

FARMER´S COMPOST

FARMER´S COMPOST HANDBOOK

Experiences in Latin America

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Preface

This "Farmer´s Composting Handbook" is a learning guide about the production of compost at household and small farmer level, prepared by the FAO Regional Office for Latin America and the Caribbean, in collaboration with the Research Group on Soil, Water, Crop and Microorganisms of Universidad Técnica Federico Santa María.

The aim of this paper is to disseminate suitable technologies to develop a healthy and safe product for use as fertilizer in family orchards. The manual presents the vision of FAO regarding agriculture: Sustainable Intensification of Agricultural Production, with higher production in the same land surface while conserving resources, reducing negative impact on the environment and enhancing the natural capital and the provision of ecosystem services.

This publication is divided in four thematic blocks:

- Theoretical Foundations of Composting
- Practical Foundations of Composting
- Related compost products
- Experiences in Latin America and the Caribbean.

The section "Theoretical Foundations of Composting" details important parameters to be measured to determine the quality and safety of the finished material and outlines the benefits of compost in its different uses.

The section of "Practical Foundations of Composting" presents practical examples that allow the reader to understand how a composting system is implemented in the field.

The section "Related Compost Products" includes the production and use of compost tea and vermicompost. The first one contains soluble products of compost or organic materials used and the second, is obtained from a process with earthworms that use compost as food.

Finally, the chapter on "Experiences in Latin America and the Caribbean" includes examples of production or use of compost compiled in different countries of Latin America, that guide the reader to adjust his own process or verify field use.

The approach in this Manual is the conservation and improvement of the agricultural soil health. A healthy soil maintains a diverse community of organisms that help controlling crop diseases, insects and weeds, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improves soil structure with positive effects on the capacity of the soil to retain water and nutrients and, ultimately, improve agricultural production.

Glossary (FAOTERM[1])

Fertilization: The act or process of rendering land fertile, fruitful, or productive; the application of fertilizer, either synthetic or natural

Organic manure: Organic manure covers manures made from cattle dung, rural and urban composts, and other animal and crop wastes. Efficacy of organic manure for improving the fertility and productivity of soils has been demonstrated.

Aerobic: A process where gaseous oxygen is present. A successful composting requires enough oxygen to keep the aerobic process.

Anaerobic: A process where gaseous oxygen is not present. If this occurs during the composting process, it slows down and can release malodours as a result of decay processes.

Mesophilic microorganisms: Group of bacteria and fungi (yeast or filamentous fungi) that can live, grow and multiply during composting in the temperature range 30-40 °C.

Thermophilic bacteria: Group of bacteria that can live, grow and multiply during composting in the temperature range 40°-70°C.

CDC: Demonstration Training Centres.

Mature compost: Compost that has finished all the phases in the composting process.

Immature compost: Compost that has not finished the thermophilic phase in the composting process.

Decomposition: Organic matter degradation.

Manure: Organic matter that is used to fertilize land, usually consisting of the faeces and urine of domestic animals. It can be mixed with straw, hay, or bedding. Although manure is rich in nitrogen, phosphorus and potash, compared to synthetic fertilizers the content is lower and found in organic form. It may be applied in much greater quantities, to provide the soil with the quantity needed by the crop, but in general, it is longer available in the soil. It is rich in organic matter and thus increases soil fertility and improves the capacity of soil to absorb and retain water.

Humus: Decomposed, dark brown and amorphous organic matter of soils, having lost all trace of the structure and composition of the vegetable and animal matter from which it was derived. Humus hence refers to any organic matter that has reached a point of stability and which is used in agriculture to amend soil. The product from the earthworm is wrongly named Humus instead of vermicompost.

Humification: The formation of humic and fulvic acids, from mineralized organic matter.

Inoculant: Concentrate of microorganisms that applied to compost, accelerate the composting process. Immature compost can serve as inoculant.

Inorganic: Mineral substance.

Nitrogen: Indispensable element for plants that can be in organic (proteins and organic compounds), or inorganic form (nitrate NO^{-}_{3} or ammonium: NH^{+}_{4})

Nitrate: Inorganic form of nitrogen. It is oxidized and soluble in soil solution. It is easily lost through leaching.

1 http://www.fao.org/termportal/thematic-glossaries/en/

Ammonium: Inorganic form of nitrogen. It is reduced and soluble in soil solution. It is easily lost through volatilization.

Nitrate leaching: As water comes into contact with nitrogen fertilizer or animal manure, nitrates and other soluble components in the manure may be dissolved into the water. The water may then carry these soluble constituents along with it as it infiltrates into the soil and moves down into the groundwater. Soils that have high water tables and rapid water percolation rates are more likely to allow contaminated water to reach the groundwater.

Macroorganisms: Live organisms that can be easily seen to the naked eye (spiders, earthworms, rodents, ants, beetles….). It is also called mesofauna.

Organic matter: Plant and animal wastes and microorganisms at various phases of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

Microorganisms: Microscopic living organisms (fungi, including yeast, bacteria actinomycetes, protozoan, nematodes, etc…).

Mineralization: The conversion of organic compounds by the action of aerobic microorganisms and the release of inorganic forms essential for plant development.

Organic compound: A substance that contains carbon and hydrogen and usually other elements such as nitrogen, sulphur and oxygen. Organic compounds can be found in nature or they can be synthesized in the laboratory. An organic substance is not the same as a natural substance. A natural material means that it is essentially the same as it was found in nature, but organic means that it is carbon based.

Pathogen: Microorganism causing disease. It can be phytopathogen when causing disease in plants, or human or animal pathogen.

Nutrient recycling: Biogeochemical cycle, in which inorganic nutrients move through the soil, living organisms, air and water. In agriculture, it refers to the return of nutrients absorbed by plants from the soil, back to the soil. Nutrient cycling can take place through leaf fall, root exudation (secretion), residue recycling, incorporation of green manures, etc.

C: N ratio: Carbon - Nitrogen ratio.

Executive Summary

During the XXXIII FAO Regional Conference for Latin America and the Caribbean (Santiago de Chile, May 2014), Member States reaffirmed the need to promote the development of more inclusive and efficient agricultural / food systems at international, national and local level. Moreover, the United Nations General Assembly has declared 2015 as the International Year of Soils, to raise awareness of the importance of this resource. These, regional and global frameworks reinforce the work that FAO undertakes to support the development of family farming as one of the pillars of food security and nutrition in the region.

Fertile soils are a challenge to the world, and Latin America and the Caribbean is no exception. In this region, countries have increased their agricultural, fishery and forestry production at above world average rate, but must face, among others, problems of deforestation, water pollution, loss of biodiversity, degradation and depletion of soils. These factors threat social, economic and environmental sustainability of food systems producers. 14% of South American soils, and 26% in Mesoamerica, suffer from some degree of degradation, affecting, directly or indirectly, agriculture livelihoods. Soils are one of the most important components for agrifood systems, but also one of the most fragile: the formation of a centimeter of land requires hundreds of years of work, and can be destroyed in seconds. Therefore, we must encourage conservation practices and the adoption of technologies to restore degraded land and protect those that are still functional.

Composting reduces pollution, reuses organic waste, reduces the cost of fertilizers and agricultural production inputs and especially returns to soil the nutrients taken to produce food. This publication provides examples of technologies for farmers to produce organic fertilizer for their crops. It also includes examples of composting experiences in the region, and techniques to determine its quality and safety parameters. This handbook is intended for extensionists and community leaders, who provide support for the education on agriculture.

"Healthy Soils for a healthy life" is the motto of the International Year of Soils 2015 held in the framework of the Global Soil Partnership, since healthy soils are the foundation of a healthy environment, a productive food system and an improved rural livelihood.

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1. Role of FAO in soil preservation

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1. Role of FAO in soil preservation

The basis of all sustainable agricultural system is a fertile and healthy soil. The edaphic and water resources are

At present, agriculture uses 11% of the land surface for crop production and the growth rate in cropping area over the last 50 years has been 12%. Agricultural production has grown between 2.5 and 3 times during the same period. This strong growth is due to a significant increase in the yield of major crops. However, global production gains in some regions have caused land degradation, reduction of water resources and the deterioration of ecosystem services (SOLAW, 2011).

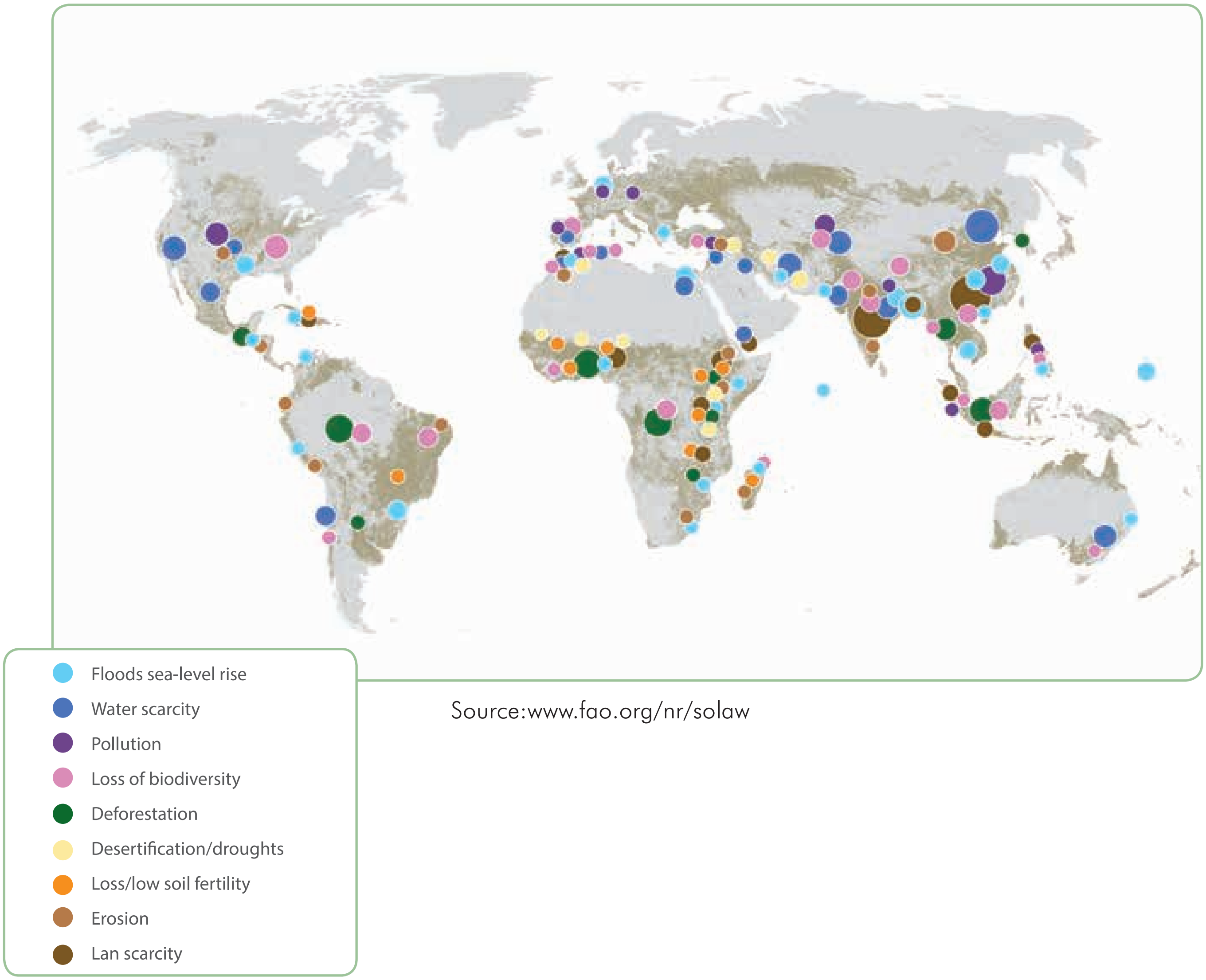
Soil ecosystem services include carbon storage, storage and supply of water, biodiversity and social and cultural services. Improving soil carbon content is a long term process, which also decreases the rate of erosion, and increases carbon sequestration to mitigate climate change. At country level, it is desirable to have a policy based on long-term commitment to maintain or increase the organic matter content. This vision of protecting the edaphic resource gave origin to the Global Soil Partnership in 2011.

FAO launched, with the support of the European Commission, the Global Soil Partnership (GSP) in September 2011. This partnership is an intergovernmental mechanism. Its aim is to educate decision makers about the important role of edaphic resources in achieving food security, adaptation to the effects of climate change and sustainable provision of environmental services. Its purpose is to promote soil protection and sustainable management.

In the study performed by FAO on The State of the World's Land and Water Resources (SOLAW, 2011) it is made clear that, globally, farm production systems are highly vulnerable due to the combination of excessive demographic pressure and unsustainable production practices. The global figures on the rate of use and degradation of land and water resources hide large regional differences in availability. It is anticipated that the scarcity of land and water, will jeopardise the capacity of the main farming systems to meet the demand for food and food security (Figure 1). These physical constraints may get worse in different places due to external factors, including climate change, competition with other sectors and socio-economic changes.

The map in Figure 1 shows the main risks associated with large areas of food production. It is noted that in Latin America there are serious problems associated with the edaphic resource, such as risks of deforestation in Central America and the Southern Cone, erosion on the Pacific coast, low soil fertility in the Caribbean and to the interior of the Southern Cone, and loss of biodiversity in Latin America as a whole.

Figure 1 Map of risks associated to production areas



Source:www.fao.org/nr/solaw

FAO promotes agricultural practices and policies to protect natural resources for future generations. Unsustainable management practices can also cause degradation (e.g., removal of nutrients and erosion), along with the emission of greenhouse gases (GHG). Globally, agriculture is an important part of climate change, being responsible for 14% of global GHG emissions (30% when considering also deforestation and changes in land use). However, agriculture has the potential to contribute to mitigate this global phenomenon, through mitigation, reduction and/or elimination of a significant amount of global emissions: about 70% of this potential mitigation can be implemented in developing countries (FAO-Adapt, 2012)

Faced with the challenge of food security, climate change and soil conservation, a more productive and resilient agriculture will require better management of natural resources such as water, soil and genetic resources through practices such as conservation agriculture, integrated nutrition and preservation of organic matter, integrated pest and disease management and agroforestry.

The transformation of agriculture is being promoted by FAO and other partners through the “Climate-Smart Agriculture” which sustainably increases productivity and resilience (adaptation) and reduces/eliminates greenhouse gases (mitigation)[2].

Recycling organic waste from forestry, farming and cattle management production process, transforms waste into inputs that can be returned into the soil, providing nutrients and beneficial microorganisms, improving water retention and cation exchange (CIC) and increasing production profitability. From the environmental point of view, this recycling of materials and their application to the soil, provides many benefits, such as increasing organic matter in the soil, reducing the methane produced in landfills or municipal dumps, replacement of peat as substrate, the uptake of carbon, the soil temperature control and increasing the porosity of the soil, thereby reducing the risk of erosion and desertification.

Composting is a widely accepted practice as a sustainable practice used in all systems associated with climate-smart agriculture. It offers enormous potential for all sizes of farms and agro-ecological systems and combines environmental protection with a sustainable agricultural production.

2 http://www.fao.org/climatechange/climatesmart/es/

2. Importance of organic matter in the soil

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2. Importance of organic matter in the soil

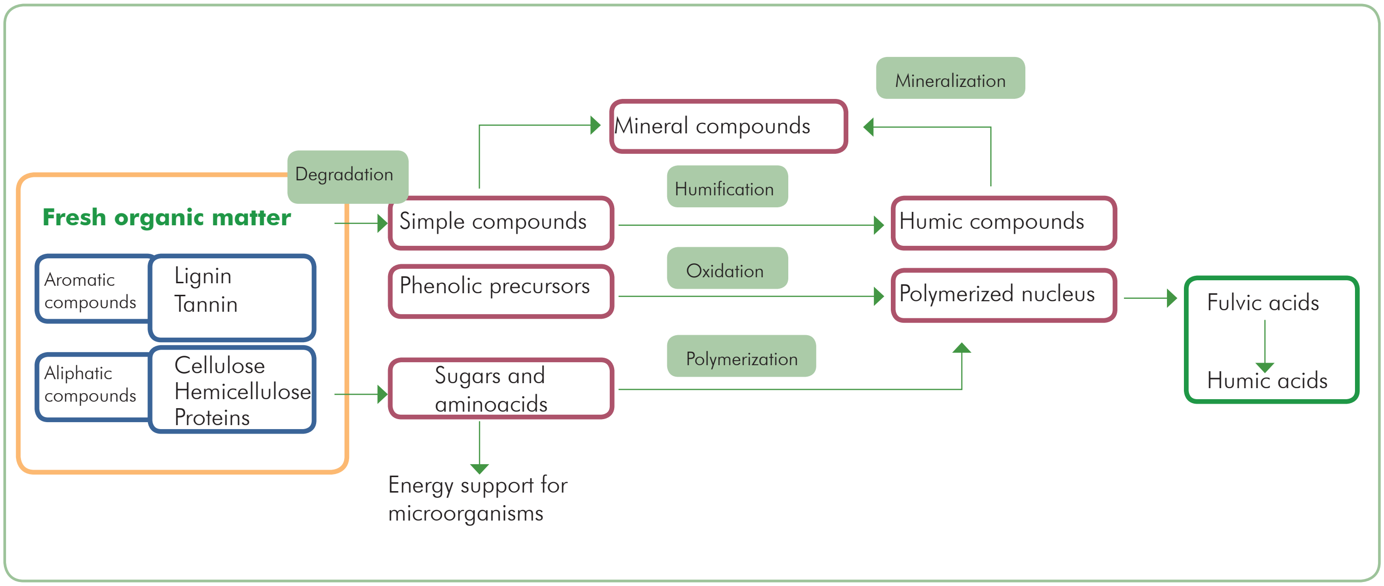
The organic matter is one of the most important components of soil. Although we think it as a single compound, its composition is quite diverse since is the result of the decomposition of animals, plants and microorganisms in the soil or in off-farm materials. It is this diverse composition what makes organic matter important since many different products are obtained from the decomposition process which acts as the bricks of the soil that build organic matter.

