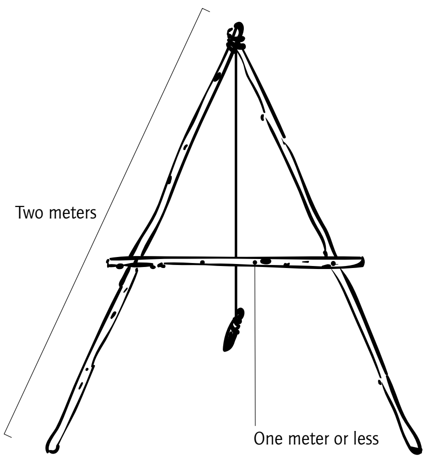
Spread the water across and through the soil so all plants can use it. Water that infiltrates slowly is able to spread throughout the soil profile, providing more plants and roots with access to moisture and nutrients required for optimal production.

Sink the water deep into the soil. By implementing water-holding practices throughout the garden (swales, berms, holes, and other micro-catchments), captured rainwater is encouraged to sink and infiltrate deep into the soil. The deep soil quality in permagardens also enables water to sink far deeper into the soil than in conventional approaches. In effect, double digging stores water in the soil and helps roots grow deep to access it, especially in drier conditions when normal gardens may have already dried out.

Mango tree with boomerang berm blooms while other mango tree does not bloom.
Photograph: **Eric Carlberg**

Understanding the contour of the land

A key idea behind designing and building a permagarden is to understand how water will enter and flow through the land. By understanding the flow of water, the gardener will be able to more effectively slow, spread, and sink the water, leading to increased water capture and less soil erosion. One good way to do this is to find the contour across the slope and build micro-catchment structures to both control and capture the rainwater. A contour line is defined as a line whose every point shares the same elevation, such that water flows perpendicular to the contour down the slope. Even land that looks flat likely has some slope, and a gardener should always find the contour when designing and building a permagarden. To begin measuring contour lines for a permagarden, a gardener should start at the top of his or her garden and work down the slope. Starting at the top ensures that there is less volume of water and that the water is moving as slowly as possible before it is brought into the garden.



Building and using A-frames

An A-frame is a low-cost, yet valuable tool that gardeners can use to determine the contour of the land to effectively design a permagarden.

Adding straw reduces water loss through evaporation and water runoff (above).

Building an A-frame (right).

Photographs **Thomas Cole**

How to build an A-frame

1. Gather three sticks (two at least 2 m long and one 1 m long), a few nails, twine, and a small rock. The sticks can be bamboo, cut boards, or taken directly from a tree. They should be thick enough to not break when nails are put into them or bend when used in the field.
2. Nail/tie the two longer sticks together at one end with the opposite ends approximately 1.5 m apart. In place of nails, thin strips of bicycle inner tube work well to lash the sticks together.
3. Nail/tie the 1 m stick halfway down each of the two longer sticks,

connecting the two longer sticks together. This should create a capital 'A' with the sticks.

4. Nail one end of the twine at the top of the 'A' with the string flowing down the middle of the A-frame, approximately 30–50 cm past the middle stick.
5. Tie a rock at the end of the twine. The rock should be sitting 10-20 cm below the bottom of the middle stick.
6. It is now time to calibrate the A-frame.
   a. First, put one leg of the A-frame on a flat, elevated place approximately 10–15 cm above the ground, while the other leg is on the ground. The elevated leg can be put on a rock, stick, or just an elevated piece of land. Make sure the A-frame is stable. Mark a light line where the string crosses the middle stick.
   b. Next, put the other leg at the exact same elevated spot and put the second leg on the ground at the same spot where you put the first leg. Mark a second light line where the string crosses the middle stick.
   c. Finally, put a line halfway between the two light lines on the middle stick. Make this mark bold so it stands out. This will be the center of the A-frame.

Determining contours of the land using an A-frame.
Photograph: **Thomas Cole**

How to use an A-frame to determine the contour of the land

The gardener can now use the A-frame to determine the contour of the land:

1. Start at the highest point in the garden site, at one corner of the garden. Place one leg of the A-frame on the ground and put a stake, small stick, or rock at that point. Digging a mark with a hoe can work in the absence of other items.
2. While keeping the first leg at the starting point, move the second leg until the twine is exactly on the center line on the middle stick. Put another stake in the ground at that point. These first two stakes share the same elevation across the slope and are the beginning of the first contour line.
3. Keep the second leg at the last marked point on the ground and rotate the A-frame, moving only the first leg, until the next point in the garden that centers the twine in the A-frame is found. Mark the third point with another stake. At all times, at least one leg should be at a marked point on the contour line.
4. Continue this process until the other side has been reached, resulting in a contour line across the length of the garden site.

The line that connects all of the stakes in the ground is the contour line and is continually at the same elevation. This process can be repeated as many times as desired to find contour lines throughout the land. Once a contour line is known, then water micro-catchment structures such as swales and berms can be constructed to slow, spread, and sink the water.

Rainwater harvesting practices

Swales, berms, half-moons, basins, and holes are agriculture practices that can be integrated into the design of a permagarden and work to slow down the water, which allows it to spread and sink slowly through the soil profile. It is then readily absorbed within the amended soil of the permagarden bed. In extremely arid areas, rainwater harvesting practices (swales, half-moons, basins, or holes) can be used as planting areas to accumulate enough water to grow a crop (see page 35).

Swales

Swales are an important rainwater harvesting tool, especially in dryland regions where the goal is to store 100% of the rain on the land. Contour swales are shallow trenches dug along the contour to capture rainwater as it flows down the slope. Drainage swales are also shallow trenches, but are measured and dug with a slight slope to the swale (i.e., not perpendicular to the slope). Drainage swales help divert water away from a problem area or toward a larger water catchment basin. Drainage swales are useful in areas of heavy rainfall, where problems with flooding exist around the permagarden or the homestead. The water-holding capacity of a swale is greatly increased by building earthen berms on the downslope edge of the swale (see page 13). Swales are a good strategy in resource-poor environments due to their minimal cost to construct and maintain, and their overall effectiveness in capturing and directing water. When digging swales, it is important to remember to design and build an overflow route.

In times of heavy rains, planned overflow routes enable water to safely move down slope.

Digging a swale.
Photograph: **Thomas Cole**

Swales and berms may not be straight.
Photograph: **Eric Carlberg**

The number, design, and size of the swales are up to the farmer, and depend on the maximum amount of water that may need to be captured. There is not an exact order or way to design swales. Design and construction of a permagarden's swales was already discussed (see page 13).

Berms

A berm is a raised earthen structure, often placed downhill or beside a swale. The primary functions of the berm are to help protect a garden from runoff water and to store more water in a given area. It is effective in a permagarden, as well as in the larger landscape around the homestead or in the main farm field. It is constructed by mounding soil in a line along the contour, or in small half circles called half-moons. Using the soil dug out from a swale, a berm can greatly increase the capacity of the micro-catchment system to catch water. Berms also play another key function in the permagarden. By amending the soil within the berm, much in the same way as for the garden beds, they become a vital space to plant medicinal, nutritious, or culturally important perennial plants and crops. In areas of heavier rainfall, berms can act as a raised path to walk.

How to amend and plant a berm

1. Standing over the beginning of the smoothed berm, loosen the soil down to the compacted subsoil.
2. Remove a 50 cm wide portion of this topsoil and place it on a grain sack or in buckets for later use.
3. Stand to the side, facing the exposed subsoil, and loosen this subsoil as deep as possible (a further 30 cm is sufficient).
4. Amend the subsoil with several handfuls charcoal, manure, and wood ash. Mix well.
5. Again standing to the side of the berm, remove the next 50 cm of loosened berm topsoil to expose the next section of subsoil.
6. Amend the subsoil and then pull the topsoil down the entire length of the berm.
7. Return the initially removed topsoil to cover the final section of amended subsoil.
8. Rake the entire surface smooth and flat.
9. Amend each meter length of the berm with half a bucket manure, a quarter of a bucket of charcoal, and several handfuls of wood ash. Mix all amendments into the top 20 cm of the berm.
10. Water the berm with one 20 L watering can or bucket.
11. The berm is now ready to plant with useful perennials and annuals.

Boomerang berm Mazvihwa Zimbabwe.
Photograph: **Brad Lancaster**

Half-moons and basins

Half-moons and basins are other micro-catchment strategies to harvest and retain rainwater, particularly in dryland regions. (In some areas, half-moons are referred to as boomerang or even 'smile' beds because of their shape, while in the Francophone area of the Sahel, where they are found in widespread use, they are known as demi-lunes.) Half-moons are small, generally 2–3 m, curved berms or ridges in the shape of a semi-circle. The end tips of the half-moon are located along the contour of the slope, pointing uphill. Multiple half-moons can be placed in a row across a field or at the top a garden to trap the flow of rainwater. A second row is then placed below, though staggered to catch any overflow that continues down the slope. The area within the half-moon, and even the berm itself, is often amended with compost, manure, or other amendment, and planted with annual or perennial crops. Half-moons are important structures around the homestead and permagarden as they create viable planting areas for fruit or medicinal trees. Basins are similar in concept and practice, though the berm, or ridge, of the basin itself is closed in a circular shape to form a basin.

