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SMALLHOLDER COFFEE PRODUCTION IN PAPUA NEW GUINEA – FARMER TRAINING GUIDE

UNIT 2: MANAGING YOUR COFFEE GARDEN

MODULE 7:
SOIL FERTILITY AND NUTRIENT MAINTENANCE

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SOIL FERTILITY AND NUTRIENT MAINTENANCE

The Smallholder Coffee Production in Papua New Guinea Training Program

The training program contains modules prepared in partnership with the Australian Centre for International Agricultural Research (ACIAR) and by CARE-International.

The structures of the Extension Officer Training Program and the Farmer Training Program are shown in the table below.

Some modules also contain references to additional training that learners are encouraged to complete as part of their training.

ACIAR Resource

Monograph MN220 Smallholder Coffee Production in Papua New Guinea: a training package for extension officers and farmers. This package contains the modules for both the extension officer training guide and the farmer training guide. The ACIAR monograph is available online from **www.aciar.gov.au**

Hard copies of the ACIAR training package may be available by contacting ACIAR or the Coffee Industry Corporation (CIC)

CARE Resources

Organisational Strengthening Training
CARE Family Money Management Training

The CARE modules are available online from **https://pngcdwstandard.com/resources-for-use-by-cdws-working-with-wards-communities-groups-and-smes**

Hard copies of the CARE modules may be available by contacting the CIC or CARE-International.

Extension Officer Training Program

Title	Module reference
Introduction to smallholder coffee production in Papua New Guinea	ACIAR Smallholder Coffee Production in Papua New Guinea Training Package
Extension Principles	
Introduction to the Coffee Extension Officer and Farmer Training Guides	ACIAR Extension Officer Training Guide Unit 1 Module 1
The extension officer - roles and effectiveness	ACIAR Extension Officer Training Guide Unit 1 Module 2
Knowing Your Farmers	
Getting to know our coffee smallholders	ACIAR Extension Officer Training Guide Unit 2 Module 1
What factors affect smallholder coffee production?	ACIAR Extension Officer Training Guide Unit 2 Module 2
Strongim grup: course facilitator guide	CARE Organisational Strengthening Training

Farmer Training Program

Title	Module reference
Becoming a Coffee Farmer	
Knowing your coffee tree	ACIAR Farmer Training Guide Unit 1 Module 1
Coffee nursery development	ACIAR Farmer Training Guide Unit 1 Module 2
Establishing a new coffee garden	ACIAR Farmer Training Guide Unit 1 Module 3
Managing Your Coffee Garden	
Weed control	ACIAR Farmer Training Guide Unit 2 Module 1
Maintenance pruning and rehabilitation	ACIAR Farmer Training Guide Unit 2 Module 2
Shade management	ACIAR Farmer Training Guide Unit 2 Module 3
Drainage	ACIAR Farmer Training Guide Unit 2 Module 4
Pest and disease management	ACIAR Farmer Training Guide Unit 2 Module 5
Coffee berry borer management	ACIAR Farmer Training Guide Unit 2 Module 6
Soil fertility and nutrient maintenance	ACIAR Farmer Training Guide Unit 2 Module 7
Intercropping in your coffee garden	ACIAR Farmer Training Guide Unit 2 Module 8
Harvesting and Processing Coffee	
Coffee harvesting and processing	ACIAR Farmer Training Guide Unit 3 Module 1
Coffee grading systems and pricing	ACIAR Farmer Training Guide Unit 3 Module 2
Establishing a mini wet factory	ACIAR Farmer Training Guide Unit 3 Module 3
Coffee Marketing	
Understanding the domestic coffee market	ACIAR Farmer Training Guide Unit 4 Module 1
Kamapim ol praioriti	CARE Organisational Strengthening Training
Kamapim ol eksen plen	CARE Organisational Strengthening Training
Setim gutpela kastom bilong ronim grup	CARE Organisational Strengthening Training
Wok bilong meneja na memba na lida	CARE Organisational Strengthening Training
Coffee certification	ACIAR Farmer Training Guide Unit 4 Module 2
Fairtrade certification	ACIAR Farmer Training Guide Unit 4 Module 3
Family money management	CARE Family Money Management Training

CONTENTS

MODULE TOPICS

CONTRIBUTING AUTHORS

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The knowledge of the following contributors has been invaluable in the development and writing of this module:

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INTRODUCTION

Aim of Module:

The aim of this module is to provide smallholder farmers with information on soil fertility, nutrient requirements of coffee trees and how best to manage the soil in the coffee garden. Using both recommended and local strategies, the supply of nutrients and their availability to the coffee trees can be optimised.

The focus of this module is the soil environment in which coffee trees are grown. Coffee trees require fertile soil to be healthy and productive. The supply and availability of soil nutrients can be optimised for the coffee tree if the coffee garden is correctly managed. The application of good pruning, shade tree management and mulching practices will produce best possible yields of quality cherry and reduce the requirement for expensive fertilisers.

LEARNING OUTCOMES:

By the end of this module you will:

- Understand the functions and properties of soils
- Know what makes a soil fertile
- Understand the complexity of the balance of nutrients in the coffee garden
- Know the important nutrients required by coffee trees and those that may be either deficient, or become deficient, in PNG coffee gardens
- Understand how to best manage the coffee garden in order to protect the soil and optimise the availability of nutrients to the coffee trees
- Understand that soils will degrade if nutrients taken from the soil are not replaced when cherry is exported from the coffee garden

LESSON PLAN:

The module has three parts

Sections 7.1 and 7.2:	The properties of soils and what makes a soil fertile
Sections 7.3 and 7.4:	Nutrient requirements of coffee trees and potential nutrient deficiencies
Section 7.5:	Managing the coffee garden to protect the soil and optimise the availability of nutrients

TIME REQUIRED TO COMPLETE THIS MODULE: 3 DAYS

LIST OF SYMBOLS:

Information relating to CBB

Farmer notes, brochures & factsheets

Information for farmers that must be taken very seriously

For the Extension Officer

TEACHING AIDS:

- Farmer notes and the Plant Health Troubleshooting Guide (one copy for each farmer plus spare copies)
- The coffee calendar and stickers
- Coloured white board markers and white board eraser
- Butchers' paper and marker pens for each group of 4 participants
- Soil samples of varying levels of fertility (sand, loam and clay)
- Samples of organic matter

PRE-TRAINING ACTIVITIES:

- Confirm number of training participants
- Print sufficient copies of farmer notes
- Source soil samples and samples of organic matter
- Arrange access to a coffee garden that uses good soil management practices

PRELIMINARY ACTIVITIES

The farmers will complete two exercises prior to undertaking the module topics. These include the coffee calendar and the quiz. The purpose of these exercises is for the extension officer to assess the level of knowledge of farmers in the group prior to completing the module.

The Coffee Calendar

The coffee calendar lists the main events and activities occurring during an annual cycle of coffee production. The first item on the calendar is coffee berry development. All other activities are linked to the stage of development of coffee berries from flowering through to overripe cherry.

Annual coffee production events and activities (stickers)

1. Flowering and berry development
2. Harvesting coffee
3. Pulping and drying coffee
4. Maintenance – weeding, pruning, mulching, shade management, digging and maintaining drains, and maintaining fences
5. CBB control measures

Using the stickers for each of the annual coffee activities listed above, work with the farmer group to attach them to the appropriate rows of the coffee calendar.

- Begin by attaching the progressive stages of coffee berry development from flowering through to bright red cherry, and to overripe cherry
- Complete the remaining sections linking each activity with the different stages of berry development
- For this module, integrate the activities relating to soil fertility and nutrient maintenance listed below

Soil fertility and nutrient maintenance

Identify when in the coffee calendar the following activities should be undertaken:

In a new coffee garden

1. Choose the best place to start the garden by considering suitable land and soil conditions, such as a gentle slope with deep soils. If this is not possible, prepare a good drainage system to prevent waterlogging if low in the slope, or erosion if it is steep
2. Plant appropriate nitrogen fixing shade trees prior to planting the coffee seedlings
3. After planting the coffee seedlings, apply mulch such as coffee pulp, and residues of weeds and other crops, to increase the supply of nutrients, suppress weed growth, retain soil water, and prevent soil erosion
4. Maintain a weeding program to minimise competition for nutrients
5. Plant intercrops or a cover crop (intercrops and cover crops can also be grown prior to planting the new coffee garden)
6. Harvest intercrops and leave residues to decompose in the coffee garden or slash the cover crop and leave on the ground to decompose

In an established coffee garden

1. If coffee cherry has been processed in or near the coffee garden, return coffee pulp to the coffee garden as mulch soon after the cherry is processed
2. Prune coffee trees and leave residues in the coffee garden to decompose
3. Manage shade trees so they provide approximately 30% shade cover in order to moderate flowering and minimise nutritional stress of the coffee trees. Prune just prior to commencement of coffee flowering and leave pruning residues in the coffee garden to decompose
4. Regular weeding

Quiz

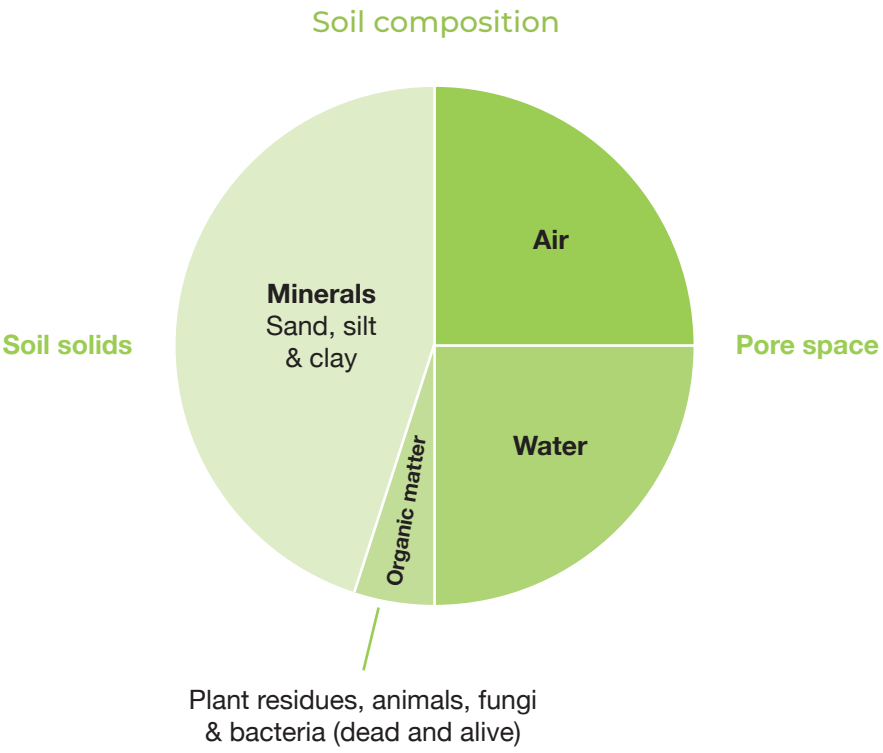
- Refer to the Quiz located at the end of this module and have farmers complete the questions
- Repeat the Quiz on completion of the module topics

7.1 SOIL AND ITS FUNCTIONS IN COFFEE PRODUCTION

What is soil?

Soil is a complex mixture of four ingredients:

1. Minerals
2. Organic matter
3. Air (gases)
4. Water



Soil composition is dependent on:

- The parent material – the rock or other material from which the soil is derived. This dominates the mineral content
- The type and amount of organic matter (dead and alive)
- Climate – moisture, temperature, light intensity, and wind
- Position in the landscape, e.g., ridge/crest, valley side or valley bottom
- Age – younger soils like those developed from volcanic ash are likely to contain high levels of some nutrients and deficiencies of others. Minerals are lost as the soils age

Soil solids

The solid component of soils is made up of minerals and organic matter.

