Permagarden

Technical Manual

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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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The Technical and Operational Performance Support (TOPS) Program is made possible by the generous support and contribution of the American people through the U.S. Agency for International Development (USAID). The contents of this report were created by The TOPS Program and do not necessarily reflect the views of USAID or the U.S. Government.

The Technical and Operational Performance Support (TOPS) Program. 2015. TOPS *Permagarden Technical Manual*. Washington, DC: The TOPS Program.

Photograph (front cover)
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Photograph (back cover)
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Acknowledgements

The TOPS *Permagarden Technical Manual* 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 content of this manual, and the broader toolkit, was adapted and developed under the Agriculture and Natural Resource Management component of The Technical and Operational Performance Support (TOPS) Program. The practices and examples used throughout the manual and associated guidelines originate from the trainings and methodology developed and led by Thomas Cole and Peter Jensen.

The TOPS Program would sincerely like to thank Thomas Cole for his expert technical knowledge and for developing the content of this manual and the associated toolkit. The TOPS Program would also like to thank Peter Jensen for his significant contribution to the content of these adapted materials based on his personal permagarden training materials.

Sincere gratitude to Eric Carlberg, who led the development of the manual and toolkit, and provided significant writing and technical content, and to Joseph Little and Amy English for contributing time to reviewing the resources.

Finally, The TOPS Program is deeply grateful to all the field staff and farmers who have contributed to the development of these materials through the various practical training events and technical discussions, and who continue to use sustainable permagarden methods to address the challenges of food security.

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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 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 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 permaculture and bio-intensive agriculture 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, water management, and inputs to produce nutritious crops year-round. The method shows how farmers around the world with only a small amount of land can produce food throughout the year by learning the natural principles behind proper gardening 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 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 all of the key concepts in creating a permagarden and matches them with appropriate practices, like double digging, making botanical fertilizers, bio-intensive seed spacing, and succession planting. It is intended to be paired with the The TOPS Program training materials to enable project staff, together with farmers, to successfully implement a thoughtful, strategic approach to home gardens.

How to use this manual

The TOPS *Permagarden Technical Manual* is a resource for agriculture project staff implementing permagarden 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, and is therefore designed to provide agriculture staff with both the theory behind the permagarden method and the practical activities needed to work together with farmers to implement a permagarden.

This manual specifically focuses on the production part of permagardens. 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 challenges in accessing markets are location-specific, and linking poor farmers to markets 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 a training of trainers (ToT). The guidelines for the 3-day training provide instructions for teaching program participants; the ToT guidelines provide instructions for a trainer teaching agriculture staff from development projects. The toolkit also includes other teaching tools for agriculture staff, including pictorial sheets, a productive behavior checklist, a set of "Walk and Talk" questions, and barrier analysis questionnaires on permagarden practices.

It is important to note that any transfer of knowledge about new technologies, including testing and adapting the practices regarding permagardens, requires a significant amount of time. Therefore, 3-day trainings should be backed up by continued technical support through standard extension methods, such as farmer field schools. It is important that farmers fully understand how to implement each practice of effective home garden management and why it is important. Therefore, the learning process should continue over at least two cropping seasons.

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. 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 that a large-scale agricultural approach is not required and, in fact, is counterproductive for them and their landscapes. This new paradigm of "Small is Bountiful" stands in stark contrast to the "Bigger is Better" approach of commercial agriculture.

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 low input techniques, causing 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 increasing soil fertility and resilience to shocks and stresses.

Women with small children are often the target audience for home garden initiatives in FFP programs, but 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 and digging after a rainfall, should be integrated into program work plans to increase the likelihood of successfully implementing a home garden initiative.

Large yields of nutritious vegetables from small spaces.

Photograph: **Thomas Cole**

Overview of the permagarden method

Garden observation and dialogue.

Photograph: **Thomas Cole**

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. The method is sustainable, as it involves only local materials, and strengthens the local environment in an economically viable manner. It is also a method that works in the rainy season and in the dry season with proper water management. Overall, the permagarden methodology has four goals:

1. Nutritional goal: To increase access to a diverse diet, which improves intake of critical micronutrients
2. Economic goal: To maximize the benefits of intensive production, leading to excess harvest that can be sold to increase income
3. Ecological goal: To enhance environmental resilience through water conservation and the use of local waste materials to improve soil fertility
4. Social goal: To build the skillset, capacity, and confidence of gardeners to understand their environment and become more productive members of the community

The permagarden approach is a combination of permaculture and bio-intensive agriculture. Permaculture teaches how to understand and work with nature, while bio-intensive gardening teaches about maximizing soil and plant health for optimum yield.

"Permaculture," a combination of the words "permanent" and "agriculture," results in permanent, soil-based structures, such as swales to direct rainwater into the soil and holes to capture rainwater rather than have it flood over the garden, as well as plantings of perennials within and along berms (raised beds) created to direct water. In essence, permaculture helps in understanding natural patterns that affect the homestead. Specifically, it is used around the edges of permagardens to control and manage water and to provide a potential for year-round supplemental food production on the berms.

"Bio-intensive agriculture" refers to the efficient system of deep digging, composting, planting, and management of annual crops in beds that are found within these protective and productive berms.

This permanent garden is a small-scale, high-yield, nutrition-focused engine of food security that anyone can create close to home. **The key components of the method are local resource assessment, proactive crop protection, and low labor management, all of which rely on local**

materials to create year-round production. The permagarden does not rely on expensive material from outside the community; it can be successfully 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 table 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 permanent 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 floral 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. Higher yields of nutrient-dense fruits, vegetables, and legumes close to home builds empowered families who can be hopeful for a future free of hunger and income insecurity.

Empowering gardeners to make decisions

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

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 empower households to carefully consider what decisions to make to maximize their livelihood.