Rainwater catchment holes

Catchment holes are a critical part of a permagarden, both to harvest and store rainwater and to catch any overflow from the swales. They are usually placed at the ends of the berms and swales and help form part of the protective barrier for the permagarden beds at the center of the garden. The catchment holes should be dug at least 50 cm deep (deeper for areas with greater rainfall) and 50-100 cm wide. As with a berm, the downhill edges of the catchment hole can be amended and planted, increasing the hole's functionality and use to the gardener. In dryland climates, more shallow and narrow catchment holes are often dug across an entire field, amended with compost or manure and planted with sorghum or maize. Different than a hole whose primary purpose is to store water, these planting holes are the primary crop-growing area for many farmers in dryland environments, especially in West Africa. In this region they are called zai or tassa.

Water retention

After the gardener designs the land and integrates rainwater harvesting practices to capture the rain, additional practices should be added to retain the water. Especially in hot climates, a lot of water can be lost due to evaporation.

A gardener should not burn crop residues, grasses, and weeds in a permagarden, or even in their main cropped fields, because it causes the garden to lose a lot of moisture to evaporation and runoff. An important way to maximize water capture and retention is to keep some form of cover on the field at all times, such as mulch or crop residue. This is critical in both the rainy and the dry seasons. Once water enters the field, the goal should be to preserve as much of that moisture for as long a period as possible, helping keep the temperature of the soil low, even during hot, dry weather, thereby slowing evaporation rates. This moisture retention is often enough to get crops through extended dry spells in the rainy season. Additionally, soils protected in such a manner can conserve remarkable amounts of water for the following crop.

Water-retention practices

Mulch

Mulch is a covering for the soil that helps conserve moisture, lessen weeds, prevent erosion, and improve soil structure. Good organic mulch consists of leaves, grass, straw, compost, banana leaves, maize or sorghum stover, bean stalks, and/or other reusable materials found close to home. A 3–5 cm layer of mulch added to the surface of a permagarden's beds can help in important physical, biological, and chemical ways, as described below.[12]

Physical

- Helps regulate the temperature by keeping the soil cool and moist.
- Prevents weeds from growing easily, leaving more water and space for growing crops.
- Stops the force of raindrops, preventing erosion and allowing rainwater to sink deeply into the soil.

Biological

- Serves as food for good microbes, which provide many values to the soil, as well as important 'housing' for beneficial insects and earthworms.

Chemical

- Regulates soil pH.
- Releases nutrients into the soil.

How to apply mulch

1. Gather leaves, crop residue, and/or dry grasses.
2. Keep them in or near the garden.
3. Place a 3–5 cm layer of dry material around the base of plants, including trees. Make sure to keep the material a little distance from the stem or trunk itself (about 5–10 cm), as placing mulch too close to the stem or trunk can lead to fungal problems.

Organic mulch keeps the soil cool and moist, compared to uncovered ground.
Photograph: **Thomas Cole**

12 In addition, a gardener could grow living mulch, which would act as a cover crop and help retain water in the garden.

4 Any material not placed around the plants can be left on the soil surface to keep the sun off the soil and to prevent erosion from rainfall impact. Many things can be used as mulch, but it is important that the materials be dry. Wet, green plant material can be used, but if it is placed too close to stems or leaves of growing plants, it can cause them to rot. Therefore, if using green materials as mulch, make sure they are placed away from tender stems and leaves.

5 All bare ground, including pathways and the main garden fields, should receive some form of mulch. Whenever possible, mulch in these areas can be thicker (5–10 cm) to help weed suppression and moisture retention.

Land preparation and planting

How a gardener prepares the garden beds and plants will affect the amount of water retained in the garden. A few practices leading to increased water retention include:

- Preparing the soil deeply (double digging).
- Adding compost to the garden beds.
- Planting and managing trees around the garden.
- Practicing close plant spacing, which provides more foliage coverage in the garden beds, leading to less evaporation (more on page 41).
- Preventing and removing weeds in the garden.

Using mulch to conserve water in the swales and paths (above).
Photograph: **Thomas Cole**

Contour berm and contour plantings, Mazvihwa Zimbabwe (right).
Photograph: **Brad Lancaster**

Household spare-water management

Gardeners are sometimes able to gather water from other sources around the household, such as from a borehole, stream, or waste water. There are several practices gardeners can do to maximize the effectiveness of this water in the garden while using minimal resources.

Plastic water bottles allow water to slowly seep into the root of plants.
Photograph: **Peter Jensen**

Household spare-water-management practices

Plastic water bottle

Besides irrigating by watering can or other container in the garden, a plastic water bottle can be used to slowly add water directly onto the roots of a plant. This is a simple, localized form of drip irrigation for a single plant or a group of closely sown plants. A small hole or a group of small holes in the bottom of the bottle allows water to slowly drip or seep into the root zone of the targeted plant or plants. This method is very effective when water is in short supply and needs to be rationed in the garden. It also works well to help irrigate newly planted trees.

How to use the plastic water bottle

1. Find an empty 500 ml or 1 L plastic water bottle with a good cap.
2. Using a sharp knife or a thin nail, make a few small holes on the side of the bottle, 1 cm from the bottom.
3. Fill with water and replace the cap. Notice that the water does not come out if the cap is on tight.
4. Twist open the cap slowly until water comes out.
5. Bury the bottle 10 cm deep—into the root zone—near a vegetable seedling. A 1 L bottle is enough for three plants (tomato, pepper, eggplant, cabbage, and kale, for example) if triangular spacing is used (see page 41).
6. Open the cap a little more until bubbles can be seen coming up inside the bottle. This means that water is now slowly coming out through the holes in the bottle.
7. Cover the entire area with water-conserving mulch.
8. Add water to the bottle every 2–3 days, depending on moisture levels in the soil, making sure to leave the bottle in place. As the moisture level increases in the soil, the water will come out of the bottle more slowly. The rate that the water will come out of the bottle will increase only as the soil becomes dry, as the plants take in more water through their roots.
9. The bottle can also be hung in the air tied to a stick about 15 cm above a plant.

Clay pots

Another good practice for irrigating permagarden beds is to use clay pots buried in the soil. This technique works best in the dry season as a way to conserve and use less water while still being able to grow vegetables. In dryland environments, this approach can prove very useful, as the pots need to be filled with water only about twice each week.

How to use the clay pot method

1. Before planting, dig unglazed clay pots (20–30 cm in diameter) into the bed, spaced anywhere from 50 to 100 cm apart. Bury the pots so that the soil line is level with the top of the pot.
2. Sow seeds or transplant seedlings at the proper interplant spacing for the given crop. Place seeds 10 cm from the edge of the pot and all around it. There should be four plants around each pot.
3. Fill the pot with water. Cover it (with a banana leaf or dry grass, for example) to prevent evaporation. Household wastewater works well here, as the clay pots help filter the water before it reaches the plant roots.
4. Make sure to water seedlings when they are first planted. Water in the clay pots will then seep through the pots to the soil and reach the seedlings' roots.
5. Refill the pots with water as needed (usually around twice a week).

Household waste water

In many areas, it can prove difficult to provide enough water to a permagarden on a sustained and regular basis, particularly during dry seasons. With care, wastewater can be reused to help irrigate parts of the garden and can be an important additional water source for moisture for crops' roots. Wastewater should be poured onto the soil around plants; do not throw it on or over the garden. It is especially important to keep the water off plants' leaves as much as possible; many plant diseases need moisture to thrive. It is best to put the wastewater on a mulched garden bed, because the mulch helps filter any soap or impurities in the wastewater.

Possible sources of wastewater:

- Cooking water.
- Dishwater from cleaning dishes.
- Bathing water.
- Water from washing and rinsing clothes.

Using wastewater can be a practice that is sometimes difficult for a farmer to adopt due to cultural norms or habits. If the gardener is not comfortable putting the waste water directly on the garden bed then they can put it in the swale or a basin with a tree planted.

5 Bio-intensive planting

By improving the soil physical properties, available nutrients, and biological activity, along with deep soil quality, the garden has the foundation for healthy plant growth. The effort put into digging these beds ensures that every plant put into the garden has enough space to allow full root and leaf growth without creating competition with neighboring plants, one of the keys of bio-intensive planting. The process also allows crops to be planted closer together than normal practice, helping maximize crop yields while reducing moisture loss. In addition, gardeners can get creative and use fences, trellises, or sticks to grow plants vertically.

There are many things for gardeners to consider when deciding what to plant, when to plant, and how to plant. The goal of the permagarden is to maximize production of nutritious crops throughout the year. Therefore, the planting decisions in the permagarden should reflect how the gardener plans to achieve this goal. This section of the manual details the bio-intensive approach and provides guidance on how best to plan for and plant permagarden beds while taking into account the following:

- Seed availability.
- Triangular plant spacing.
- Transplanting and seed spacing.
- Seedlings.
- Crop rotation and multicropping.
- Succession planting.
- Nutritional decisions in planting.
- Other plants in the garden.

Seed availability

One benefit of the permagarden method is that it uses locally available plants and varieties, and the garden is designed to utilize the types of plants that are accessible. Gardeners should be encouraged to use indigenous varieties that people already eat locally and that are readily available in the informal market. The seeds gathered for the garden should reflect a household's diverse diet.

Planting a diverse set of plants is good for the household diet and helps limit pests in the garden. In most areas, there are many different local varieties of greens, squashes, beans and other vegetables and plants. Households might have different preferences based on taste, cooking time, availability, days to harvest, or storage, all of which should be considered when deciding which crops to grow.