Although there is no single concept regarding soil organic matter, it is defined as any matter of animal or plant origin returned to the soil after a decomposition process that involves microorganisms. It may be leaves, dead roots, exudates, manure, urine, feathers, hair, bones, carcass, and microorganisms such as bacteria, fungi and nematodes that provide the soil with organic substances or its own cells when dead.

These materials initiate a process of decomposition and mineralization, and change its organic form (living beings) to its inorganic form (minerals, soluble or insoluble). These minerals flow through the soil solution and finally are used by plants and organisms, or stabilized to become humus, through the process of humification.

This same process occurs in a compost pile. In the soil, the organic matter composed of complex sugars (lignin, cellulose, hemicellulose, starch, present in plant wastes especially)

Figure 2 Schematic of the evolution of organic matter in the soil



Source: Adapted from Ribó 2004.

and proteins (present in animal waste in particular), is attacked by microorganisms, that decompose it to form more microorganisms. This process also generates biomass, heat, water and more decomposed organic matter. However, no reference is made to composting in the soil because the process can occur under aerobic or anaerobic conditions (such as rice crops under flood), and the typical heating phases (or thermophile or sanitation) are not present. This means that in the microorganisms present in the field such as cattle manure for example, (when applied fresh on the field or leave the excrement unturned) parasites' eggs and cysts are left.

The organic matter can be applied to the soil in the following state:

- fresh, as manure in the same plot,

- dry, as mulch or dead coverage from crop waste (straw or cultivated fallow),

- processed, whether as compost, vermicomposting, slurry or stabilized (for example, manure or guano).

Once these substances have reached the maximum degree of decomposition, they remain in the soil, forming carbon complexes, highly stable and slowly degraded. This new material is humus. It is then, the most stabilized matter as humic and fulvic acids, that has undergone a process of mineralization, involving microorganisms and then a humification process.

Humic substances that are part of organic matter are formed by chemical and biological degradation of plant and animal waste and synthesis activities carried out by soil microorganisms.

The content of organic matter in soils varies between 2 and 8 grams of organic matter per kilogram of soil; the first number corresponds to deserts, the second to peatlands, being common for mineral soils to contain between 10 and 40 grams of organic matter per kilogram of soil in the most superficial area (Magdoff and Weil, 2004). However, the amount of organic matter depends not only on soil microorganisms, but also the type of soil, vegetation, environmental conditions such as moisture and temperature. Rise in rainfall or irrigation under average temperature conditions causes the multiplication of microorganisms that use more organic matter and the decomposition continues. Therefore, the application of organic matter to soils must be a permanent practice, considering not only increasing the percentage of organic matter or feeding soil microorganisms, but also the various benefits to the soil.

- **Improves physical properties:**

- Facilitating soil management for ploughing or seeding

- Increasing moisture retention capacity of soil.

- Reducing the risk of erosion.

- Helping to regulate soil temperature (edaphic temperature).

- Reducing water evaporation and regulating moisture.

- **Improves chemical properties:**

- Supplying macronutrients such as N, P, K and micronutrients.

- Improving cations exchange capacity.

- **Improves biological activity:**

- Providing organisms (such as bacteria and fungi) capable to transform insoluble matter into plant nutrients and degrade harmful substances.

- Improving soil conditions and providing carbon to keep biodiversity of micro and macro fauna (earthworms).

Other additional benefit of composting is the reduction of bad odour from rotting and elimination of vectors such as insects and rats. It also has a very important role in the elimination of human pathogens, food contaminating bacteria, and also weed seeds and other unwanted plants.

3. Theoretical foundations of composting

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3.Theoretical foundations of composting

3.1 Composting process

One of the environmental problems of farms are the organic waste from pruning, harvesting, post-harvest, manure, grass, fallen fruit, among others. Normally, due to ignorance, lack of adequate space, or time, the common practice with these wastes is burning, burying or abandoning them out in the open until rot.

Composting provides the chance to safely transform organic waste into inputs for agricultural production. FAO defines composting as the mixture of organic matter digested aerobically that is used to improve soil structure and provide nutrients (FAO Term Portal, FAOTERM[3]).

However, not all materials that have been transformed aerobically are considered compost. The composting process includes several phases that must be met to obtain quality compost. The use of a material that has not successfully completed the composting process (raw or only stabilized) (See Chapter 3.3) can lead to risks such as:

• **Phytotoxicity.** In a material that has not finished the composting process adequately, nitrogen is in the form of ammonium instead of nitrate. Ammonium in hot and humid conditions is transformed into ammonia, creating a toxic environment for plant growth, resulting in odours. Similarly, unfinished compost contains unstable volatile chemicals such as organic acids that are toxic to seeds and plants.

• **The biological block of nitrogen, also known as "nitrogen starvation".** Occurs in materials that have not reached a balanced C:N ratio and are far richer in carbon than in nitrogen. When applied to soil, microorganisms quickly use de C present in the material increasing the consumption of N and exhausting the reserves of N.

• **Root oxygen reduction.** When material in the decay phase is applied to soil, microorganisms will use the oxygen of the soil to continue the process, exhausting it and not making it available to plants.

• **Excess ammonium and nitrate in plants and contamination of water sources.** A material with excess nitrogen in the form of ammonium tends to lose it by infiltration into the soil or volatilization and contributes to contaminate trickling and underground water. Likewise, it can also be taken by the crop, producing an excessive accumulation of nitrates, with negative consequences on the quality of fruit (softening, short post-harvest time) and human health (especially leafy vegetables)

3 http://www.fao.org/termportal/thematic-glossaries/en/

3.2 Composting phases

Composting is a biological process that occurs under aerobic conditions (presence of oxygen). With adequate moisture and temperature, a hygienic transformation of organic wastes in a homogeneous and plant available material.

Composting can be interpreted as the sum of complex metabolic processes performed by different microorganisms that, in the presence of oxygen, use nitrogen (N) and carbon (C) available to produce their own biomass. In this process, additionally, the microorganisms generate heat and a solid substrate, with less carbon and nitrogen, but more stable, which is called compost.

Upon decomposition of C, N and all initial organic matter, microorganisms release measurable heat through temperature variations over time. Depending on the temperature generated during the process, three main phases are identified in composting, besides a phase of maturation of variable duration. The different phases of composting are divided according to temperature in:

1. Mesophilic phase. The composting process starts at ambient temperature and in a few days (or even hours), the temperature rises to 45°C. This temperature increase is due to microbial activity since, in this phase, the microorganisms use C and N sources generating heat. Decomposition of soluble compounds, such as sugars, produces organic acids and hence, pH can drop (to about 4.0 or 4.5). This phase lasts a few days (two to eight days).

2. Thermophilic and Hygienization phase. When the parent material reaches temperatures higher than 45°C, the microorganisms that develop at average temperatures (mesophilic microorganisms) are replaced by those that grow at higher temperatures, mostly bacteria (thermophilic bacteria) that facilitate degradation of complex sources of C, such as cellulose and lignin. These microorganisms act transforming nitrogen into ammonia, so the average pH rises. In particular, over 60°C, bacteria producing spores and actinobacteria which are responsible for breaking down waxes, hemicellulose and other compounds of C complex, begin to develop. This phase can last from days to months, depending on the parent material, climatic and site conditions, and other factors.

This phase is also called hygienization phase since the heat generated destroys bacteria and contaminants of faecal origin such as Escherichia coli and Salmonella spp. Similarly, as discussed in Chapter 3.4, this phase is important as temperatures above 55°C eliminate the helminth's cysts and eggs, spores of phytopathogen fungi and weed seeds that can be found in the parent material, giving rise to a hygienized product.

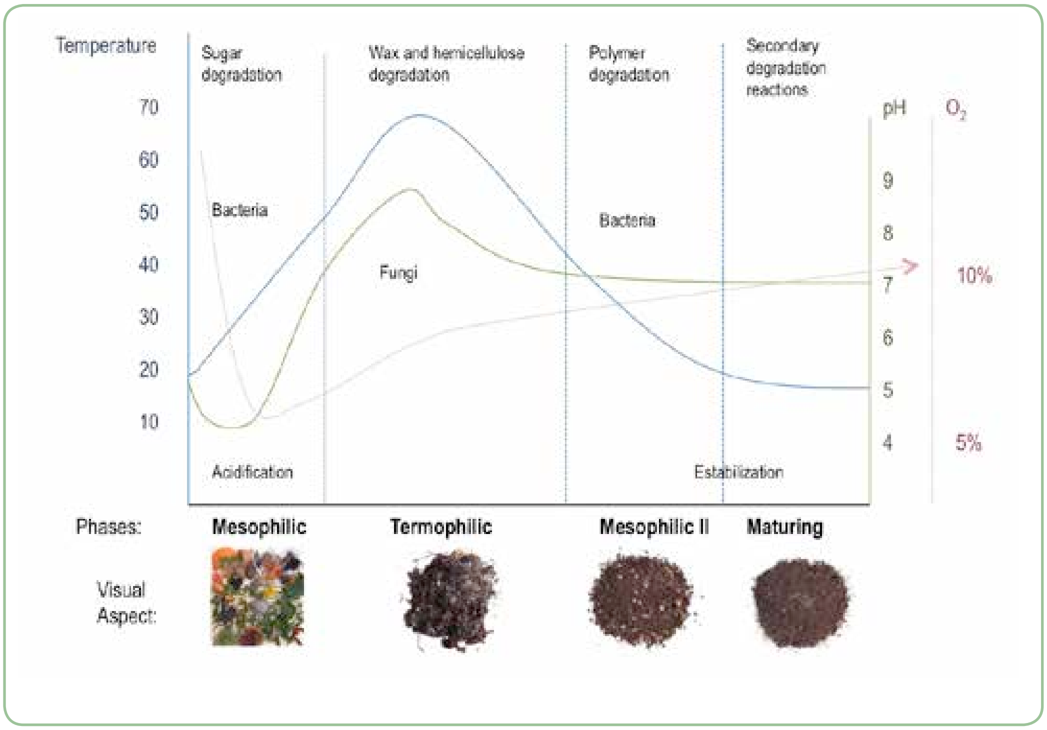
3. Cooling or Mesophilic phase II. Once carbon and nitrogen sources in composting material are exhausted, temperature drops again to about 40-45°C. During this phase, polymers degradation as cellulose continues and some fungi visible to the naked eye appear (Figure 3). Below 40°C, mesophilic organisms resume their activity and pH of the medium decreases slightly while, in general, pH remains slightly alkaline. Some fungi can develop and even produce visible structures. This cooling phase requires several weeks and may be confused with the maturation phase.

Figure 3 fungus indicating mesophilic phase II

Source: CATA-USM, Chile.

4. Maturation phase. This phase lasts months at ambient temperature, during which side reactions such as carbonaceous compounds condensation and polymerization occur to form humic and fulvic acids.

Figure 4 Temperature, pH and oxygen in the composting process



Source: P. Roman, FAO

3.3 Monitoring during composting

Since composting is a biological process carried out by microorganisms, parameters affecting their growth and reproduction should be taken into account. These factors include oxygen or aeration, substrate moisture, temperature, pH and the C:N ratio.

Externally, the composting process largely depends on environmental conditions, the method used, raw materials, and other elements, so that some parameters may vary. However, they must be under constant surveillance to always be within an optimal range. The parameters and their optimal ranges are listed below.

Oxygen

Composting is an aerobic process and adequate ventilation should be maintained to allow respiration of microorganisms that release carbon dioxide (CO_2) into the atmosphere. Likewise, aeration prevents material to compact or fill with water. Oxygen requirements vary during the process, reaching the highest rate of consumption during the thermophilic phase (Figure 4).

The oxygen saturation in the medium should not be lower than 5%, being the optimal level 10%. Excessive aeration will cause a temperature drop and great loss of moisture by evaporation, causing the decomposition process to stop due to lack of water. The cells of microorganisms dehydrate, some produce spores and enzyme activity responsible for the degradation of the different compounds stops. Conversely, a low aeration prevents enough water evaporation, generating excessive moisture and an anaerobic environment. Odours and acidity are then produced by the presence of compounds such as acetic acid, hydrogen sulphide (H_2S) or methane (CH_4) in excess.

Table 1 Aeration control

Aeration Percentage	Problem		Solutions
<5%	Low aeration	Insufficient water evaporation, generating excessive moisture and anaerobiosis environment	Volteo de la mezcla y/o adición de material estructurante que permita la aireación .
5% - 15% ideal range			
>15%	Excessive aeration	Drop in temperature and evaporation of water, causing the decomposition process to stop due to lack of water	Chop the material in order to reduce porous size and hence, aeration. Moisture should be regulated by adding water or fresh material or with more water content (fruit and vegetative scraps, grass, liquid manure and others).

Carbon dioxide (CO_2)

As in all aerobic process, either in composting or even in human breath, oxygen serves to transform (oxidize) C present in raw material (substrate or food) into fuel. Through the oxidation process, C transforms into biomass (more microorganisms) and carbon dioxide (CO_2) or gas from respiration, which is a source of carbon for plants and other organisms that perform photosynthesis. However, CO_2 is also a greenhouse gas, i.e., it contributes to climate change.

During composting, CO_2 is released through the microorganisms respiration and therefore, the concentration varies with the microbial activity and the raw material used as substrate. In general, they generate 2-3 kg of CO_2 per tonne daily. CO_2 produced during the composting process is generally deemed to have low environmental impact, because it is captured by plants for photosynthesis.

Moisture

Moisture is a parameter closely related to microorganisms, because, like all living beings, they use water to transport nutrients and energy elements through the cell membrane.

The ideal moisture of the compost is around 55%, although it varies depending on physical condition, size of the particles and the composting system (see chapter on Particle Size). If moisture drops below 45%, microbial activity decreases, the degradation phases cannot be completed and hence, the resulting product is biologically unstable. If the moisture is too high (> 60%), water will saturate the pores and interfere oxygenation through the material.

In processes in which the main components are substrates such as sawdust, wood chips, straw and dry leaves, the need for irrigation during composting is greater than in wetter materials such as kitchen waste, vegetable, fruit and grass clippings.

The optimal moisture content for composting is 45% to 60% water by weight of the base material.

Table 2 Optimal moisture parameters

Moisture percentage	Problem		Solutions
<45%	Insufficient moisture	Can stop composting due to lack of water for microorganisms	Moisture should be regulated, either by adding water or fresh material with higher water content (fruit and vegetal waste, grass, liquid manure or others)
45% - 60% ideal range			
>60%	Insufficient oxygen	Too wet material, oxygen is displaced. Can develop zones of anaerobiosis.	Turn the mixture and/or add low moisture content material with high carbon content such as sawdust, straw or dry leaves.

Temperature

Ambient temperature has a wide range of variation depending on the phase of the process (Figure 4). Composting begins at ambient temperature that can rise up to 65°C with no need of human intervention (external heating). During the maturation phase temperature drops at ambient temperature.

It is desirable that temperature does not drop too fast, since the higher the temperature and the longer the time, the higher the decomposition rate and hygienization.

Table 3 Optimal temperature parameters

Temperature (°C)	Related causes		Solutions
Low temperature (ambient T < 35°C)	Insufficient moisture.	Low temperatures can occur by several factors, such as lack of moisture, so that microorganisms reduce the metabolic activity and therefore, temperature drops.	Wet the material or add fresh material with higher moisture percentage (fruit or vegetable waste or others)
	Insufficient material.	Insufficient material or inadequate pile shape to reach the appropriate temperature.	Add more material to the composting pile.
	Nitrogen deficit or low C:N ratio	The material has a high C: N ratio and hence, the microorganisms are lacking the necessary N to produce proteins and enzymes and slow down their activity. The pile takes more than week to increasing the temperature.	Add high N content material such as manure.
High temperature (ambient T >70°C)	Insufficient ventilation and moisture	The temperature is too high and the decomposition is inhibited, since most microorganisms are inactive and die.	Turn the mixture and/or add high C content material of slow degradation (wood or dry grass) to slow down the process.

pH

The composting pH depends on the source materials and varies in each phase of the process (from 4.5 to 8.5). In the early phases of the process, the pH was acidified by the formation of organic acids. In the thermophilic phase, due to the conversion of ammonium into ammonia, the pH rises, the medium is alkalised to finally stabilize at values close to neutral.