The key concepts of the permagarden method are:

- Small changes can make big differences (small doable actions for behavior change)
- Water control and conservation with swales, holes, and berms can lead to higher soil moisture levels and production into the dry seasons
- Long-term soil fertility management increases year-round production
- Necessary resources—tools, seeds, plants, and soil amendments—are available locally
- Year-round food production with a diverse harvest of nutritious crops is possible for smallholder farmers
- Home gardens can create environmental enhancement around the homestead
- Home gardens provide practical linkages between agriculture and nutrition

Building resilient households

The permagarden method aims to build the capacity of farmers to withstand and adapt to shocks and stresses, whether it is drought, flood, conflict, or something else, and still be able to produce nutritious crops throughout the year. This is achieved by teaching the principles of creating a productive garden and by preventing dependence on outside or expensive resources. All of the materials needed for a permagarden are available and affordable to the farmers on a year-round basis.

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

Barrier analysis to effectively implement the permagarden method

It is important to conduct some formative research to better understand the target population. The Barrier Analysis[1] 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. While the permagarden method has been shown to increase productivity for smallholder famers, its individual efficacy—the desire to produce an intended outcome—may vary by household depending on individual perceptions, cultural beliefs and fears, and other factors. Conducting a Barrier Analysis prior to implementing this strategy allows for the highest levels of adoption. By interviewing "Doers"—people who are already practicing a behavior—and "Non-Doers" within the community and comparing their perceptions, program staff can generate an evidence base around most critical enablers and obstacles to behavior change. It is important to remember that Barrier Analysis requires interviewing 90 total members of a target group, 45 "Doers" and 45 "Non-Doers," so with relatively new behaviors it is often necessary to use other formative research approaches. The findings of the Barrier Analysis can then be directly integrated into the messaging during the 3-day permagarden training and follow-up conversations with the smallholder farmers.

Photograph: **Maggie Mcloughlin**

1 Identifying assets and resources

The permagarden method uses only local resources to build and sustain the garden. A simple walk around a 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, bicycles, animals, 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, all 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. Within the household, there are spaces that could be better used and waste areas that could be converted into a bounty of produce with just a little extra work to clear the land, control the water, and manage new plants. After determining what might be valuable in the household and the community, the next step is to walk around the homestead to map suitable potential garden areas. 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 participants. Several key items should be identified as assets and resources for the garden:

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. Look for areas next to buildings or fences that are currently not well used but still offer sunlight at least 4 hours a day. Walls, trellises, and fences allow plants to grow vertically, allowing significant production from a small planted area.

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. Dried 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.

Water sources Sources of water include runoff from roofs, hillsides, roads, and pathways that can be controlled and redirected within the homestead, or homestead wells or municipal taps nearby. 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 of the most important and nutritious vegetables to promote are the indigenous varieties that people already eat and that are readily available within the informal seed markets. Neighbors, friends, and the extended family may have seeds or plants that they have and 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.

Tools Contrary to popular belief, the only tools needed to create a vibrant garden are hoes, buckets, and a machete. Survey the household and neighborhood for additional tools that could be useful, such as rakes, watering cans, empty grain sacks, and twine.

Discussing uses of local plants.
Photograph **Thomas Cole**

2 Site design

Long-term planning and mapping of the garden can help avoid loss of nutrients and resources on the land and can build resources for the future. One of the first steps is to understand the natural flow of rainwater across the landscape, determining where and how runoff water enters the land and where it exits as it passes through. Tremendous amounts of rainfall will fall on this garden space. The issue is not the amount of water, but controlling water during the wet season and accessing it during the dry season. Once water flow is understood, basic agronomic practices can be employed that build on principles to capture the water. In this way the gardener can build a garden that stops and slows the water on the land, allowing it to spread and sink into the soil.

Site assesment.
Photograph **Thomas Cole**

Size and location

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/internally displaced person (IDP) settings, the permagarden approach allows important food production even as more traditional vegetable growing can be extremely difficult. In the dry season, garden beds can be smaller to accommodate the greater difficulty in accessing water. Key characteristics of an ideal permagarden site are:

- Sunlit at least 4 hours a day
- Accessible to all family members
- Protected from extreme winds, livestock, or other damaging elements
- Soil that can be amended (improved) and that is relatively free of ¬rocks

A good starting size for a typical household garden in an FFP program is 16 m^2 (e.g., 4 m by 4 m). More space can be added later, depending on family acceptance and desire to expand, but the key message is to start small. A large starting space can become too labor intensive too quickly and discourage farmers from continuing. Starting small ensures the best possibility for further expansion to meet family needs. Once a farmer has a complete understanding and the 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. In addition, a gardener must commit labor and time when creating a garden; starting with a smaller garden will prevent a gardener from being overburdened and prevented from carrying out other important activities.