Minerals

- Minerals are the non-living solid components of the soil
- Minerals in Highlands soils mainly originate from volcanic activity; either basalt (which is lava flow) or volcanic ash
- The mineral component is divided into three size ranges known as sand, silt and clay

Soil organic matter

- The organic matter usually makes up less than 10% of the soil. However, it is a critical ingredient. The percentage of organic matter in a soil is among the best indicators of soil quality
- A good indicator of organic matter content is the colour and friability of the soil. The darker and crumblier the soil, the greater the amount of organic matter. If a dark stain or streak is left on the palm of your hand after smearing it with soil, you can conclude that the soil has high organic content
- Organic matter has both living and non-living fractions:
  1. **Non-living organic matter**
     Includes plant litter and the degraded material from decomposing plant and animal residues such as manure
  2. **Living organic matter**
     Includes plants (roots) and animals (microscopic animals, or microorganisms, and small animals such as insects, nematodes and worms), fungi, bacteria and algae

Pore space

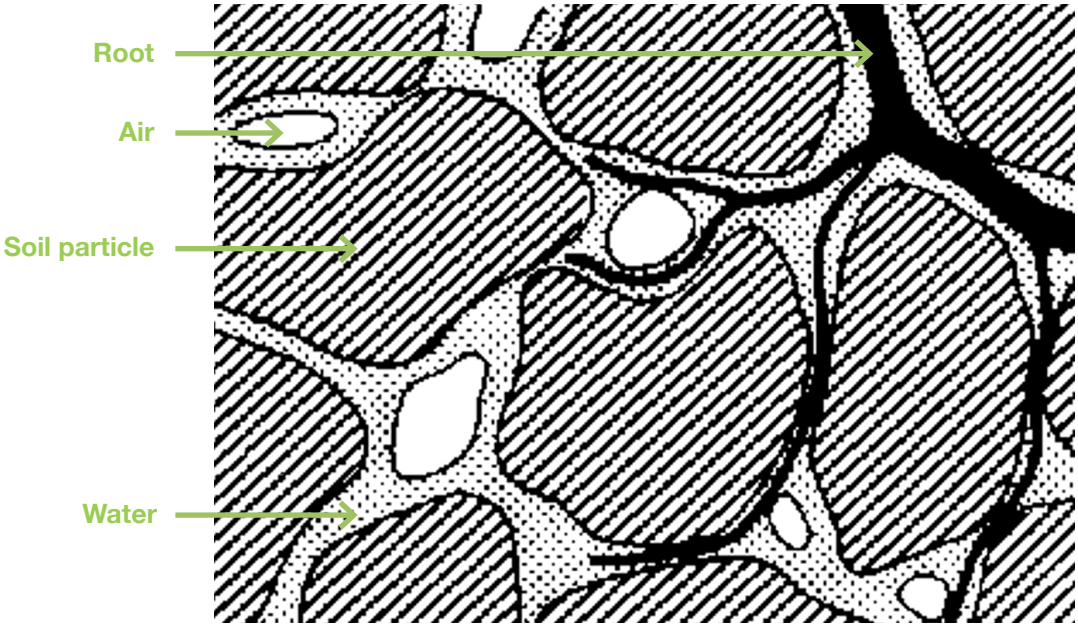
- The spaces between the solid soil particles are called the pore space. They contain either air or water
- When the soil is dry the spaces are filled with air but after rainfall they are mostly filled with water

Air (gases)

- Soil air is found in the spaces or pores between soil particles
- Soil air is primarily composed of nitrogen, carbon dioxide and oxygen
- Oxygen is a critical element for plant growth as it is important for processes such as respiration and nutrient and water uptake, and affects the activity of microorganisms
- The amount of air in the soil is dependent on the size of the soil particles and the spaces between them, as well as the amount of water held by the soil

Water

- Like the air, the soil water is found in the spaces between soil particles
- The amount of water and how it moves through the soil is dependent on the size of the soil particles and the spaces between them
- Sand does not hold onto water well, so it is free draining. Water is also easily evaporated
- Clay holds onto water strongly, and if the soil is not well structured, it does not drain freely



The composition of soil *(Source: FAO)*

What is the function of soil in promoting the growth of healthy coffee trees?

The functions of soil in promoting plant growth include:

1. Making mineral nutrients (e.g., nitrogen, phosphorus and potassium) available to the roots
2. Holding water in sufficient quantities
3. Containing pores to provide pathways for root growth and the exchange of gases like oxygen and carbon dioxide
4. Supporting microorganisms that promote plant growth
5. Providing sufficient rooting depth for access to water and nutrients, and physical support to enable the roots to anchor the plant

How important is the management of soil health in coffee production?

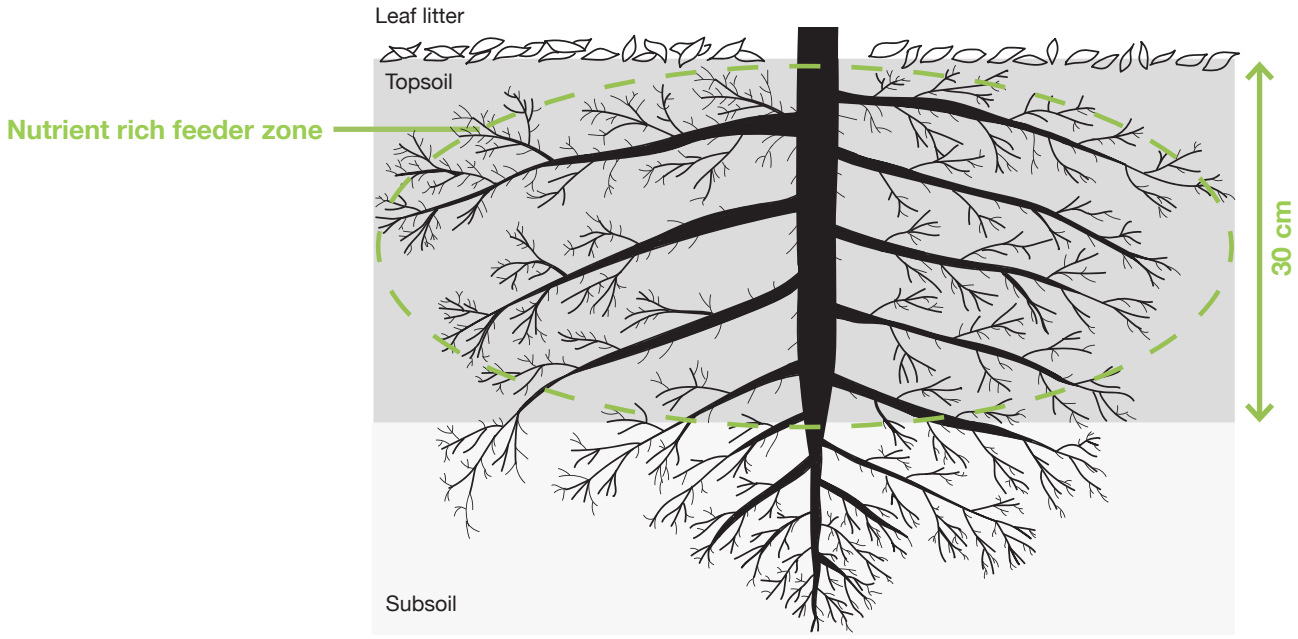
- It is very important to keep the soil healthy as it is the primary system from which the coffee tree lives and absorbs water and critical nutrients
- Farmers can produce healthy coffee trees if soils are well managed. This means having the right balance of organic matter, moisture, sunlight, air, nutrients and vegetative cover to protect and enhance the soil
- Disturbing the balance may stress the system and the coffee trees will become unhealthy and less resilient to attack by pests and diseases. The coffee trees will be less productive and farmers will receive less income

Soil health and CBB

Healthy soils produce coffee trees that are vigorous and productive and more resilient to attack by CBB

Refer to the Farmer Training Guide Unit 2, Module 6 'Coffee berry borer management' for further information

- Soil is a valuable resource that needs to be carefully managed. Maintaining a balanced system preserves soil nutrient stocks, promotes nutrient cycling and protects the soil from being damaged due to waterlogging or erosion
- The topsoil, in particular, needs to be protected and conserved as it has:
  - the best soil structure (ideal structure and composition for seed and seedling establishment)
  - contains most nutrients
  - has the highest level of microbial activity and root density
- Approximately 80% of the coffee tree roots are in the top 30 cm of soil which usually includes all the topsoil, so it is important that the roots are able to access appropriate amounts of air, water and nutrients from this zone



Coffee tree root system

7.2 WHAT MAKES A SOIL FERTILE?

Activity 1:

Before commencing this section discuss with farmers their knowledge of soil fertility. You might like to pose the following questions to the group to engage them more fully in training. It would also show farmers that you value local knowledge and practices. Ensure that you include women in this exercise because as expert gardeners, they will have much to contribute to this topic.

1. What makes a soil fertile?
2. How do people assess if a soil at a particular location is ready for planting food crops?
3. What soil properties do they look for?
4. What fallow vegetation species or characteristics would indicate a healthy or poor soil?

What is soil fertility?

The fertility of the soil is its capacity to provide nutrients to plants so that they can achieve their potential in terms of growth and yield. Fertile soils have the capacity to produce healthy coffee trees that yield good quality cherry.

What are the characteristics of a healthy fertile soil?

A soil that easily crumbles in the hand indicates that:

- Nutrients, organic matter and air are in good supply
- The soil is permeable to water and holds water well
- The soil does not hamper root growth and activity of soil animals
- Healthy soils are less likely to erode
- They are usually darker in colour because of higher amounts of organic matter and useful iron minerals

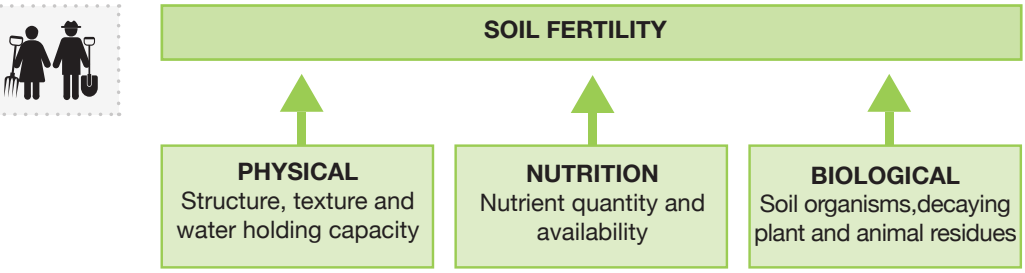
A healthy fertile soil *(Credit: © FAO/Giuseppe Bizzarri)*

What is a healthy soil?

- A healthy soil maintains enough water, air, balanced nutrients, structure, and biological activity so that all life that depends on it is sustained
- This means that soil is not lost to erosion and farm produce does not generate a net loss of nutrients from the soil

Soil properties

Soil fertility is the result of the interactions among the physical, nutrient and biological components of the soil.



Physical properties

The physical properties of a soil include its structure and texture, and its ability to hold water.

Soil structure

- Soil structure is an important property of soils which is governed by the arrangement of the solid particles (minerals and organic matter) and the pore spaces between them (containing either air or water)
- It is a vital property of soils as it influences soil quality and how it functions
- The soil structure:
  - Influences plant growth by affecting the movement of water, air and nutrients to plants
  - Affects how roots penetrate the soil
  - Determines the drainage and water holding capacity of the soil

Soil texture

- Soil texture reflects the proportions and balance of the mineral particles: sand, silt and clay
- Sand particles are the largest of the mineral soil particles. Sand particles cannot be rolled into a ball
- Silt particles are smaller than sand but larger than clay
- Clay particles are the smallest of the soil particles. Soils high in clay can generally hold more water and nutrients. They swell when wet and shrink when dry. When wet, they feel sticky and roll like plasticine

Water holding capacity

- The water holding capacity is the amount of water that a soil can hold and relates to the size of pore spaces
  - Sandy soils often have little or no structure, are often well aerated and free draining and hold little water
  - Sands, silts and clays, when mixed in the right proportions, have high water holding capacity
  - Heavy clay soils can hold large amounts of water but generally drain slowly and can have poor structure
- The drainage of a soil is an important characteristic to assess because coffee trees prefer well-drained soils
- If a soil is poorly drained, sufficient oxygen cannot get to the coffee tree roots which can stunt or kill the tree
- Soils that are too well drained can limit water availability to coffee trees in drier environments or in dry years due to insufficient water and nutrient holding capacity

Nutrition

- The nutrient properties refer to the **amount of nutrients** in the soil and the **soil's ability to make nutrients available** to plants. The soil's ability to make the nutrients available to plants is determined by the soil's pH and cation exchange capacity
- The **pH** is a measure of the acidity (pH<7) or alkalinity (pH>7) of the soil. Most tropical soils are neutral (pH7) to slightly acidic, e.g. pH 5.5
- The **Cation Exchange Capacity** (CEC) is the soil's ability to hold and release important nutrients to plants. This capacity is governed by the soil mineralogy (clay content), organic matter content, and pH
- Soils with a higher clay and organic matter content tend to have a higher CEC. These soils have greater ability to hold onto nutrients. Soils containing a lot of sand can hold few nutrients

Biological properties

Soil biology includes all living and non-living plants and animals present in the soil.

Although the soil biological matter generally makes up a very small proportion of the soil it has a great influence on soil properties and the processes that occur in the soil.

Living components

- Many living organisms are found in healthy soil. They range in size from large earthworms and ants to very small organisms such as, bacteria, fungi and algae
- Soil organisms are a very important component of the soil, and their presence is encouraged by high organic matter levels, adequate soil moisture, and good drainage and aeration
- Soil organisms help to break down organic matter releasing nutrients into the soil
- Many organisms fix nitrogen, an important plant nutrient, converting it to a form that is usable by plants

- The burrowing habit of larger organisms, such as worms, ants and termites, draws litter and other plant material from the surface into the soil, and incorporates the organic matter into the soil. These organisms create large pore spaces that aerate the soil and improve water infiltration and drainage. They also mix the soil
- The smaller organisms, such as bacteria, fungi and algae, further decompose the organic matter, which releases nutrients in a form that plants can use
- Some fungi and bacteria can only live in association with roots and rely on the plant as a host. In turn, the plants rely on them to break down organic matter to deliver particular nutrients
- Soil organisms bind soil particles together thereby improving soil structure
- Soil organisms are usually most active in the surface soil (top 0–15 cm), because this zone has an accumulation of organic residues and available nutrients
- Having a high diversity of soil organisms creates competition between them and limits the numbers of any one group thereby making a healthy microbial population. This increases the capacity of the soil to suppress pests and diseases

Non-living organic components

- These include dead or decaying plant and animal residues such as manure
- They improve soil structure and increase the nutrient and water holding capacity of the soil
- They provide a food supply and nutrients for the living components of the soil
- Humus, which is what is remaining once all the plant and animal material has fully broken down, has a high capacity to hold onto nutrients and water. It is important for maintaining a loose, friable soil structure
- The rate of decomposition of organic matter depends on how favourable the soil environment is for microbial activity. Higher decomposition rates occur where there are:
  - warm, moist conditions
  - good aeration
  - a favourable ratio of nutrients
  - a pH near neutral (pH7)

Management of soil properties

- It is important for farmers to focus on the management of the **three** properties (physical, nutrient and biological) of soils to ensure that their coffee trees are healthy, highly productive and resilient to attack by pests and diseases
- While some soils are naturally more fertile than others, some characteristics of soils can be improved with good management
- Adding organic matter to improve soil structure and nutrient availability, and preventing erosion and waterlogging will assist in maintaining or improving soil fertility in the coffee garden

Objective:

To understand what makes a soil fertile and how different levels of soil fertility can be identified

You will need:

A minimum of three soil samples of varying levels of fertility:

1. **Sandy, light-coloured**
2. **Loamy brown**
3. **Clay, red/black/ brown**

(If possible, Include samples of typical coffee growing soils)

EXERCISE 1

Levels of soil fertility

Ask the group to observe the samples and then:

1. Discuss the characteristics that make a soil fertile
2. Ask them to describe the soil samples
3. Discuss with them the characteristics that may affect the fertility of the samples

Give the participants some soil from the samples (noting which sample you have given them). Ask them to roll it into a ball.