The pH determines the survival of microorganisms and each group has optimal pH for growth and multiplication. Most bacterial activity occurs at pH 6.0-7.5, while most fungal activity occurs at pH 5.5 to 8.0. The ideal range is from 5.8 to 7.2

Table 4 Optimal pH parameters

pH	Related causes		Solutions
<4,5	Excess of organic acids	Plant materials such as kitchen waste, fruit, release many organic acids and tend to acidify the medium.	Add material rich in nitrogen until an appropriate C: N ratio is achieved.
4,5 – 8,5 ideal range			
>8,5	Excess of N	When there is excess of nitrogen in the source material, with poor C: N ratio related to moister and high temperatures, ammonia is produced and the medium is alkalised.	Add dry material with high carbon content (pruning, dry leaves, sawdust)

Carbon-Nitrogen (C: N) ratio

The C: N ratio changes according to the parent material and the numeric ratio is obtained by dividing total C content (total C %) over the total N content (total N %), of the material to compost.

This ratio also varies throughout the process, with a continuous reduction from 35:1 to 15:1.

For more information, see Table 15.

Table 5 Carbon/Nitrogen ratio parameters

C:N	Related causes		Solutions
>35:1	Excess of Carbon	There is a large amount of carbon-rich materials in the mixture. The process tends to cool and to slow down.	Add nitrogen-rich material until an appropriate C: N ratio is achieved.
15:1 – 35:1 ideal range			
<15:1	Excess of Nitrogen	There is a higher amount of nitrogen-rich material in the mixture. The process tends to overheat generating odours from the ammonia released.	Add material with high carbon content (pruning, dry leaves, and sawdust).

Particle size

Microbial activity is related to particle size, that is, easy access to the substrate. If particles are small, there is a greater specific surface, which facilitates access to the substrate. The ideal size of the parent materials for composting is 5 to 20 cm.

The material density, and therefore the aeration of the pile or moisture retention, is closely related to the particle size, being the density approximately 150 -250 kg/ m^3. As the composting process progresses, the size reduces and therefore, the density increases, 600-700 kg/ m^3.

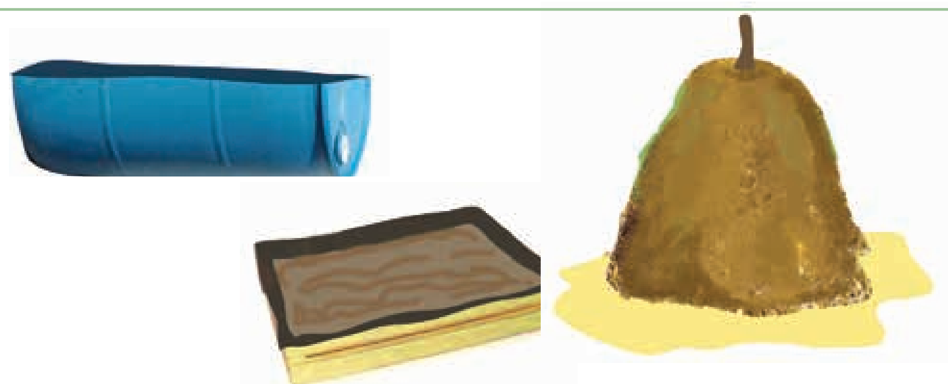
Table 6 Particle size control

Particle size (cm)	Problem		Solutions
>30 cm	Excess of aeration	Oversized materials form aeration channels, dropping the temperature and slowing down the process	Chop the material up to an average size of 10-20 cm.
5 – 30 cm ideal range			
<5 cm	Compaction	Too fine particles form small pores that fill with water, facilitating compaction of the material and a restricted flow of air causing anaerobiosis.	Turn and/or add larger particles to homogenise.

Compost pile or volume

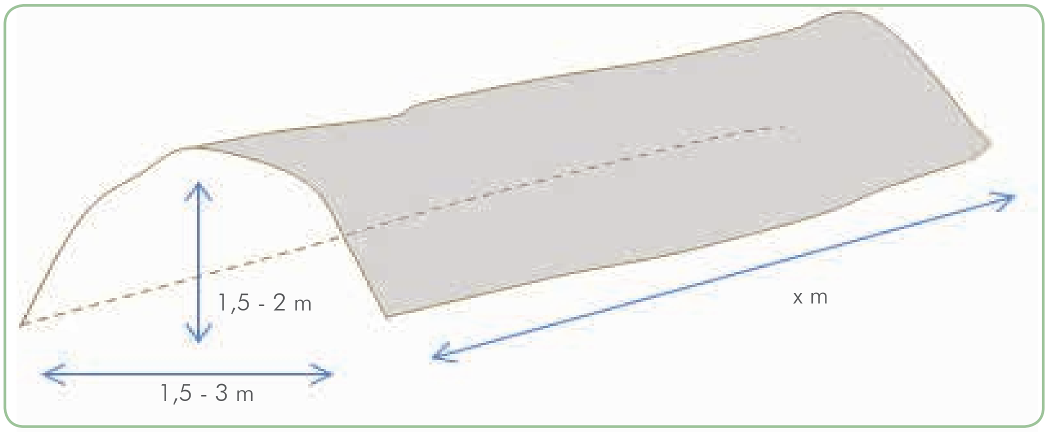
There are different compost systems: in boxes, piles, open or closed.

Figure 5 Common compost systems



The size of the compost pile, especially height, directly affects the moisture and oxygen content and temperature. Piles of low height and wide base, despite having good initial moisture and good C:N ratio, easily lose heat generated by the microorganisms so, the few degrees of temperature achieved, is lost. The size of the pile is determined by the amount of material to be composted and the available area to perform the process. Normally, compost piles are 1.5 - 2 meters high to ease turn over, and 1.5 - 3 meters wide. The length of the pile depends on the area and handling procedures.

Figure 6 Dimensions of a small farmer compost pile



In the estimation of the compost pile dimensions it is important to consider that during composting, the pile decreases in size (up to 50%) due to compaction and loss of carbon as CO_2.

Table 7 Compost parameters

Parameter	Ideal range at the beginning (2-5 days)	Ideal range of thermophilic phase II (2-5 weeks)	Ideal range of mature compost (3-6 months)
C:N	25:1 – 35:1	15/20	10:1 – 15:1
Moisture	50% - 60%	45%-55%	30% - 40%
Oxygen concentration	~10%	~10%	~10%
Particle size	<25 cm	~15 cm	<1,6 cm
pH	6,5 – 8,0	6,0-8,5	6,5 – 8,5
Temperature	45 – 60°C	45°C- Ambient temperature	Ambient temperature
Density	250-400 kg/m^3	<700 kg/m^3	<700 kg/m^3
Organic matter (Dry base)	50%-70%	>20%	>20%
Total Nitrogen (Dry base)	2,5-3%	1-2%	~1%

3.4 Hygienization and safety

As a result of the high temperatures reached during the thermophilic phase, pathogenic bacteria and parasites in the parent waste are destroyed. It is in this phase that material hygienization occurs. In subsequent phases recontamination of the material due to several factors may occur, such as the use of contaminated fresh material as a shovel for turning over, or the addition of fresh material after the thermophilic phase.

A mature compost should not contain toxic compounds for plants or the environment. For example, the presence of ammonia and sulphate (NH_3 and SO_4) in leachates generated in the composting processes with excess moisture, favour the production of hydrogen sulphide and nitrogen dioxide (H_2S and NO_2) which together with the methane (CH_4) are considered greenhouse gases (GHG) with significant negative impacts on the environment, particularly on climate change.

Various Latin American countries that base its work on both US standards (EPA) and the European Union (EU) have developed regulations to define the quality of compost and its use (see Annex 7.3). In addition to defining the quality of compost, in Chile, Colombia, Mexico, they separate the compost into two classes, A and B, with or without restrictions on use, based on the presence of pathogens and heavy metals. One of the problems of using compost relates to the possibility that could have pathogenic bacteria such as Salmonella spp. and Escherichia coli (Islam 2005, Lasaridi 2006), Listeria monocytogenes (Oliveira 2011), and parasite eggs that can reach consumers through contaminated fruit and vegetables. Therefore, it is important to ensure that the compost used, in especial, to grow short stem or leaf vegetables, as well as for the production of fruits, does not contain these pathogens and indicators of faecal contamination.

Another key aspect is the presence of heavy metals in compost, as they are compounds that do not destroy or decompose, and can be absorbed by plants, and then animals and man, along the food chain. The guarantee that the compost does not contain these pathogens or heavy metals, besides toxic compounds, hydrocarbons etc., is what is called safety and offers the user the certification that the compost will not contaminate the food to be fertilised.

The presence of pathogens in compost comes largely from the use of manures, followed by use of contaminated water and compost handlers (Bernal 2009). One control method is the use of high temperatures hence, the importance to control the time and temperature of the thermophilic phase.

The biological safety of the compost, which depends on the temperature reached by the material, but also moisture, aeration and particle size. In a pile with adequate moisture, microbial activity causes the temperature to increase, being higher inside than outside (Gong 2007). Thus, by aerating the pile or turning it over, temperature and moisture can be homogenized and kill pathogens. Similarly, the particle size to be composted, the shape and size of the pile also affect the rate of aeration and the tendency of the material to hold or release heat. Consideration should also be given to the temperature of the place and management practices in each case. Another important aspect is the amount of pathogenic microorganisms in the compost because, if this number is high, more time will be required to eliminate them.

So, the final compost may contain pathogen microorganisms that affect the quality of the fertilizer. Table 8 shows data regarding time and temperature to eliminate some pathogens.

Table 8 Temperature required to eliminate some pathogens

Microorganism	Temperature	Exposure time
Salmonella spp	55°C	1 hour
	65°C	15-20 minutes
Escherichia coli	55°C	1 hour
	65°C	15-20 minutes
Brucella abortus	55°C	1 hora
	62°C	3 minutes
Parvovirus bovino	55°C	1 hour
Ascaris lumbricoides eggs	55°C	3 days

Source: Jones and Martin, 2003

Annex 7.3 Compost safety analysis, provides more information on quality standards.

3.5 Composting material

The vast majority of organic materials are compostable. Below there is a list of materials that can be composted:

- Rests of harvest, orchard or garden plants. Crushed or chopped branches from pruning, tree and shrub leaves. Hay and mown grass. Lawn or grass (preferably pre-dried in thin layers)
- Pig manure, cattle dung manure, cow dung.
- Organic waste from kitchen (fruit, vegetables). Damaged or out of date food. Egg shell (preferably crushed). Coffee, tea waste. Dried fruit and nuts shell. Orange, lemon or pine apple skin (a few and chopped). Damaged, rotten or germinated potatoes.

- Edible oil and fat (fairly spread and in small quantity).
- Wood shavings (fine layers).
- Napkins, tissues, paper and cardboard (not printed or coloured or mixed with plastic).
- Hair cut (not coloured), animals' shear.

No inert, toxic or harmful materials should be included, namely:

- Chemical-synthetic residues, adhesive, solvents, petrol, lubricants, paint
- Non-degradable materials (glass, metals, plastics).
- Agglomerate or plywood (free from shavings or sawdust).
- Tobacco, since it contains a powerful biocide such as nicotine and various toxic substances.
- Detergents, chlorinated products, antibiotics, drug residues.
- Carcass (animals should be incinerated in special conditions or composted in special piles).
- Cooked food leftovers, meat.

3.6 Fertilization

Compost contains fertilizing elements for plants, although in an organic form and in a smaller amount than synthetic mineral fertilizers. One of the biggest advantages of using compost as input of organic matter, is that it contains available nutrients of slow release, beneficial for plant nutrition. Moreover, the compost has a high content of organic matter with the advantages that entails (Chapter 2). It is recommended that, before applying compost or organic matter (knowing its chemical composition), as well as mineral fertilizers, perform a soil test to control nutrient levels and adjust fertilization based on the release mechanism and crop needs.

The nutrients needed for plant growth come from air, water and soil, being the soil solution the means of transport of nutrients. They are divided into macro- and micronutrients, depending on the amounts that the plant needs. Primary macronutrients are Nitrogen, Phosphorus and Potassium, and secondary macronutrients are

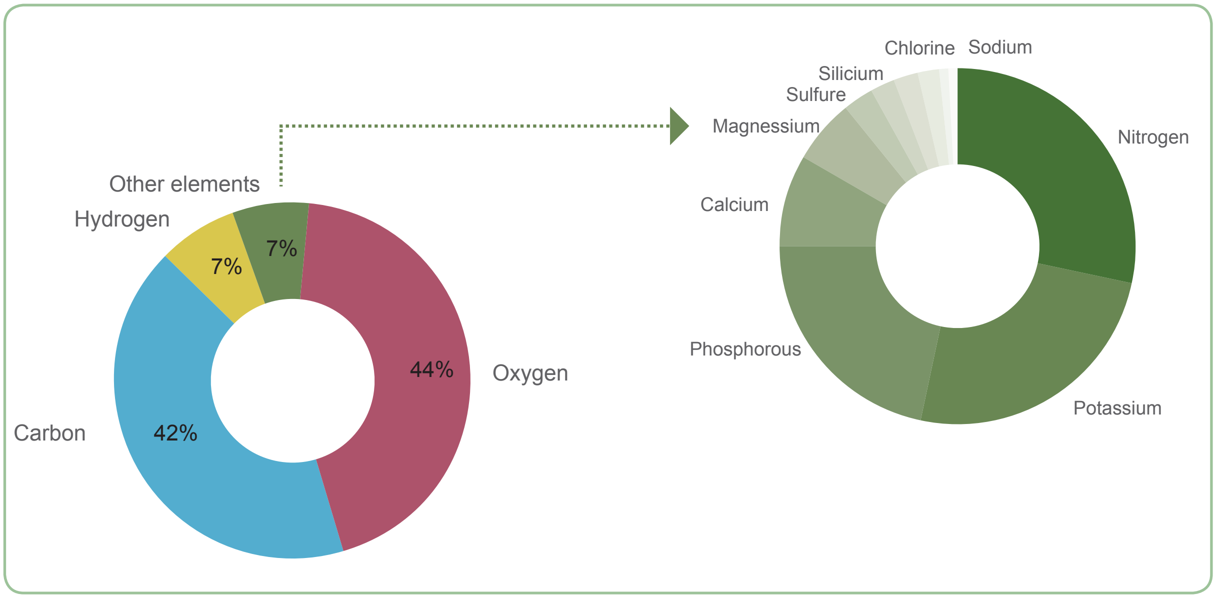
Magnesium, Sulphur and Calcium (Figure 7). Micronutrients are required in very small quantity but, in general, are important for plant and animal metabolism. These include iron, zinc, manganese, boron, copper, molybdenum and chlorine.

Nitrogen, N (1% - 4%) of the dry matter of the plant) is the growth engine of the plant because it is involved in all major processes of plant development. A good nitrogen supply is also important for the absorption of other nutrients.

Phosphorus, P (0.1% - 0.4%) of dry plant extract) plays an important role in energy transfer, so it is essential for the efficiency of photosynthesis. Phosphorus is scarce in most natural or agricultural soils or where the pH limits its availability, favouring its fixation.

Potassium, K (1% -4%) of the dry plant extract) plays a vital role in the synthesis of carbohydrates and proteins, and therefore, in the structure of the plant. Potassium improves the hydrologic regime of the plant and increases its tolerance to drought, frost and salinity. Plants with appropriate supply of K are less susceptible to diseases.

Figure 7 Average composition of plants



Compost nutrients content is highly variable (Table 9) since it depends on origin material:

Table 9 Average nutrients content in compost

Nutrient	% in compost
Nitrogen	0.3% – 1.5% (3g to 15g per kg of compost)
Phosphorus	0.1% – 1.0% (1g to 10g per kg of compost)
Potassium	0.3% – 1.0% (3g to 10g per kg of compost)

Source: Jacob, 1961, Martínez, 2013

To decide on the application of compost as organic fertilizer as well as integral nutrition with mineral fertilizers, the following parameters should be taken into account:

- Crop fertilization requirement (soil and leaves analysis)
- Access and availability of both fertilizers locally
- Cost of both fertilizers
- Soil requirements of organic matter

Each crop requires a specific quantity of nutrients that depends on the expected crop yield. To calculate the actual requirement of fertilizers, other factors such as soil nutrient reserves and immobilization or loss of nutrients when applied either by fixation or leaching should be take into account (See Annex 7.2 How to determine nutrient requirements in the field).
Table 10 shows nutrient requirements per crop although, in general, due to aforementioned loss, nutrient requirements exceed their availability.

Table 10 Extraction of nutrients per crop (kg/ha)

	Capacity	Nitrogen	Phosphorous		Potassium	
	Kg/ha	N	P_2O_5	P	K_2O	K
Rice	3.000	50	26	11	80	66
	6.000	10	50	21	160	132
Wheat	3.000	72	27	11	65	54
	5.000	140	60	25	130	107
Corn	3.000	72	36	15	54	45
	6.000	120	50	21	120	99
Potato	20.000	140	39	17	190	157
	40.000	175	80	34	310	256
Sweet potato	15.000	70	20	8	110	91
	40.000	190	75	32	390	322
Yucca	25.000	161	39	17	136	112
	40.000	210	70	30	350	289
Sugar cane	50.000	60	50	21	150	124
	100.000	110	90	38	340	281
Onion	35.000	120	50	21	160	132
Tomato	40.000	60	30	13	124	124

Source: Fertilizer Industry Advisory Committee of Experts (FIAC)

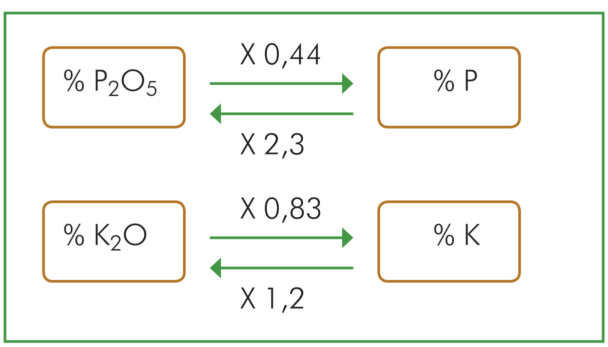
A mineral fertilizer is such industrialized product containing at least 5% of one or more of the primary nutrients (N, P, K). These nutrients are generally expressed in percentages of N, P_2O_5, K_2O (Table 11). These fertilizers can be simple (with one primary nutrient) or multi-nutrients (with two or three primary nutrients).