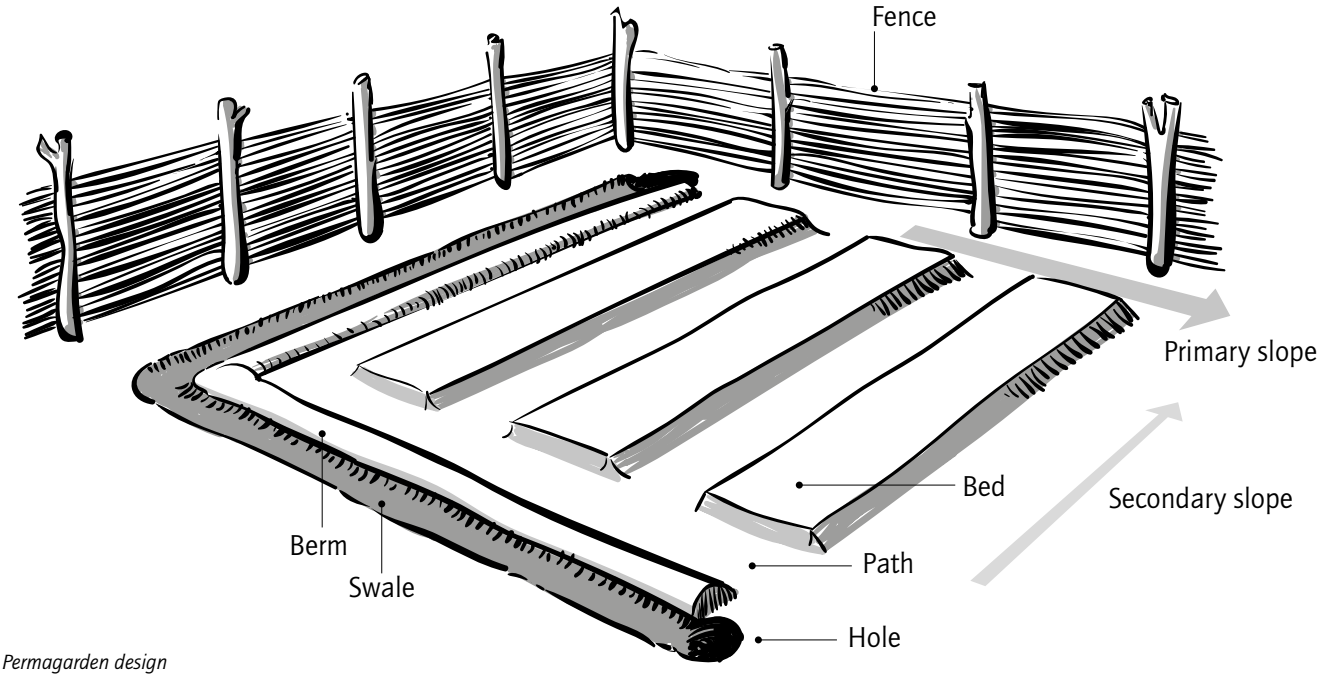
Garden design and layout

After the garden site is chosen, it should be cleared of rocks, weeds, and other debris and then lightly cultivated 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 needs to determine where rainfall will enter the cleared garden and how the water will flow through the garden. The key concept here is that the gardener can direct this flow. The gardener is in control and can make decisions that make the most sense for the garden and surrounding landscape. The purpose of the design is to increase the amount of water entering and absorbed into the soil in dry regions, especially to help in the dry season or during dry periods in the growing season. Likewise, proper management can help prevent flooding in wet regions by diverting excess water away from the garden, which will prevent crops from getting waterlogged.

All of the components of a permagarden—the swales, berms, holes, beds, pathways, and fence—should be planned out on the cleared site. Each one of these components is discussed in greater depth later in this manual.

The specific instructions for planning and laying out a permagarden are 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 plan allows for enough space for a fence surrounding the garden.



Permagarden design

Fenced permagarden.
Photograph: **Thomas Cole**

One example of how to plan and layout a permagarden (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."
2. A swale should be placed at the highest point of the garden so that it blocks the main flow of water at the top of the garden and instead collects the water and allows it to slowly seep into the garden's soil.
3. Draw a line along swale on the side where the garden is planned. Try to keep the points of the line at the same elevation. This line forms the border of the upper part of the top berm.
4. Draw a second line parallel to the first line 50 cm down the slope. These two lines mark the entire upper berm.
5. At either end of these two lines draw a 50 cm wide circle. This marks the receiving hole that will capture water coming into the garden.
6. 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 ditch along the side of the garden that will carry this water down the slope eventually into another hole that will be part of the side swale. Draw a line parallel to the ditch 50 cm toward the outside of the garden. This is the side berm.
7. Draw a lower swale, along with a 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 line 40 cm down the slope from the upper berm that parallels the berm. The area between the berm and this line form the upper permanent pathway.
9. Draw another parallel line 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.

3 Soil health

Healthy soil is the basis of a healthy, productive garden where plants get all the minerals and moisture they need, when they need it. Increasing and improving the quality of the air, water, and organic material in the soil leads to increased root health, resulting in healthier crops and higher yields.

Compost.
Photograph **Thomas Cole**

With a sound long-term approach, healthy soil can be achieved regardless of initial soil quality. Locally available soil amendments can be used to grow healthy plants, all from proper soil management using local tools. It is important to understand these basic themes that relate to the soil itself:

- Soil is a living substance that must be nourished, managed, and protected.
- Soil organic matter (SOM) improves the structure of the soil, increases microbial activity, enables water retention, and helps make nutrients available for the plants that are growing in it.
- Soil organisms help break down crop residues and plant matter into SOM.
- Sustainable soil health can be achieved in a relatively short time using local tools, plants, amendments, and good management practices.
- Soil fertility management is based on conserving soil, water, and SOM; increasing SOM content; and supplementing nutrients through soil amendments.
- Deep soil preparation in the permagarden (called "double digging") and the use of locally prepared compost and other amendments are the keys to proper soil health and moisture retention, leading to resilient plants.
- Garden management gets easier with time as the foundational elements are implemented.

Analyzing the existing soil helps unlock its potential to grow more crops. The critical elements of soil are texture, structure, acidity, and organic matter. The "ideal" soil is 25% air, 25% water, 45% mineral particles, and 5% organic matter. All of the elements combine to create a healthy soil.

Soil texture

Knowing the textural class informs a farmer about how best to improve it and gives clues about current nutrient and water-holding capacity.

- 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.
- Clay soils (soils with a higher percentage of clay than sand and silt) hold onto

plant nutrients, but they easily get waterlogged and compacted. They are older and less fertile than silt and loam soils.

- Silt soils (soils with a higher percentage of silt than sand and clay) are relatively fertile compared to clay and sandy soils, but they are most at risk to water erosion.
- Loam soils (soils with approximately 40% sand, 40% silt, and 20% clay) have the ideal soil texture. They drain well, but they also hold water better than sandy soils. They have high soil fertility and are best suited for agriculture.

Organic matter, incorporated 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

A soil that holds together either too much or too little gives clues as to what needs to be done to change it and what would grow best in it. A soil that is too compacted, where the soil particles are pressed too close together, restricts root growth and prevents nutrients from reaching the plant. Soil pores can be blocked under several conditions. Heavy foot traffic and cultivating wet soil can both lead to soil compaction. Heavy rains can also block soil pores. When soil is waterlogged, all the pores are filled with water, leaving very little air available to plant roots. Soil compaction can be solved by using a deep soil amending technique known as double digging and by protecting the soil by using pathways for walking and fencing to keep animals away from the garden beds.