Triangular spacing.
Photograph: **Peter Jensen**

Since most permagardens are small, few seeds are required to fill the garden beds and berms. Neighbors, friends, and family may have seeds or plants that they are willing to share. Many perennial herbs, such as lemongrass and aloe, can be divided and replanted. Fodder plants and grasses can similarly be divided and planted strategically to provide food for animals. Where possible, gardeners should also be encouraged to save seeds of certain plants. The permagarden method can also help strengthen and promote varieties that are well adapted to local environmental and cultural conditions, as well as pests and diseases.

In addition to planning for the current season's garden, a gardener should also plan for future planting cycles. Gardeners should plan ahead to save and store seeds when appropriate or to save money to purchase seeds for the next season. This is an opportunity for program staff to teach skills around financial literacy and basic budgeting, planning, and saving practices.[13]

Triangular plant spacing

Bio-intensive planting uses a triangular approach when planting most crops in the garden, rather than the usual square or rectangular pattern. This allows a greater density of plants per square meter, which increases yields and creates a beneficial microclimate in the bed. Using a triangular spacing method, where the sides of the triangle are all the same length, means planting seeds or seedlings at their correct spacing at an angle from one another instead of in a straight row, a process that is described below.

Deep soil quality allows crops to be planted closer together. By using close, precise triangular spacing (see photo), plant density, plant health, and overall yield per square meter are maximized. The close leaf canopy maximizes sun to the leaves and shade over the soil, increasing photosynthesis and decreasing moisture loss from evaporation. As a result, up to 30% more plants can fit within a given space and each plant has the potential to be 2–3 times as productive. Overall yield increases while labor spent watering decreases.

Benefits of triangular spacing

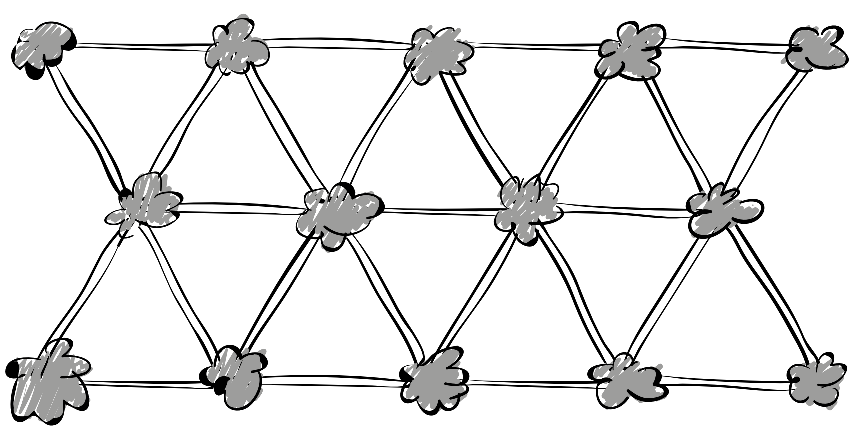
- **Increases plant density** Deeper roots allow closer spacing, resulting in growing more plants in a given area.
- **Increases plant/root health** Allows better capture of moisture and carbon dioxide.
- **Increases root quantity** Results in more organic material and biological activity.

13 More information around financial planning can be found in The Tops Program's Farming for a Profit: Technical Guidance for Smallholder Financial Planning guide, http://www.fsnnetwork.org/farming-profit-technical-guidance-smallholder-financial-planning

- **Decreases weed pressure** From canopy shading of bare soil.
- **Decreases water requirements** From canopy shading of bare soil and less moisture loss.
- **Decreases erosion** From decreasing speed and impact of rain on the soil.
- **Regulates soil temperature** From increased canopy shading on the soil.

How to plant using triangular spacing (Appendix 5)

1. Choose the garden bed to be planted.
2. Select seedlings for planting (seeds can also be directly sown this way, though it is most commonly used for transplanted seedlings).
3. Locate a straight stick that is the length of the correct between-plant spacing for the crop (see charts below).
4. Use the stick to mark planting locations along the end of the bed. Dig those holes by hand.
5. Use the stick to form a triangle between two of the holes and a point further into the bed. Dig a new hole at that point. All three sides of the triangle formed by the three points should be the same length.
6. Continue until all holes have been dug. After the whole bed is marked and dug, the pattern should appear as many small triangles.
7. Water the holes and then plant the seedlings, ensuring that all the roots are covered with soil.
8. After covering the plants' roots with soil, water again and apply mulch.



Triangular plant spacing.

Transplanting and seed spacing

There must be enough space in the garden for each plant to grow, but not so much space that production drops because plant spacing is not maximized. The permagarden method uses closer plant spacing than many gardeners may be used to. Less space is needed between the plants because the deep-dug beds allow the roots to go down deeper into the soil rather than being forced sideways in search of nutrients, which means there is less competition between the plants for soil air, water, and nutrients. Below are two tables that describe the space needed between seeds and seedlings in a permagarden bed.

Seed spacing for direct-seeded crops

Crop	Spacing in garden bed (cm)
Amaranth (seed/greens)	Broadcast lightly, thin to (30 cm/15 cm)
Beans (dry/green) and cowpea	15 cm
Carrots	Broadcast lightly, thin to 5 cm
Chickpeas (garbanzo beans)	10–15 cm
Garlic (cloves)	10 cm
Groundnuts	22 cm
Irish potatoes (sprouted tubers)	25 cm
Maize	30 cm
Millet	15 cm
Onions (use root portion from past crop)	15 cm
Pumpkins	100 cm (allow to spread within bed)
Radishes	5 cm
Sweet potatoes (stem cuttings)	25 cm
Wheat	12 cm
Zucchini	45 cm (can plant hill with 2 per hill)

Seed spacing (in trays) for transplanted seedlings

Crop	Spacing in seed nursery tray/bed (cm)	Spacing in garden bed (cm)
Broccoli	5 cm	45 cm
Cabbage	5 cm	45 cm
Cucumber	5 cm	30 cm (train to grow up trellis)
Eggplant	5 cm	45 cm
Kale	5 cm	20 cm
Head Lettuce	Broadcast then thin to 6 cm	25 cm
Onion	5 cm (or less)	15 cm
Pepper (sweet or hot)	5 cm	45 cm
Spinach	Broadcast then thin to 6 cm	12 cm
Swiss Chard	5 cm	20 cm
Tomato	5 cm	45 cm (stake up with poles)

Correct plant spacing maximizes yields
Photograph: **Thomas Cole**

Seedlings

To ensure quality growth while limiting water use, most vegetable plants, with the exception of legumes and root crops, should be planted in garden beds as seedlings so that they have the best chance for survival and a productive life. Less water is required to grow these plants in a nursery bed than in a garden because the soil is shallower, allowing less water to flow away from the small roots of the seedlings. Additionally, when the time comes to transplant them to the garden, a gardener can easily choose only the healthiest plants. There are many benefits to planting the permagarden using seedlings transplanted from a well-protected and fertile nursery bed.

- Uses less seed compared with seeding a whole permagarden.
- Uses less water than in the main permagarden.
- Provides more protection from pests and weather for vulnerable, germinating seeds and young seedlings, promoting better germination rates and healthier plants.
- Reduces the time to harvest in the permagarden itself, allowing for more crop cycles during the year.
- Enables more uniform spacing and more efficient resource use (e.g., of sun, nutrients, and land).
- Accelerates time to canopy cover in the permagarden and to realize the advantages of close plant spacing (described on page 41).

How to prepare a seedling nursery for a permagarden

1. Prepare soft, well-aerated soil (compost mixed with topsoil and sand is a good mix) in a small section of a garden bed, directly into small boxes, or wrapped in a banana leaf. Moisten the surface, allowing water to soak down at least 5 cm.
2. Sow seeds 1–2 cm deep and close together using triangular spacing according to the Seed Spacing Chart (see page 43). Cover the seed with soil and firm the soil lightly. Gently water the entire surface. Water should be reapplied before the soil dries out; this is where compost is particularly useful as it helps retain moisture around the developing seedlings.
3. Cover this small prepared area with a simple thatch structure to keep intense sun and heavy rain off the fragile seedlings once they emerge from the soil. As the seedlings emerge (within 1–2 weeks), gradually increase the amount of sunlight that they receive so that by the time they are 4 weeks old they are strong enough for transplanting into individual boxes and then, at 7–8 weeks, are ready to be planted into the garden bed itself. As seedlings grow, it is important to thin out weak or overcrowded plants, ensuring that each strong seedling is given the proper spacing in the nursery bed to grow healthy and vigorous.

Seedlings can be grown in locally-made biodegradable planting containers.
Photograph: **Thomas Cole**

4 After 7–8 weeks when seedlings have strong stems and at least three sets of leaves, they are ready to be planted at their proper spacing in the permagarden.
5 Make a small hole in the garden where each seedling will be planted based on the guidelines in the Seed Spacing Chart (see page 43). The hole should be the same depth as the soil in the seedling container.
6 Carefully remove the seedling and soil from the container, keeping the soil intact. Make sure the larger roots are intact and are extended.
7 Place one seedling in each hole. Brush soil around the seedling so that the roots are covered but all of the leaves are above ground level. Lightly firm the soil around the seedling.
8 Water the seedling. Keep the soil moist over the next several days.