Table 11 Fertilizers most commonly tosed

Fertilizer sources	Molecular Formula	N-P_2O_5-K_2O
Urea	$CO(NH_2)_2$	46 — —
Ammonium nitrate	$NH_4(NO_3)$	34 — —
Ammonium Sulphate	$(NH_4)_2SO_4$	21 — —
Monoammonium phosphate	$NH_4H_2PO_4$	12 50 —
Simple Superphosphate	$Ca(H_2PO_4)_2$	— 20 —
Potassium Chloride	KCl	— — 60
Potassium Sulphate	K_2SO_4	— — 52
Compost	-	0.6 – 0.7 – 0.6

According to Table 10 a 50 kg bag of urea will have 23kg of Nitrogen (46% of 50 kg). To calculate P and K, the molecular weight of its oxide should be considered (Table 11).

Table 12 Conversion among P_2O_5, K_2O, y P, K



Example 1: Calculation of N, P y K

To know the quantity of N, P and K available in a fertilizer 16-6-12. The bag weight is 25 kg.

The numbers related to the fertilization degree are a percentage of the weight of the nutrients in the fertilizer:

- N content= 0,16 x 25 kg = 4 kg of N

The conversion factor for P_2O_5 es 0,44, so

- P content = 0,06 x 0.44 x 25 kg = 0,66 kg of P

The conversion factor for K_2O es 0,83, so

- K content= 0,12 x 0,83 x 25 kg = 2,5 kg of K

N, P and K content in 25 kg of that fertilizer is: 4 kg of N, 0,6 kg of P and 2.5 kg of K

The use of mineral fertilizers creates farmer dependency; it is expensive in terms of production and transport.
The fertilizer cost and availability are important factors in the decision about its application.

Example 2: Economic comparison of fertilizers

To compare the economic value of a fertilizer and market value of a compost and various simple fertilizers. (Urea, Simple Superphosphate and Potassium Chloride)

Table 13 Fertilizer cost

Fertilizer	Cost 1 tonne*	Nutrients per tonne
Compost	50 USD**	15 kg N, 10 kg P and 10 kg K (Table 9)
Urea	393 USD	460 kg N (Table 10)
Simpe superphosphate	435 USD	88 kg P (Table 10)
Potassium chloride	395 USD	498 kg K (Table 10)

Therefore, the unit cost per nutrient is:

Nutrient	Compost	Urea	Simle Superphosphate	Potassium Cloride
N	3,33 USD/kg	0,85 USD/kg		
P	5 USD/kg		4,94 USD/kg	
K	5 USD/kg			0,79 USD/kg
Total	13,33 USD		6,58 USD	

It is noted that compost has a higher price than mineral fertilizers for its content of N, P and K. Not only the economic cost of its application should be taken into account, but also the additional benefits, such as micronutrient content or organic matter content. (See Chapter 2)

*Source: World Bank, January 2013
**bulk compost (when packed, the price may rise up to USD 100 per tonne)

The farmer must analyse the pros and cons and decide what fertilizing mechanism will apply to the crop. The actions of the two fertilizers (organic and mineral) can combine and complement.

Demand = Δ Organic supply + Δ Mineral supply

Example 3: Calculation of fertilization requirements of a crop

We want to fertilize two hectares of wheat, combining compost and other simple fertilizers.

The requirements of wheat nutrients for 3t/ha are:

N: 72kg/ha, P_2O_5: 27kg/ha, K_2O: 65kg/ha

It is noted that the application of a compost dose of 9th/ha will cover the phosphorus requirements (it is considered an average composition per kg compost of: 6 g Nitrogen, 3g Phosphorus and 3 g Potassium):

9t compost is: N: 54kg/ha, P_2O_5: 27kg/ha, K_2O: 45kg/ha

Urea and chlorine may be applied to cover nitrogen and potassium requirements.

- Nitrogen requirements after compost application: 72 – 54= 18kg/ha

Urea has 46% N (46 kg N per 100 kg urea) so the application of urea of 39kg/ha urea

100 kg urea 46 kg N

X kg urea ➔ 18 kg N

X = 39 kg urea

It should be considered that just a 65% N will be available for the plant since N loss are estimated due to denitrification, leaching and mobilization.

- K_2O requirements after compost application: 65 – 45 = 20 kg/ha

Potassium chloride has 60% K2O, so an application of 33kg/ha of potassium chloride will cover potassium requirements.

100kg KCl 60kg de K_2O

X kg KCl ➔ 20 kg K_2O

X = 33 kg KCl

Fertilizer requirements for two hectares are:

18 tons compost
78 kg urea
66 kg potassium chloride

In organic agriculture and family farming is common to use only organic fertilizers such as compost, compost tea, vermicompost (Chapter 5).

3.7 Compost application

Compost may be applied as semi-mature (Mesophilic phase II - 3) or mature. The semi-mature compost has high biological activity and the percentage of nutrients easily assimilated by plants is higher than in mature compost. On the other hand, having a pH not yet stable (closer to acidity) can adversely affect germination, so this compost is not used to germinate seeds, or delicate plants.

The application of semi-mature compost in horticultural crops is usually a spring application of 4 – 5 kg/m^2 on land previously cultivated (cauliflower, celery, potatoes ...). For field crops, the application is 7-10 t/ha of compost.

The mature compost is used largely for seedlings, planters and pots. Is usually mixed (20% -50%) with soil and other materials such as peat and rice husk as substrate preparation (Figure 8).

Figura 8 Preparation of the substrate.

3.8 Costs

In order to analyse the economic costs of composting, it is necessary to analyse the following three factors:

- Decision on the preferred system (Chapter 4.2 Composting Techniques)
- Quantity and type of organic matter used to compost
- Quantity of compost to be used in the farm and quantity to be sold

For this, an "income-expenses" table like the one below could be used. The economic example is the production compost from pig litter (Experience in Neiva, Colombia, detailed in 6.1).

Under this system, 10 compost tons are produced every 6 months, from slurry of 20 pigs and 750kg of rice husk. The economic balance of Table 14 corresponds to a batch (6 months) of 2012.

Table 14 Economic balance of a compost plant

Costs*			
Detail	**Quantity**	**Unitary cost (USD)**	**Total cost (USD)**
Material collection (wage)	2	14	28
Transport (wage)	2	14	28
Control of parameters (wage)	6	14	84
Weighing and packaging (wage)	0,5	14	7
Polyethylene bags	200	0,1	20
Rice husk (kg)	750	0,1	75
Shovel	2	5,5	11
Wheelbarrow	1	78,5	78,5
Composter construction	1	11,3	11,3
Total costs			342,8
Incomes			
Detail	**Quantity**	**Unitary cost (USD)**	**Total cost (USD)**
Compost (tonnes)	10	80	800
Total incomes			800
Economic balance			**+457,2**

* Pig slurry not included as it is a farm surplus

In this case, all the compost produced will be sold. Another option is to cover production costs by selling part of the compost and the rest for use in the farm.

Regarding the example presented in Table 14, to cover the costs equivalent to USD 342.8 USD, it will be necessary to sell 4.2 tons of compost, setting aside 5.8 tons available for the farm.

4. Practical foundations of composting

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4. Practical foundations of composting

4.1 Recommended tools

-**Pitchfork and/or shovel:** to add material, turn and removed finished compost.

-**Running shears or crusher:** to get appropriate particle size from 5 to 20 cm (See Chapter 3.3)

-**Watering can, hose or sprinkler:** to keep proper moisture of the composting material from 45% to 60% (see technique to measure moisture in Chapter 3.3)

-**Thermometer:** to measure temperatures of the composting material (See Figure 4). A metal bar or wooden stick may be used instead.

-**Screen:** to sieve the material at the end of the composting process and separate large pieces those have not decomposed yet (Figure 19).

-**pH strips (optional):** to control acidity during the process (See Chapter 3.3)

There are other tools that help in the work, while not critical, such as rakes, wheelbarrows, hand aerators, etc.

Figure 9 Recommended tools

4.2 Composting techniques

The aim of the techniques to compost organic material is to measure and optimize process parameters to obtain an end product of quality both, from a sanitary and fertilization perspective.

Key factors to choose the technique:

- Process time.
- Space requirements.
- Requirements of hygienic safety.
- Parent material (absence or presence of animal origin material).
- Climatic conditions (temperatures below zero, strong winds, torrential rains or other critical climatic events).

The different techniques are generally divided into closed and open systems. Open systems are those that are carried out outdoors, and closed systems are carried in containers made, whether or tunnels drums.

4.3 Open systems or piles

This composting technique can be performed when there is an abundant and varied amount of organic waste (about 1m^3 or higher).

Figure 10 Compost piles. Ciudad Sandino. Nicaragua.

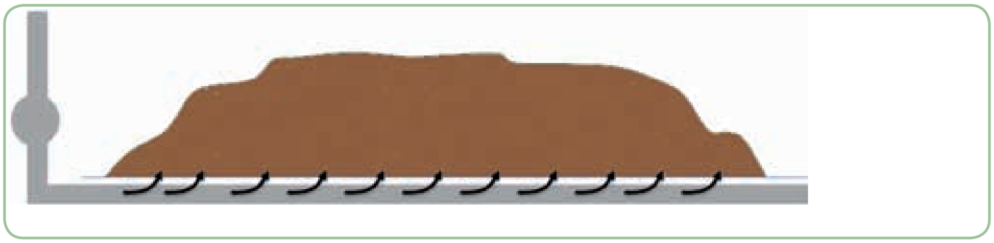
Depending on the compost pile management in the plant (space, technology, retention time), there is a wide variety of piles, shapes, volume, shape, layout and the space between them.

FAO publication "On-farm Composting Methods"[3] (FAO 2003), describes various techniques of pile formation such as Indore (Indian method) and rural Chinese composting. All methodologies share the technique of alternating layers of different material in order to get a good C: N (30:1) ratio and temperature and moisture control (See Sub-Chapter 4.3.1).

At industrial level, piles are managed with state of the art technology. Some examples are given below:

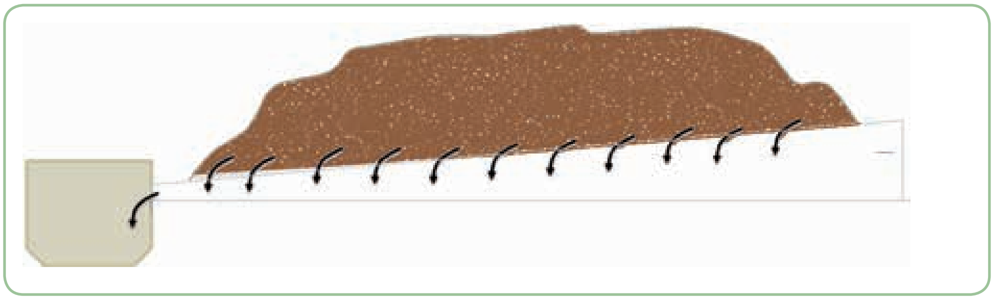
- Forced aeration, where air enters through ground channels to keep optimal oxygen levels.

Figure 11 Forced aeration system



- Leaching collection and subsequent treatment.

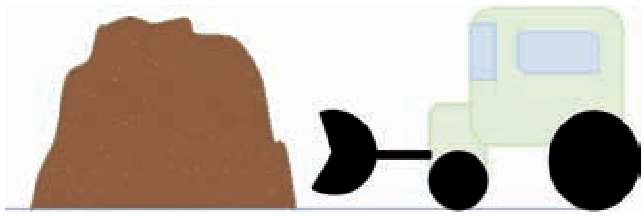
Figure 12 Leaching collection system



- Compost piles with a mechanized turning system, using either lateral screwed canter adapted to a tractor, or a front loader. The first system the pile height varies with the height of the lateral canter, while in the second system, the piles can reach three meters height. At family level this is not realistic and the desirable height should not exceed 1.5 metres to ease the turning activity.

3 On-farm Composting Methods http://www.fao.org/docrep/007/y5104e/y5104e00.htm

Figure 13 Mechanized turning



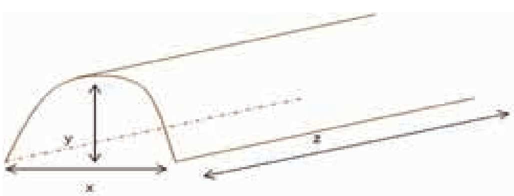
Before starting the composting process, calculate the area to be used and the volume of the pile. This may pose several limitations, such as the amount of material to be composted, the area to apply the compost, or the area where the composting process is carried out.

Example 4: Calculation of the compost pile dimensions according to the amount of material to compost

A family farmer produces a total of 100 kg a week of vegetable waste from the orchard and kitchen. He decides to build a pile with the 100 kg a week*. Considering a density of 250kg/m^3 **, the volume of the pile would be:

$$250 \text{ kg/m}^3 = \frac{100\text{kg}}{\text{m}^3}, \text{ x es } 0{,}40\text{m}^3$$

This volume is insufficient to build the pile (minimum volume of 1m^3), so at least 250 kg would be needed to meet the minimum requirements of base and heigth.
If various farmers work jointly and get 1,250 kg a week, the volume would be 5 m^3
The pile dimensions would be:



$5 \text{ m}^3 = (x \cdot y \cdot z)$

In this case, the formula for the volume of a parallelepiped is used as an approximate measure of a pile volume:

$$Volume_{parallelepiped} = x \cdot y \cdot z$$

Assuming a height (y) of 1.5 m and a width (x) of 1.5 m, then the length (z) of the pile will be: 5 m^3 =(1,5·1,5·z) => length= 2,2 m
*It is advised to build a new pile each week or extend the existing one to avoid adding fresh material to the thermophilic phase and interrupt the process.
** To calculate the density of the material: take a bucket or bucket of known volume. Weigh the bucket filled with uncompacted material and subtract the bucket weight. Finally, the weight of the material is divided by the known volume to obtain the density of the material.

Example: A 10 L bucket (0.01 m3) weighs 3.27 kg (the weight of the bucket is 270 g).

$$\text{Density} = \frac{3\text{kg}}{0{,}01\text{m}^3} = 300 \text{ kg/m}^3$$

Example 5: Calculation of the compost pile dimensions according to final compost requirements

A family has an orchard of 100 m^2 and wants to add compost. The average recommended quantity is 4-5 kg compost per m_2 so it would require 400 to 500 kg of compost.

Considering that during the decomposition process up to 50% material is lost (see section Compost pile size or composting volume), it is estimated that the parent material should double the final material. In this example, the parent material should be 800-1000 kg.

From this value, follow the same steps as in the previous example:

1000 kg => 4 m^3 (250 kg/m^3 density)

The area is calculated from the volume (the pile of Figure 14 has a pyramidal shape, so the formula for the volume of a pyramid is used instead of a parallelepiped, which is more appropriate for this case).

Figure 14 Compost pile

©Field - Nicaragua

$$4\ m^3 = \text{triangle area}\cdot\text{length} = \frac{b x h}{2} \text{ x length} \Rightarrow 4 = \frac{1{,}7 x 1{,}2}{2} \text{ x length}$$

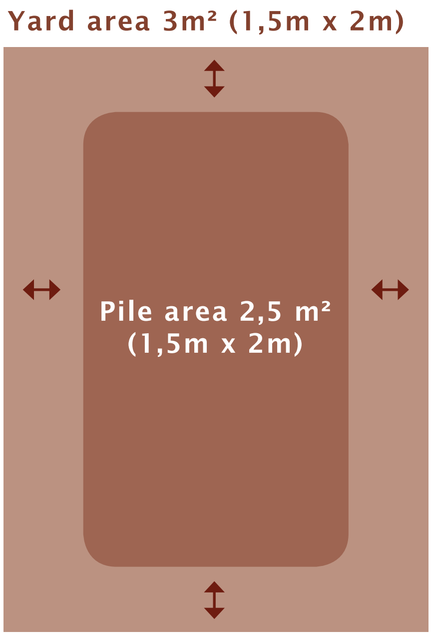
Pile's length= 3,9m

Example 6: Calculation of the compost pile dimensions according to the available area

If the limitation is the composting area, then the fixed value is the base area (pile's length and width)

A family can allocate an area of 3 m^2 of the yard to composting. That is the maximum area. Usually, a 15% of the area is left for contingencies since some material rolls downpile (due to wind, rain, small animals) to the pile side.

Figure 15 Available composting area



If the maximum height is 1.5 m, then:

Volume $m^3=(1,5\cdot 1,2\cdot 1,7)=>3m^3$

$3m^3$ (Density: 250 kg/m^3) correspond to about 750kg parent material to compost.