1. Determine whether the soil is sandy or high in clay
   - If the soil is sandy, it will be gritty and the ball will fall apart
   - If high in clay it will be sticky and roll like plasticine
2. How much organic matter is in the soil?
   - If high in organic matter a dark stain will be left on their hands

Objective:

To understand the level of fertility of soils in the local area and how they are classified by farmers

EXERCISE 2

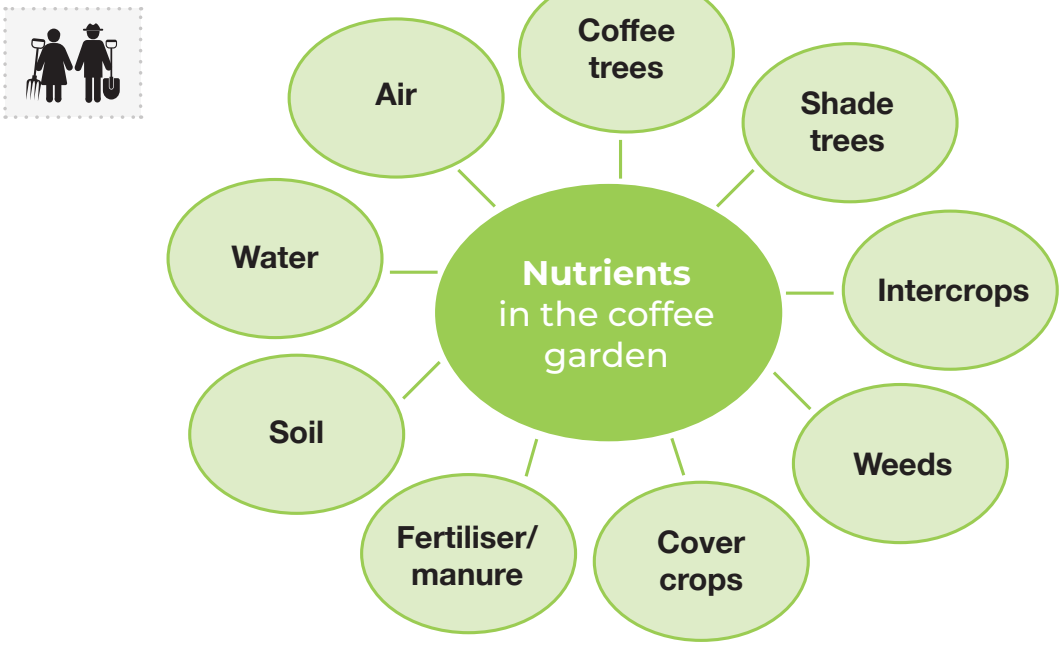
Soils in the local area

Discuss with the group:

1. The types of soils in the local area. How do farmers classify them?
2. Do any of the soil samples from Exercise 1 resemble any of the farmers' own soils?
3. What is the level of fertility of the different soils in the area?
4. Do farmers feel their own soils are adequately fertile for growing coffee? Why?

7.3 NUTRIENTS IN THE COFFEE PRODUCTION SYSTEM

The nutrient balance in a coffee garden is complex. Nutrients are contained within all plants growing in the coffee garden (including the coffee trees, shade trees, weeds and any cover crops or intercrops) and in the soil, water and air. Nutrients enter the system from the atmosphere, from surface organic matter, and from fertilisers, if applied. Nutrients leave the garden: in coffee cherry and wood (for firewood or construction); are leached deep into the soil and so beyond the reach of roots where they may enter waterways; are lost through erosion; or are lost into the air as gases.



Components of the nutrient pool in the coffee garden production system.

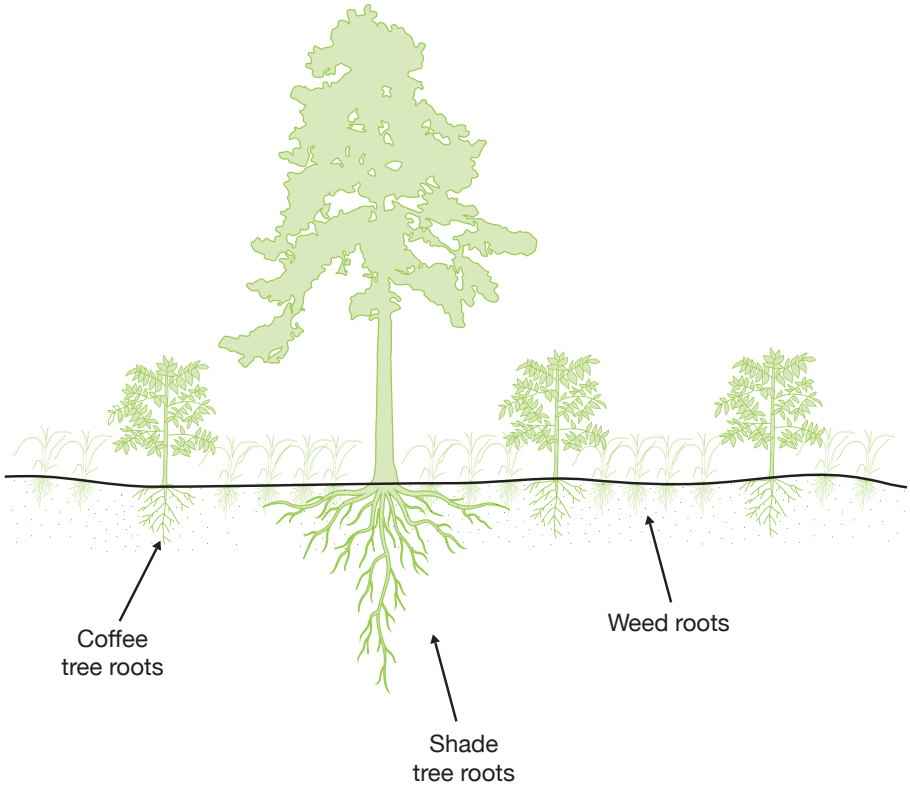
Plants in the coffee garden

Nutrients are contained within the roots, stems, leaves, branches and fruit of all plants growing in the coffee garden.

Below ground

Roots

- Roots contain valuable nutrients, and their continuous cycle of growth and dieback contributes to the cycling of nutrients in the soil
- Living roots also release chemicals that assist in the breakdown of organic matter in the soil, often in association with microorganisms



Some examples of roots present in the soil in a coffee garden.

Above ground

Stems, leaves and branches

- Nutrients accumulate in the stems, leaves and branches and are required for plant growth and fruit production
- Leaf litter regularly falls from all plants, whether they be large or small, and as it decomposes it releases nutrients back into the soil

Leaf litter from a Casuarina shade tree. Nutrients will be released back into the soil as it decomposes.

Fruit/seeds

- Plant fruits and seeds contain nutrients, often in high quantities. If the fruit and seeds remain in the coffee garden they will also decompose and release nutrients back into the soil

Impacts of plants on nutrients in the coffee garden

Coffee trees

- Coffee cherries are rich in nutrients and at harvest these nutrients are removed from the coffee garden. Some nutrients may be returned after processing *(see Section 7.5 for further detail)*

Shade trees

- Shade trees have deep root systems which enables them to access nutrients deep in the soil. There is little competition with coffee trees for nutrients in the upper soil layer
- Shade trees capable of fixing nitrogen, such as Yar (*Casuarina oligodon*) and Marmar (*Albizia stipulata*), will add nitrogen to the soil which is accessible to the coffee trees

Weeds

- Weeds compete with coffee trees for nutrients as both the weed roots and coffee tree feeder roots grow in the surface layer of the soil
- During their growth period, weeds can take up a considerable amount of nutrients
- These nutrients are still in the coffee garden production system but are no longer available to the coffee trees unless, when removed, they are used as mulch or returned as compost

Cover crops

- Cover crops are planted to cover, protect and improve the soil. They are not harvested for marketing so the nutrients contained within them will not leave the coffee garden
- Cover crops, such as Pinto peanut, capable of fixing nitrogen, will add nitrogen to the soil which is accessible to the coffee trees
- Like weeds, cover crop roots typically occupy the same soil near the surface layer as the coffee trees

Intercrops

- Intercrops such as maize, peanuts or cabbages are generally grown for household food consumption or marketing
- Their root systems occupy the same soil layer as the coffee trees and may compete with them for nutrients, water and light
- Nutrients contained in seeds, fruits, leaves or stems of intercrops that are removed from intercrops when harvested will be lost from the coffee garden
- As for cover crops, intercrops capable of fixing nitrogen, such as peanuts, will add nitrogen to the soil which is accessible to the coffee trees

Fertiliser

- Applications of either mineral or organic fertilisers like animal manure to intercrops or coffee will add nutrients to the coffee production system

Soil

- Soil contains nutrients derived from the original parent material which is commonly volcanic ash in coffee growing areas in PNG
- The soil also contains nutrients derived from decomposing plant and animal material and from soil microbial activity

Water

- Water in the spaces in the soil contains dissolved nutrients important for plant growth
- Plants can access these nutrients via their roots
- Nutrients in soil water may be lost through leaching which is where the soil water washes deep down into the soil below the plant roots and may eventually pass into waterways

Air

- Plants take carbon dioxide from the air into their leaves to make their own food via the process of photosynthesis
- A large proportion of air (almost 80%) is nitrogen gas. Nitrogen plays a key role in plant growth and development. Plants can only access nitrogen from the air if it is fixed or broken down by microorganisms in the soil. Some plants, such as legumes, can obtain additional nitrogen through their partnership with certain nitrogen fixing bacteria that colonise their roots

Objective:

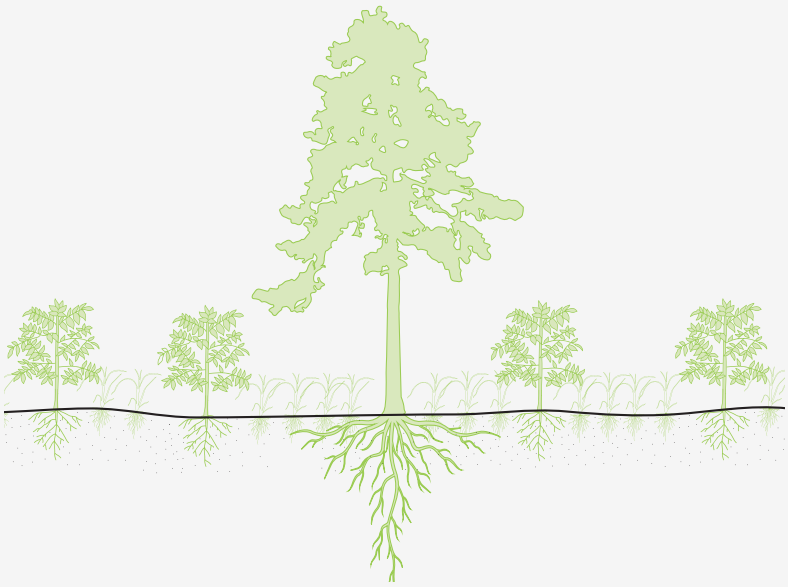
To identify the nutrients present in farmers' coffee gardens

You will need:

Butchers' paper and coloured marker pens

EXERCISE 3

Nutrients present in coffee gardens



Using coloured marker pens, add the sources of nutrients to the diagram while having the following discussion:

Discuss:

1. The sources of nutrients that farmers have in their own coffee gardens
2. What is growing in their coffee gardens in addition to coffee?
3. Do any farmers grow cover crops or intercrop with vegetable crops? Which ones?
4. Do farmers have any animals foraging in their coffee gardens?
5. Do they apply fertilisers to their coffee trees or intercrops?
6. Is the garden on a slope, and what might this mean in terms of nutrient losses?

7.4 COFFEE TREE SOIL NUTRIENT REQUIREMENTS AND DEFICIENCIES

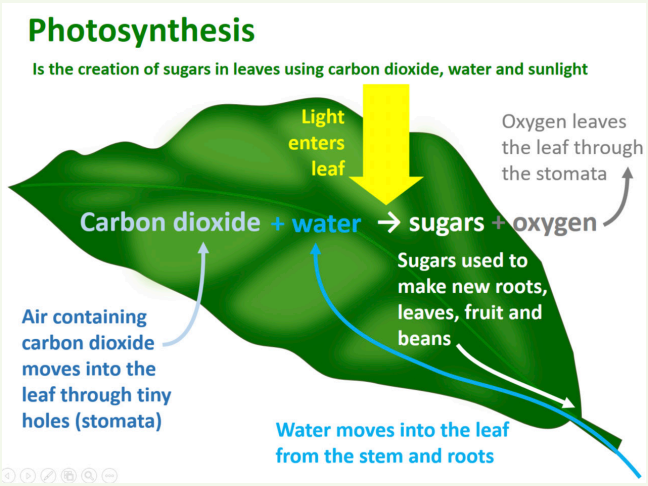
Coffee trees require many nutrients for healthy growth and fruit production and the soil is the source from which most nutrients are obtained. **All these nutrients are important** but are required by plants in different amounts.