In sandy soils with too much pore space, water quickly drains before plants can access it, while in dense clay soils, the soil easily gets waterlogged, as all the pore space is quickly filled with water, thus suffocating plant roots and soil organisms. SOM is the key element to add to both a clay soil to allow the soil to drain water and a sandy soil so that it can hold water. SOM also acts as a source of food for microbes and holds nutrients for improved plant growth. A gardener can increase SOM by adding fully cured compost, well-rotted manure, or crushed charcoal during cultivation.

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.[2] 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). 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 acid or basic soils by adding large amounts of compost, manure, and charcoal dust.

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 not unchanging, but is in fact 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. 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. Through composting, crop residue management, and the addition of other organic matter, bio-intensive agriculture encourages 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). In exchange, the legume gives some food it created from sunlight to the microbes. When these plants die, the converted nitrogen gas is released into the soil.

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

Role of microbes in soil

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.

Compost

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

Compost is a key way to add organic matter to the garden. It bears repeating that organic matter, best applied as compost or rotted manure, is the most important ingredient that can be added to improve garden soil. It ensures 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; manure; and water. Composting works best when the pile has one-third "green material" and two-thirds "brown material." 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, 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.

A well-made compost pile heats to 120–140° Fahrenheit (49–60° Celsius) after just 2 days. One 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 square meter.

When blended and managed over the course of 2–3 months, composting creates a material that works to improve the health of the soil and the plants that grow in it. 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 to the plants. A soil stripped of its organic matter resists water penetration, leading to crusting, erosion, and flooding.

Aeration Plants can obtain 96% of the nutrients they need from the air, the sun, and water. 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, where it is absorbed by the canopy of leaves of closely spaced plants.

Fertilization While compost is not a fertilizer, it does contain some 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 Cation Exchange Capacity (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 of 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 to allow 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 a thermometer
- A machete or hoe to chop the material into small pieces

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

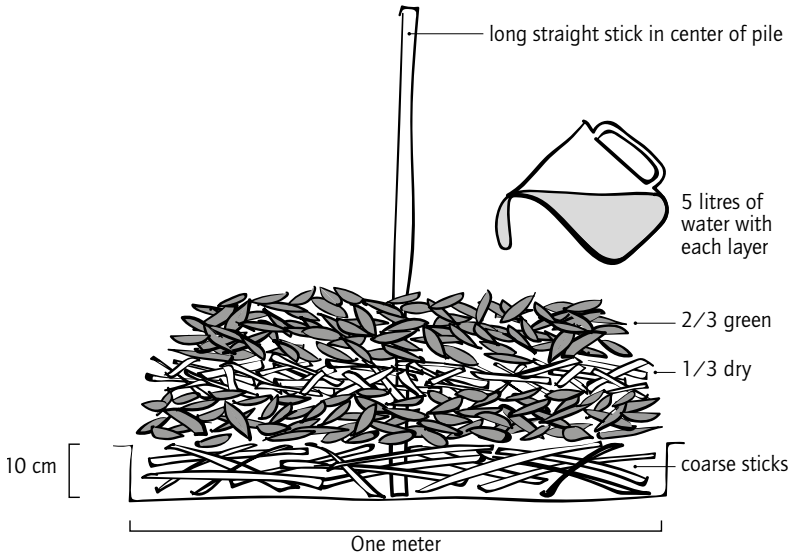
Materials that should NOT be added to a compost pile:

- Plants known to be diseased or under severe insect attack (they should be removed and burned rather than composted; the risk of further infection outweighs the benefit of the organic material)
- 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: wild morning glory; 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

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.
3. Put down an initial 5 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 12 cm layer of brown.
5. Add a 4 cm layer of green.
6. Add 4 large handfuls of topsoil, manure, or finished compost.
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.
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.

Making compost (right)

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.

Local soil amendments

Many local resources exist around the home or the neighborhood 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 double digging the permagarden (see page 28). 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 to be further decomposed, burned, or crushed before adding to the garden.

Applying woodash increases the soil's pH level (above).
Photograph **Thomas Cole**

Wood ash is a primary source of calcium carbonate, which can be used to 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 1 kg 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 especially the small chips and dust no longer useful as fuel, is an important soil amendment. 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 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.

Gathering soil amendments (right)
Photograph **Thomas Cole**

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 the Appendix 3.

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, often simply tossed away, 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.

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, and 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 are going to be planted
- Mix into the top 20 cm of the soil
- Repeat before every planting cycle

Double digging

Double digging with local soil amendments allows for closer plant spacing, as the roots can grow down rather than merely to the sides. Crops can more easily be rotated between beds from season to season to maximize control, break disease and insect cycles, and achieve higher yields without a decline in soil fertility or quality.

The average garden or agricultural field 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 near 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 good air-water dynamics 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 digging deeper in the permagarden. By preparing the soil deeply, breaking through and amending that compacted subsoil layer, ample air, water, and carbon allow healthy plant roots to go much deeper. This practice, known as double digging, can be done using local tools. This is one of the most important parts of a successful garden.

Double digging requires a lot of effort, but ultimately it creates a garden bed that is easier to manage. A double-dug garden bed does not need to be re-dug for another 5–6 years. Since double digging requires so much work, it is

Mixing manure into the soil. (above)
Photograph **Thomas Cole**

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.

Double digging
Photograph **Thomas Cole**

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

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

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.

1. Begin by marking the edge of the beds using sticks and string or using 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.
2. 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.
3. Remove 20–30 cm of topsoil from first 40 cm section, digging down until the hard pan is reached. The removed topsoil should be kept at the end of the bed.
4. When possible, have a partner dig the next 20–30 cm of subsoil, loosening and digging but not removing the soil. Keep digging the whole section until most of the larger pieces have been broken up.
5. 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.
6. Using a shovel or a hoe, mix these amendments into the subsoil.