4.3.1 Tasks to be performed to build and manage a compost pile

• **Selecting and levelling the area**. The area is selected according to: weather conditions, distance from the area of waste production, distance from the area where the final compost will be applied and ground gradient. It is preferable that the area is protected from strong winds, at a safe distance from water sources (over 50 metres) to avoid contamination, and with a slight gradient (<4%) to prevent leaching and erosion problems.

• **Material chopping and pileing.** I general, a week is considered as the time unit to pile up material in the same pile, before the starting of the thermophilic phase, to prevent re-contamination of the material with fresh material. Another important aspect here is the mix of materials to achieve an appropriate C: N ratio. According to Cornell University (1996) the formula to follow is:

$$R = \frac{Q_1 x (C_1 \times (100 - M_1) + Q_2 (C_2 \times (100 - M_2) + Q_3 (C_3 \times (100 - m_3) + \ldots}{Q_1 x (N_1 \times (100 - M_1) + Q_2 (N_2 \times (100 - M_2) + Q_3 (N_3 \times (100 - m_3 \quad) + \ldots}$$

Being Q the quantity of material to be added; C and N the weight of Carbon and Nitrogen; M the weight of the moisture of the material.

For a quantity Q1 (e.g., straw), calculate the quantity Q2 required (e.g., manure). This can be estimated as follows:

$$Q_2 = \frac{Q_1 \times N_1 \times \left(R - \frac{C_1}{N_1}\right) \times (100 - M_1)}{N_2 \times \left(\frac{C_2}{N_2} - R\right) \times (100 - M_2)}$$

To ease the task, use a basic table showing the C:N value of the materials most commonly used (Table 15 C:N ratio of some materials used in composting) and make an estimate:

Table 15 C:N Ratio of some materials used in composting

High nitrogen level 1:1 – 24:1		Balanced C:N 25:1 – 40:1		High carbon level 41:1 – 1000:1	
Material	**C:N**	**Material**	**C:N**	**Material**	**C:N**
Fresh liquid manure	5	Cattle dung manure	25:1	Recently mown grass	43:1
Poultry litter	7:1	Kidney bean leaves	27:1	Tree leaves	47:1
Pig manure	10:1	Crotalaria	27:1	Sugar cane straw	49:1
Kitchen waste	14:1	Coffee pulp	29:1	Fresh urban garbage	61:1
Poultry litter with pen bedding	18:1	Cow dung	32:1	Rice husk	66:1
		Banana leaves	32:1	Rice straw	77:1
		Vegetable wastes	37:1	Dry grass (grasses)	81:1
		Coffee leaves	38:1	Bagasse	104:1
		Pruning	44:1	Corn cob	117:1
				Corn straw	312:1
				Sawdust	638:1

Source: Adapted from UNDP-INFAT (2002)

The ideal C:N ratio to begin composting ranges from 25:1 to 35:1. To calculate this, the available materials are selected from Table 14 and the C:N ratio of the materials is calculated separately. A proportional calculation is made to obtain the amount of each material to be applied to the pile.

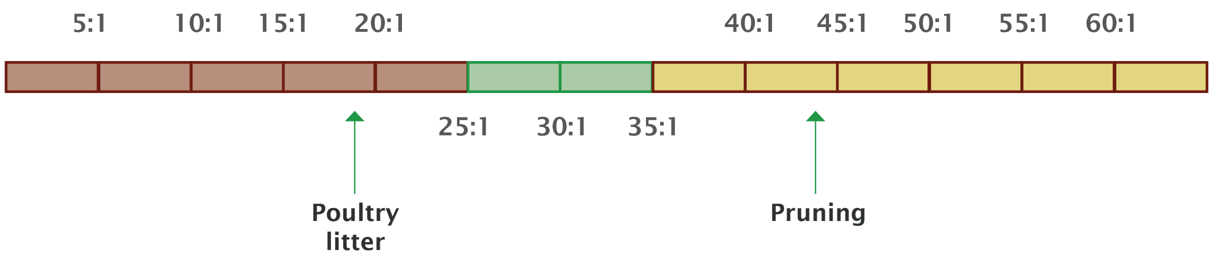
This calculation can be used as reference but there will always be a margin of error, because no adjustment is being made to the moisture of the material or availability of C or N (for example, cardboard has a high carbon content but it is slow to decompose).

Example 7: Calculation of the C:N ratio in the mix of various materials.

A farm has poultry litter mixed with pen bedding and fruit tree pruning.

C:N ratio is:

Poultry litter with pen bedding: 18:1 Pruning: 44:1



A 1:1 ratio from both will give a ratio close to 30:1, so the worker may intersperse layers of both materials of mix the materials with a shovel and build de pile.

There are also online calculators to calculate the C:N ratio up to three materials (Figure 16), as the one of Cornell University (in this case, C/N Ratio corresponds to the C:N ratio).

Figure 16 Calculator of C: N ratio

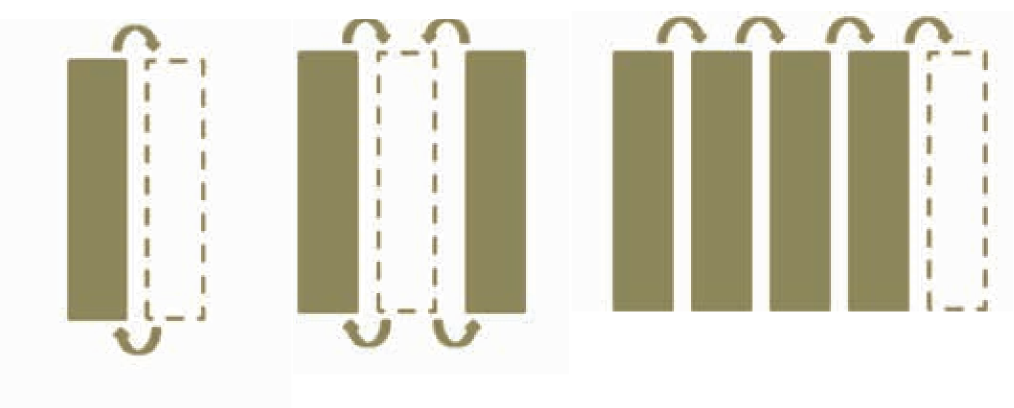
Ingredient	% H20	Weight	% Carbon	% Nitrogen	C/N Ratio
				Result:	

Source: Cornell University, available at http://compost.css.cornell.edu/calc/2.html

• **Turning system.** Normally, a weekly turn is done during the first 3-4 weeks and then, one turn every fifteen days. This depends on weather conditions and the material being composted. It is necessary to check the visual appearance, odour and temperature to decide when to turn (see next point, temperature control, moisture and pH).

It is important to optimize the space and turning operation. Figure 17 shows some examples of space optimization.

Figure 17 Turning modalities according to the number of piles



Temperature, moisture and pH control.

• Temperature, moisture and pH control. The homeowner should perform the following controls:

Temperature. If a thermometer was not available, a metal pole (or wood stick, see Figure 10) may be used. The rod is inserted in various points of the pile and by touching it, an approximate temperature is determined according to the composting phase and then it is compared with the recommended temperature for each phase (Table 3 Optimal temperature parameters).

Moisture. It is possible to apply the so called "fist technique", which consists of introducing the hand into the pile, take out a handful of material and open hand. The material must be matted with no dripping water. If water drips, turn and/or add drying material (sawdust or straw). If the material is loose in hand, add water and/or fresh material (vegetables waste or lawn trimming).

Acidity of pH. There are two ways to measure pH: directly in the pile or in a compost extract.

- Measuring pH in the pile: If the compost is wet but not muddy, insert a pH strip in the compost. Let it stand for a few minutes to absorb the water, and then read the pH by comparing the colour.
- Measuring pH in aqueous solution[4]: Take several samples of compost and put them in containers with water (volume/volume 1:5). Stir and read, preferably with a pH meter,or pH strip instead.

To follow up on the various parameters, use a spreadsheet like the following:

Figure 18 Process control spreadsheet

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Temperature												
Ref temperatura	15°-40°		40°-65°			15°-40°					~T°ambiente	
pH												
Ref pH	4-6		8-9			7-8					6-8	
Humidity												
Ref humedad	variable, depending on the humidity of input material (30% - 60%)											
Aspect												
Ref visual aspect												

Source: P. Roman. FAO

4 Protocol of "US Compost Council " 2010

• Verification that composting has finished (maturation phase). To verify that the compost is in the maturation phase, the material still wet, should not be heated again despite turning it. However, there are other tests to verify this phase.

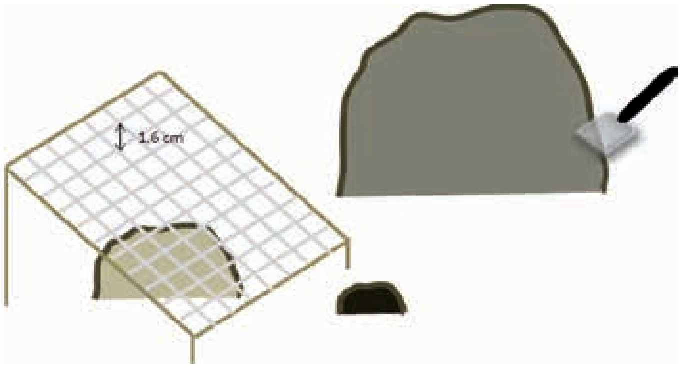
If there is access to a laboratory, perform a respiration test.

If there is no laboratory available, take several samples (minimum 3 samples) representing the size of the pile to analyse the look and smell of composted material. It must be dark, brown, moist soil scented, and not excessive moisture at the fist test. A quarter can be performed (division of the pile into 4 equal parts) and take 3 samples of 100 grams of composted material from each quarter, introduce them in plastic bags and leave for two days in a cool, dry place. If the bag swollen (air-filled) and shows condensation, this may indicate that the process has not been completed (immature compost). Another technique is to introduce a machete or metal instrument, 50 cm long, in the centre of the pile. If after 10 minutes, the machete is taken out and feels hot (cannot touch because it burns), it means that the material is still in the process of decomposition. In all these cases, the pile must left to continue the composting process.

• Sieving. Once the compost is mature, the material is sieved in order to remove large elements and other contaminants (metals, glass, ceramic, stones). The screen mesh size depends on the regulations of the country, but typically is 1.6 cm.

The big material that does not pass through the screen mesh (Figure 19 Screen used in the sieving process) is mostly lignocellulosic material (wood) that will return to a new compost pile to fulfil a dual function, that is, to continue decomposing and serve as composting bacteria inoculant.

Figure 19 Screen used in the sieving process



There are numerous non-industrial alternatives to the metal mesh, as the examples of Figure 20.

Figure 20 Alternative sieving instruments

©Field - Paraguay

Shade screen. Paraguay.

Rear grill of a stand fan
Nicaragua

Field activities monitoring

To monitor field composting activities, it is advisable to use spreadsheets such as the ones shown in Figure 18 and Figure 21.

Figure 21 Composting monitoring spreadsheet

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Site selection and leveling												
Choping and stacking of fresh material												
Temperature and humidity control												
Sieving												

Source: P. Roman.

4.3.2 Experiences of compost piles in Latin America

In very rainy or cold weather areas, the pile may be covered with plastic to favor the rise in temperature and avoid stagnant water.

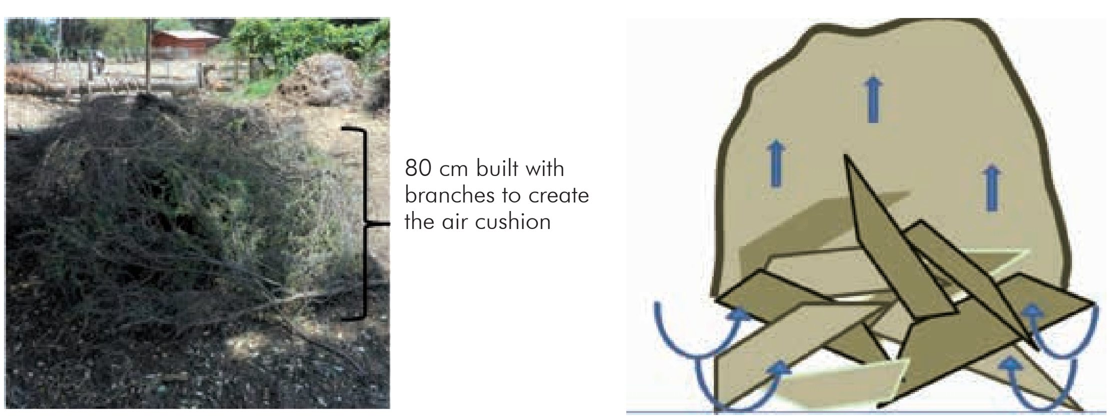
Figure 22 Compost pile cover to avoid temperature drop and excess rain. Nicaragua.

©FAO/E.Murillo

Aeration can be improved with different modes of passive ventilation.

- "Air cushion". This cushion is formed with thick branches, and is placed as a first layer of the pile (80 cm). The compost tends to create anaerobic bags in the bottom centre area and this method improves air circulation homogeneously.

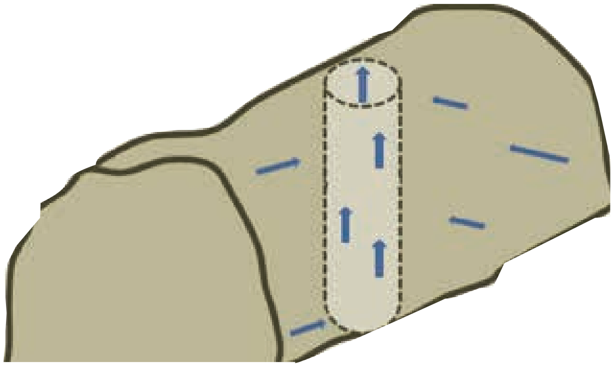
Figure 23 Photograph and schematic of the air cushion technique



©FAO/Pilar Roman

- Ventilating stack. During the formation of the pile it is common to insert a pole of at least 20 cm in diameter and 1.5 meters high. When the pile has already formed, this pole is removed and the space left acts as a ventilating stack, thus improving air circulation in the pile.

Figure 24 Photograph and schematic of the ventilating stack technique



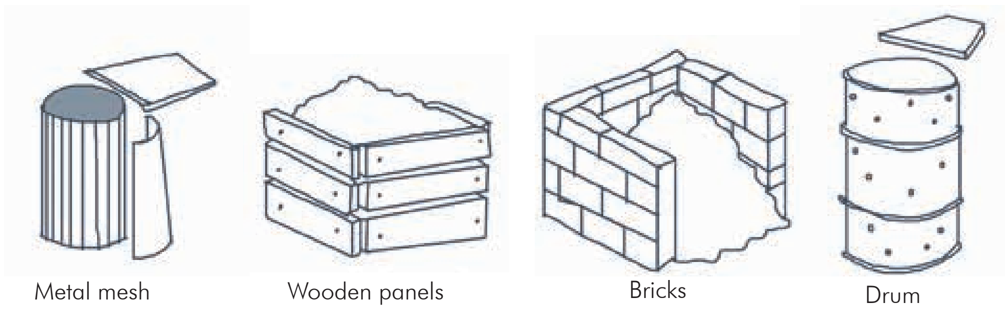
Pile in the Ecologic Farm Fen, Chile

The two techniques can be used together, as in the "pile without turning" (Case Study 6.3).

4.4 Holding units

This method is often used at homeowner level. The container has a number of characteristics that favour its replication: prevents accumulation of rain, protects the material from strong winds, facilitates the turning, facilitates removal of leachate, controls the invasion of vectors (mice, birds) and prevents access to the composting material by unauthorized personnel and farm animals. The disadvantage of this method is that it can reach high temperatures, so the control of parameters becomes particularly important. In warm climates, earth is usually added to the container (up to 10%) to control temperature, since earth is stable and does not generate heat.

Figure 25 Types of holding units



In Latin America is common to use 220 L plastic drums, which can be reuse as compost bins with some minor modifications. The composting process time is shorter than in a pile. Depending on the ambient temperature and the parent material, the product can reach the maturation phase in six to ten weeks.

Figure 26 Turning a horizontal compost bin

Before starting the process, it is important to choose a suitable container. This choice is based on the type of drums available, the amount of material to be composted, the area where the container will be placed (horizontal or vertical), and the type of process (static or dynamic, which is explained below).

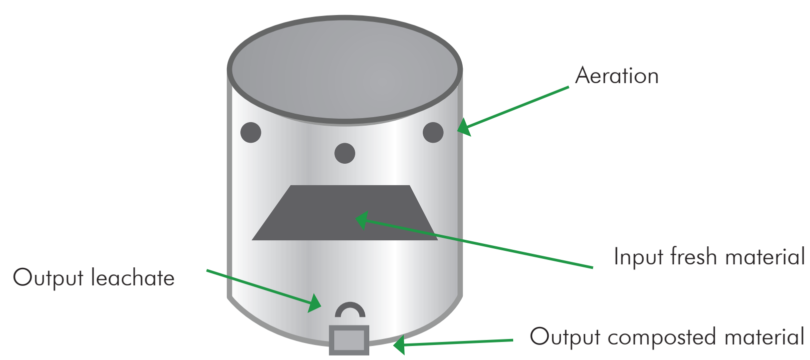
There are many materials available to use as compost bin; however, there are two basic modes to arrange the containers: Vertical (continuous/static) and horizontal (discontinuous/dynamic).