Crop rotation and multicropping

With the proper climate, resources, and management, it is possible to grow continuous crops of vegetables throughout the year in the permagarden. This requires using crop rotation and intercropping principles, as well as staggering plantings, instead of planting everything all at once. These principles help provide continual harvests of healthy vegetables and disrupt pest and disease cycles in the garden.

Crop rotation is the practice of moving crops from one bed to another, or from one place in a bed to another place in the same bed, from season to season. Crop rotation in a permagarden provides both nutrients to the crops for the household and nutrients for the soil. This is contrary to the widespread practice of planting the same crop in the same place in the garden every year. Crop rotation is arguably one of the most important agricultural practices to both enhance soil fertility and limit garden pests and diseases.

Benefits of crop rotation

- Greater control of pests.
- Reduction in soil-borne diseases.
- Maintenance of soil structure.
- Balance and management of soil nutrients and fertility.

As different crops have different nutrient needs, rotation allows successive crops in the garden to use the nutrients available to them most efficiently. A good rotation plan that optimizes nutrients in this way is **leaf** then **fruit** then **root** then **legume**.

- **Leaf** crops (amaranth, broccoli, cabbage, cauliflower, chard, kale, maize, sorghum, spinach) enjoy lots of nitrogen, so they should be planted 'first' in a newly prepared and fertilized garden bed.

- The following season, plant a **fruit** crop (cucumber, eggplant, gourd, Irish potato, melon, pepper, pumpkin, squash, tomato) that likes some nitrogen, but that needs more phosphorus for proper flower development. Too much nitrogen will result in tomatoes that are 'all plant, no fruit' and could develop various imbalances that cause blossom end rot or make the plants susceptible to fungal diseases.
- Next plant a **root** crop (beets, carrots, garlic, leeks, onions, radishes, shallots, sweet potatoes, turnips), as they require even less nitrogen, but need more potassium for proper root development.
- Then plant a **legume** (beans, groundnuts, peas), which will use few nutrients while adding nitrogen back into the soil through the process of atmospheric nitrogen fixation.
- Start the whole process over again with a **leaf** crop.

Permagarden beds make crop rotation simple. Don't change the location of the beds; rather, change what is planted in each from season to season. Following a good crop rotation plan will also break the pest and disease cycles, which will yield healthier, stronger plants and will reduce or eliminate the need for potentially dangerous pesticides. Before planting any new crop, however, additional compost is needed to maintain micronutrient-rich organic matter and beneficial microbe levels.

Although crop rotation is a good technique to use due to the benefits described above, the goal of a permagarden is to have a continual variety of food plants available for harvest. Therefore, as well as crop rotation, it is best to also practice multicropping in the same space.

Multicropping is the practice of growing two or more crops in the same space at the same time. Groups of multicropping plants that grow well together or share some cultural benefit are known as 'companion' plants. Multicropping takes advantage of qualities or traits of one crop that can affect the growth of other crops or can help lead to higher overall yields. Some of the important approaches to multicropping include:

- Using space within the soil profile optimally by planting shallow- and deep-rooted plants together.
- Mixing slow- and fast-growing crops in the same space so they don't compete.
- Growing heavy feeders and light feeders that require nutrients in different amounts from the soil together.
- Sowing aromatic plants that can help protect non-aromatic plants.
- Planting flowering plants that provide pollen and nectar for beneficial insects ('good' bugs that eat 'bad' bugs).

- Planting crops that attract and trap pests next to other high-value crops.
- Planting crops that grow in different ways above soil, e.g., climbers or vines planted with bush plants.

Staggered succession planting with amaranth

1. Gather local amaranth seed.
2. Smooth and prepare first 1⁄3 of a garden bed.
3. Scatter seeds, cover and water.
4. Wait 2 weeks.
5. Repeat seeding, covering and watering on next 1⁄3 of the garden bed.
6. Wait 2 weeks.
7. Repeat final 1⁄3 planting.
8. Harvest and eat from first 1⁄3 of the bed.

Succession planting

One of the keys to creating a garden that can be harvested throughout the year is succession planting. Succession planting involves planting new crops right after one is harvested, planting multiple crops with different maturity dates in the same space, and planting crops at staggered dates to harvest at different times. With proper management, it is possible to grow continuous crops of vegetables through one or all of these succession methods. This is also one of the key ways to extend the season of a certain vegetable. Additionally, this type of succession or multicrop planting can help to increase overall garden yield, pest control, nutrient management, space utilization and wise use of resources, such as water and improved soil quality and health.

Succession planting (above).

Intercropped vegetables in the permagarden (right).

Photographs: **Thomas Cole**

Nutritional decisions in planting

This section was adapted from the *Sustainable Nutrition Manual* by Stacia Nordin.[14] For a more in-depth explanation, please refer to that manual.

A permagarden can provide households with access to a wide variety of foods and medicinal plants throughout the year. With careful planning, a permagarden can help achieve a complete human diet. A complete human diet is a diet that provides sufficient calories (the amount of energy provided in food) and all the required nutrients. A household garden is a key resource to help provide access to a complete diet. It can provide many of the fruits, vegetables, legumes, nuts, whole grains and roots needed for a balanced diet, as well as, animal protein if animals such as chickens are integrated into the garden design.[15] In addition, the household is much more likely to consume the nutrients it needs when the fruits and vegetables are conveniently located next to the house or just outside the kitchen.

Planting a garden near the household (above).

Permagardens provide a regular supply of nutritious vegetables for the family (right).

Photographs: **Thomas Cole**

Classes of nutrients

There are six major classes of nutrients required for the human diet.

- **Proteins** help make the body strong. Bones, hair, muscle and skin are built from proteins.
- **Carbohydrates** provide energy that is not stored in the body for long periods of time.

14 Nordin, Stacia. Sustainable Nutrition Manual: Food, Water, Agriculture & Environment.2nd ed. Sarah Beare. Lilongwe: World Food Programme Malawi, 2016. www.NeverEndingFood.org/Sustainable-Nutrition-Manual.

15 Households need to be aware of possible dangers of children's exposure to fecal bacteria, also known as environmental enteropathy.

- **Fats** provide energy that can be stored in the body for long periods of time, if needed. Any excess energy that a person consumes is stored as fat.
- **Vitamins** protect the body from infection and disease.
- **Minerals** allow the body to perform essential functions in bones, teeth, blood, skin and hair.
- **Water** allows the body to maintain all its functions and continually removes waste products. The body cannot survive more than a few days without water.

Functions of nutrients

These six classes of nutrients work together to perform three essential functions: provide energy, protect the body from disease, and promote growth. As described in the *Sustainable Nutrition Manual*, these three functions can be explained with the Go, Glow, Grow explanation:

Energy foods (GO) Several nutrients provide energy: carbohydrates (from grains, roots, legumes, nuts, and fruits) and fats (from animals foods, oilseeds, nuts, some legumes such as soybean, and some fruits such as avocado or coconut) provide us with energy. Ideally, most energy should come from carbohydrates, and a little from fats. These nutrients provide the energy a gardener needs to do daily activities. While balancing our energy intake from these three nutrients, at the same time it is important to get as much glow and grow as we can from our energy sources.

Protection foods (GLOW) Vitamins, minerals and water are the most important nutrients for protection. All of the food groups can provide vitamins and minerals, but they are especially high in vegetables, fruits, legumes, nuts, oilseeds, animal foods and water. Grains and tubers can provide vitamins when they are eaten as 'whole grains' or with their edible skins (for example, cleaning an Irish potato well and cooking and eating it with its skin on).

Building foods (GROW) Protein is the main nutrient that helps the body grow. Key protein-rich foods include animal-source foods, legumes, and nuts. Most protein-rich foods also provide minerals. Protein deficiency is a common problem in many developing countries.

Eating a balanced diet

Food groups

A healthy diet is a balanced diet.

- Fruits, vegetables, legumes and nuts combined, should cover more than half a plate of food.
- Staples (cereals, roots, and tubers) should cover just over a quarter of the plate.

