

GUIDANCE J

Soil Fertility and Conservation

Version 1



**RAINFOREST
ALLIANCE**



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OBJECTIVE

In an agroecological system, every part is interconnected to everything else through a web of relationships. The structure of this relationship-web is the manifestation of the underlying processes in which the individual parts interact and influence each other. This system will always strive to achieve and maintain a state of dynamic balance and sustainability. Agricultural practices have an impact on the agroecological environment in which they are employed and need to be assessed in a context or site-specific manner. Correct assessments are the basis for good decision-making and the identification of appropriate and timely interventions. This knowledge is needed to understand these underlying processes, and also careful observation is needed to notice the visible symptoms and changes in which they are expressed.

The direct objective of the soil chapter in the standard (and this guidance) is to provide some of this necessary background knowledge and thereby *enabling the producers to understand* the main characteristics, the potential and limitations of the soils and physiography¹ of the land where the production plots of the farm(s) are located. The Internal Management System (IMS) trainers/technicians or farm managers should take main responsibility for this.

We hope to empower farmers/farmer groups to make balanced decisions on the most adequate crop choices and other land-use aspects that may influence sustainable productivity (especially changing climate conditions).

SCOPE

This guidance focuses on section 4.4 in the standard, in particular regarding different options for soil assessment and its importance in decision-making, as well as the major processes effecting soil fertility and soil fertility management. This guidance includes the Soil Matrix (referenced in the standard document 4.4.2. The Soil Matrix guides readers through a series of possible applicable situations that help to define important characteristics/conditions and offer possible soil management solutions for identified threats and problems as categorized in requirement 4.4.1.

In requirements 6.4.5 and 6.4.6 of the standard further content is covered on erosion and the use of fire. As this is related to soil conservation, the guidance also addresses these subjects.

AUDIENCE

This guidance is intended to serve management of large farms, management of farmer groups and technical staff who are preparing farmer organizations (or plantation owners) for certification, helping them to understand the importance of the requirements in the standard and how it can best be achieved in their circumstances. The document also provides guidelines for auditors who check on compliance with the requirements, to be better able to assess the situation found on the ground as well as the suitability of farmers' management practices in the given agroecological environment. The assessment and the preparation of a Soil Management Plan is not a compulsory requirement for all small farms. Nevertheless, if small farmers go individually for certification, a soil assessment and Soil Management Plan is recommended.

¹ The subfield of geography that studies physical patterns and processes of the Earth. In this context the changing climatic conditions should also be taken into account (Climate Change preparedness).



1. GUIDANCE

REQUIREMENT 4.4.1

Core Requirement

Applicable to: *Large farms part of a group, Group management, Individual certificate holders*

Requirement 4.4.1 Management conducts a soil assessment for a representative sample of areas, and updates this at least once every three years. The soil assessment includes, if relevant:

- Erosion prone areas and slope
- Soil structure
- Soil depth and soil horizons
- Densification of compaction areas
- Soil moisture and water level in the soil
- Drainage conditions
- Identification of areas with visual symptoms of nutrient deficiency

Note:

- The soil assessment also considers the risks of soil deterioration identified in the climate change risk analysis.
- Soil nutrient analysis is related with specific crop needs and is covered in requirement 4.4.4.

Objective of the requirement:

This assessment refers to a basic understanding of what the important characteristics of soils are in a landscape context. The idea is NOT to force farmer/groups to implement high-tech analysis for which expensive instruments, costly lab-tests and/or non-available fertilizers and soil additives are needed, but to enable farmers to make the best choices given Available, Affordable and Accessible means in their specific situations and what farmers can do to adapt to soil and climate limitations current and future. Eventually this will empower farmers to implement sustainable farm planning measures (with short- and long-term effects).

For the first audit it is important that a draft assessment exists. Auditors and (IMS) management agree upon a plan for further improvement.

Basic characteristics of soils to be assessed

Definition:

The soil is the upper layer of the Earth's surface, and consists predominantly of solid material. This solid material (or solid phase) has been formed by weathering, leaching, erosion, sedimentation, biological and microbiological activity and sometimes by tillage. Soils also contain a non-solid phase: the pores that allow aeration and water storage. Water and air are interchangeable.

Soil depth is determined by the presence of biological activity, usually to a depth where roots of plants reach (normally to ~1.5m). Soils are dynamic: ongoing leaching, capillary water movement and biological activity make soils subject to continuous change.



Which characteristics are important in the soil assessment?

- 1) Soils are a result of long-term formation processes, which often result in soil layers (horizons) with particular features in each layer. Intervention in the physical and chemical composition of these layers may have positive and/or negative effects. Changes in water availability (drought and/or long-term water saturation/floods, irrigation) may also change the possible soil/land-use.
- 2) The main function of soils for a crop are:
 - Support.
 - Provision of air to the roots (oxygen, nitrogen).
 - Water, hydrology: shortage, excess, influence of the ground water table and the fluctuations in it.
 - Nutrient storage (Cation exchange capacity)
 - Host for symbiotic microorganisms that contribute to access to nutrients and water for plants (nitrogen fixing symbiosis, mycorrhiza, etc.).

It is important that farmers understand on which horizons these characteristics can be found, and further, which horizons are/can be limiting for agriculture (e.g. due to changing climate or erosion) and why.