It is the **vertical arrangement** in which the container rests on its base (Figure 27). Fresh material is added from the top and the composted material is usually removed from the bottom. It is called continuous because fresh material enters continuously and the composted product also goes out continuously from the bottom (if the container requires to be turned to remove the material, then it is a discontinuous composting container, batch)

The advantages of this system are: easy to handle, requires little investment, suitable for small areas (the base diameter of a 220 L drum is usually 60 cm) and better control of the leachate (it usually has a small valve to extract leachate).

Among the disadvantages of this method is that it requires a turning area. The material within the container can be mixed with a bar, but the result is heterogeneous and there is the risk of creating anaerobic bags. The material tends to compact and therefore, the moisture distribution is not uniform, and the top dries faster.

Figure 27 Vertical or continuous compost container



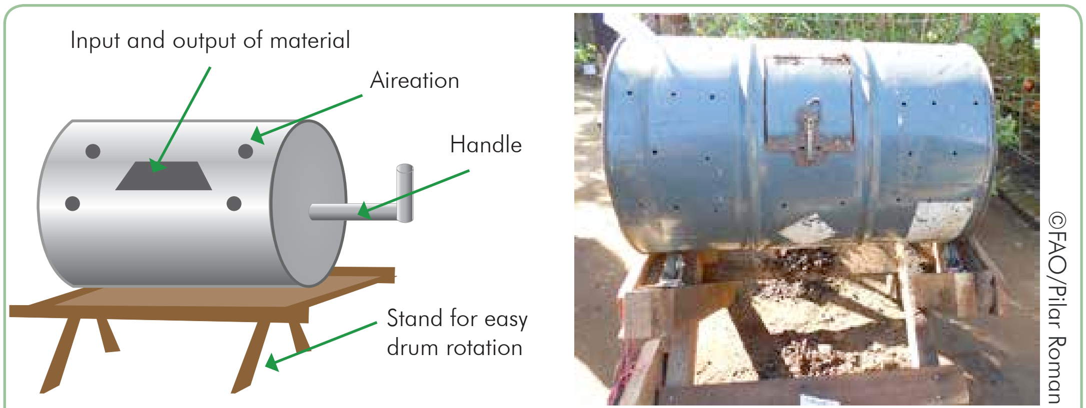
The leachate output is normally a valve or tap than can be open manually every week to extract the excess flow.

The horizontal arrangement (Figure 28) is one in which the container rests on its longitudinal axis (in a 220 L drum, the length is 90 cm). It is called discontinuous because it is a "batch" process. Once the container is loaded, the process should be finished before removing the compost and introduce new material.

The advantage is that this system has a better moisture distribution and compaction since it is easy to be turned (crank) and the product obtained is homogeneous.

The disadvantage is that this system requires greater investment than the vertical system since at least two containers are required for the continuity of the process. As the leachate can leak out through the vents during the turning, a second container needs to be placed underneath.

Figure 28 Horizontal or discontinuous compost drum



CDC de Managua. Nicaragua

Table 16 Advantages and disadvantages shows a summary of the closed composting systems.

Table 16 Advantages and disadvantages of closed composting systems

	Investment	Handling	Area	Final material
Horizontal	Low	Medium Easy	Small	Heterogeneous
Vertical	High	Complex	Large	Heterogeneous

4.4.1 Tasks to be performed when composting in containers

Selection of the container. The choice of a vertical or horizontal compost container will depend on the available space, amount of material to be added and time to be dedicated to the composting process (See Table 16).

Material chopping and filling the container. It is important that the material have a size between 5 and 20 cm for optimal decomposition process.

The material should have a C: N ratio from 25:1 to 35:1 for appropriate start of the process (see Example 5 for the calculation of the C: N ratio). The container is filled during two or three weeks. After this period, the container is left standing until the composting process is over and the finished compost is removed.

Control of moisture and aeration, turning, material extraction and sieving. The same techniques of the pile composting are applied. (See 4.3.1Tasks to be performed to build and manage a compost pile).

Example 8: Calculation of the appropriate volume of the compost container.

A family with a home garden of 35 m^2 produces 20 kg per week of vegetative food scraps and kitchen material. The material inside the container tends to compact up to 400kg/m^3.

$$400\ kg/m^3 = \frac{20kg}{m^3}\ ,\ x => 0{,}05m^3 = 50\ dm^3$$

If material is added to the container during five weeks, the container should have a volume of at least 200dm^3(equal to 220 L).

A drum of 220 L (220 dm^3) would be appropriate for this situation.

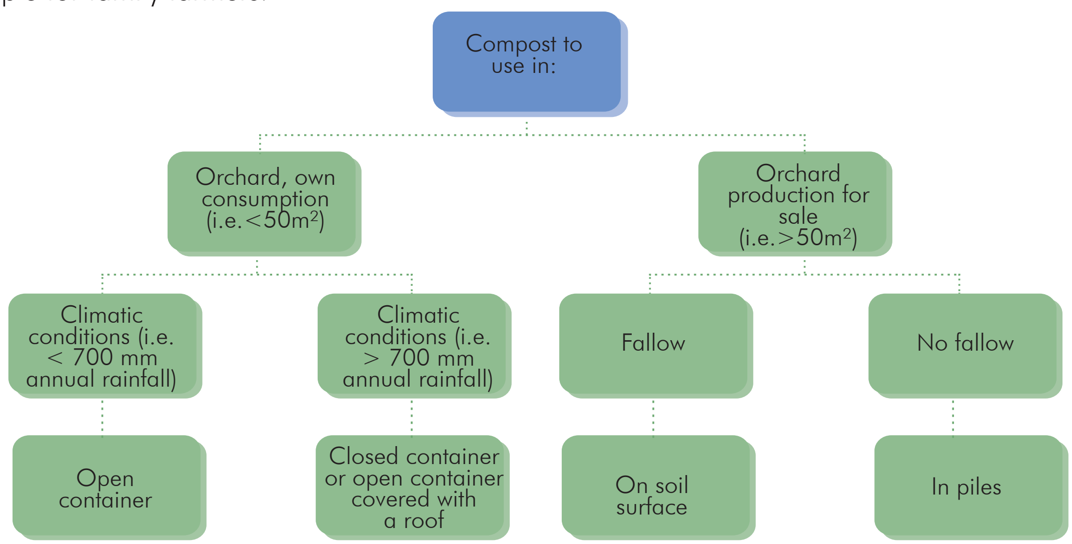
This drum can be used and fill the free space with soil.

4.5 Decisions Tree

A good way to decide what composting technique to follow is through a decisions tree.

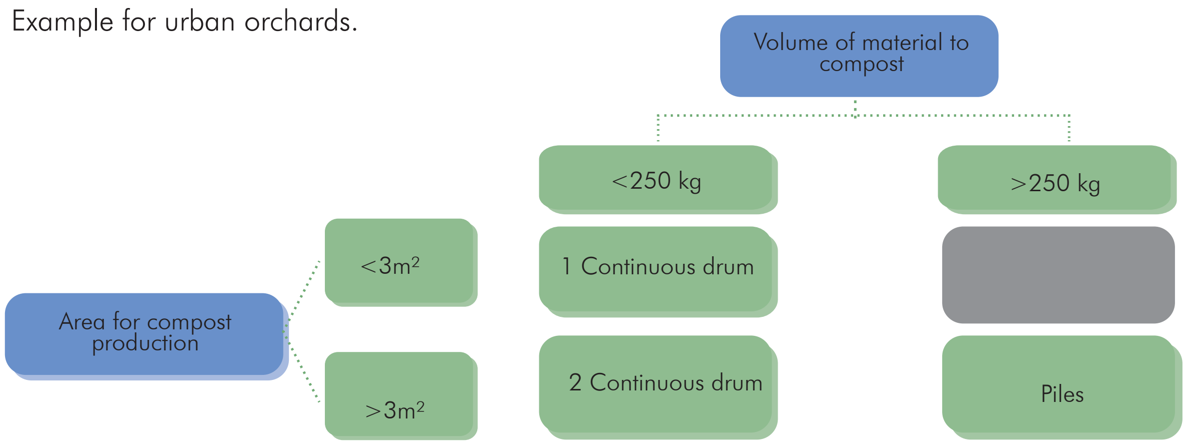
Example 9: Choice of a composting method in family farming

Example for family farmers.



Example 10: Choice of a composting method in urban farming

Example for urban orchards.



5. Compost-related products

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5. Compost-related products

5.1 Vermicompost

Vermicompost is the process of composting using earthworms and microorganisms. It is an oxidative process (with air) which ends in the stabilization of organic matter. Like the mature compost, the final product is organic matter, but the earthworms perform the process with the help of microorganisms (Lazcano, 2008).

During this process, insoluble minerals are solubilized and made available to plants when the vermicompost is applied to the soil. Similarly, other complex organic compounds such as cellulose, are partially degraded to simple compounds by bacteria in the digestive tract of the earthworm, increasing the availability of N.

To produce vermicompost, the most widely earthworm species used is Eisenia foetida commonly known as the California red earthworm, despite being native to Europe. The species receives the name foetida because the odour of its exudates, which are presumably an anti-predator adaptation.

This species of earthworm is very skilled in the way it feeds because every 24 hours eats food equivalent to its own weight. The earthworm gets its food from vegetable, animal or mixed organic matter, fresh or in different decomposing stage, to produce earthworm biomass (growth and new earthworms) and manure.

This species requires high concentrations of organic matter to feed on and some environmental conditions such as optimal temperature between 19-25 °C, 80% moisture, pH of 6.5-7.5, in low light. The earthworm survival depends on the amount of organic matter in the medium, being reduced as the percentage of organic matter decreases.

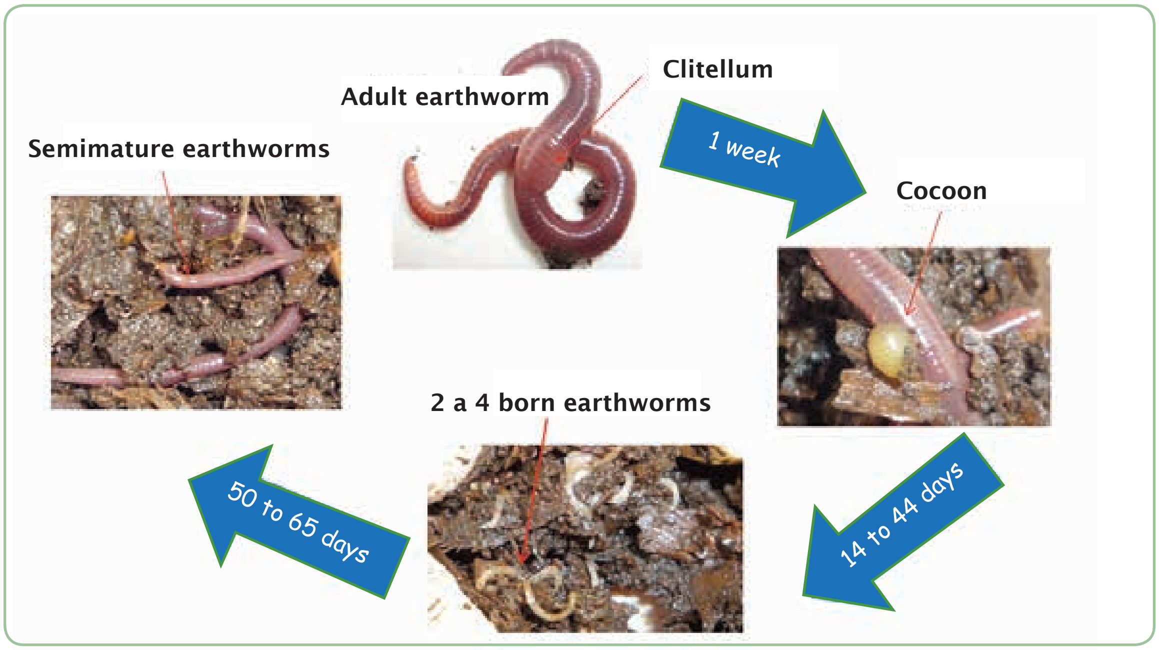
The body of the earthworm looks like a chain of rings. The larger ring called clitellum contains the reproductive organs. The earthworm is hermaphrodite, i.e., the same individual has both sexes, but the reproduction requires two individuals. Cross-fertilization is carried out by joining the clitellum of two individuals where copula takes place every 7-10 days. The two individuals produce eggs, called Cocoons or Cocun. The eggs are in the shape of a lemon and yellow-transparent appearance at the beginning, turning brown as the earthworm grows (Figure 29). capullos son visibles a simple vista. Cada capullo contiene de 2 a 12 lombrices que emergen a los 21 días de ser depositadas. La lombriz recién eclosionada mide 1mm de longitud. The cocoons are visible to the naked eye. Each cocoon contains from 2-12 earthworms that emerge after 21 days of being deposited. The newly hatched earthworm measures 1mm in length.

Figure 29 California red earthworm cocoon

©M.M.Martinez

Juveniles begin the reproductive period at 3-4 months, when they become adults and are sexually mature. By that time, they have approximately 3cm. Finally at 7 months they reach their final weight and size of 1 g and 7-8 cm respectively. In average, they live 10 years (Figure 30). To get vermicompost, it is necessary to have a container or bedding, food, broodstock and, of course, proper environmental conditions.

Figure 30 Earthworm life cycle



Source: M. M. Martinez. CATA-USM, Chile

For the vermicompost is necessary to have a container or bed, the material to be composted, the broodstock and suitable environmental conditions to growth the earthworm.

Container or bed: there are different options, sizes and quality of containers to grow earthworms. The containers should be open to ease feeding and visualization and are usually made of wood. The earthworms usually dig deeply into the substrate looking for food, but do not reach farther than 40 cm (Schuldt et al., 2007), so the bed should have a depth of 50-60 cm and 1 m wide; the length depends on the available area. The bed should be protected from rain, sunlight and extreme temperatures in times of frost or winter.

Figure 31 Vermicompost container in a school orchard. Tegucigalpa (Honduras)

©FAO/Pilar Roman

Figure 32 Vermicompost container in a family orchard. Managua (Nicaragua)

©FAO/Pilar Roman

Figure 33 Vermicompost container in peri-urban farming. Asunción (Paraguay)

©FAO/Pilar Roman

Figure 34 Vermicompost in family farming. Neiva (Colombia)

©FAO/Pilar Roman

Substrate: usually a mixture of soil with fresh organic material (vegetable waste, manure, etc.) is used in a 3:1 ratio; or composted organic material with fresh material in a 2: 1 ratio respectively.

Broodstock: The most common recommendation is one kilogram broodstock per square meter of bed. The broodstock can be purchased also be obtained from the beds. Depending on the country, one kilogram of earthworm may cost between USD 50-100.

Table 17 Environmental conditions:

Parameter	Ideal Range
Moisture	70%-80%, this is the maximum moisture, as the worm breathes through the skin, and a higher moisture may prevent breathing.
Temperature	20-30°C
pH	5-8.5. Verify with a pH strip before feeding the earthworm.
Light	The earthworm is photosensitive so, it will always prefer a dark environment.

The following materials may be added to the vermicompost:

Manure, paper and unpainted cardboard, fruits and vegetables, eggshell, pruning, grass clippings, straw, crop waste, coffee pulp, cereal grains. Biosolids from home waste water treatment plants (Lotzof 2012) may also be applied.

Vermicompost harvest

The finished vermicompost is harvested depending on the production system and size. The earthworm trapping system, which is used at a small scale, consists of stopping feeding the earthworms for 8-10 days. Then, “fresh food” is placed at one end of the bed or on the material in the same container to attract earthworms. Thus, the earthworm moves towards fresh material looking for food and can be collected in that place.

In this work, the newly hatched earthworms and new cocoon are left in the vermicompost, so they are not recovered. The vermicompost is more stable than compost and contains more humic and fulvic acids (see Annex 7.4)

The material obtained can be sieved in order to homogenize the size or drying (Figure 35) to be stored and subsequently applied to soil. It is also used as a basis for the production of vermicompost tea.

Figure 35 Vermicompost drying area in colombia 2008

©M.M.Martinez

Like compost, vermicompost improves soil structure, increases water retention, provides the soil with beneficial microorganisms, in addition to other metabolites and enzymes involved in the transformation of organic matter.

5.2 Compost tea

Compost tea is the water-soluble extract obtained from the compost. This is a system to extract compost compounds that are soluble in water and additionally, microorganisms. This system is similar to that used to make herbs tea or regular tea, but with cold water which is clean but not necessarily potable.

The production of compost tea is intended to increase the microbial load of compost, so additives can be incorporated to the process which act as catalysts to induce microbial metabolism and thereby, increase populations more quickly and efficiently (Scheuerell, 2004 ; Angulo et al, 2011)..

Compost tea should be differentiated from other products such as compost leachate, manure tea and compost extract:

1. Compost leaching: corresponds to water that drains due to over-saturation (excessive moisture) of the material during the composting process. This excess water, leaks out of the compost and can be collected. It also contains soluble nutrients and some microorganisms. However, when the compost is too wet and still immature, anaerobic zones are developed where compounds such as sugars produce acids and other compounds that may be toxic to plants (phytotoxic). When the leachate comes from fresh compost, the liquid is usually dark, acid pH and unpleasant odour (Figure 36).