7 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.

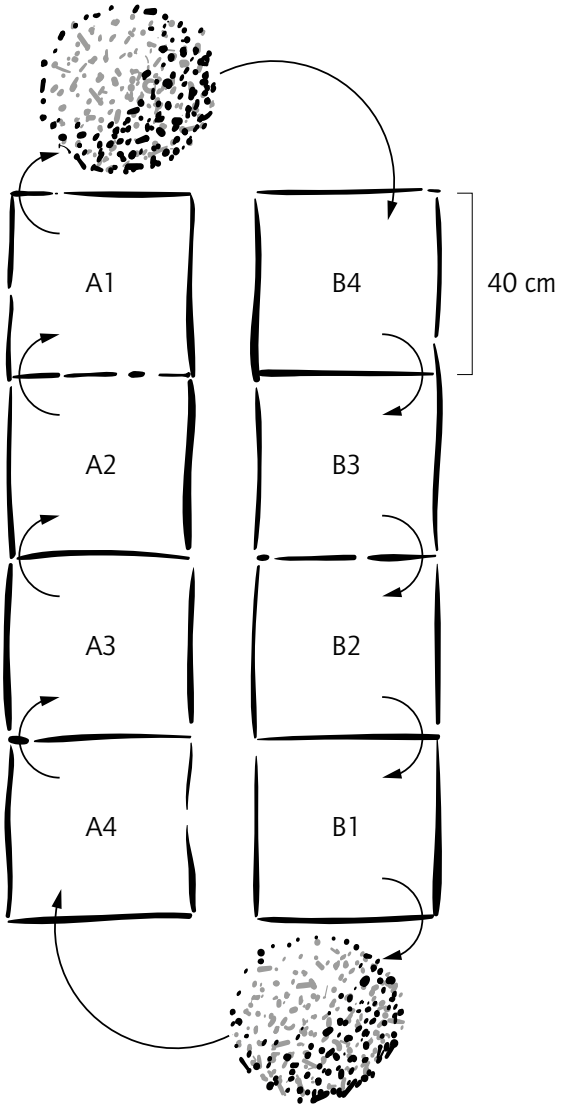
8 When possible, have a new person loosen the subsoil as in Step 4. Repeat Step 4.

9 Amend the soil, following Steps 5–6.

10 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.

11 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.

12 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 a permagarden bed (right)

4 Water management

Water is the most critical element to plant growth. Without it crops cannot grow. It can also be the most limited and precious resource. With the expected higher temperatures brought on by global climate change, water management is becoming even more of an issue, even in places that normally enjoy "reliable" rainfall patterns. 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.

Swales help to conserve and store water in the soil.

Photograph **Thomas Cole**

Even in dry locations, a lot of rain falls 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, more than enough to grow a wide variety of crops. And this does not include all the rainfall on the rest of the land near the garden, which, with proper management, can also be used.

An interesting practical exercise with gardeners is to compute how much rain falls on 1 m^2 during a 100 mm rainfall. How many jerry cans is this? 100 mm of rain falling on 1 m^2 = 100 L. This is equivalent to five 20 L jerry cans of water. Some 60,000 L of water falls on a 20 m by 30 m garden in a 100 mm rain. This is equivalent to 3,000 jerry cans of water.

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 is lost due to rain. By effectively managing rainfall, the impacts of erosion can be minimalized and the nutrients and organic matter built up in the soil can remain in the garden.

The permagarden design allows for the efficient capture and retention of even the most minimal rainfall through micro-catchments. 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, whether it is rainwater, wastewater, or collected from a water point. This involves minimizing water runoff, evaporation, and waste. Any water that leaves the homestead is a lost opportunity. A gardener should work to stop the water from running off the land and allow it to enter the soil. Water can be captured from several sources:

- Rainwater collection and utilization
- Surface water management
- Water retention with mulch
- Household wastewater management

The first step to effective water management in a permagarden is to understand the four key "S" principles of water management: Stop, Slow, Sink, Spread. Once the idea of effective water management is understood, a gardener can identify his or her main sources of water and then implement the best range of practices to use those resources.

Stop, slow, spread, sink

Effective water management in the garden begins with the four "S" principles: stop, slow, spread, sink.

Stop the water. This principle focuses on stopping the destructive potential of rainfall on bare soil, as well as rainwater runoff flowing down a slope. Without some type of perennial cover—plants or mulch—soils can lose significant amounts of productive topsoil to erosion, even in a single rainstorm. Likewise, unchecked runoff down a slope can quickly create irreversible damage to a garden or larger landscape through erosion. Learning to stop water from such damage is a basic principle of water management. Mulch and micro-catchments practices, such as swales and half-moons (discussed on page 34–36), are some key activities to help stop the water.

Slow the water down so it can infiltrate. Once the initial force of the water has been stopped, the next principle focuses on practices to slow the water down. 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 all of the roots of more plants access to the moisture that they need to grow and produce healthy crops.

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 nature of double digging 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.

Keeping the land covered

A gardener should not burn crop residues, grasses, and weeds in a permagarden, or even in their main cropped fields. This would cause the garden to lose a lot of moisture to evaporation and runoff. An important way to maximize the capture of water is to keep some form of cover on the field at all times. This can be achieved by keeping mulch or crop residue on the garden beds. 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. This helps keep the temperature of the soil low, even during hot, dry weather, thereby slowing evaporation rates. This retention of moisture is often enough to get crops through extended dry spells in the rainy season, while soils protected in such a manner can also conserve remarkable amounts of water for the following crop.