Plant nutrients obtained from the soil and their functions

- Nutrients are referred to as either macronutrients or micronutrients. Macronutrients are required in large amounts, micronutrients in small amounts
- The nutrients required by plants in the greatest amounts are nitrogen (N), phosphorus (P) and potassium (K). Often these three nutrients are packaged and sold together as NPK
- Other important macronutrients are calcium, magnesium and sulphur
- Plants also need small quantities of iron, boron, manganese, zinc, copper and molybdenum. These are known as micronutrients or trace elements because only very small amounts are needed by plants. However, they are just as important for growth and fruit production as the macronutrients, so deficiencies can have a negative effect on the coffee trees
- It is important to realise that the **balance of nutrients** or the nutrient ratio is just as important as the amount of nutrients available to the coffee trees as too much of one nutrient may create a deficiency of another. When in excess they can reduce plant growth or even be toxic

Nutrients required by coffee trees and their function

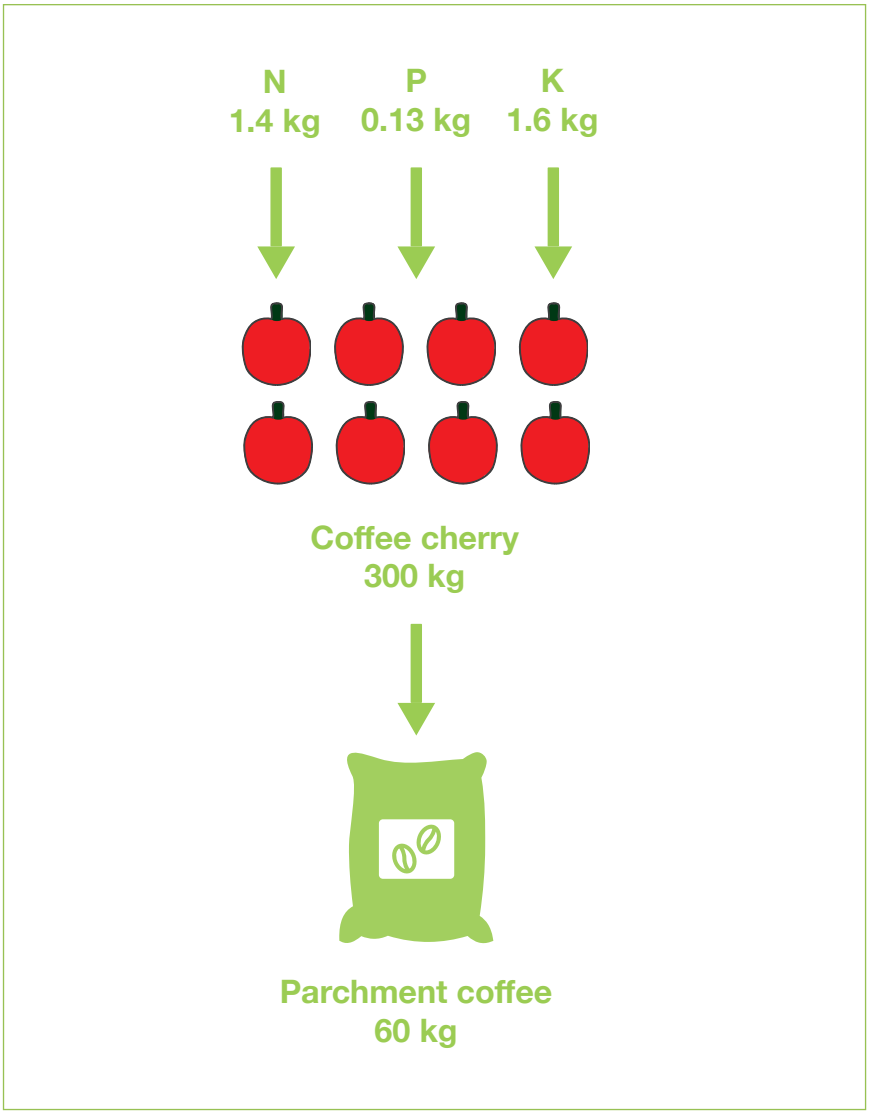
Category	Nutrient	How it is used by plants
Macronutrients	Nitrogen (N)	Plant growth, protein, enzymes, hormones, photosynthesis
	Phosphorus (P)	Energy, root development, ripening, flowering
	Potassium (K)	Fruit quality, water balance, disease resistance
	Calcium (Ca)	Cell walls, root and leaf development, fruit ripening and quality
	Magnesium (Mg)	Photosynthesis, seed germination
	Sulphur (S)	Amino acids and proteins, photosynthesis, disease resistance, seed production
Micronutrients	Iron (Fe)	Photosynthesis
	Boron (B)	Development and growth of new shoots and roots, flowering, fruit set and development
	Manganese (Mn)	Photosynthesis, enzymes
	Zinc (Zn)	Hormones, enzymes, plant height
	Copper (Cu)	Photosynthesis, protein formation
	Molybdenum (Mo)	Nitrogen metabolism

Some important plant chemicals and processes	
Hormones	Plant hormones are chemical signals that control all aspects of plant growth and development, and responses to the environment (e.g., seed germination, growth stimulation, fruit ripening, water loss)
Proteins, amino acids and enzymes	Chemicals that form part of the plant structure and are involved in plant functions such as photosynthesis, storage and transport of nutrients
Photosynthesis	Plant leaves act like solar panels to capture light energy from the sun and use it to convert carbon dioxide and water into food and energy for the plant  *(Credit: Paul Nelson)*
Nitrogen metabolism	1. Conversion of nitrogen in the air to a form usable by plants 2. Releasing nitrogen from organic matter in the soil which can then be used by plants 3. Incorporating usable nitrogen into plants so that it can be used for plant structure and function

Soil nutrient requirements of coffee trees and indicators of deficiencies

The following is an example of the nutrient requirements of coffee trees to be productive:

- To sell a 60 kg bag of parchment coffee a farmer will need to produce approximately 300 kg of fresh cherry. This amount of cherry contains on average:
  - 1.4 kg nitrogen (N)
  - 0.13 kg phosphorus (P)
  - 1.6 kg potassium (K)



(For more detail see Section 7.5)

- These quantities are only those that are required to produce parchment. The plant also needs nutrients from the soil to support overall plant growth and maintenance, and to become more resilient to pests and diseases, and tolerant of moderate changes in weather
- It is important to give a lot of consideration to the nutrient requirements of the coffee garden so that coffee trees are healthy and productive

Nitrogen (N)

- Of the nutrients required by plants, nitrogen is the one required in the largest quantity
- Nitrogen is removed from coffee gardens in cherries when they are harvested, when nitrogen is leached deeper into the soil, and when lost to the atmosphere
- In addition to the nitrogen removed by harvesting cherry, the coffee trees require a lot of nitrogen to sustain healthy tree growth
- Sufficient nitrogen in a plant produces healthy, dark green leaves. A deficiency can present as pale or yellow leaves
- Adequate soil nitrogen can be maintained if certain management strategies are followed *(see Section 7.5)*

Phosphorus (P)

- In most instances, coffee trees are able to extract sufficient phosphorus even from soils low in phosphorus
- The decomposition of organic matter supplies the bulk of the phosphorus requirement

Potassium (K)

- Many coffee growing areas have soils deficient in potassium, which is inherited from the low amounts often found in the volcanic ash from which the soils are formed
- Potassium deficiency presents itself initially as yellowing bands along the leaf margins of older leaves with brown spots developing along the margins as symptoms advance. Younger leaves are usually unaffected
- A lot of potassium is contained within the cherries. After pulping, half of this potassium can be returned to the coffee garden if the skin, pulp and mucilage is used as mulch *(see Section 7.5 for further information)*

Calcium (Ca)

- Soil calcium is mostly in the optimal range in highland coffee growing areas. The ratio of Ca to K is often high, however, which limits the availability of K

Magnesium (Mg)

- Like calcium, magnesium is also mostly in the optimal range. Mg to K ratios are also often high limiting the availability of K

Boron (B)

- Boron deficiency is common in Arabica growing areas in the highlands and appears in both coffee and food gardens
- In coffee, boron deficiency causes poor cherry formation
- Dieback of the top of the tree and crinkled leaves towards the end of a dry period and at the start of the rainy season are often the first signs that the coffee tree is suffering from boron deficiency

- High demanding periods for boron are after harvest, flowering, fruit formation, and fruit growth
- Boron is cheap and simple to apply and application can result in dramatic yield increases. **Care must be taken in its application as there is a narrow range between boron deficiency and toxicity**
- Borax is the cheapest form of boron fertiliser. It is sparingly soluble and therefore less likely to be lost via leaching. Boron in the form of boric acid is very soluble and will leach
- Casuarina (Yar) and other shade trees are also susceptible to boron deficiency so they may also require an application of boron fertiliser

Suspected boron deficiency in cabbage (left) and orange (right)

Zinc (Zn)

- Zinc deficiency occurs in Arabica coffee throughout the highlands and is usually more severe in unshaded coffee
- Zinc deficiency can be corrected using foliar applications of zinc fertiliser such as zinc sulphate

Iron (Fe)

- Slight symptoms of iron deficiency in Arabica coffee are common throughout the highlands, particularly on pruned trees
- The deficiency of iron is not a serious problem in Arabica coffee and no corrective measures are necessary

Nutritional stress

- Dieback from nutritional stress lowers energy availability for the coffee tree and makes it more susceptible to leaf diseases. Yield falls proportionally to the level of stress
- It is important to monitor the nutrient status of your coffee trees and keep the soil healthy to maximise coffee tree productivity

Monitoring for nutrient deficiencies

Symptoms of nutrient deficiency

While there is a large array of symptoms associated with soil nutrient deficiency, each of which is connected to particular minerals (e.g., N, P or K), the following symptoms are tell-tale signs the soil is lacking nutrients more generally;

In young trees

- Leaves bronzed along edges and/or cupped downward
- New leaves are dead

In mature trees

- Uniform yellowing over the whole tree or light yellowing between the leaf veins
- Localised dead tissue or yellowing between the veins on older leaves

Various nutrient deficiency symptoms may become apparent in the coffee garden. The next section of the module describes how to optimise the supply and availability of nutrients to the coffee trees. However, before jumping to the conclusion that there is a nutrient deficiency in a coffee garden, check that other factors are not the cause of unhealthy-looking coffee trees. Some common reasons for unhealthy looking coffee trees are:

- Inadequate drainage (waterlogged soils)
- Competition from weeds
- Too little or too much shade cover
- Poor planting (e.g., too high a planting density, or badly prepared planting holes)
- Attack by a pest or disease

Plant Health Troubleshooting Guide

- Give all participants a copy of the ‘Plant Health Troubleshooting Guide’
- Show farmers how to use the Guide. Use examples to explain how symptoms of a nutrient deficiency may be confused with those caused by the impact of a pest or disease

Objective:

To understand what soil nutrient deficiencies may be present in the local area

EXERCISE 4

Soil nutrient deficiencies in the local area

Discuss with the group:

1. Are farmers aware of any nutrient deficiencies in their own coffee gardens?
2. How do they recognise different nutrient deficiencies?
3. What strategies do the farmers use to correct nutrient deficiencies? Do any of the farmers use inorganic fertilisers to correct nutrient deficiencies?

Farmer management strategies

- Farmers often use management strategies based on local knowledge. These strategies may be very effective, yet extension officers may not be aware of them
- By this point in the module you, as the extension officer, should have some knowledge of the strategies farmers use in soil nutrient management (see Activity 1). Strategies that are effective can be incorporated into or supplement the methods recommended in the next section of the module
- Farmers may suggest additional strategies while progressing through the next section. It is important that their strategies are given credence
- Record effective local strategies so that they can be incorporated into future training sessions (and updates to this module)

7.5 HOW TO MANAGE SOILS SO THEY PROVIDE ADEQUATE NUTRITION FOR YOUR COFFEE TREES

Activity 2

Have a discussion with farmers about soil management strategies

- What do farmers consider to be the key soil management strategies in making coffee trees healthy?
- Do farmers have the capacity to implement these strategies (e.g., time, labour, other inputs)?

What are the key factors in soil management that facilitate good coffee tree health?

The key strategies in achieving good coffee tree health are to optimise:

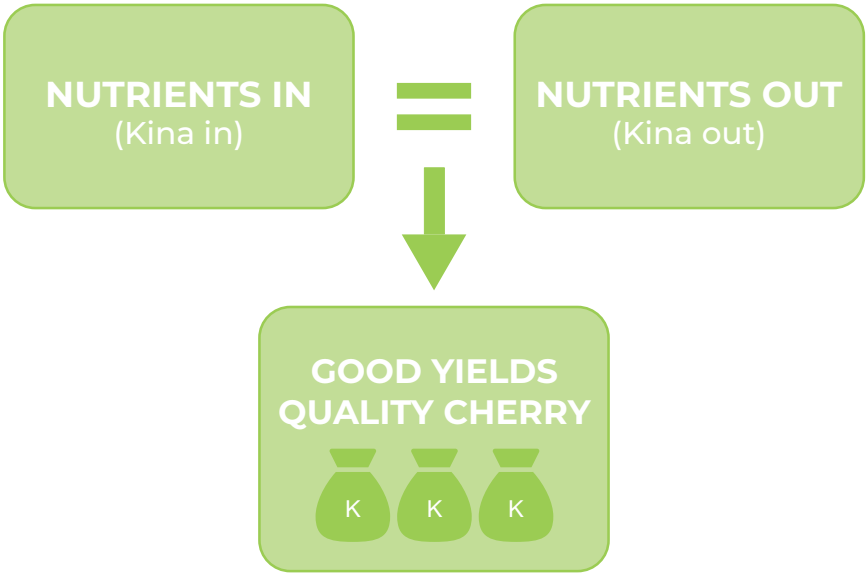
1. The **amount** of nutrients in the soil required by the coffee trees
2. The **availability** of the nutrients to the coffee trees

This is achieved by maximising nutrient cycling which is a primary process determining the level of soil **organic matter content**. Nutrient cycling is the use, movement, and recycling of nutrients. If nutrient cycling is maximised, then coffee tree health will be improved. Increasing organic matter to optimum levels in the soil will:

- Increase the diversity and activity of soil organisms
- Increase the amount of organic carbon or the solid component of the soil
- Improve the soil's ability to hold nutrients and make them available to plants, i.e., the cation exchange capacity (discussed in Section 7.2)
- Regulate soil temperature and prevent extreme temperature fluctuations which may have negative impacts on the coffee trees and soil organisms
- Improve root health
- Improve water infiltration, water holding capacity and drainage

Optimising nutrient supply and availability

- **Nutrient budget.** Managing nutrients in the soil is like managing a household budget. Farmers have to consider what nutrients (or money) come into the system and what nutrients (or money) leave the system. The aim is to try and balance these incomings and outgoings so that soil health and nutrient levels are sufficiently maintained to enable ongoing good yields of quality coffee cherry



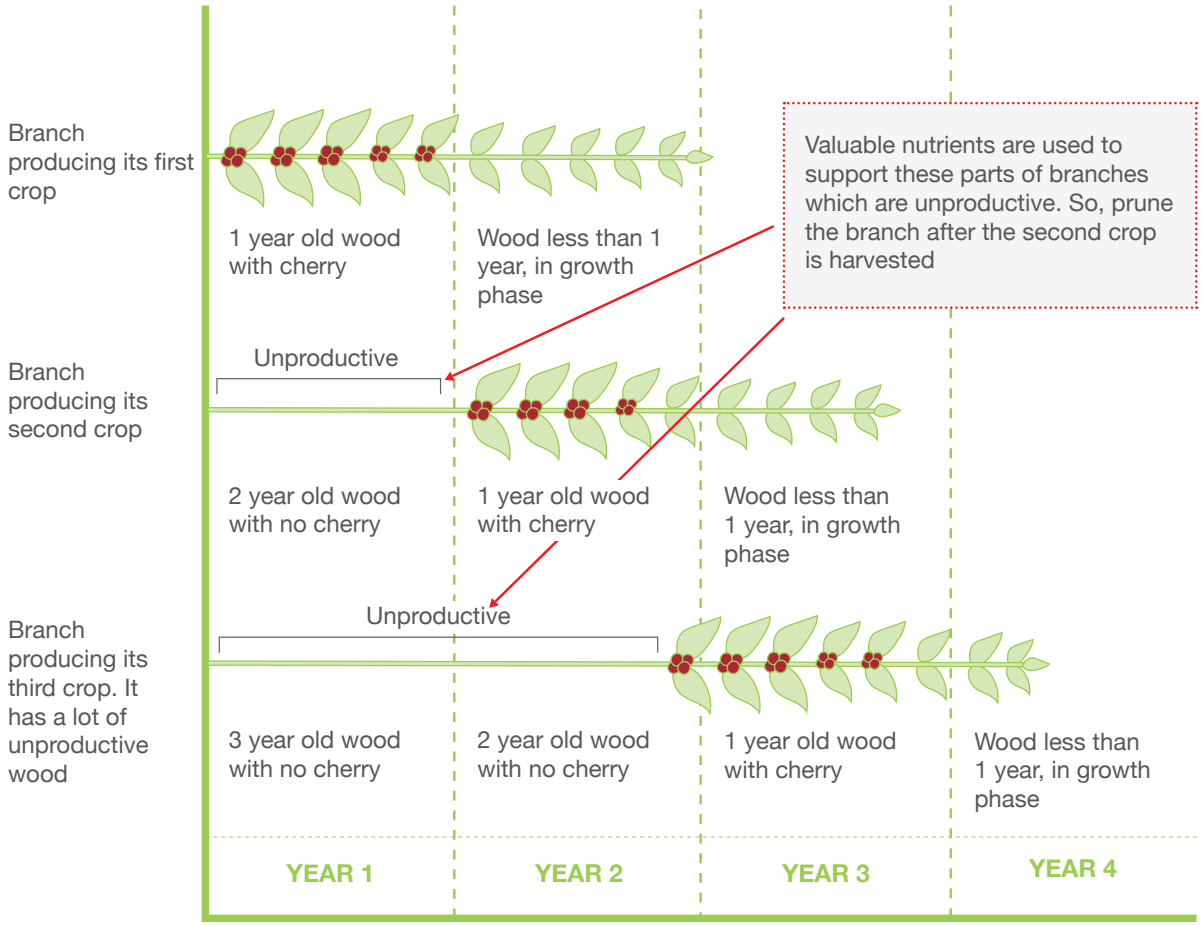
Balancing the nutrient budget

- Certain management strategies can be applied in the coffee garden to maximise nutrient cycling and increase soil organic matter. These can be applied to the coffee trees, shade trees and weeds, and any cover crops or intercrops that may be growing in the coffee garden
- It is also important to keep the root system healthy so that the coffee trees can be supplied with, and access, sufficient nutrients. The ability of the roots to access nutrients is limited by soil depth, soil structure, soil moisture and organic matter content, soil organism activity, the soil nutrient status, and drainage
- Coffee trees growing in an unhealthy soil environment with restricted root growth will have shallower root systems. When growing in a smaller volume of soil the roots will have reduced access to water and nutrients, and will be less effective in providing secure anchorage for the coffee trees

Using coffee tree by-products

Stems, branches and leaves

- When leaf litter from the coffee trees decomposes it returns nutrients to the soil, so it is important to leave the litter under the coffee trees as mulch. Do not pile and burn litter or remove it from the coffee garden
- Where possible, after maintenance or recycle pruning, leave the pruning debris in the coffee garden to decompose so that the nutrients contained in them are retained in the coffee garden
- Because cherry is only produced on new wood it is best to prune the primary branches after they have produced **two crops**. If the branches are not pruned, valuable nutrients are wasted supporting the inner unproductive sections of the branch



Stages of development of primary branches *(Adapted from Lambot and Bouharmont, 2004)*

Do not burn leaf litter and pruning debris

Do not burn leaf litter or pruned branches as you will lose **valuable nutrients.**

An exception for burning may be if you are using it as a method to control diseases, or pests such as CBB

Pruning and CBB

- Before pruning, it is important to strip pick **all** berries from the coffee trees. Removing the berries removes habitat for CBB and breaks its life cycle
- Berries heavily infested with CBB must be destroyed either by burning, burial or solarisation

(Solarisation: place berries in **sealed** black plastic bags or garbage bins and leave in the sun for several weeks)

(See the Farmer Training Guide, Unit 2, Module 6 'Coffee berry borer management' for further information)

Coffee cherry

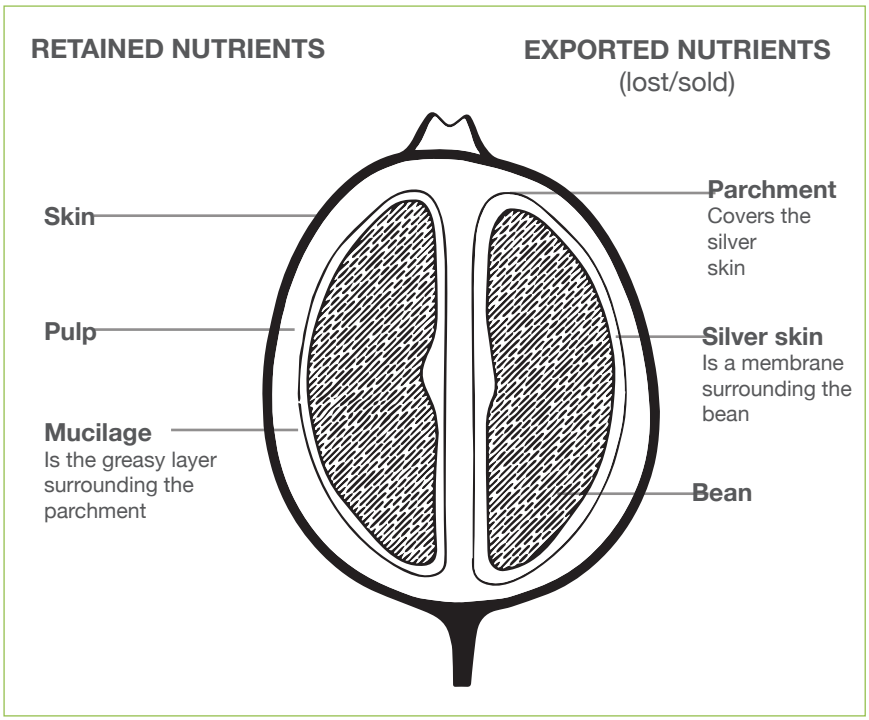
A lot of nutrients are exported from the coffee garden when cherry is harvested.

Selling fresh cherry

- The sale of fresh cherry means that all nutrients contained in the cherries are taken away from the garden and **permanently lost**

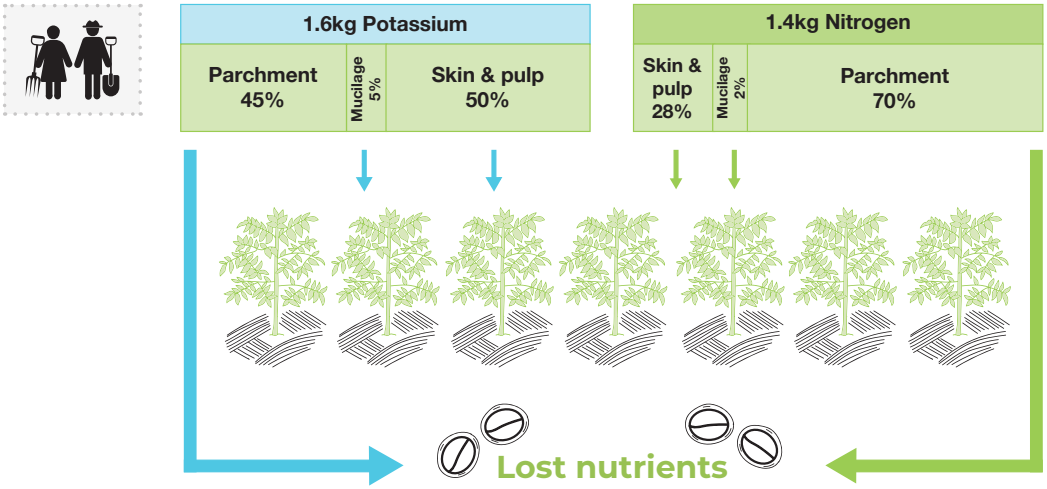
Selling parchment

- While some nutrients are permanently lost from the coffee garden when cherry is processed and sold as parchment coffee, those in the pulp, skin and mucilage can be retained
- During on-farm processing of cherry, the **skin**, **pulp** and **mucilage** are removed. The skin, pulp and mucilage make up 40% of the weight of the cherry. The nutrients contained within these components are retained by the farmer and so can be recycled by returning them to the coffee garden or food gardens in the form of mulch
- The **parchment**, **silver skin** and **beans** are sold. These nutrients are **permanently exported or lost** from the coffee garden



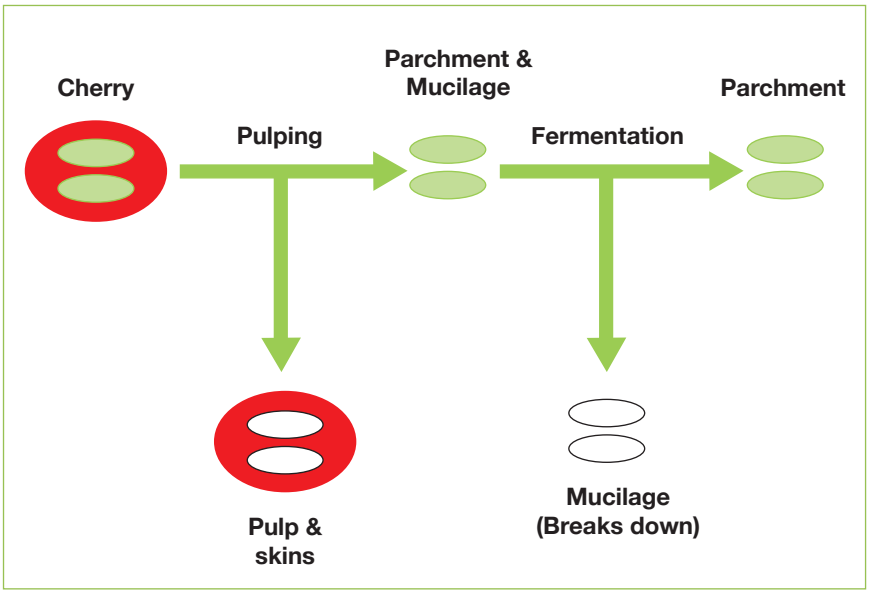
Parts of a coffee cherry retained and exported after on-farm processing.