Figure 36 Fresh compost leachate. Vegetable compost, funza, colombia

©M.M.Martinez

2. Compost extract: is the product of passing water through the compost. This water also contains soluble nutrients and microorganisms, but due to the contact time of water with the material, the recovery is lower. Some producers recycle this liquid on the compost piles and may recover microorganisms, but this labour is expensive and the recovery not significant.

3. Manure tea: is the aqueous extract of manure. It contains soluble elements according to its maturity. It is a nitrogen source, either as nitrates (mature) or ammonium (fresh). It also contains soluble phosphorus and potassium, high number of bacteria, and since it has not gone through a maturation process, it may also contain other unwanted elements such as antibiotics or drug residues. Microbiologically, it may contain pathogens such as protozoal eggs and cysts as well as other phytopathogen nematodes.

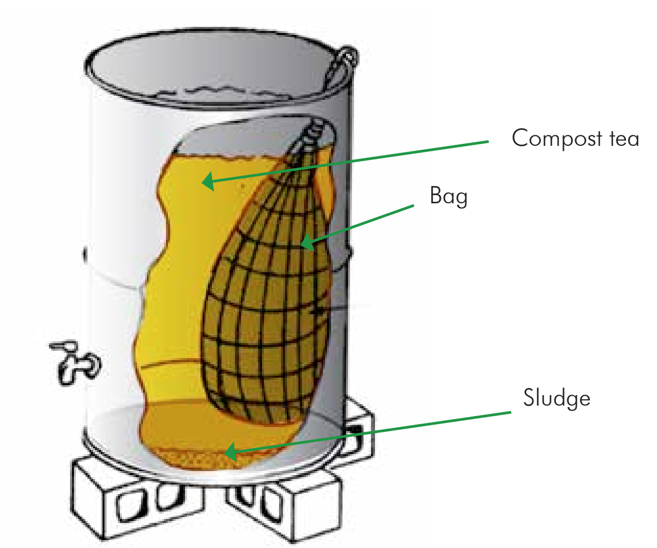
4. Obtaining compost tea

Compost tea is obtained from finished and mature compost, but there are those who make tea from fresh or partially composted manure. It should be noted that the quality and content of substances in the aqueous extract will depend on the quality and composition of the raw material.

Once the compost is ready, the extraction is performed. The following is required:

- A plastic tank located in a cool and clean area, protected from direct sunlight and rain. Ambient temperature.
- A mesh, bag or porous container for compost.
- A motor and an adapted piping inside the tank to maintain aeration.
- Clean water, preferable potable water.

Figure 37 Tank to obtain compost tea



At commercial level, there are tanks designed with special devices to ease permanent and homogenous aeration.

Preparation:

- The compost is placed into the mesh or porous bag in a ratio equivalent to 10% (weight/volume) the volume of the tank water approximately.
- he mesh or bag is hanged on the edge of the tank ensuring that the solid material is in contact with water. This is similar to a tea bag in a cup.
- The motor is switched on and the continuous and mechanical aeration process runs for about 24-36 hours. The motor can be programmed to work for two hours and one hour off (2x1).
- When the time is over, the mesh with damp compost is removed, and this material can return to a compost pile in its initial phase.
- The liquid turns caramel colour (lighter or darker depending on the source material). If the source material is fresh manure the colour is green and vermicompost or humus, the colour is dark brown.
- It is necessary to verify that the process is carried out correctly. A simple verification way is through odour, because unpleasant odour is produced when oxygen is insufficient; an aerobic process should not produce offensive odours.

Application of compost tea

The compost tea can be applied to foliar level spraying the surface of the leaves or directly to the soil together with irrigation water.o.

Compounds present in the compost tea

Compounds present in the compost tea include organic substances that have been produced by microorganisms during the process, namely, organic acids, amino acids and sugars, among others.

It also contains soluble inorganic elements such as N, P, K, among others, that contribute to the nutrition of microorganisms and plants once applied to a farming system (Annex 7.4).

Likewise, it contains high concentration and variety of beneficial microorganisms such as bacteria, fungi and nematodes which, in agricultural systems, help preventing disease, increase the availability of nutritional elements and stimulate plant growth.

Quality of the compost tea

The quality of the compost tea depends on the quality of compost or material, where appropriate. If the compost is matured, there would be higher certainty that pathogens, seeds, nematodes and other phytopathogens have been eliminated.

Conversely, if the composting process does not reach the required temperature and time, or materials are raw, it is highly probable to find in both, the material or "compost" and in tea, bacteria such as ***Salmonella spp***., ***E. coli*** and ***Clostridium spp.*** and viruses such as Enteroviruses, Hepatitis A and Adenovirus, as well as parasites such as ***Taenia sp.*** and ***Ascaris lumbricoides***, which can cause major intestinal diseases (Ingram, 2009), causing health problems for both the farmer and the consumer. So, safety precautions should be taken before application.

6. Experiences in Latin America

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6. Experiences in latin america

6.1 Compost production from pig breeding in deep litter[5]

Location. Monte Heliconia Farm, located in Las Ceibas river watershed, Colombia. Land with an average temperature of 25 °C and annual rainfall of 1,300 mm. The property is situated at an altitude of 780 MASL, in an ecological system classified as Tropical Dry Forest.

Project background. Fattening pig in deep litter is a system that was introduced in 40 farms in the area with very good results (Figure 38). The biggest advantage of this system is the considerable saving of water since it does not require washing the pig pens that uses 2 m^3 water, per pig a month, approximately. Another important advantage of this system is the production of organic fertilizer from aerobic composting of excreta, minimizing the potential for contamination.

Figure 38 Pig fattening in deep litter, monte heliconia farm

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Process description. This example corresponds to the collection of organic waste (excreta and bed) of 20 fattening pigs, housed in a pen 4·10 m^2 (area: 40 m^2).

The productive cycle (growing and fattening) lasts five months, during which each animal produces 450 kg of excreta (faeces plus urine) on average. In the present study the total excreta collected at the end of the cycle with 20 pigs was 9,000 kg and 1,200 kg of litter (rice husk), which made a total of 10,200 kg of organic material collected, that goes to the next composting phase.

The deep litter is made up of the following:

5. FAO project experience: Watershed Management Plan of Las Ceibas river. UTF/COL/030/COL

Rice husk. This husk performs like drying agent, being this property that enhances its use as a deep litter in pigs fattening, to dry excreta.

Pig manure and urine. The main element of the litter (88% of the total area).

The deep litter system implies the following tasks:

Litter preparation. The pig pen floor is compacted earth with perimeter drains to prevent entry of water runoff. The litter should be 40 cm deep for good absorption and drying of organic material (Figure 39). In the current example, 750 kg of rice husks were used for a 40 m^2 pig pen.

Figure 39 Preparing the litter with rice husk

©FAO/Pilar Roman

By natural behaviour pigs are permanently rooting, turning the litter, allowing in this way a rapid drying of excreta (Figure 40). It is here were composting begins with the rise in ambient temperature of 15°C above the ambient temperature, up to 40°C. This increase in temperature reduces offensive odours and disrupt the life cycle of the housefly.

Figure 40 Pigs rooting the litter

©FAO/Pilar Roman

Litter collection and transport. Once the fattening cycle (5 months) is over, the pigs are taken out to be sold. The litter is immediately collected and moved (Figure 41) to a 100 m^2 flat site, roofed and earthen floor. All the material, about 10 tons, is placed in a row of about 1 m height.

Figure 41 Litter collection and building the compost pile

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Composting management: After loading the material in the compost, the control of the three most important variables in this aerobic composting process starts:

Aeration. The material of the row is turned manually with shovels (Figure 42). This procedure is intended to improve the aerobic conditions of the substrate, as well as promote the homogenization of the mixture and achieve a stabilization process. This procedure is performed every two months, with a total of 3 turns in six months.

Figure 42 Periodical turning of the compost pile

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In this case study, the composting process lasted six months, what was a decision of the person responsible for this operation. Under other operating conditions such as many more turnovers, the final product can be obtained in less time, apart from the fact that the material from pig pens has already begun the process favoured by the animals' rooting, litter temperature and dehydration of excreta.

Moisture. Together with turnings, water is added in spray form (Figure 43), trying to achieve approximately 65% moisture in the material, what is verified by the fist test.

Figure 43 Watering the compost pile

©FAO/Pilar Roman

Temperature. It should be monitored every week using a thermometer, recording measurements at various points in the pile.

The final product obtained (Figure 44) should have a pleasant smell of earth, dark brown and homogeneous texture of small grains [6].

6. There may be a high concentration of copper, since this element is present in pig slurry. Therefore, we must regulate the addition of drying material.

Figure 44 Packaging final product

©FAO/Pilar Roman

Use. This organic material is used in fertilization of grasses, which are used as coverage in bioengineering works to control erosion (Figure 45).

Figure 45 Compost in bioengineering. Colombia

©FAO/Pilar Roman

Source: CDC J.A Saldivar. Paraguay

It has also been used in neighbouring farms as soil breeder for crops like cacao, citrus and passion fruits which have visually offered good growth, development and leaves colour.

6.2 Compost pile in Peri-urban farming[7]

Location. CDC of municipalities of J. A. Saldivar and Nueva Italia, Asunción, Paraguay. The local climate is subtropical with a dry winter (July), the annual rainfall is 1,400mm at an altitude of 40 MASL.

Process description. First, clean and delimit an area of approximately 2m x 1m (Figure 47). A sheet of crossed branches is placed to favour pile drainage and aeration. A pole of about 2.50 m in height is placed in the centre of the pile (see Chapter 4.3.2).

Figure 46 Cleaning the pile area

©FAO/Pilar Roman

Source: CDC J.A Saldivar. Paraguay

Then, layers of organic waste of about 15-20 cm are disposed, interspersing vegetable waste and hen bedding. A thin layer of earth (2 cm) can be spread every four layers as buffer for temperatures rise and also as inoculant of microorganisms. The process is repeated until the pile reaches 1.5 metres in height. During stacking of the material, if they are too dry, it is advisable to moisten the layers.

Perform moisture and temperature controls according to chapter 4.3.1. The composting process lasts 12 weeks in summer and up to 24 weeks in winter. The final product has a pleasant smell of earth and dark brown.

Use. This organic material is used to fertilize planks for the production of leafy vegetables in the CDC, with an application of 3-5 kg/m^2 to the soil.

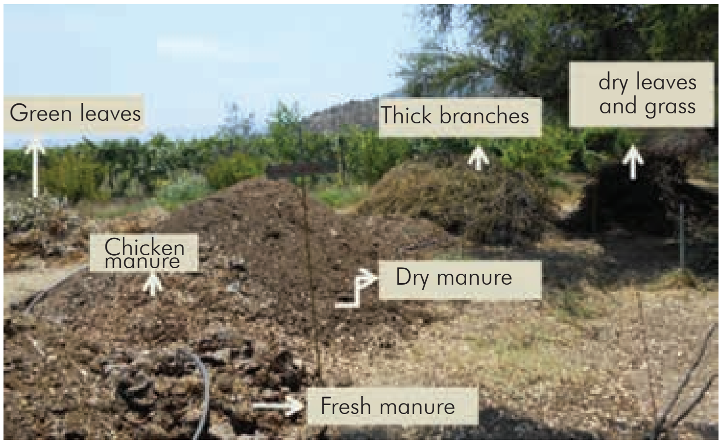
7. FAO project experience: Strengthening family farming productive chains for a sustainable social and economic integration in peri-urban areas of the Central Department of Paraguay. TCP/PAR/3303

6.3 Compost piles that are not turned

Location. Ecologic Farm FEN, Curacaví. Chile. Zone with 15 ° C average temperature and 312 mm annual rainfall.

Process description. In order to facilitate the work to build the pile, it is advisable, if there is available area, to pile materials separately (Figure 47). This makes it easy to arranging the pile in layers of different materials.

Figure 47 Segregated material to build the pile



©FAO/Pilar Roman

The first step is to build an air cushion with thick branches (Chapter 4.3.2), 80 cm in height, which is laid along the area where the pile will be built (Figure 48).

Figura 48 Thick branches forming an air cushion

©FAO/Pilar Roman

Then, the material is arranged in layers, interspersing layers of carbon-rich material (leaves and branches) and nitrogen-rich material (manure and poultry litter). Figure 49 shows different layers of 10-15 cm thick. A hose with two micro-sprinklers may be is placed on top of the pile, at 2.5 metres to keep moisture in the pile. The micro-sprinklers are in operation during the formation of the pile.

Since this system does not require turning, it is necessary to add a ventilating stack to improve aeration of the pile (see Chapter 4.3.2). A pole of about 2 m high and 20-25 cm in diameter is inserted in the centre of the pile while the layers of materials are placed. After the pile is built, the pole is removed (Figure 50).

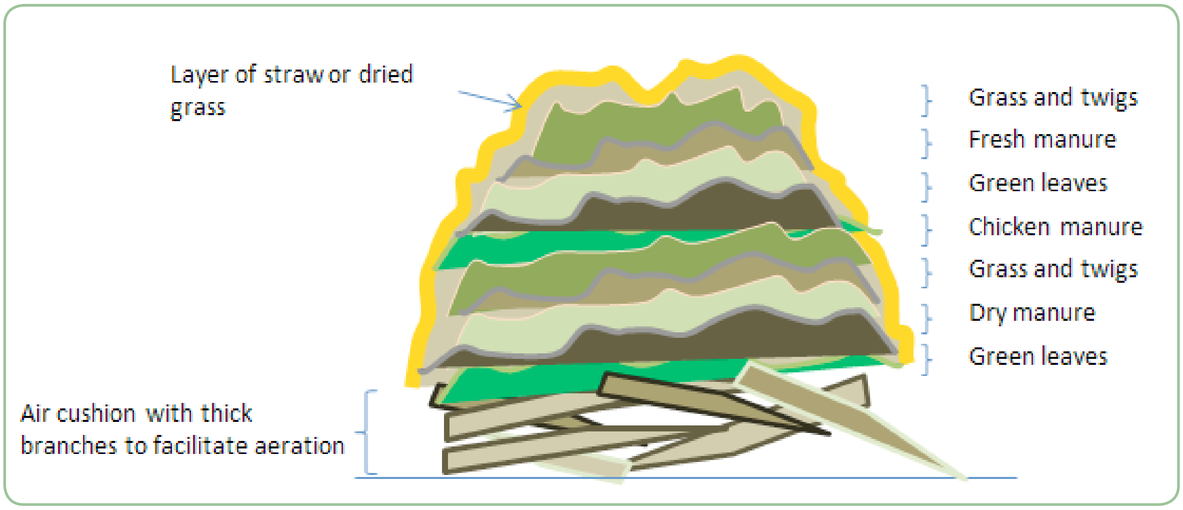
The driest layers of material are placed in the first centimetres of the pile because water irrigation is accumulated in that zone.

Figura 49 Interspersed layers of material rich in carbon and nitrogen

When the pile reaches about 2 m height, is covered with a layer of straw to insulate from the outside temperature (Figure 50).

Parameters are controlled every week and watering as required (Chapter 4.3.1). After 4-6 months the pile will be reduced to half its size and the material will be ready to be collected and used as fertilizer.

Figure 50 Schematic of pile without turning



Source: P. Roman, FAO

6.4 Horizontal metal compost barrel in Urban Farming [8]

Location. CDC of Urban Farming in Los Laureles, Managua, Nicaragua. Managua is one of the warmest capital of Central America with an average temperature of 27°C. The annual rainfall is 1,100 mm and the city is located at an altitude of 35 MASL.

Process description. The Demonstration Centre uses a compost container built with local materials, such as a 200 L metal barrel supported by a wooden structure and wheels to facilitate turning (Figure 51). The compost barrel is placed in a shaded area.

Figure 51 Horizontal metal compost barrel

©CDC-Nicaragua

The material used in composting come from the same training centre, as fruit and vegetable scraps, dry or green leaves from crops. Fresh and dry manure comes from nearby centres and the mixture is enriched with plant ashes (micronutrients). It is common to add molasses as a source of energy (C) for microorganisms and whey as microorganisms' inoculant.

The mix of materials has a density around 500 kg/m^3, so a 0.2 m^3 drum has a capacity of 100 kg of this mixture.

8. FAO project experience: Implementation of Urban and Peri-urban Farming in the Municipality of Ciudad Sandino and Los Laureles Sur borough. GCP/NIC/038/SPA

Table 18 Material to compost in barrel

Type of Material	kg
Fruit and vegetative food scraps	40
Green leaves	20
Dry leaves	5
Fresh Cow dung	20
Dry Cow dung	10
Ash	5

If molasses and whey are included in the process, 1 L of each product should be added at the beginning of the process.

The materials of the table are mixed and put in the barrel and periodical controls of temperature and moisture are performed (See Chapter 4.4.1). The process under local conditions with the materials of Table 18 Material to compost, lasts 8 weeks; after that time, the material enters into the maturation phase and is ready to be used.

6.5 Horizontal plastic compost drum in Family Farming[9]

Location. Alcira Arzamendia Estate, in the Municipal district Nueva Italia, Asunción, Paraguay. The local climate is subtropical with a dry winter (July), the annual rainfall is 1,400mm and the estate is at an altitude of 42 MASL.

Process description. The material used for composting comes from the same estate, as fruit and vegetable scraps, green leaves of crops. Cattle dung manure, poultry litter and plant ashes mixture was also used (as a source of micronutrients).