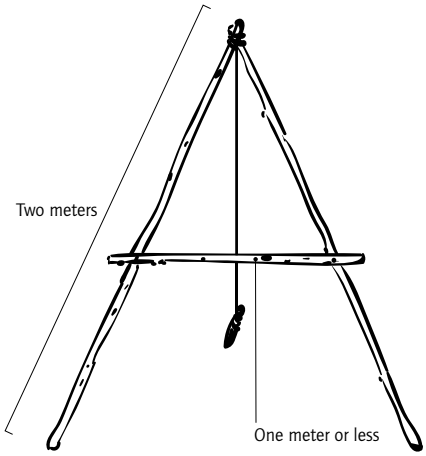
Understanding the contour of the land

A key idea behind designing and building a permagarden is to understand how water will enter and flow through the land. 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 this practice should always be done when designing and building a permagarden. To begin measuring contour lines for a permagarden, a gardener should begin 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.

Adding straw reduces water loss through evaporation and water runoff.
Photograph **Thomas Cole**

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.[3]



Building an A-frame (above and right)
Photograph **Thomas Cole**

How to build an A-frame

1. Gather three sticks (two 2 m and one 1 m), 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 put into use in the field.
2. Nail/tie the two longer sticks together at one end with the opposite ends approximately 1.5 m apart.
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 approximately 10 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 line 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 twine crosses the middle stick.

c Finally, put a line in the middle of 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 or small stick at that point.
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 a contour line is drawn across the length of the garden site and the other side has been reached.

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 stop, slow, and sink the water.

Water management practices

Swales, berms, and holes are part of the design of a permagarden and work to stop and 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 bio-intensive garden bed. Other micro-catchment and water management practices that can be incorporated into a permagarden include half-moons, mulch, wastewater reuse, plastic water bottles (see page 33), and clay pots (see page 34).

Swales

Swales are an important water management tool, especially in dryland regions where the goal is to stop and 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

Digging a swale.
Photograph **Thomas Cole**

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 17). Swales are important in resource-poor environments due to their minimal cost to construct and maintain and their overall effectiveness in capturing water.

The number, design, and size of the swales are up to the farmer, and understanding 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 17).

Berms

A berm is an earthen structure, often placed below or beside a swale. The primary function of the berm is to help protect a garden from runoff water. 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.

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 soil 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 straddling the berm, pull 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.

Half-moons

Half-moons are another micro-catchment strategy to harvest and retain rainwater, particularly in dryland regions. (In some areas, half-moons are referred to as boomerang 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. Micro-basins are similar in concept and practice, though the berm, or ridge, of the micro-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 double-dug 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 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.

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

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.

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

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 water needs to be rationed in the garden; it also works well to help irrigate newly planted trees.

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

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.
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. This is a good opportunity to reuse household wastewater.

9 A 1 L bottle is enough for three plants (tomato, pepper, eggplant, cabbage, and kale, for example) if triangular spacing is used (see page 42).

10 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.

11 The bottle can also be hung in the air tied to a stick about 15 cm above a plant, enabling a slow drip onto the plant's root zone below.

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 form 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 uptake of this technique is limited, conducting a barrier analysis to ascertain why farmers are not using wastewater can help identify next steps (see page 12).

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 only about twice each week.

How to use the clay pot method

1. Before planting, unglazed clay pots (20–30 cm in diameter) are dug into the bed, spaced anywhere from 50 to 100 cm apart. The pots are buried so that the soil line is level with the top of the pot.
2. Seeds are then sown or seedlings transplanted at the proper interplant spacing for the given crop. The seeds are placed 10 cm from the edge of the pot and all around it. There should be four plants around each pot.
3. The pot is filled with water and then covered (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. Seedlings need to be watered when first planted. Water in the clay pots will 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).

5 Bio-intensive planting

By providing good soil structure, adequate nutrients and amendments, and a deep root zone, a properly prepared permagarden with double-dug beds is the foundation of 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 what may be normally practiced, helping maximize crop yields while reducing moisture loss. This section of the manual details the bio-intensive approach and provides guidance on how best to plan for and plant permagarden beds taking into account household nutritional requirements, planting times, and plant nutrients to create a garden that continually produces crops throughout the year.

Seeds

Triangular spacing.
Photograph **Peter Jensen**

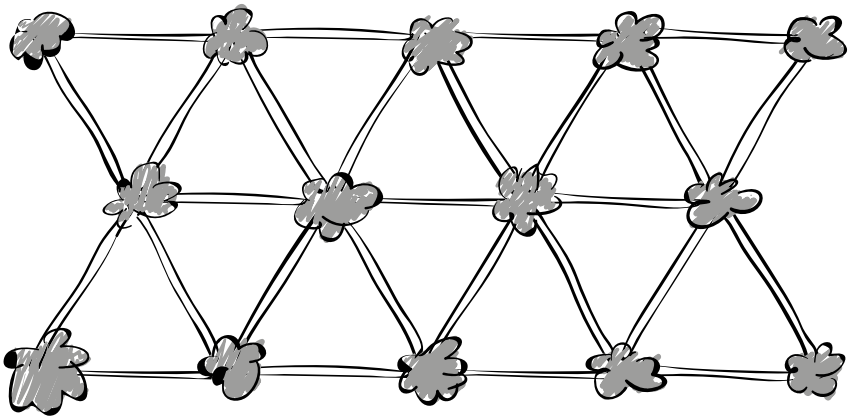
One benefit of the permagarden method is that it uses locally available plants and varieties, and the garden is designed around the types of plants that are accessible. Gardeners should be encouraged to use indigenous varieties that people already eat locally and that are readily available in the informal 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 a good strategy to limit pests in the garden. In many areas, there are several different local varieties for vegetables and other plants, and households might have different preferences based on taste, cooking time, availability, days to harvest, or storage.

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 local varieties for consumption.

In addition to planning for this season's garden, it is important that a gardener plans for future planting cycles. Gardeners should plan ahead to save 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.

Triangular plant spacing

Bio-intensive planting uses a triangular approach when planting most crops in the garden, contrary to the usual square or rectangular pattern. This allows a greater density of plants per square meter, thus increasing yield. Using a triangular spacing method (the sides of the triangle in the triangular spacing method should all be 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.