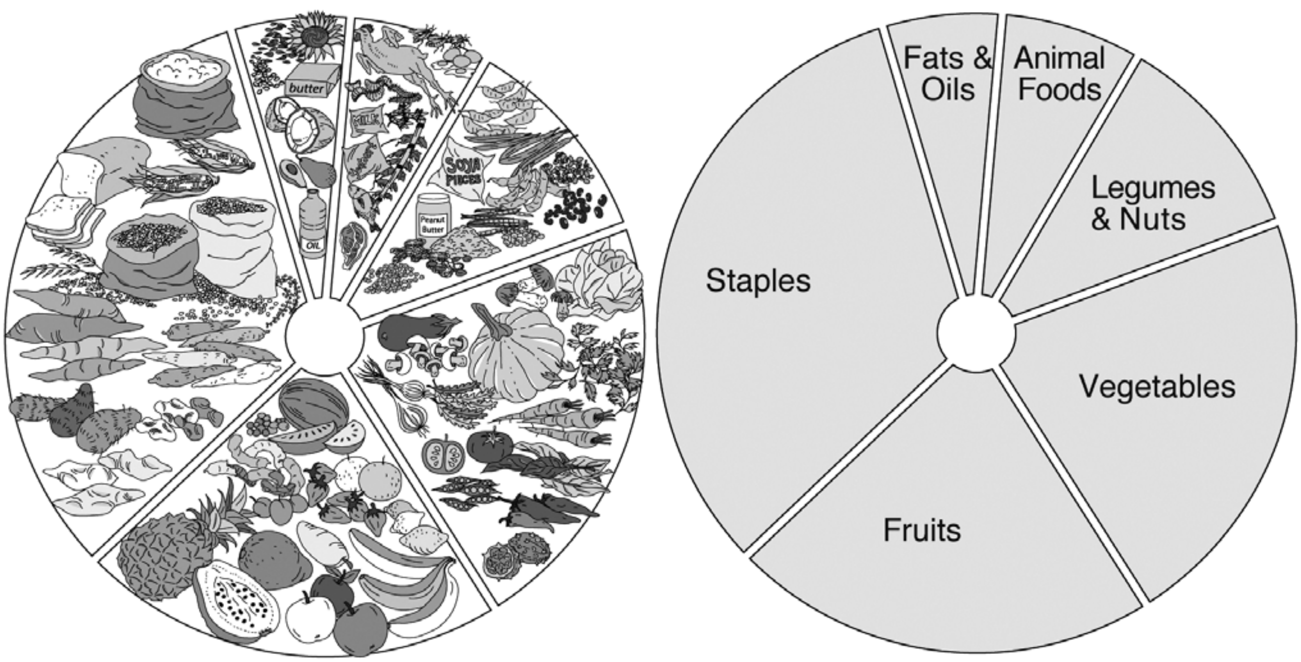
- Animal foods should be included, at least in small amounts.
- Fats and oils should be included in the smallest amounts, usually mixed with other foods on the plate.

The visual representation below of a balanced, varied diet shows that there are many options for each food group; it does NOT mean that you have to eat all those foods in one day.

You do not have to eat all the food groups at every meal, but by the end of the day all the food groups should have been included.

How much of each food group do I need?

Adult food needs by food groups		KCal (per day)	KCal (%)	Per day (g)	Per year (kg)
Staples	Grains	838	38	250	91.3
	Tubers	240	11	250	91.3
Fruits	Fruits	150	7	300	110
Vegetables	Vegetables	96	4	300	110
Legumes and nuts	Plant proteins	588	26	150	55
Foods from animals	Animal proteins	58	3	75	27
Fats	Fats	235	11	50	18
Totals		**2,205**	**100**	**1,375**	**503**



A balanced diet.
Nordin, Stacia

Planning for a balanced diet

To increase household nutrition, it is not enough to just produce the foods described; each individual in the household must consume them. Therefore, programs should pair home garden production with lessons about food planning and consumption and ideally include hands-on activities to prepare and eat balanced meals together.

The nutritional messages complementing permagardens should focus on the key nutritional imbalances for the local region. The main nutrition imbalances that impact human health and productivity in most developing countries include:

- Excess carbohydrates (cereals, tubers and refined sugars).
- Inadequate protein and fat consumption.
- Inadequate vitamin and mineral consumption.

By balancing and diversifying agriculture and the diet using the food groups described above, the nutrient imbalances that are currently seen in developing countries can be reduced.

A good strategy to improve household nutrition is to design and plant a permagarden that contains a diversity from the food groups that are often lacking: fruits, vegetables, legumes and nuts.

- Brightly colored fruits and vegetables, especially orange, yellow, and dark green leaves have higher levels of vitamins and minerals than light colors.
- Some vegetables and fruits also have edible seeds that are high in fat, protein and minerals (for example, pumpkin seeds or melon seeds).
- Legumes and nuts are high in proteins, vitamins, minerals and some are also high in fat.

The following table contains the key nutrients that are often lacking in a diet, the foods that contain those nutrients, and the function of those nutrients in the body.

Key vitamins

Nutrient	Fruits	Vegetables	Legumes and nuts	Animal foods	Fats and oils	Staples	Functions
Vitamin A	Dark orange or red fruits	Dark leafy greens Orange or red vegetables		Milk Butter Fish	Palm oil Moringa oil Fish Butter	Orange-fleshed tubers	Improves eyesight and strengthens the immune system
Vitamin C	Baobab Tamarind Citrus Hibiscus	Dark leafy greens Peppers Broccoli Cabbage Tomatoes				Yams Raw cassava	Helps strengthen the immune system

Key minerals

Nutrient	Fruits	Vegetables	Legumes and nuts	Animal foods	Fats and oils	Staples	Functions
Calcium		Dark leafy greens Okra	Legumes and nuts	Dairy Fish bones. Some meats Insects	Sesame seeds and several other seeds	Millet	Helps make bones and teeth strong
Iron	Dried fruits such as raisins	Dark leafy greens	Legumes and nuts	Meat Poultry	Oil seeds		Needed to create blood cells and carry oxygen to your tissues
Zinc		Dark leafy greens	Legumes and nuts	Animal foods	Oil seeds	Whole grains	Helps all parts of the body grow and develop

Other key nutrients often lacking

Nutrient	Fruits	Vegetables	Legumes and nuts	Animal foods	Fats and oils	Staples	Functions
Proteins		Dark leafy greens	Legumes and nuts	Animal foods	Oil seeds	Whole grains	Helps the body grow muscle and repair from injury
Fats			Soybeans Nuts	Animal foods	Fats and oils		Energy source, absorption of fat soluble vitamins

A diverse planting of perennials and annual vegetables.
Photograph: **Peter Jensen**

Other plants in the garden

Perennials

Perennials are important for a permagarden to sustain healthy soil and to provide harvests throughout the year. Perennials are beneficial to:

- the garden because they reduce the amount of bare soil, limit soil erosion, and improve subsoil structure
- the ecosystem by acting as windbreaks, suppressing weed growth, and drawing nutrients from deep subsoil layers to the surface
- the harvest because they produce at different times of the year.

Since perennials grow for multiple growing seasons, they are able to develop extensive root systems that cover more area than the roots of annual crops. Perennials can be planted in the berms or around the outside of the garden.

Perennial	Benefit
Aloe	Medicine, income, immune system support, gift
Banana	Food, income
Lemongrass	Palliative tea, income, gift
Papaya	Food, shade, medicine, income, gift
Passion Fruit	Growing on fencing, income
Tephrosia	Pest repellent, insecticide

Fodder, trees and shrubs

Trees and shrubs incorporated in the garden provide several extra benefits, including medicines, insecticides, shade, fuelwood, water conservation, reduced erosion, wind management, and compost materials.

A steady diet of fodder crops significantly increases both the weight of animals and the quantity and quality of milk from goats or cows kept at the homestead. Having a year-round local fodder source enables farmers to raise at least one cow on a minimal grazing system. Households benefit from increased milk production, greater control and use of manure, and the potential to harvest slurry and urine for pest remedies and fertilizers. These crops and grasses can be planted on berms and other areas linked to the protective swales.

Certain tree species can be planted as a living fence around the permagarden, providing multiple benefits and functions as they grow. Proper management and coppicing (regular cutting and regrowth of the trees) ensures greatest benefit to the entire system. Shrubs such as Tithonia can be grown around the compound for their biomass, used regularly in building compost piles and making liquid botanic fertilizers to feed crops in the permagarden.

Tree/Shrub	Benefit
Glyricidia	Green manure, fencing, shade, firewood
Lantana	Nutrient accumulator, hedges, insecticide
Leucaena	Green manure, fodder, fencing, medicine, firewood
Moringa	Green manure, food, medicine, firewood
Neem	Green manure, medicine, insecticide, soap, firewood, shade
Tithonia	Green manure, fodder, compost material, liquid fertilizer

A permagarden with a diverse mix of fruiting trees, vines and vegetables (above).
Photograph: **Thomas Cole**

6 Plant health

Soil health and plant management are foundational to plant health and nutrient-rich foods. Regular weeding, the removal of weeds from the garden, and pruning, the removal of unnecessary parts of the plant to promote growth, are two key management practices to keep plants healthy. At times, however, the plants in the garden need extra protection or a boost of food to help them grow and stay safe. This section outlines plant fertilizers, pest control methods, and protection practices. All of these remedies are designed to be made using only local resources.

Making liquid fertilizers from the Tithonia plant.
Photograph: **Thomas Cole**

Plant fertilizers

Plant fertilizers are natural teas and recipes that can be applied after the plant starts growing in order to provide the macro- and micro-nutrients a plant needs to be healthy.

Botanical and manure teas

Liquid fertilizers can be made from manures, vegetable waste, and plant leaves. Inputs used in botanical and manure teas are cheaper and more ecologically sustainable than chemical fertilizers and are often made from materials that are locally abundant.

Botanical and manure teas can be applied at the soil level to feed the roots or they can be used to foliar-feed crops through the leaves. There are a variety of different botanical and manure tea recipes. Below are a few that use ingredients from common resources found throughout many project areas. Vegetables in the permagarden can be fed with some form of botanical or manure tea every 2–3 weeks to help healthy plant growth, to improve yields, and to resist pests.

Tithonia

Tithonia (*Tithonia diversifolia*) is a shrub often found in abundance throughout sub-Saharan Africa. Since the plant accumulates large amounts of nitrogen and phosphorous from the soil, its green biomass is one of the best natural sources of fertilizer for a permagarden. In fact, it is one of the best sources of phosphorous available from any plant. It can be used as a green manure and dug into the soil several weeks prior to planting, used as a primary component of compost, or made into a nutrient-rich liquid fertilizer. The best time to use tithonia in all of these cases is when the leaves are dark green and the plant is about 1 m high.