Figure 52 Preparation of the compost drum with material of local farmers

©FAO/Pilar Roman

9. FAO project experience: Strengthening family farming productive chains for a sustainable social and economic integration in peri-urban areas of the Central Department of Paraguay. TCP/PAR/3303

The materials used in the compost container are: 1 plastic drum (Figure 52) of 200 L (0.2 m^3) with lid; 3 rods 1.50 m and ¾" (2 cm) in diameter to mix the materials.

The material of the compost container is:

Table 19 Material of the compost container

Type of Material	%
Grass clippings, dry leaves, fruit skin	70%
Dry cattle dung manure	20%
Poultry litter (hen bedding with rice husk)	10%
Urea	0.1%

The mix of materials has a density around 500 kg/m^3, so a 0.2 m^3 drum has a capacity of 100 kg of this mixture.

10 L of water are used to maintain the optimum moisture content of the mixture. The drum is rolled daily (two turns) to facilitate the homogeneity of the mixture. After 8-10 weeks, the material is brown colour, has a pleasant odour and is ready for use

6.6 Compost production from lettuce industry waste

Location. Hortícola de Hoy, Funza, Cundinamarca, Colombia. Average Temperature 15°C. Average rainfall 600 mm/year

Process description. The farm has 2 hectares of intensive plant production (Figure 53). Plant production is performed in greenhouse and open field and the main crop is lettuce (Lactuca sativa). Before seeding, the soil is prepared by removing roots, leaves and unharvested plants and then, adding organic matter (compost) and rice husks.

Figure 53 Fertilization of lettuce with compost

©Gutiérrez & Fernández

Process description. The parent material for composting is lettuce waste (Figure 54), rice husk and Kikuyu grass cutting ***(Pennisetum clandestinum)*** to build the pile in a 50:40:10 v/v ratio.

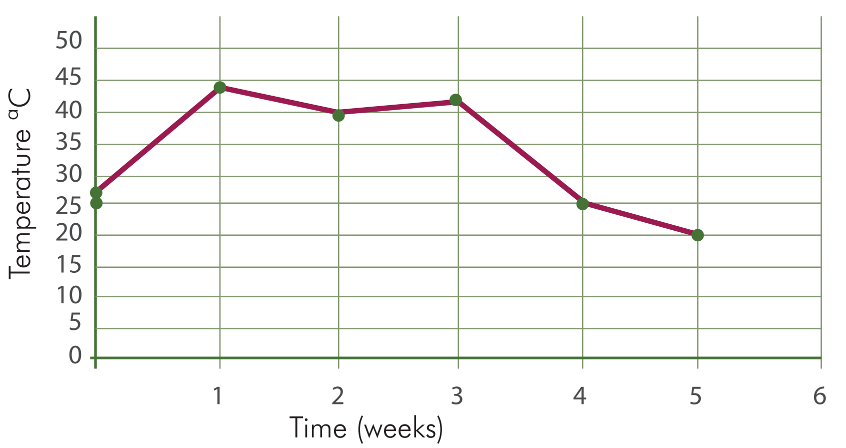
The soil was prepared tamping the soil and spreading a layer of sand-gravel-clay in a 30:20:50 ratio to isolate leachates. Because lettuce is 85% water with low content of C and N, is important to compensate moisture through mixtures with dry materials that provide not only C but also N.

In this particular case, the piles had a base of 2 x 3 m^2, starting with a 5 cm layer of rice husk, a mix of crop waste and weeding, covered with grass cutting. Then process was repeated until the pile reached 1.50 m.

Figura 54 Fresh material to compost

The thermophilic phase starts the day 4 of the process, reaching 44°C in the first week and remaining constant for three weeks. Every 4 days manual turns are performed. At week 4 the temperature decreases to ambient temperature. The maturation process lasts until week 8 and the compost is turned once a week. Temperatures recorded during the process are shown in Figure 55.

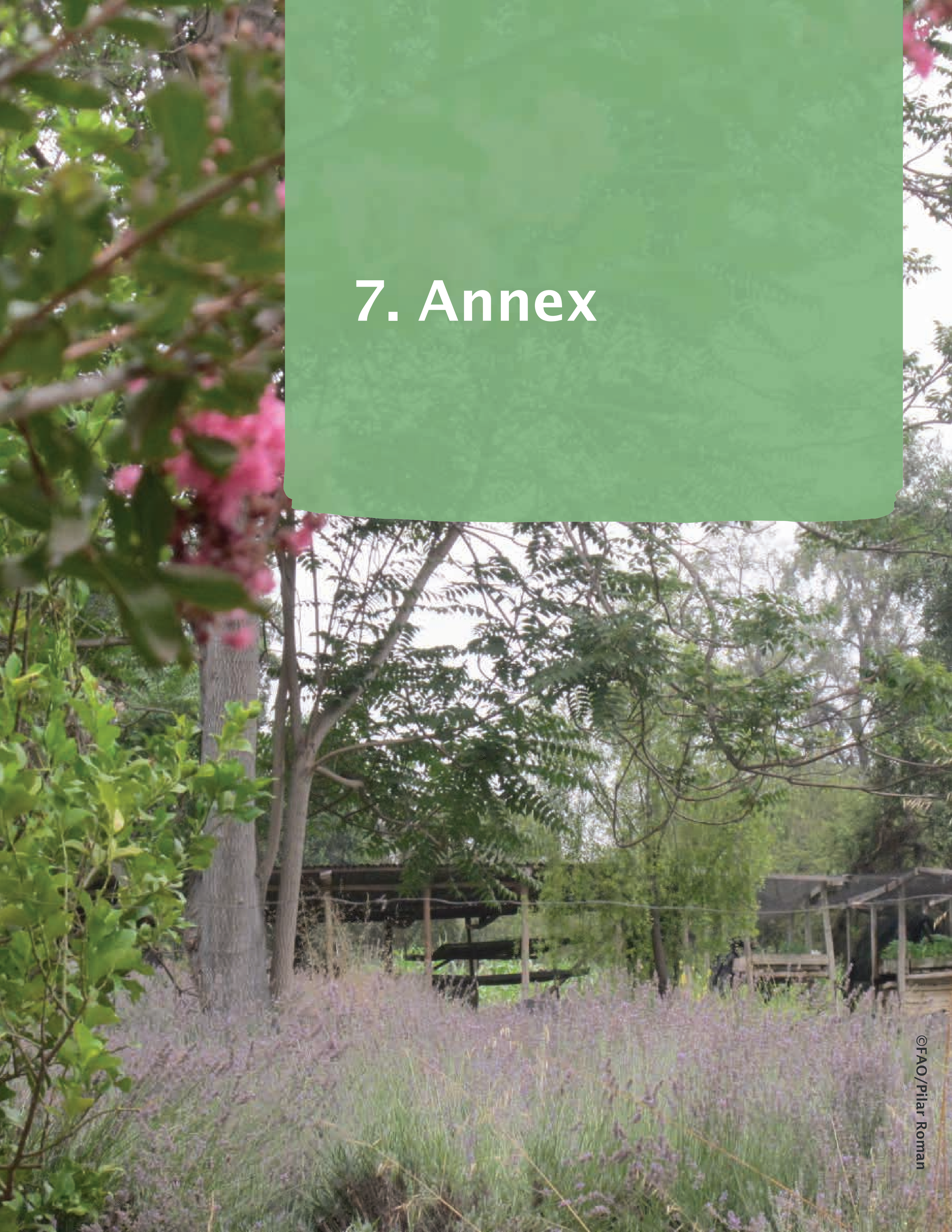
Figure 55 Temperatures recorded during the process



Source: Barrera, Charry y Martinez, 2008

The compost obtained after 8 weeks, is loose like soil, and with a pleasant damp earth odour. Particle of husks were covered with decomposed organic matter.

7. Annex



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7. Annex

7.1 Conversion factors

Distance

1 metre = 1.09 yards = 3.28 feet = 39.37 inches

1 yard = 3 feet = 0.91 metres

1 foot = 12 inches = 0.3 metres

Area

1 hectare = 10.000 square metres = 2.47 acres

1 acre = 4.48 square yards = 0.4 hectares

Weight

1 kilogram = 1,000 grams = 2.2 pounds

1 metric tonne = 2,204 pounds

1 pound = 0.45 kilograms

1 kg/ha = 0.89 pound/acre

1 pound/acre = 1.12 kg/ha

7.2 Field analysis of the need of fertilizers

If plants fail to absorb sufficient quantities of a particular nutrient, the symptom of deficiency appears on the appearance of the plant; thus, it is possible to determine the need of a particular nutrient. Clear symptoms will only express in cases of extreme deficiency.

Table 20 Symptoms of plant deficiency

Nutrient	Sign of deficiency in the plant
Nitrogen	Stunted growth plants, yellowing of the leaves from the tip (chlorosis). The lower leaves may die prematurely while the top of the plant remains green.
Potassium	Reduced growth, dwarfism. Dark outer edges of the leaves (edge necrosis); withered leaves. Small fruits. Lodging.
Phosphorus	Stunted growth. Dark blue and purple leaves from the tip. The fruits appear deformed and empty grains.

7.3 Analysis of compost safety

Microbiological analyses are an important aspect in determining the sanitary quality of compost through indicators and pathogens.

Thermotolerant Coliforms (also known as faecal coliforms)

Thermotolerant coliforms are a class of Gram negative bacteria that belong to the enterobacter which can ferment lactose to produce indole 44.5°C. According to EPA[10] the presence of this group in a high number is a possible indicator of the presence of pathogenic bacteria such as Salmonella, Shigella and E. coli verotoxigenic. Their presence in high concentrations in compost or organic material indicates that the thermal process has been insufficient or deficient; i.e., compost did not reach the appropriate temperatures or were reached but for short periods of time or a subsequent water contamination occurred during the cooling stages. It has been established that counts below 1,000ufc per dry weight gram of compost means that enteric pathogens are destroyed.

Bacterial pathogen

Bacterial pathogen for humans and animals can be found in raw materials like manure, being the presence of ***Salmonella spp.*** of particular interest. This microorganism is one of the main agents of Foodborne Diseases and may be a usual inhabitant of the digestive tract of animals including poultry (chicken being an important reservoir), cattle, and pigs, among others. (Carrascal 2011).

Also of interest is ***E. coli*** O157: H7, which has been associated to diseases caused by the intake of fruits, raw vegetables and unpasteurized products (Islam 2005). It can be found in animals such as cattle, deer and sheep, and can survive up to 70 days in manure, depending on concentration and temperature. Other pathogens found in compost that could reach men though the intake of contaminated foods include: ***Clostridium perfringens, Listeria monocytogenes, Bacillus cereus and Cryptosporidium parvum*** (Beuchat 2006).

10. Environmental Protection Agency of United States

Table 21 Microbiological limits according to different standards

Microorganism	Tolerance limit				
	Chile NCh 2880/04		EU European Union	Colombia 5167/04	Mexico NTEA-006-SMA-RS-2006.
	A	B			
Fecal coliform (dry base)	<1000 NMP/g	<2000 NMP/g	< 1 x 10^3 NMP/g	<1000 ufc/g Total enterobacterial	<1000 NMP/g
Salmonella spp	Absent in 25g of product	Absent in 25g of product	Absent in 25g of product	Absent in 25g of product	<3 /g en bs
Enteroococcus faecalis	-	-	1000 NMP/g	ND	-
Viable helminth eggs / Ascaris	Absent in 1 g	Up to 1 in 1g	Absent in 1 g	ND	<10 /g bs

NMP= Most probable number, ufc= colony formation units, bs= dry base

Heavy metals

Heavy metals are a group of chemicals that become undesirable because they do not decompose (only change its oxidation state). They have negative effects on human health and impact on food chain at ground and water level. Although found in nature, when the concentration exceeds defined limits, there may be problems of accumulation in plant tissues (fruit, root) or vital organs (liver, brain, fat tissue) with usually long term effects (chronic) .

Heavy metals, together with the presence of pathogens, are considered to determine the quality of compost. The limits vary between countries, although EPA and the European Union (EU) regulations are taken as example.

7.4 Vermicompost

Tabla 22 Chemical properties of vermicompost

Fulvic acid	14 - 30%
Humic acids	2,8 - 5,8%
Sodium	0,02%
Copper	0,05%
Iron	0,02%
Manganese	0,006%
C:N ratio	10 - 11%

7.5 Benefits of compost Tea

1. Plant Health. Since compost tea contains nutrients and microorganisms that have multiplied in preparation tanks, it may contain biological agents for disease control. Microorganisms such as Trichoderma, Pseudomonas, or Pantoea spp., are present in compost and are capable of growing in the compost tea and perform disease suppression processes. This suppression is associated with substances that occur during compost maturation and depend on biological and physicochemical characteristics (Temorshuizen et al., 2006).

2. Biological fixation of nitrogen and biofertilization. As in compost, compost tea may contain (usually to a lesser extent) bacteria associated with crops fertilization. They are nitrogen-fixing bacteria (Azotobacter sp., and Rhizobium sp., Klebsiella sp.) and phosphates solubilisation agents (Dubeikovsky et al., 1993)

3. Improvement of soil carbon content. As it is the soluble extract of the compost, compost tea also contains water soluble carbohydrate. This carbon positively affects native soil populations, being energy source for microorganisms in the plant's root zone (rhizosphere) or leaves (phyllosphere). This soluble carbon may also be used by microorganisms to build microaggregates, thus improving water retention capacity and structure of the soil(Ha et al., 2008)

4. Increasing the number of microorganisms. Compost tea uses different products to help with microorganisms' multiplication during the preparation time. These products called catalysts, favour the movement of microorganisms from the compost into the water and also serve as a source of nutrients. Sugar, molasses, fish emulsion and phosphate rock are used as effective substrates in this catalytic process (Ingham, 2005, Shrestha et al., 2011).

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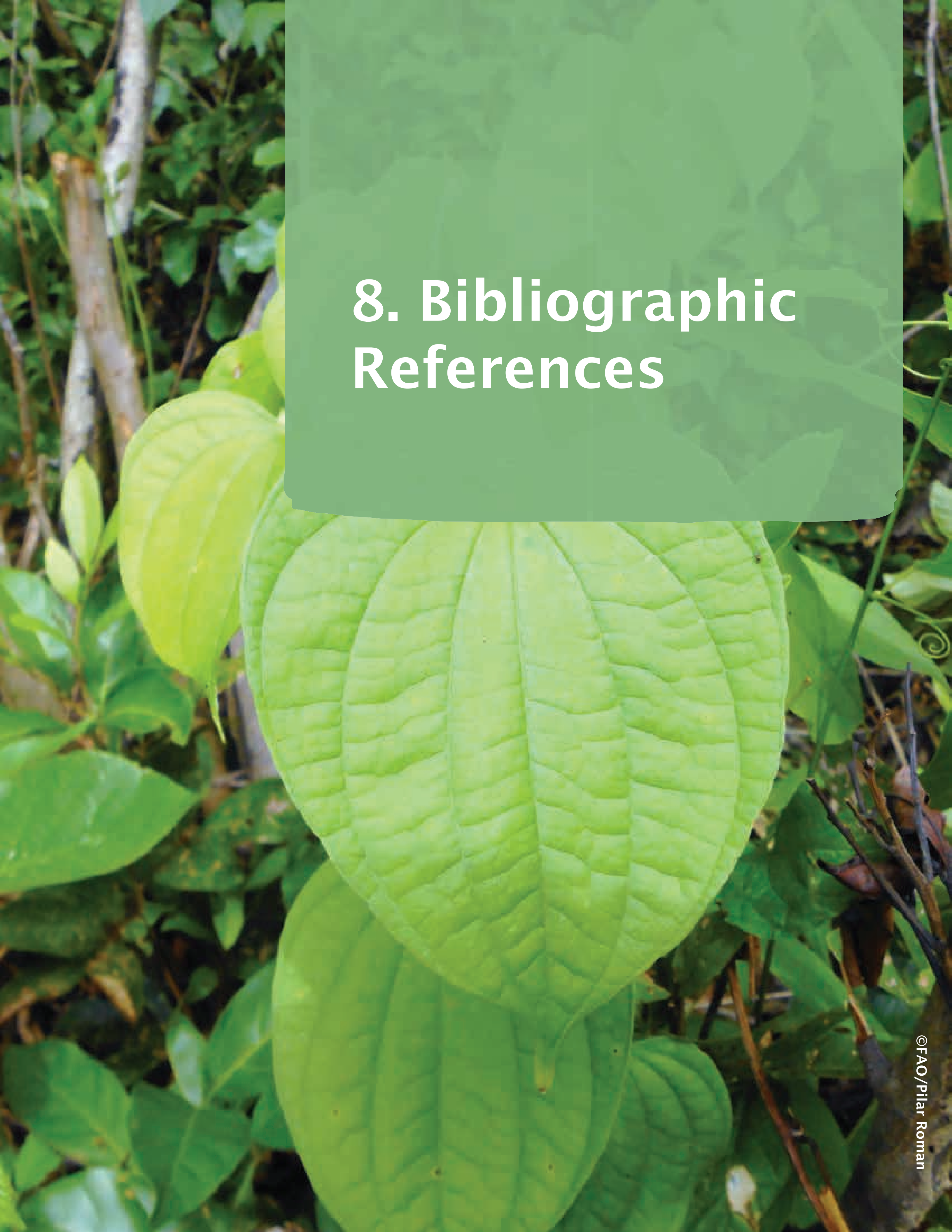

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Notes

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