Triangular plant spacing (right)

Benefits of triangular spacing:

- Increases plant density: Deeper roots allow closer spacing, resulting in growing more per unit area
- Increases plant/root health: Allows better capture of moisture and carbon dioxide
- Increases root quantity: Results in more organic material and biological activity
- Decreases weed pressure: For canopy shading of bare soil
- Decreases water requirements: For canopy shading of bare soil and less moisture loss

Deep digging allows crops to be planted using close, precise triangular spacing (see photo). By planting in triangles, 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 resource needs decrease.

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. After the whole bed is marked and dug, the pattern should appear as many small triangles.
7. Water 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.

Seed spacing

There must be enough space in the garden for each plant to grow, but not so much space that production drops because the plant spacing was not maximized. The permagarden method uses closer plant spacing than what many gardeners may be used to. Less space is needed between the plants because the deep-dug beds allow the roots to go down more and sideways less, 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. These figures are useful to follow when planting in lines across the bed or when the triangular plant spacing approach is used.

Seed spacing (in centimeters) for direct-seeded crops

Crop	Spacing in garden bed (cm)
Amaranth	Broadcast lightly, thin to 4 cm
Beans (dry/green) and cowpea	15
Carrots	Broadcast lightly, thin to 5 cm
Chickpeas (garbanzo beans)	15
Garlic (cloves)	8
Groundnuts	14
Irish potatoes (sprouted tubers)	18
Maize	35 (plant 2 in each hole, but remove the weaker one at 2 weeks)
Millet	15
Onions (use root portion from previous)	6
Pumpkins	100 (allow to spread within bed)
Radishes	5
Sweet potatoes (stem cuttings)	18
Wheat	5
Zucchini	30 (can plant hill with 2 per hill)

Seed spacing (in centimeters, in trays) for transplanted seedlings

Crop	Spacing in seed nursery tray/bed	Spacing in garden bed
Broccoli	5	30
Cabbage	5	30
Cucumber	5	25 (train to grow up trellis)
Eggplant	5	35
Kale	5	20
Leaf Lettuce	Broadcast then thin to 6	15
Onion	5	10
Pepper (hot or not)	5	25
Spinach	Broadcast then thin to 6	12
Swiss Chard	5	15
Tomato	5	35 (stake up with poles)

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

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

Starting 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 productive life. Less water is required to grow these plants in a nursery bed than in a garden, and, when the time comes to transplant them to the garden, it is easy to choose only the healthiest plants.

How to prepare seedlings for a permagarden

1. Prepare soft, light 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.[4] 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. Cover and firm the soil lightly, and 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. If using the box method, simply move them in and out of the sunlight. 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 will be strong enough for transplanting into individual boxes and then, at 7–8 weeks, ready to be planted into the garden bed itself.
4. 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. Before planting, remove a few of the lower leaves to allow the roots to recover from "transplant shock" and develop quicker.

Crop rotation and intercropping

With proper 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 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. In the permagarden, the best practice is to rotate crops to provide both nutrients to 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 organic cultural 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 need more phosphorus for proper flower development. Actually, 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 them 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 mean healthier, stronger plants and little to no need for costly and potentially dangerous pesticides. Before planting any new crop, however, additional compost is needed to maintain micronutrient-rich, organic matter and beneficial microbe levels.

It is important to note that crop rotation does not require only rotating the planting of crops from one of the four categories (leaf, fruit, root, legume). The goal of the permagarden is to continually have a variety of vegetables available for harvest. Therefore, a gardener can also intercrop the plants—basically have multiple plants in the same space. This can be done by planting vegetables that mature at different times and/or have different growing requirements.

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

Intercropping is the practice of growing two or more crops in the same space at the same time. Groups of intercropped plants that grow well together or share some cultural benefit are known as "companion" plants. Intercropping 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 reasons and approaches of intercropping include:

- Using space within the soil profile optimally by planting shallow- and deep-rooted plants together.
- Mixing slow-growing 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.

Intercropped vegetables in the permagarden.
Photograph: **Thomas Cole**

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.

Nutritional decisions in planting

With a permagarden, households can have access to a wide variety of vegetables and fruits throughout the year. For a permagarden to be an effective solution to achieving food security, a gardener must plant a variety of nutritious foods. A healthy, well-balanced diet can be secured from locally grown foods found in household permagardens. The household is much more likely to consume the needed vitamins and minerals when they are conveniently accessible next to the house or just outside the kitchen. In addition, a program may want to pair home garden vegetable production with activities on cooking and preparation of vegetables. It is important to promote the consumption and cooking of vegetables and not just the production of vegetables.

Brightly colored vegetables, especially orange, yellow, and dark green leafy crops, are the best to grow for their nutritional value (they are high in vitamins A and C and iron). They can be paired with legumes, which are high in zinc. The following list contains vegetables (and their edible parts) that are high in nutrients:

- Amaranth: stem and leaves
- Beets: roots and leaves
- Carrots
- Cassava leaves
- Climbing beans
- Kale and collards: stems and leaves
- Mustard: stem and leaves
- Orange fleshed sweet potatoes: roots and leaves
- Pumpkins: fruit and leaves
- Sweet potatoes: leaves

A diet of key vitamins and minerals maintains a body's immune system, promotes physical and mental development, and is essential for good health:

Vitamin A helps improve eyesight and protects the body from sickness. Eating enough foods with vitamin A is especially important for growing children. Foods high in vitamin A include dark leafy greens and orange-fleshed roots and tubers.

Vitamin C is an effective antioxidant[5] and is beneficial to the immune systems. Foods high in vitamin C include citrus fruits and peppers.

Iron is an important mineral in the bloodstream. It helps the body circulate nutrients through the body. Having low amounts of iron causes fatigue and weakened endurance for learning and physical labor. Getting enough dietary iron is especially important for pregnant women. Dark leafy greens are a good source of iron.

Zinc helps all parts of the body grow and develop. By having enough dietary zinc, the body is better able to reach a healthy height and weight. Eating foods high in zinc is especially important for pregnant women and young children. Legumes are especially rich in zinc.