- Of the 1.6 kg of potassium and 1.4 kg of nitrogen used to produce a 60 kg bag of parchment coffee *(see Section 7.4)* over half of the potassium and almost one third of the nitrogen is contained in the pulp, skin and mucilage
- The pulp and skin also contain the greatest concentration of boron



Nitrogen and Potassium in 300 kg of coffee cherry
(equivalent to 60 kg of parchment)

- During the first stage of processing cherry (pulping), nutrients are retained in the pulp and skins; some are still present in the mucilage and parchment. Further processing (fermenting) will release a small amount of nutrients in the mucilage

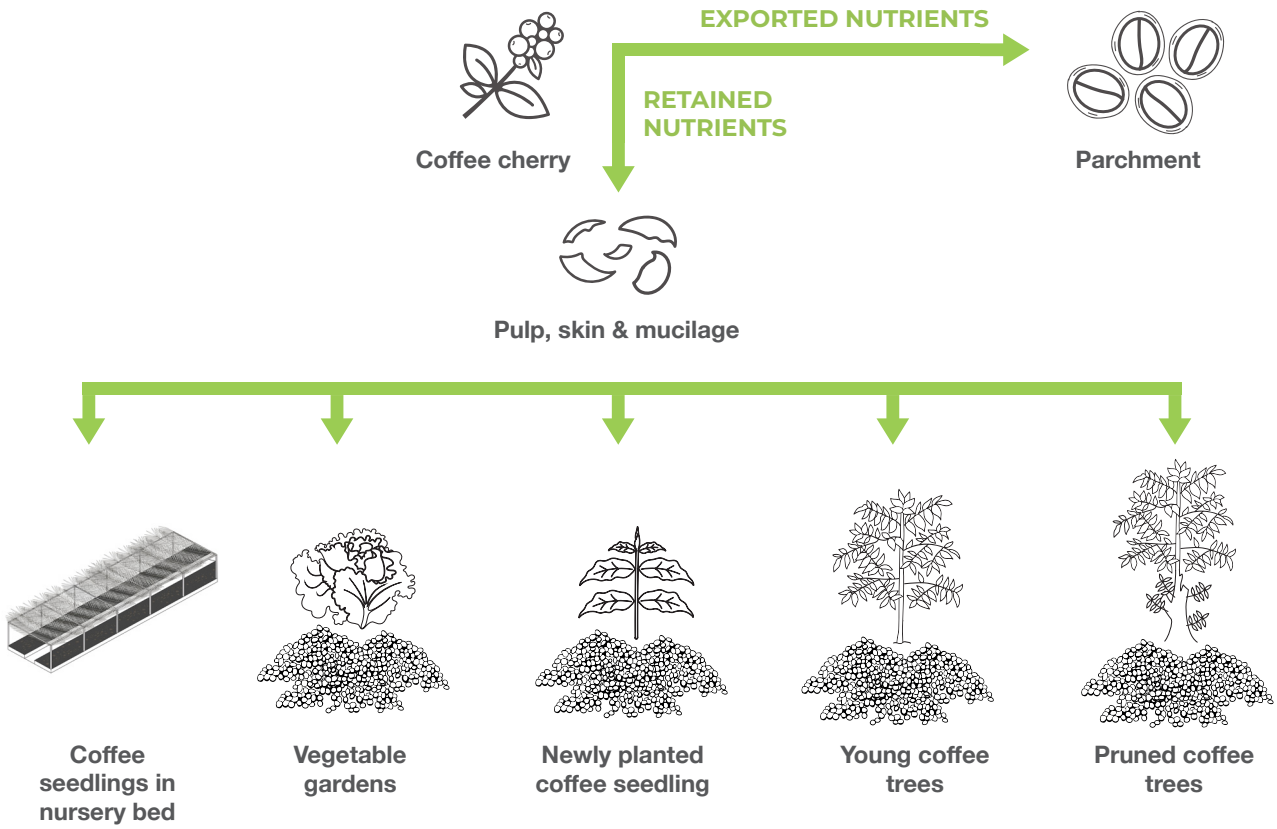


Nutrient distribution during preparation of parchment *(Source: Mike Webb)*

- Nutrients contained in the mucilage are also lost during fermentation and washing. The wastewater from washing off the fermented mucilage could be returned to the coffee garden or used on food crops if processing is done in the coffee or food garden
- If a mechanical demucilager or ecopulper (mini wet mill) is used, the skins, pulp and mucilage are all removed in a single process. They can all be retained and returned to the coffee garden

Returning skin, pulp and mucilage to the coffee garden

- The valuable nutrients exported from the coffee garden in the skin, pulp and mucilage can be returned to the garden and used as mulch. The mulch contributes to the soil organic matter and replenishes the soil with some of the nutrients that had been removed in the cherry
- The mulch can also be used on food gardens or in the coffee seedling nursery
- As the pulp begins to decompose, valuable nutrients will be leached into the soil, therefore, the pulp should be applied **promptly** to the coffee garden (or to land prepared for food crops) after processing is complete



Coffee pulp spread around the base of a coffee tree.

Pulping cherry in the coffee garden or food garden

When pulping coffee cherry, the pulp is often left at the pulper site or thrown into waterways which is a waste of valuable nutrients. Most often this is due to the considerable labour involved in moving it from the pulping station and spreading it. If possible, pulp cherry in a coffee or food garden so the pulp can be easily applied in the garden.

Cherry pulp containing valuable nutrients is often left at the pulping station.

Composting cherry pulp

- Because the pulp is bulky it may be difficult for some farmers to apply. The pulp can be left to compost which will make it lighter and more manageable
- The risk of composting is that nutrients may be lost via leaching into the soil
- Pulp can be composted by heaping it (on a tarpaulin if possible, or banana leaves) and then turning and mixing it every three to four days. Turning the compost aerates it and speeds up the composting process
- The heap should be covered to retain the heat, but some air must also be able to escape. Cover the heap with banana leaves, hessian sacks or plastic sheets with a few 2 cm wide holes pierced through them
- The pulp could be protected from direct rainfall by constructing a simple, low roof over the heap
- The heap may require watering if it gets too dry
- If managed correctly composting should be completed in about 3-4 weeks. It can then be spread around the coffee garden or food gardens

Shade trees

- If coffee is not shaded, excessive light stimulates heavy flowering and high cherry production. High cherry production places high demands on soil nutrients. Unless supplemented with fertilisers, most soils cannot provide sufficient nutrients for the coffee trees resulting in heavy swings in biennial production and overbearing dieback. Shade reduces light and in turn reduces flowering
- When coffee trees are planted at **low to medium density**, with the right **level of shade** and the right **type of shade** tree, the need for farmers to buy expensive fertilisers to replace nutrients lost in harvested cherry is reduced

Dieback and unshaded coffee

Dieback is more common in unshaded coffee where the high nutrient demands of the coffee trees cannot be met by the soil unless there are regular applications of inorganic fertilisers

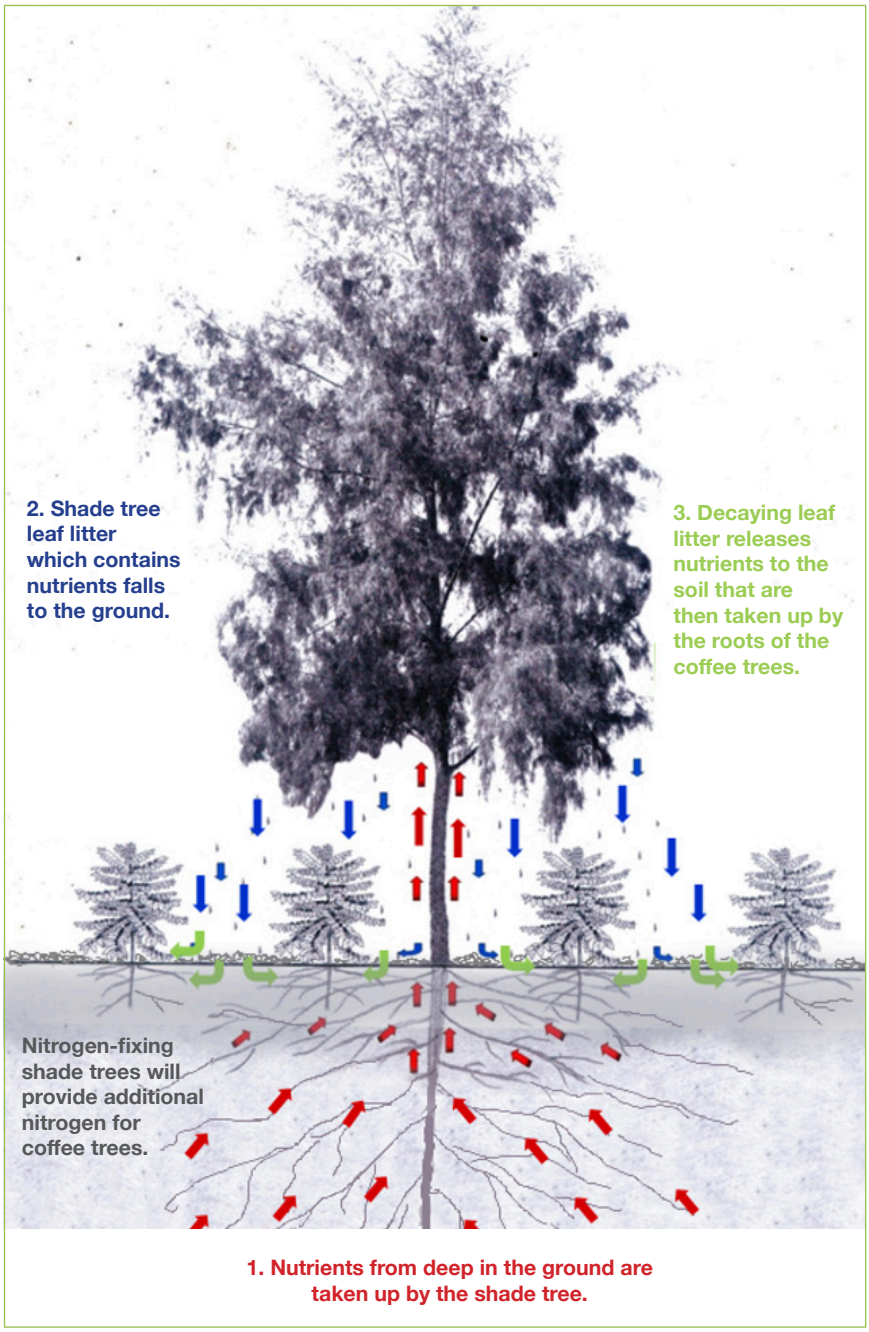
- Shade trees are very important for increasing nutrient availability to the coffee trees
- It is important to plant suitable shade trees in the coffee garden at the appropriate density so that they provide approximately 30% shade; they must also be kept well maintained
- Any shade trees removed for firewood should be replaced as the nutrients in the wood will be permanently lost from the coffee garden. Coffee trees that become unshaded will have high nutrient demands due to excessive flowering

Nutrient cycling by shade trees

- Shade tree roots **'pump' nutrients** up from below the roots of the coffee trees and make them available to the coffee trees via leaf litter. This function is particularly important during periods of heavy rain when nutrients are leached deep down into the soil, well below where the coffee trees can access them
- Shade trees such as Yar *(Casuarina oligodon)* produce a deep litter layer. As the leaf litter breaks down it provides the coffee trees with **nutrients**, like a slow release fertiliser

Nitrogen fixation

- Some shade trees like Yar and Marmar **add nitrogen** to the soil through the process of nitrogen fixation. With the help of soil microbes they take nitrogen from the air and convert it into a form that can be taken up by the coffee trees



Nutrient cycling in a coffee garden with shade trees

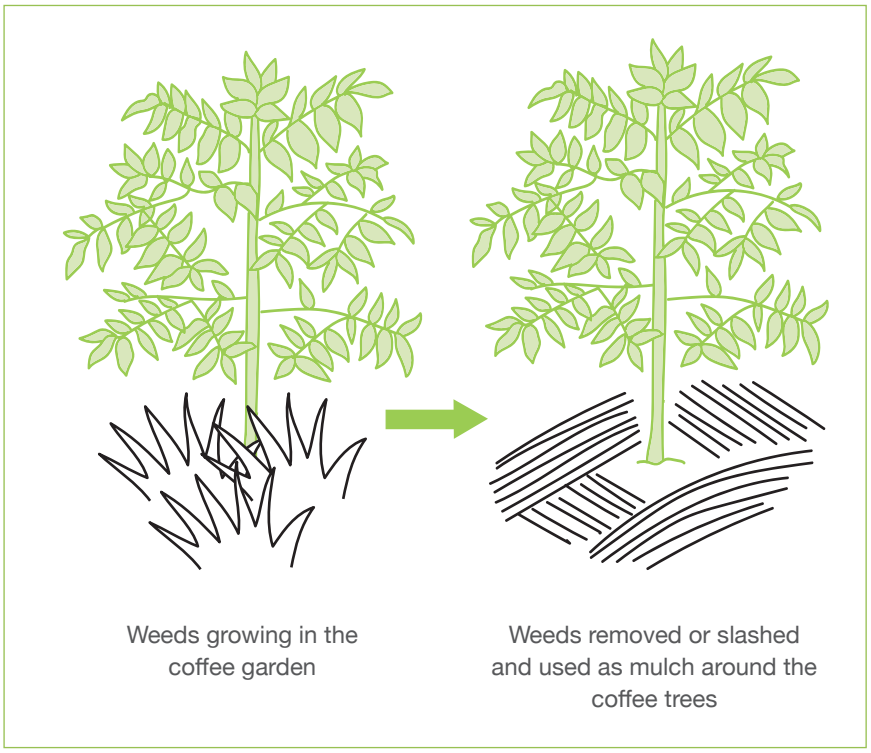
Nutrient availability

- Shade trees reduce the **rate of breakdown of organic matter** in the soil making nutrients available to the coffee trees for longer
- Leaf litter from shade trees improves the **entry of water and nutrients** into the soil making these more accessible to the coffee trees
- Deep litter improves the soil's water and **nutrient retention** properties. It also encourages **soil microbial activity** making nutrients more available to coffee roots
- As for the coffee trees, when the shade trees are pruned it is better if the debris is retained in the coffee garden

Deep litter from Yar trees

Weeds

- Nutrients taken up by weeds can be recycled by removing the weeds and using the weed debris as mulch around the coffee trees. As the mulch decomposes the nutrients contained within it will be made available to the coffee trees
- Weed debris may contain weed seeds so it is better to remove weeds prior to them flowering and producing seed



Weeds growing in the coffee garden

Weeds removed or slashed and used as mulch around the coffee trees

Cover crops

- The purpose of growing cover crops is to protect the soil. They help manage soil erosion, suppress weeds, retain moisture and improve soil fertility
- Slash the cover crops at the end of the wet season and leave the debris on the ground to mulch the soil and provide nutrients for the coffee trees
- It is best to grow leguminous groundcovers, such as pinto peanut, because they can add nitrogen to the soil
- It is preferable not to grow crops that climb and smother the coffee trees

A cover crop of peanuts *(Source: Esley Peter)*

Intercrops

- Like cover crops, intercrops protect the soil from erosion
- High value intercrops, such as cabbages, grown for marketing may receive an application of fertiliser. Any excess fertiliser not taken up by the cabbages will stay behind in the soil to benefit the coffee trees
- The roots of food crops remaining after harvest will add to the soil organic matter, and improve soil fertility and drainage
- Residues from intercrops, such as leaves of cabbages, cauliflowers or pineapples, should be retained in the coffee garden and not taken to the market or left at the house. The nutrients in them will be added to the soil as they decompose
- Leguminous intercrops like peanuts and beans will also add nitrogen to the soil
- As for cover crops, avoid those that may climb and smother the coffee trees
- Weeding, a task that is essential when intercropping with food crops, will benefit the coffee trees as the weeds can be used as mulch
- When growing intercrops, land preparation between the coffee rows should ideally be done during the dry season
- Intercropping means that family members spend more time in the coffee garden. This provides more opportunity to monitor the status of the coffee garden (for example, the levels of pests and disease like CBB) and also garden security

Coffee trees intercropped with food crops.