Recipe to make liquid fertilizer with tithonia

1. Chop 5 kg (about one large basin) of dark-green leaves.
2. Soak chopped leaves in 10 L of water for 2 weeks, stirring every 3–5 days.

3 After 2 weeks, most of the nutrients will have dissolved in the water and the mixture should be dark green.
4 Dilute with 2–3 parts water to one part tithonia tea.
5 Apply as a fertilizer to the leaves or drench the roots of vegetables, young trees, and grain crops.

Moringa

Moringa oleifera is a multipurpose Indian tree that has been planted widely throughout the world. Apart from its widespread use as a food source, moringa leaf extract contains a plant growth hormone that can be used to fertilize crops and help increase yields.

Recipe to make liquid fertilizer with *Moringa oleifera*

1. Grind young moringa shoots (not more than 40 days old) and mix with water, following the ratio of 1 L of water to 10 kg of fresh shoots. Make enough for only one application, as the compounds in the tea break down within 5 hours of extraction.
2. Strain the solid out of the solution. This can be done by placing the solution in a cloth and wringing out the liquid. The solid matter, which will contain 12–14% protein, can be used as livestock feed.
3. Dilute the extracted liquid with water at a 1:32 ratio.
4. Spray directly onto plants immediately after extraction. Follow an application rate of 25 ml per plant. The spray should be applied to the leaves 10 days after the first shoots emerge from the soil, again about 30 days before plants begin to flower, again when seed appears, and finally once more during the maturation phase.

Manure tea

Liquid fertilizers are the easiest form of food for plants to absorb, especially as they move quickly into the root zone and are taken up immediately by plants when applied to plant leaves as a fertilizer. Animal manure is full of organic matter, beneficial organisms, bacteria, and enzymes that help plants grow.

Making manure tea helps dissolve and ferment these materials into a form that is readily available for the plants to use.

Recipe to make manure tea

1. Gather as much chicken or cow manure as possible and place it in a breathable burlap sack.
2. Place the closed burlap sack holding the manure in some type of bucket or modified jerry can. Use a rock or heavy object to hold the sack in place.

3 Add water to the bucket. Follow a mixture ratio of 8 L of water for every 1 kg of manure. For instance, 2.5 kg of manure will yield 20 L of manure tea. Submerge the sack in the water.
4 Soak for 3 weeks, making sure that the sack is aerated and stirred (as one would steep a normal tea bag) every 4 or 5 days.
5 At the end of 3 weeks, pull out the sack. The manure that remains can be added to your compost pile or used to fertilize fruit trees around the courtyard.
6 Dilute the manure tea until what is left looks like weak coffee. This is now ready to be applied to plants. A watering can is recommended for use on transplanted vegetables. The manure can be poured directly into crop holes.

Compost tea

How to make a vegetable-waste compost bucket

Kitchen waste can also be used to make a daily liquid compost tea that is full of beneficial nutrients for plants in the garden. This tea can be added to other liquid fertilizers or can be used on its own.

1 Poke a small hole in bottom of a bucket.
2 Add 10 cm of dry brown leaves.
3 Add a handful of fresh manure.
4 Each evening, add saved vegetable waste cut into small pieces (no meat).
5 Add a 4 cm layer of dry crushed leaves.
6 Add half a liter of water and cover the bucket.
7 Place a basin below the bucket to capture the nutrient-rich tea for morning watering. Before using in the garden, dilute with water using a 3:1 ratio.
8 If there are two buckets available, use the first bucket until it is full; then start the second bucket.
9 When the second bucket is full, use compost from the first bucket.
10 Continue using the first bucket while the contents of the second bucket decompose.

Other plant fertilizer recipes

Local ferment fertilizer recipe

A local ferment fertilizer recipe uses ingredients found in many communities and may be a good fertilizer for urban areas which may have less access to other ingredients.

1 Gather the following items:
   - 30 mm flat beer or local ferment
   - 30 mm honey
   - 30 mm raw milk
   - 4 liters of water (no chemicals in water)

2 Mix all ingredients together in a bucket or other container.
3 Let sit for eight hours.
4 Splash around planting areas to feed soil microbes before planting and then around the plants during the growing season.

Urine fertilizer

Urine is mainly comprised of water, but also contains nitrogen, phosphorous and potassium. When used in the proper ratio it can be beneficial for the garden. The trainer should be sensitive to the local culture if promoting this fertilizer.

Mix 1 part urine with 20 parts water.

Pest control

Organic pest and disease control

The term 'organic' does not refer simply to what we do not use, e.g., synthetic fertilizers and pesticides; rather, 'organic measures' refer more to what we do use and what actions we take in terms of soil health and water control, planting timing, rotation, and care during the various growth stages. The key word here is 'control'. Gardeners should not try to kill every insect, good or bad. The job is to manage pests with practical interventions based on preventing problems before they appear in the garden. Only when a problem exceeds the capacity of the control measures should a gardener consider options that target specific pests and diseases.

Creating a good environment to prevent pest and disease problems includes:

- Healthy, fertile soil.
- Disease-resistant seeds adapted to the local context.
- Timely seed sowing and transplanting.
- Vigorous seedlings.
- Good garden hygiene.
- Crop rotation.
- Companion planting and multicropping.
- Use of landscape plantings on berms and in swales to create habitats for beneficial insects.

Incorporating all of these steps into a permagarden can help reduce or eliminate most of the pest and disease problems that commonly afflict gardeners. They are part of what is called 'integrated pest management' (IPM), an approach that is based on prevention, proper insect or disease identification, and cultural, physical, and/or botanical interventions for pest control.

Cultural interventions

Sound agricultural practices give a plant a healthy root system and steady growth. A healthy plant is better able to outgrow an insect invasion, as most insects are attracted to weak, over-fertilized, water-stressed plants. Cultural interventions include:

- Soil that is well-amended with local soil amendments to create a healthy, biologically active environment.
- Compost and biochar to build microbial life.
- Crop rotation to break disease and insect life cycles while promoting balanced nutrient needs.
- Compost and manure teas to provide plants and the soil with active beneficial microorganisms.
- Mulch application to help minimize soil-borne diseases by preventing soil splash during rain or irrigation.

Physical interventions

This component of IPM is based on the physical exclusion of problem insects and the careful removal of existing problems, including:

- Timed applications of nets or baskets over garden beds to keep away flying insects and birds.
- Pruning of any dead, diseased, or damaged limbs or leaves as soon as possible when problems are observed; burning or burying the diseased sections.
- Traps, such as yellow sticky boards, shallow cups of beer, or circles of char and ash around the stems to deflect insects.
- Barriers, such as burned rice hulls, placed on the soil to help stop crawling insects from reaching the crops.
- Mulch application to help minimize soil-borne diseases by preventing soil splash during rain or irrigation.

Biological and botanical interventions

This component helps maintain pest and disease populations at a minimum level through living organisms. Basically, it is the use of various biological allies to control garden pests. These measures can be applied or developed naturally by maintaining habitats for beneficial organisms both above and below the soil surface (Appendix 6). Techniques include:

- Compost tea used as a leaf spray to ward off fungus and certain insects that are discouraged by the aroma.
- Perennial flowering borders and living fences to serve as housing for beneficial predatory insects.

- Botanical sprays, such as tephrosia, melia, tithonia, oil, and soap, to prevent invading aphids and other pests from amassing in large numbers.
- Neem seed oil, which acts as a potent insecticide and fungicide
- dried crushed leaves of certain plants to help protect grain from weevil infestations.
- Milk to help prevent the tomato mosaic virus.

Making a botanical pesticide to protect plants.
Photograph **Thomas Cole**

Pesticide recipes

Organic pesticides can be made from different local resources. These recipes offer cheap, locally available solutions that are environmentally friendly and cost very little to prepare.

Household ingredient insect deterrent teas

Garlic and chili peppers recipe #1

1. Gather the following ingredients:
    - 1 bulb of garlic
    - 1 small onion
    - 3 hot chilis
    - 50 g soap
2. Crush one garlic bulb together with one small onion.
3. Add three crushed chili peppers and mix with 1 L of water.
4. Let soak for 1 hour and then filter.
5. Dissolve 50 g of soap in a small amount of warm water and then add to filtered garlic and pepper solution. Mix thoroughly.
6. Spray the entire plant, including the undersides of the leaves.

Garlic and chili peppers recipe #2

1. Gather the following ingredients:
   - 2 hot chilis and their seeds
   - 2 large onions
   - 1 bulb of garlic
   - 1 liter of glycerin soap
2. Mix all ingredients together in a bucket or other container.
3. Cover with warm water and allow to steep for 24–36 hours.
4. Strain the mixture to remove large pieces of ingredients.
5. Dilute 1 part mixture to 1 part water.
6. Spray or splash on infected areas (will wash off in rain).

Oil pesticide recipe #1

1. Gather the following ingredients:
   - 1 cup cooking oil (i.e., canola or vegetable)
   - 1 tablespoon liquid dishwashing soap
2. Mix all ingredients together in a bucket or other container.
3. Dilute 2 1⁄2 teaspoons of this mixture in 1 cup of water.
4. Sprinkle on effected leaves with a grass brush or bundled twigs. Can be used weekly.