Permagardens provide a regular supply of nutritious vegetables for the family.
Photograph **Thomas Cole**

Incorporating 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 by making sure that less soil is bare, soil erosion is limited, and subsoil structure is improved; to the ecosystem by acting as windbreakers, suppressing weed growth, and drawing nutrients from deep subsoil layers to the surface; and to the harvest by providing 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 Vera	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

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

Fodder, trees and shrubs

Trees and shrubs incorporated in the garden provide several extra benefits by providing medicines, insecticides, shade, fuelwood or 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 milk cows kept at the homestead. Having a year-round local fodder source enables at least one cow being raised on a minimal graze 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 protective 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.
Photograph **Thomas Cole**

6 Plant health

All the steps of planning and planting a permagarden are designed to grow healthy, strong vegetables and fruits that can resist pest or disease problems and produce good yields. At times, however, the plants in the garden need extra protection or a boost of food to help them grow. This section outlines ways to give plants the nutrients that they need, as well as methods to prevent and treat pest and disease problems. All of these remedies are designed to be made using only local resources.

Plant health – fertilizers

Botanical and manure teas

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

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 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 plant growth and considerably improve yields.

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 a 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 fresh, young tithonia 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 is a plant growth hormone that can be used to fertilize crops and help increase yields. This is because plant hormones positively influence every stage of plant growth and development.

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.

Application of liquid fertilizer with Tithonia.
Photograph **Eric Carlberg** *Mercy Corps*

Chicken or cow manure

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 as a leaf fertilizer. Tea made from animal manure is full of organic matter, beneficial organisms, bacteria, and enzymes that help plants grow. Making manure tea helps dissolve 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 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.
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. The most efficient method for transplanted vegetables is with a watering can, but it can be poured directly into tree crop holes.

How to make a vegetable-waste compost bucket

(for daily compost tea)

Kitchen waste can also be used to make 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 3:1)
8. If there are two buckets available, use the first barrel until it is full; then start the second barrel

9 When the second barrel is full, use compost from the first barrel

10 Continue using the first barrel while the contents of the second barrel decompose

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 control 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 options that target specific pests and diseases be considered.

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 intercropping

Incorporating all of these steps into a permagarden can help 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 plant is able to outgrow or grow through any insect invasion, as most insects are attracted to weak, overfertilized, water-stressed plants. These practices 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
- Application of mulch 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:

- 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
- Application of mulch 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 defeat a garden's biological enemies. These measures can be applied or developed naturally by maintaining habitat for beneficial organisms both above and below the soil surface (Appendix 6):

- 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

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.

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

Garlic and chili peppers

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

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

Plant various plants within the margins of the garden or property to assist in pest control:

- 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)

Protection

The importance of strong fencing to protect a permagarden cannot be overstated. Without this simple structure, damage from livestock, wind, and people is inevitable. It is important to identify where within the community materials that can be used 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 protection, food from vines, fodder from the cuttings off the living fence posts, 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**

A well-protected permagarden.
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 the 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 a 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.

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 be discouraging. 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 rote 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 goals of the permagarden method. Keep in mind the goals of a successful permagarden: 1) improved access to a diverse, nutritious diet; 2) increased household income from surplus produce; 3) enhanced environmental resilience to extreme events; and 4) empowering knowledge and skillsets that build gardeners' confidence. 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
Photograph: **Thomas Cole**

Endnotes

1 FSN Network Social and Behavioral Change Task Force and CORE Group. 2013. Designing for Behavior Change: For Agriculture, Natural Resource Management, Health and Nutrition. Available at: http://www.fsnnetwork.org/designing-behavior-change-agriculture-natural-resource-management-health-and-nutrition

2 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. Acid 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.

3 http://reap-eastafrica.org/blogs.info/reap/pdf/AFrame.pdf

4 Using a banana leaf, instead of a box or plastic, provides a local, decomposable solution.

5 Antioxidants are compounds that help protect the human body against cancer and other diseases.

Glossary

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 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.

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.

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, shrub, or tree that grows every year.

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

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

Swale A small ditch approximately 30–40 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.

Triangular spacing Planting crops in a triangular pattern.

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

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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

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.

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.

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.

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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 a 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.

1 55 gallon drum with holes in bottom

2 Burn hole with good ventilation

3 Stuff holes with wicks of leaves

4 Light wicks and material in the burn hole

5 Add materials and allow all to burn

6 Cover once engulfed in flame for 3 min

7 4 hours later, finished biochar

8 and ready to add to soil

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How to make biochar

- Gather dry crop residues, newspaper, and a match.
- 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 air flow.
- Place rolled newspaper and dry leaf (such as maize cob leaves) "wicks" into each of the small holes in the bottom of the barrel.
- Tip the barrel over the hole or onto the bricks.
- Add the crop residue in a pyramid shape along with highly combustible paper or dry leaves. Fill three-quarters of the barrel. More will be added later.

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- Light the wicks. Encourage the flame by tilting the can slightly to maximize air flow. Build a small fire in the hole to encourage a better flame.
- 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.
- Remove the bricks from below the barrel or add soil to cover the vents of the hole while also placing the lid on 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.
- Wait. Allow the materials to be carbonized for at least 4 hours. Woody materials will need more time.
- Remove the soil and the lid from the top of the barrel and tip the barrel onto a grain sack. Place the fully carbonized pieces into the sack and crush into small pieces now ready for use in 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 handful
- dry manure (3 handful)
- wood ash (1 handful) and
- 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 plant 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.

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.

3 Plants should form an equilateral triangle.

Plant seeds or seedlings where sticks have been placed.

Once planted, water in seeds and mulch the garden well.

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.

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.

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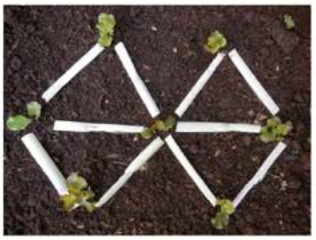

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Appendix 6 Botanical tea

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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