Other sources of nutrients

Animal manures

- **Well composted** animal manures may be used as mulch in the coffee garden to add nutrients to the soil

Composting animal manure

To compost manure:

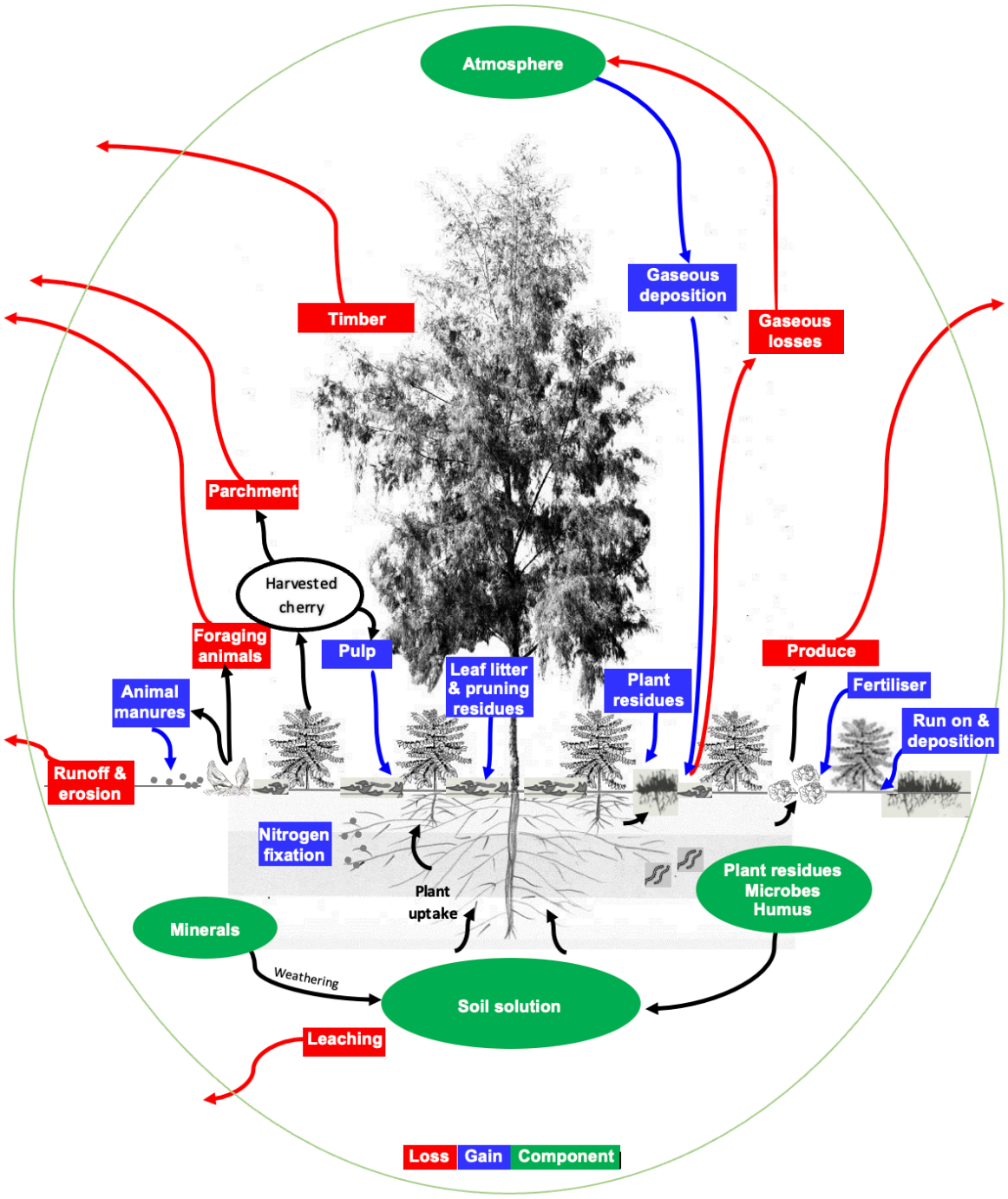
- Locate your compost heap somewhere dry and shaded
- Mix the manure with plant debris such as branches, twigs, dry leaves and grasses making a heap about 1 m x 1 m
- Mix the compost heap well
- Aerate the heap by turning regularly. It may require watering if it gets too dry
- Composting will take approximately 3-4 months depending on the conditions
- When complete the compost will be dark brown in colour, smell earthy and look uniform (i.e., can't distinguish the manure from other materials)

- Animals, such as chickens, foraging in the coffee garden will recycle nutrients
- Larger grazing or foraging animals like pigs or goats are not recommended because of the damage they can do to coffee trees and roots. Also, these animals are more likely to export nutrients if the manure is not later returned to the coffee garden

Fertilisers

- It is important to stress that not all nutrients exported in harvested cherry can be replaced with nutrients in organic matter from pruning, crop and weed residues, or coffee pulp. The addition of fertilisers may be required at times
- Farmers who belong to a farmer group may be able to source fertilisers from their coffee exporter

Nutrients entering and leaving the coffee production system



Losses and gains through soil nutrient movement in the coffee garden.

Maintaining a healthy root environment

Maintaining good levels of soil organic matter and nutrient reserves through applications of mulch, leaf litter and plant residues will not benefit the coffee trees unless they can access the nutrients. An unhealthy root environment can restrict the supply and availability of nutrients in the soil.

Access to soil nutrients by the coffee trees can be limited if the soil is subject to waterlogging or erosion. Waterlogging restricts nutrient uptake while erosion reduces the amount of soil nutrients and soil volume. While the impacts of waterlogging and soil erosion can be quite obvious, in many situations the process of each is slow and may go unnoticed. In situations where waterlogging, and in particular soil erosion, occur over a long period of time, the soil gradually becomes degraded reducing the long-term productivity of the coffee trees.

Waterlogging

- Waterlogging reduces the ability of plant roots to take up nutrients as the roots cannot access oxygen which they require for growth and nutrient uptake
- Soil microbes which help in accessing nutrients cannot survive in waterlogged soils
- Boggy soil, water ponding on the soil surface, dark, wet or slimy topsoil, often with algae on the surface, and yellowing leaves on trees, are indicators of waterlogging

Waterlogged soil

- The presence of weeds that typically grow in wet areas, such as nutgrass, rushes and mosses are also indicators of waterlogging
- The use of mulch and a good drainage system will prevent waterlogging in most soils *(Refer to the Farmer Training Guide, Unit 2, Module 4 'Drainage' for further information)*

- If planting seedlings in a low point in a coffee garden, slightly raising the planting bed around each seedling to allow the soil to drain may be beneficial for tree establishment

Some typical weeds that may be present if the soil is waterlogged
(A) Bulrush, *Typha* sp. (B) Nutgrass, *Cyperus rotundas*
(Credit: Pacific Pests, Pathogens & Weeds).

Soil erosion

- Much of the rainfall in coffee growing areas in PNG is of high intensity and this can cause the soil to become dislodged and wash away
- Many coffee gardens are located on slopes and these are the sites most susceptible to soil erosion
- When soil is washed away by erosion, valuable nutrients are also washed away. These nutrients are then permanently lost from the coffee garden
- Erosion of the topsoil will have a significant impact on the nutrient supply for the coffee trees as the majority of the coffee tree roots are concentrated in the top 30 cm of soil
- A good drainage system in combination with shade trees is the key to minimising erosion and loss of nutrients *(see Farmer Training Guides, Unit 2, Module 3 'Shade management' and Module 4 'Drainage' for further information)*
- Leaf litter provided by suitable shade trees significantly reduces the erodibility of soils as it forms a protective barrier. Shade trees also improve soil structure making it more resilient to erosion (It is important to note, however, that some shade trees promote erosion because they concentrate rainfall energy through dripping)
- Planting of cover crops or intercrops will improve the ground cover and protect the soil from erosion

Eroded soil in a coffee plantation – valuable nutrients have been washed away. Note soil loss has exposed the roots of some trees
(Credit: CIRAD - downloaded from CIRAD website 12-Aug-2020)

Objective:

To understand what nutrients are gained and lost in the coffee garden by producing a nutrient budget.

Divide participants into groups of 4.

You will need:

Butchers' paper and a marker pen for each group

EXERCISE 5

Nutrient cycling and budgeting

List and discuss:

1. Make two lists:
   - Sources of nutrients gained
   - Causes of nutrients lost
2. Discuss the best ways to balance the nutrient budget, that is, how to balance what is coming into and what is leaving the system

Discuss with the whole group:

1. Local strategies used in soil management
2. How can farmers combine their methods with those recommended in this section to optimise the quantity and availability of soil nutrients?

7.6 KEY MESSAGES

The important messages for farmers are:

- Soil is composed of minerals, organic matter, water and air
- The fertility of the soil is determined by its capacity to provide nutrients to plants. Fertile soils with adequate moisture have the capacity to produce healthy coffee trees that yield good quality cherry and have better resistance to disease
- Soil fertility is the result of the interactions among the physical, nutrient and biological components of the soil, so it is important that farmers manage all three components adequately to ensure the coffee trees are healthy and productive
- Soil organic matter generally makes up less than 10% of the soil but is a critical ingredient. It has an important function in the supply and availability of water and nutrients to coffee trees
- Farmers need to look at their soil nutrients as a budget – account for what nutrients come in and what nutrients leave. The soil nutrient pool is supplied by and taken up by the coffee trees, shade trees, intercrops and cover crops, weeds, the soil (including soil organisms) and the atmosphere
- The nutrients required by coffee trees in the greatest quantity are nitrogen, phosphorus and potassium. Other nutrients which are just as important are also required but in smaller quantities
- Most nutrients can be provided in sufficient quantities to the coffee trees so long as certain management strategies are implemented
- Much of the nutrients (in particular potassium) exported from the coffee garden in the cherries at harvest can be returned if the skin, pulp and mucilage are used as mulch around the coffee trees. In time, fertiliser applications may be required to replenish the nutrients lost through the ongoing export of parchment from the coffee garden. Fertiliser can be inorganic (e.g. commercial NPK) or organic (e.g. composted garden residue or manure)
- It is important to grow suitable shade trees at the appropriate density to moderate cherry production and minimise nutritional stress. Shade trees are important in nutrient cycling with some being capable of adding nitrogen to the soil
- Litter and residues from shade trees, coffee trees, cover crops and intercrops are important for maintaining nutrient levels in the coffee garden
- The coffee tree root environment should be kept healthy as valuable nutrients may be made unavailable through waterlogging or lost if the soil is subject to erosion

7.7 QUIZ

Place a '✓' in the correct box.

1. Soils can contain many components but what are the four primary ingredients of soils?

- A Leaf litter, microorganisms, worms and insects
- B Rocks, gravel, air and water
- C Clay, sand, silt and water
- D Minerals, organic matter, air and water

2. Why is it very important to look after the soil in your coffee garden?

- A It supports the coffee trees and is their main source of water and nutrients
- B To protect it from waterlogging and erosion
- C In order to provide the right balance of organic matter, moisture, sunlight, air and nutrients for the coffee trees
- D All the above

3. Why is it so important to protect and conserve the topsoil?

- A In most instances it has the best soil structure, the most nutrients and microorganisms, and the greatest density of coffee tree roots
- B 20% coffee tree roots are in this zone
- C It has the worst soil structure
- D It contains the least amount of nutrients

4. What is soil fertility?

- A The colour richness of the soil
- B The amount of organic matter in a soil
- C A soil's ability to provide nutrients and water to plants
- D The acidity of the soil

5. The proportions of sand, silt and clay in a soil determine soil texture. A soil with a lot of clay:

- A Drains very well
- B Holds little water and nutrients
- C Can hold a lot of water and nutrients
- D Has no structure

6. Organisms living in the soil:

A Reduce the availability of nutrients to plants growing in the soil
B Help to decompose organic matter releasing nutrients into the soil
C Ingest a lot of nutrients from the soil making them unavailable to the coffee trees
D Are more active when the soil is cool and dry

7. The nutrient pool in the coffee garden is made up of all growing plants, the soil, water and air. The key to providing good nutrition to the coffee trees is by ensuring:

A The nitrogen content in the soil is high
B The potassium content in the soil is high
C The quantity and balance of nutrients in the system are optimised
D The water and air content are balanced

8. Which of the following nutrients when in sufficient quantity produces healthy, dark green leaves and when deficient produces pale or yellow leaves?

A Nitrogen
B Phosphorus
C Potassium
D Iron

9. Harvesting coffee cherry represents a loss of nutrients from the coffee garden nutrient pool. The nutrient present in the highest quantity in coffee cherry is:

A Nitrogen
B Phosphorus
C Potassium
D Iron

10. Dieback can occur when the high nutrient demands of the coffee trees cannot be met by the soil unless large quantities of inorganic fertilisers are applied. For smallholders, what is the most effective management strategy for minimising the risk of dieback in coffee trees?