Oil pesticide recipe #2

1. Gather the following ingredients:
   - 25 ml of baking soda (in a lot of areas this is available or listed as bicarbonate of soda)
   - 15 ml cooking oil
   - 15 ml vinegar
   - 25 ml liquid soap or 15 ml glycerin soap
   - 1.2 liters warm water
2. Thoroughly mix all ingredients together with warm water.
3. Sprinkle on effected leaves with a grass brush or bundled twigs. Can be used weekly.

Tephrosia, neem, and melia leaves

Tephrosia (*Tephrosia vogelii*), neem (*Azadirachta indica*), and melia (*Melia azadirachta*) all have several insecticidal properties that are of great use to the farmer, both in the field and in post-harvest storage. Extracts and powders of the leaves of these plants can help protect crops from pests like aphids in the field and protect harvested grain against weevil infestations.

Instructions for crop protection

1. Crush 2 kg green leaves of tephrosia, neem, or melia.
2. Mix crushed leaves in 5 L of water. Soak for 24 hours.
3. Filter the solution.
4. Spray on plants affected by aphids and other sucking/chewing insects.

Instructions for post-harvest protection

1. Dry tephrosia, neem, or melia leaves in the shade.
2. Once leaves are dry, grind them into a powder.
3. Mix powder with harvested grain, using a mixture ratio of 2 kg of leaves for every 20 kg of seed.

Neem or melia oil

1. Collect, de-pulp, and wash clean the ripe seed of neem or melia.
2. Dry the seed in the shade for 3–7 days. Any bad seeds should be thrown out.
3. Crush seeds in a mortar or other vessel. Mortars used for edible crops should not be used.
4. Mix crushed seed with water, using a mixture ratio of 50 g of seed per 1 L of water. Let mixture sit overnight.
5. Filter the liquid through a cloth and put in container for use. Liquid can be used directly. If a concentration greater than 50 g seed to 1 L water is used, the mixture should be diluted before application. Using a sprayer or brush, experiment with different levels of concentrations in field trials.
6. Use no more than once a week; every 10–15 days is the optimal interval. Neem/melia oil is effective against most chewing and sucking insects on crops. Neem does not kill pests outright; it merely disrupts their feeding mechanisms so they eventually die. Neem is also good at controlling fungal outbreaks (such as early and late blight) on tomatoes, as well as controlling powdery mildew on squash and other cucurbits.

Other

Place various plants within the margins of the garden or property to assist in pest control, such as:

- Aromatic plants to discourage pests from entering garden: lemongrass, mint, marigold.
- Flowering plants and shrubs to attract beneficial insects that can eat or destroy pests: marigold, flowering vines.
- Companion plants that assist each other by discouraging pests.
- Trap crops that draw pests away from higher-value crops for hand control (sorghum planted on the margins of a maize field, for example).
- Wood ash from the fire sprinkled on the soil to detract ants, leaf miners, stem borers, and termites.

Protection

The importance of strong fencing to protect a permagarden cannot be overstated. Without this simple structure, damage from wildlife, livestock, wind, and people is inevitable. It is important to identify where within the community materials to build a fence can be located and gathered. Local materials, such as wood, bamboo, thatch, and thorny branches, are useful.

Besides providing protection from livestock, wind, and people, a fence can serve other functions. The introduction of certain trees, shrubs, and grasses, grown along the fence, can be used to create a barrier while providing useful products for the kitchen and the garden. In this way, the fence can serve multiple functions: providing physical protection, food from vines, fodder from the cuttings off the living fence posts, shade, wind protection, nitrogen fixation, and a trellis on which to grow other climbing plants. This 'live fencing' is a good long-term strategy, but it takes as much as a year or more to fully establish itself. As this lengthy period cannot be avoided, a strong fence of locally available materials should be built when the garden is created. Whenever possible, choose multipurpose trees and shrubs.

The list below highlights some possible plants to incorporate into a living fence.

Tree/Shrub	Benefit
Glyricidia sepium	Legume, green manure, fodder, firewood, poles
Lantana sp.	Shrub, green manure, pest control, thorns
Leucaena leucocephala	Legume, green manure, fodder, firewood, poles
Sesbania grandiflora	Legume, green manure, fodder, firewood, poles
Sisal, Acacia species	Fiber, thorns
Tephrosia vogelii	Legume, green manure, pest control, firewood
Vetiver, Elephant, Napier	Grasses, fodder, medicine, compost

A strong fence protects the garden.

Photograph: **Thomas Cole**

Planting a living fence

A living fence uses trees and shrubs as part of the fence. This provides additional resources to the gardener while taking advantage of space that is generally not used. To get started, a gardener should plant mature seedlings or cuttings of any of the trees listed above 1 m apart, at least half a meter outside the garden swales. In the space in between the trees, shrubs such as lantana or a spiky sisal plant can be planted. In a line outside of the trees and shrubs, Vetiver grass can be planted. This gives a multidimensional barrier to wind and animals once it is fully established. Given that these plants take time to establish, it is a good idea to use other materials, such as thorny branches or strips of bamboo, to help close off the garden. This is critical to protect the garden from chickens and/or goats just after it has been planted.

Pruning the fence

It is important to regularly manage the fence just like the other parts of the garden. Allow the trees to grow to a height of 2 m to establish a strong root system. Then cut the trees at 1 m, using the branches and leaves as kindling or in making biochar and the leaves as green manure for amending the soil directly, as green material for compost, or as fodder for animals. Where the tree was cut becomes the new top of the tree. As trees grow from the top, many new stems and branches emerge in the process known as 'coppicing'. This thickens the trunk, now a fence post, while providing large amounts of nitrogen-rich leaves. Prune the side branches as time moves on to make the fence more dense and secure. Meanwhile, prune and shape the grasses and shrubs as they mature more slowly.

A well-protected permagarden.
Photograph: **Thomas Cole**

Final thoughts

Building healthy soil, improving water management, and proactively protecting crops are activities that must be maintained year after year after year. In addition to providing guidance on the initial creation of a permagarden, this manual can be referenced to help explain the common processes that occur during a permagarden's life. By understanding the underlying processes of soils and plants, a gardener is better able to maintain a healthy, productive permagarden.

As the permagarden method is implemented, practitioners will encounter obstacles and setbacks. This should not discourage the gardener. A valuable part of the permagarden approach is experimenting with the garden, observing how an intervention succeeded or failed, and adapting the technique further. A successful permagarden entails more than garden design; it also involves a creative mindset that can adapt to problems in a way that memorization of rigid instructions cannot. Agriculture project staff can use this manual to guide the learning process and address common questions.

As project staff work with gardeners, short-term objectives of garden management should be guided by the overarching goal of the permagarden method. Keep in mind the aims of a successful permagarden: ecological, economic, energy, nutritional, and social. By investing the time and effort to build permagardens, practitioners are investing in a valuable resource that will ultimately improve food security and household welfare.

A well-managed permagarden is an important step to food security (above).
Photograph: **Thomas Cole**

Glossary

Antioxidants Compounds that help protect the human body against cancer and other diseases.

Berm A small raised barrier of dirt used to help protect a garden from runoff water.

Biochar Charcoal produced from plant matter, which is added to the soil to improve its health.

Bio-intensive agriculture An organic agriculture system that focuses on sustainably maximizing output with minimal land.

Cation Exchange Capacity (CEC) The ability for soil to hold essential nutrients.

Compost Organic material of a decayed combination of green and brown plants (such as leaves and grass) that is used to improve the soil in a garden.

Contour line A line made up of points that share the same elevation.

Crop residue The materials left on a field or garden after a crop has been harvested.

Double digging Preparing the garden bed twice as deep as normal, at least 20 cm into the subsoil.

Deep soil quality When a garden has healthy topsoil and healthy subsoil.

Fodder Food for livestock (grass, hay, feed, etc.).

Garden beds Prepared soil within a garden where crops are planted.

Holes Small dug-out pieces of land used to catch rainwater.

Humus The final product of decomposition; a dark, crumbly material that has stabilized over time.

Integrated pest management (IPM) An approach that uses environmentally sensitive practices to manage problems caused by pests, usually insects.

Mulch Material added to the top of garden beds to enrich or shield the soil.

Multicropping Growing two or more crops on the same piece of land in the same growing season.

Nutrient cycling Nutrients moving from the physical environment to living organisms and back to the physical environment.

Overflow The planned and stabilized exit route for excess water from a water-harvesting earthwork or tank.

Pathways Areas within a garden where nothing is planted; used for walking.

Permaculture An agriculture and design system that integrates human activity with natural patterns to create highly efficient, self-sustaining ecosystems.

Permagarden A permanent garden that combines practices from permaculture and bio-intensive agriculture.

Perennial A plant that lives for more than two years. Differentiated from annual or bi-annual.

pH 'power of hydrogen' A measure of the amount of acidifying ions found in the soil.

Soil amendments Resources added to the soil to improve its quality and health.

Soil organic matter (SOM) Plant and animal residues, soil organisms, and other substances found within the soil that help plants be healthy and more productive.

Swale A small ditch approximately 30–75 cm wide that runs on a contour line, used to capture rainwater, usually along the borders of a garden.

Trace element Any of various chemical elements, such as iron, manganese, zinc, copper, and iodine, that occur in very small amounts in organisms and are essential for many physiological and biochemical processes vital for optimal plant growth.

Triangular spacing Planting crops in a triangular pattern.

Wastewater Water that is normally thrown out or discarded by a person or household.

Urban garden training, learning how to make compost in Addis Ababa, Ethiopia.
Photograph: **Mestawet Gebru**

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Ecology Action Website: www.growbiointensive.org – extensive website with 45 years' worth of books, publications, self-teaching pamphlets, videos and other resources. Many free downloadable publications in Spanish, Portuguese, Russian, Turkish, English and several other languages.

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Appendix 1 Site design

1 A good starting size for a permagarden is 4m x 4m. This is easy to manage and allows growth in the future.

A well-planned site design:

- improves water management
- limits soil erosion
- increases the amount of vegetables a garden can produce.

1

2 Select a sunny site close to the household.

Clear the site of rocks, grass and other debris.

Clearly mark the boundaries of the area that will be used.

2

3 An A-frame can be used to help determine the direction rainwater will move across this area. This will help you know where to place the berms and the swales that will protect the permagarden beds.

3

4 Digging protective swales and berms around the permagarden helps to manage the flow of water into the garden.

Swales can redirect water to the garden or store rainfall in overflow holes.

Berms protect the garden and provide space to grow useful perennial crops.

4

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5 Plan how many beds will be in the garden.

Mark the boundaries of each bed with twine or by scratching in the dirt before digging and building the garden bed.

The garden beds should be 1m wide and separated by pathways for walking.

At the boundary of the garden, there should be enough space to build a fence to enclose the area.

6 The right placement of double-dug beds, swales, pathways, and fencing all contribute to a healthy, productive permagarden.

By planning the site design before starting work on building the permagarden, the gardener will be able to get the most out of their land.

7 A well designed and built permagarden. Fenced for protection and mulched to conserve water.

8 The same garden after several harvests. It is close to the kitchen and provides year-round access to nutritious food.

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Appendix 2 Composting

1 The basic ingredients for compost are brown, carbon-rich materials; green, nitrogen-rich materials; manure; and water.

In order to break down efficiently, the compost pile should consist of 1/3 green material and 2/3 brown material.

2 Materials to make the compost can be found everywhere in the community.

Dry leaves can be gathered to be brought to the compost area.

3 Dry grass is another important compost ingredient that is found throughout the community.

Before adding to the pile it is good to chop it into smaller pieces. This helps to speed the decomposition process.

4 Clear the ground where the pile will be built. The final size of the pile should reach 1 m long x 1 m wide x 1 m tall.

Dig a 1m long x 1m wide x 10 cm deep hole.

Build a base of coarse sticks as the foundation of the pile.

Add a 20 cm layer of brown material.

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5 On top of the brown layer, add a 10 cm layer of green material and a 2 cm layer of manure or topsoil.

Add 5 liters of water.

Mix all layers, except the underlying stick floor, so that brown and green material are scattered throughout the pile.

Make sure that the green material is well chopped into smaller pieces. This will quicken the decomposition process.

6 Continue adding and mixing brown, green, and manure layers. Pour 5 liters of water onto the pile each time a new set of layers has been added.

7 From the top of the pile, put a long, straight stick down through the center.

Compost gets very hot as bacteria start to break down the material. The temperature of the pile can be checked by pulling out this stick and feeling its warmth.

The stick also helps to aerate the pile.

8 Once the pile is 1m x 1m x 1m, cover with 2 cm of soil or a sheet of plastic to help hold moisture.

Turn pile every 2-3 weeks, watering each time.

9 When ready, the pile will have lost all warmth and be cool to the touch. Finished compost will be fine, crumbly, and fall apart easily in your hand.

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Appendix 3 Making biochar

Making Biochar from Crop Residues

Biochar, or carbonized plant material, is a vital source of pure carbon used for soil improvement. It has many advantages. It improves soil's ability to hold air and water; it increases soil CEC, a measure of nutrient holding and absorption; and its micropores serve as permanent housing for the billions of beneficial microbes found in healthy soil. Biochar, added year after year, will build a healthy soil structure and result in resilient, highly productive crops.

How to make biochar

1. Gather dry crop residues, newspaper, and a match. Additionally, gather a 55 gallon drum with holes in the bottom.
2. Dig a hole slightly less in diameter than the barrel with air-intake vents on either side. Alternatively, set the barrel onto three bricks. Both methods allow good initial airflow.
3. Place rolled newspaper and dry leaf (such as maize cob leaves) 'wicks' into each of the small holes in the bottom of the barrel.
4. Tip the barrel over the hole or onto the bricks.

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5 When smoke is rolling out of the top of the barrel, place the barrel back down over the hole or on the bricks. Continue to add more crop residue until the barrel is full.

Add a lighted paper through the top of the barrel so that smoke turns to flame. Allow the flame to engulf all the materials for 2–3 minutes.

6 Remove the bricks from the barrel or add soil to cover the vents of the hole while also placing the lid in top of the barrel. Be careful, as flames may shoot out from underneath at first.

Add several handfuls of sand or clay soil around the edges of the lid. Make sure no smoke is allowed to escape from within the barrel.

7 Wait. Alllow the materials to be carbonized for at least 4 hours.

8 Remove the soil and the lid from the top of the barrel and tip the barrel on a grain sack. Place the fully carbonized pieces into the sack and crush into small pieces now ready for use on the garden or blended with manure to make charcoal briquettes for cooking fuel.

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Appendix 4 Double digging

1 Prior to digging the beds, gather local waste materials:

- Charcoal chips and dust
- Wood ash
- Dry manure
- Coffee grounds
- Egg shell

2 Mark out all the borders of the permagarden beds within the entire garden.

Measure and mark out 40 cm sections of each bed that will be dug.

3 At the beginning of each bed, stand on the pathway and loosen the first 40 cm section of hard topsoil down to the compacted layer. Pull that soil into a pile at the end of the bed.

This will be 20-40 cm deep, depending on how hard or rocky is the site.

4 Standing with both feet on the path, loosen the subsoil as deep as possible, breaking up any large clumps.

5 To the trench of loosened subsoil, apply and mix:

- charcoal dust (3 handfuls)
- dry manure (3 handfuls)
- wood ash (1 handful)
- compost (if available).

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6 Dig and pull the next 40 cm of topsoil over this first section to expose the compacted subsoil of the second section.

Loosen and amend the subsoil in this section as in the first section. After amending, loosen and dig the next section of topsoil on top of this subsoil. Continue in this manner until the end of the bed.

7 When the end of the bed is reached, bring the soil from the first dug section and fill the end of the bed.

Now amend the topsoil. To every meter add:

- bucket manure or compos
- ¼ bucket charcoal
- 3 handfuls wood ash

Mix well and blend into the top 15cm of the top soil.

8 Once the entire bed has been double dug and amended, rake the top surface.

Using a rake helps to create a flat and smooth surface to plan out the crops.

9 A well-prepared double dug bed will allow crops to grow strong and healthy and produce large amounts of food in small spaces.

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Appendix 5 Triangular spacing

1 This technique uses sticks and string to plant seeds in off-set rows, or "triangle spacing."

This spacing allows bushy plants like tomatoes to grow fully with competing with each other.

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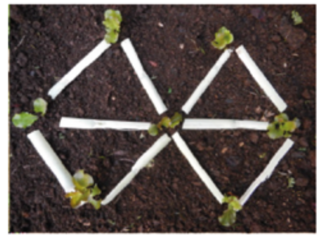

2 Use a long piece of string to mark a straight row that runs the length of the bed.

Using the long string as a guide, place sticks in the ground where each seedling will be planted in that row.

For the neighboring row, the sticks will be placed in an off-set pattern. The sticks in the second row will be "behind," not next to, the sticks of the first row.

[Run a short piece of string from the closest stick in the first row to the second row. Place a stick where this short string overlaps with the second row.]

Repeat these steps for the remaining rows in the bed.

2

3 Plants should form an equilateral triangle.

Plant seeds or seedlings where sticks have been placed.

Once planted, water seeds and mulch the garden well.

3

4 To conserve soil moisture, add mulch to the soil. This helps keep the sun off the soil until the leaf canopy covers the bed.

4

5 When the leaf canopy closes, the soil will not be exposed to direct sunlight. This will help prevent weed growth and loss of soil moisture.

A scaffold of sticks and string can support the growth of bushy plants and keep them from falling over.

5

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Appendix 6 Botanical tea

1 Gather green leaves from throughout the community.

2 kg is good to make a botanical tea.

Tithonia is one of the best plants to make a tea to fertilize plants due to its high phosphorous and nitrogen levels.

2 Chop leaves.

Chopped leaves dissolve quicker than whole leaves.

3 Put leaves in sack.

Make sure the sack is porous.

4 Place sack into container.

Tying the sack to a stick placed across the top of the container helps to suspend the sack in the water. Lifting the stick can help stir the sack.

5 Add water. 10 liters for every 1 kg of leaf material. Let soak for 2 weeks, stirring every few days.

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6 After 2 weeks the plant material will have dissolved into the water.

Remove the sack.

Dilute the green liquid that remains with water. 2-3 parts water to 1 part green Tithonia liquid.

7 Use leaves to help spread the Tithonia tea onto plants.

The tea can be added to plants in the permagarden or crops in the field to help stimulate growth.

8 A plastic water bottle with holes poked in the lid can also be used to help fertilize your plants.

Tip: plant Tithonia around the garden for low-cost way to have a high-value fertilizer available for the garden throughout the year.

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