A Grow and manage shade trees so they provide approximately 30% shade cover
B Construct an effective drainage system to avoid waterlogging or erosion
C Place lots of mulch around the coffee trees to prevent moisture loss and weed growth
D Remove all weeds from the coffee garden to prevent competition for nutrients

11. Waterlogging inhibits the ability of coffee trees to take up nutrients. What is the most effective management strategy in preventing waterlogging in most soils?

A Reduce the amount of organic matter in the soil
B Apply mulch around the coffee trees and construct an effective drainage system
C Remove all mulch from around the coffee trees
D Add inorganic fertiliser to the soil

12. Coffee gardens located on slopes can be subject to erosion, particularly during intense rainfall. This results in the loss of valuable nutrients along with secure anchorage for the roots of coffee trees. What management strategies can be implemented to reduce the risk of erosion?

A Plant shade trees at the top of the slope and coffee trees at the bottom
B Construct drains that run vertically down the slope so that water gets away quickly
C Plant the coffee trees at a lower density
D Construct an effective drainage system, and grow shade trees and cover crops to protect the soil

13. After processing cherry, to avoid losing valuable nutrients it is better if the cherry pulp is promptly spread around coffee or food gardens. If the pulp is too bulky it may be composted first to make it lighter and more manageable. So that nutrients are not lost during composting the pulp should be:

A Left in a heap and not disturbed until composting is complete
B Heaped on top of and covered with a tarpaulin or banana leaves, and turned and mixed every three to four days
C Left uncovered, and turned and mixed very three to four days
D Left to compost for 12 months

14. What is nutrient cycling?

A Allowing nutrients to leach down through the soil
B Plants taking up nutrients from the soil
C The use, movement and recycling of nutrients
D The use and movement of nutrients

15. When processing coffee cherry, the pulp, which is high in nutrients, is removed. The best way to discard the pulp is to:

A. Leave it beside the pulper as labour to move it is usually scarce

B. Wash it down a waterway so the processing area is left clean and tidy to prevent pests and diseases

C. Place it on the coffee trees after about 12 months

D. Place it around the coffee trees or on food gardens soon after processing so valuable nutrients are not lost via leaching

16. True or false.

	True	False
a. Potassium is a much more important nutrient for plants than iron because it is required in much larger quantities.	☐	☐
b. When selling fresh coffee cherry more nutrients are lost from the coffee garden than when selling parchment and recycling the pulp.	☐	☐
c. Leaf litter and pruning debris should be removed from the coffee garden to allow for easier access to the coffee trees for harvesting.	☐	☐
d. Encouraging a diversity of soil organisms improves the rate of decomposition of organic matter and availability of nutrients to the coffee trees and helps suppress pests and diseases.	☐	☐
e. Inorganic fertilisers are very expensive but the nutrients in them are much better for the coffee trees than those in organic sources such as leaf litter, pruning debris, manure and coffee pulp.	☐	☐
f. Using, moving and recycling nutrients is referred to as nutrient cycling.	☐	☐

Answers to quiz questions

Multiple choice

1. Soils can contain many components but what are the four primary ingredients of soils?

   Answer = **D**. Minerals, organic matter, air and water

   Section 7.1: Soils can contain many components including, for example, worms, insects, decaying leaf litter, plant roots, rocks, etc. The four basic ingredients of soils are minerals, organic matter (dead or living), air and water.

2. Why is it very important to look after the soil in your coffee garden?

   Answer = D. All the above. A. It supports the coffee trees and is their main source of water and nutrients; B. To protect it from waterlogging and erosion; C. In order to provide the right balance of organic matter, moisture, sunlight, air and nutrients for the coffee trees.

   Section 7.1: Healthy soil is essential for healthy plant growth and fruit production, so it is important to make all aspects of soil maintenance a high priority in the coffee garden.

3. Why is it so important to protect and conserve the topsoil?

   Answer = A. In most instances it has the best soil structure, the most nutrients and microorganisms, and the greatest density of coffee tree roots

   Section 7.2: The most fertile part of the soil is the topsoil because it has the best structure and contains the most nutrients and microorganisms. It is in this region where most of the coffee tree roots are located so it is important that fertility of the topsoil is well protected.

4. What is soil fertility?

   Answer = C. A soil's ability to provide nutrients and water to plants

   Section 7.2: A fertile soil may contain lots of nutrients but its fertility is also based on characteristics such as: texture; air content; water permeability and water holding capacity; and organic matter content, including living soil organisms. All these characteristics influence its capacity to provide water and nutrients to plants which is what makes a soil fertile.

5. The proportions of sand, silt and clay in a soil determine soil texture. A soil with a lot of clay:

   Answer = C. Can hold a lot of water and nutrients

   Section 7.2: Because clay soils are finely textured, they have a greater surface area for holding onto water and nutrients. If a soil is very high in clay it may in fact suffer from poor aeration and drainage because air and water cannot pass through the fine particles.

6. Organisms living in the soil:

   Answer = B. Help to decompose organic matter releasing nutrients into the soil

   Section 7.2: Soil organisms such as earthworms, nematodes, bacteria and fungi help to break down organic matter and make it available to plants. They are also beneficial in preventing disease and improving water infiltration, root penetration and the water-holding capacity of the soil. They are most active when the soil is warm and moist.

7. The nutrient pool in the coffee garden is made up of all growing plants, the soil, water and air. The key to providing good nutrition to the coffee trees is by ensuring:

   Answer = C. The quantity and balance of nutrients in the system are optimised

   Section 7.4: While it is important to have a good supply of nutrients available for plants it is just as important that they are well balanced. Too much of one nutrient may create a deficiency of another or when in excess they can reduce plant growth or even be toxic.

8. Which of the following nutrients when in sufficient quantity produces healthy, dark green leaves and when deficient produces pale or yellow leaves?

   Answer = A. Nitrogen

   Section 7.4: A deficiency in nitrogen can be identified by leaves turning pale yellow in colour with yellowing beginning in the older leaves and progressing up the plant if the deficiency persists.

9. Harvesting coffee cherry represents a loss of nutrients from the coffee garden nutrient pool. The nutrient present in the highest quantity in coffee cherry is:

   Answer = C. Potassium

   Section 7.4: 300 kg of fresh coffee cherry contains an average of 1.6 kg potassium, 1.4 kg nitrogen and 0.13 kg phosphorus. Iron is a micronutrient making up a very small portion of the total weight.

10. Dieback can occur when the high nutrient demands of the coffee trees cannot be met by the soil unless large quantities of inorganic fertilisers are applied. For smallholders, what is the most effective management strategy for minimising the risk of dieback in coffee trees?

    Answer = A. Grow and manage shade trees so they provide approximately 30% shade cover.

    Section 7.5: If coffee is not shaded, excessive light stimulates heavy flowering and high cherry production. High cherry production places high demands on soil nutrients. Unless supplemented with fertilisers, most soils cannot provide sufficient nutrients for the coffee trees resulting in heavy swings in biennial production and overbearing dieback. Shade reduces light and in turn reduces flowering.

11. Waterlogging inhibits the ability of coffee trees to take up nutrients. What is the most effective management strategy in preventing waterlogging in most soils?

    Answer = B. Apply mulch around the coffee trees and construct an effective drainage system

    Section 7.5: Waterlogging reduces the ability of plant roots to take up nutrients as the roots cannot access oxygen which they require for growth and nutrient uptake. The use of mulch and a good drainage system will prevent waterlogging in most soils.

12. Coffee gardens located on slopes can be subject to erosion, particularly during intense rainfall. This results in the loss of valuable nutrients along with secure anchorage for the roots of coffee trees. What management strategies can be implemented to reduce the risk of erosion?

    Answer = D. Construct an effective drainage system, and grow shade trees and cover crops to protect the soil

    Section 7.5: Much of the rainfall in coffee growing areas in PNG is of high intensity and this can cause the soil to become dislodged and wash away. Shade trees and cover crops protect the soil and an effective drainage system will enable the water to drain away in a controlled manner.

13. After processing cherry, to avoid losing valuable nutrients it is better if the cherry pulp is promptly spread around coffee or food gardens. If the pulp is too bulky it may be composted first to make it lighter and more manageable. So that nutrients are not lost during composting the pulp should be:

    Answer = B. Heaped on top of and covered with a tarpaulin or banana leaves, and turned and mixed every three to four days.

    Section 7.5: The risk of composting is that nutrients may be lost via leaching into the soil. Pulp can be composted by heaping it on and covering with a tarpaulin or banana leaves to retain the heat and protect it from rainfall. It should be turned regularly to allow air into the heap so that it decomposes more rapidly.

14. What is nutrient cycling?

    Answer = C. The use, movement and recycling of nutrients

    Section 7.5: Nutrient recycling occurs in the coffee production system when nutrients are taken up by coffee trees, shade trees and any weeds, then returned to the garden via leaf litter, coffee and shade tree prunings, weed residues and cherry pulp. The nutrients are again made available for the shade and coffee trees and weeds by the activity of soil organisms.

15. When processing coffee cherry, the pulp, which is high in nutrients, is removed. The best way to discard the pulp is to:

    Answer = D. Place it around the coffee trees or on food gardens soon after processing so valuable nutrients are not lost via leaching

    Section 7.5: After processing coffee cherry, the valuable nutrients, particularly potassium, contained in the pulp will be lost to the environment very quickly via leaching if a rain event occurs. It is important to return the pulp to the coffee garden as soon as possible after processing. Alternatively, it can be composted so long as this process is undertaken correctly so valuable nutrients are not lost.

16. True or false

a. Potassium is a much more important nutrient for plants than iron because it is required in much larger quantities.
Answer = FALSE

b. When selling fresh coffee cherry more nutrients are lost from the coffee garden than when selling parchment and recycling the pulp.
Answer = TRUE

c. Leaf litter and pruning debris should be removed from the coffee garden to allow for easier access to the coffee trees for harvesting.
Answer = FALSE

d. Encouraging a diversity of soil organisms improves the rate of decomposition of organic matter and availability of nutrients to the coffee trees and helps suppress pests and diseases.
Answer = TRUE

e. Inorganic fertilisers are very expensive but the nutrients in them are much better for the coffee trees than those in organic sources such as leaf litter, pruning debris, manure and coffee pulp.
Answer = FALSE

f. Using, moving and recycling nutrients is referred to as nutrient cycling.
Answer = TRUE

7.8 SOURCES OF FURTHER INFORMATION

Bleeker P (1983) *Soils of Papua New Guinea.* Commonwealth Scientific and Industrial Research Organisation, Australia in association with Australian National University Press.

Bornemisza E (1982) Nitrogen cycling in coffee plantations. *Plant and Soil* 67(1-3): 241-246.

CIC (2016) *The Papua New Guinea Coffee Handbook* (2nd Edition). https://www.cic.org.pg/wp-content/uploads/2021/08/52029_CIC-Handbook.pdf

Curry G N, Webb M, Koczberski G, Pakatul J, Inu S M, Kiup E, Hamago M R, Aroga L, Kenny M, Kukhang T, Tilden G and Ryan S. (2017) *Improving Livelihoods of Smallholder Families through Increased Productivity of Coffee-based Farming Systems in the Highlands of PNG.* Project Final Report FR2017-08 for ACIAR project ASEM/2008/036. ISBN: 978-1-86320-028-8. Available at: https://espace.curtin.edu.au/handle/20.500.11937/54174 or https://www.aciar.gov.au/publication/asem-2008-036-final-report

Elias L G (1979) Chemical Composition of Coffee-Berry By-Products. In Braham J E and Bressani R (Eds.) *Coffee Pulp: Composition, Technology, and Utilization,* Institute of Nutrition of Central America and Panama.

Harding P (1994) *A comparison of the nitrogen requirements of two coffee (Coffea arabica* L*.) management systems in Papua New Guinea*. PhD Thesis, Univ. of Reading, UK. ProQuest Dissertations Publishing.

Hartemink A E and Bourke R M (2000) Nutrient Deficiencies of Agricultural Crops in Papua New Guinea. *Outlook on Agriculture*, 29(2): 97-108.

Hombunaka P and Harding P (2001) *The effect of timing of fertiliser applications on coffee/Coffea arabica/L. yields in the highlands of Papua New Guinea*. Papua New Guinea Coffee Research Institute.

Kiup E (2014) *Nutrients in coffee, food crops and soil within the coffee garden system in the Eastern Highlands of Papua New Guinea.* Unpublished Independent Project and Dissertation, James Cook University.

Kiup E (2017) *Maximising Nutrient Utilisation and Soil Fertility in Smallholder Coffee and Food Garden Systems in Papua New Guinea by Managing Nutrient Stocks and Movement*. MA Thesis, James Cook University, QLD.

Kiup E, Webb M J, Placzek C J and Nelson P N (2021) Managing nutrient stocks and movement in smallholder gardens in Bena, Papua New Guinea. *PNG Coffee Journal* 15(1): 30-38.

Lambot C and Bouharmont P (2004) Chapter 8.3 'Pruning'. In Wintgens J N (ed.) *Coffee Growing, Processing, Sustainable Production*. Wiley-VCH, Weinheim.

Nelson P N (2023) Sustainable soil management in tropical agriculture. In Jayaraman S, Dalal R C and Lal R (eds.) *Sustainable Soil Management: Beyond Food Production*. Cambridge Scholars Publishing, UK.

Sengere R (2016) *The rise, fall and revival of the Papua New Guinea coffee industry*. PhD Thesis, Curtin University.

Winston E, Op de Laak J, Marsh A, Lempke H and Chapman K (2005) *Arabica coffee manual for Lao-PDR*. FAO, Bangkok.

Wintgens J N (2009) *Coffee: Growing, Processing, Sustainable Production: A Guidebook for Growers, Processors, Traders, and Researchers*, 2nd Ed. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.

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