Soils can be:

Good or bad soils (which refers to soil structure/architecture, the materials of which the soil consists, and the way in which these 'building' materials are organized):

Herein texture and structure play an important role:

- ⇒ Texture: different mineral/rock particles that make up the soil (clay, silt and sand).
- ⇒ Structure: the way the soil particles are organized, wherein texture, organic matter, pH and related hydrology play an important role.

Also, the presence of roots of vegetation (depth and functions of the roots) influences the structure and the effective depth of a soil (deep rooting contributes to the structure).

Likewise, organic matter, and the continuous production of it, is important. The organic matter content and the clay content provide nutrient storage capacity. This is indicated as the Cation exchange capacity (CEC)². Additionally, microbiologic diversity is an important indicator for good structure.

And soils can also be rich or poor: this refers to chemical aspects; the fertility/nutrient-content of the soil.

In Appendix 1, (requirements 4.4.1 and 4.4.2, for soil assessment and soil management plan: Soil Matrix), examples are given on how to assess chemical characteristics of a soil with regard to the structure, storage capacity and characteristics for releasing nutrients³.

- 3) Basic **physiographic** characteristics:
 - Topography/erosion
 - Drainage conditions (superficial and internal), waterlogging, climate and changes to it.
 - Vegetation types (original and actual).
 - The altitude in relation to climate and speed of decomposition of organic matter.
 - Climate (change) with its influences on natural vegetation, soil forming processes and disturbance in agricultural production.

² The capacity of the soil to store and release nutrients available for plant nutrition. This usually happens in the clay particles and in organic matter.

³ The presence of nutrient reserves, such as the fertility, will be addressed under requirement 4.4.4.



In the Soil Matrix, the importance of many of these aspects for agriculture is explained in an integrated manner with examples of some typical soils (soil groups).

As explained, the assessment is part of a learning and empowerment process for farmers, assisting them in getting better insights into how productivity can be made sustainable through soil, water and landscape management.

The Soil Matrix is a tool to define *step-by-step* which characteristics apply to the soil(s) of a farm or farmer group.

REQUIREMENT 4.4.2

Core Requirement

Applicable to: *Large farms part of a group, Group management, Individual certificate holders*

Requirement 4.4.2 Based on the soil assessment, management identifies soil management measures and includes these in the Management Plan to build up soil organic matter, increase on-farm nutrient recycling, and optimize soil moisture.

Based on the soil assessment, producers identify soil management measures and include these in the farm **Management Plan** to build up soil organic matter, prevent erosion, increase on-farm nutrient recycling, and optimize soil moisture.

Identified climate change risks/threats for soils and physiography will also be addressed in this plan.

Objective of the Requirement:

To ensure the IMS trainers lead a process to encourage farmers to implement farm planning that takes the landscape/land use limitations and change in climate conditions into account and works towards management of soils for long-term sustainable production.

Points of attention:

Assessing presence of organic matter in the "arable" layer(s) of the soil. Also check the presence and diversity of microorganisms (worms, woodlice, centipedes, etc.) and mycorrhizas on roots and bacteria (nitrogen-fixing nodes of Rhizobium on roots), and the depth at which they are found.

This upper soil layer requires most attention in land-use planning. Depending on the physiographic conditions of this layer a specific combination of crops may be required as well as additional measures to ensure sustainable use and productivity. If long droughts occur or excess of rainwater frequently happens, what measures can be taken to avoid an unhealthy environment for the chosen crop(s)? In other words, maintenance of this top layer requires priority in all farm- and land-use plans.

This Soil Matrix provides insights and tools in determining which combination of characteristics, physiographic factors and climatic changes require which agricultural land-use techniques or combinations thereof: climate-smart farm and landscape planning!

With the guidelines in Soil Matrix, it will become possible for all farmers to make basic improvement plans for their farms, bearing in mind the surrounding landscape. The matrix provides concrete guidance for the most important crops for Rainforest Alliance, but the methodology can be used for more crops.



REQUIREMENT 4.4.3

Core Requirement

Applicable to: *Large farms part of a group, Group management, Individual certificate holders*

Requirement 4.4.3 Management carries out regular soil tests and/or (visual) leaf tests, including macronutrients and organic matter, for a representative sample of areas. For perennial crops this is done at least once every three years and for annual crops at least once per year.

Management carries out regular soil tests and/or (visual) leaf tests, including macronutrients and organic matter. For perennial crops, these are done at least every three years and for annual crops at least every year

For groups, this is carried out for a representative sample of areas.

Objective of the requirement:

To enable producers to have the knowledge on how to maintain fertility at a favorable⁴ level for good and sustainable productivity of the crop.

Natural restoration of nutrients:

One of the main reasons for farmers to expand their farming area or to move to new areas is the decline in soil fertility. Through poor agriculture practices frequent burning, use of herbicides, lack of erosion prevention, no fallow periods, etc., and by the extraction of nutrients via the harvested products, the reserve of stored nutrients is steadily reduced. Likewise, the organic matter content is reduced. Diminishing productivity is the consequence.

Natural processes that restore fertility exist. These include:

- Nitrogen fixation by biological activities.
- Transport of dust by wind, animals and rainwater.
- Release of nutrients by weathering of matrix material in the solid soil component (feldspar), etc.
- Sedimentation along rivers.

In mixed cropping systems and/or agroforestry systems where a lot of fertility is stored in living biomass, the resilience capacity of the system is usually larger than in monocropping systems; this is one of the reasons that agro-forestry systems with low external inputs are more sustainable than monocropping systems. In all cases degradation of the soil organic matter content will be prevented by covering the soil with plants or dead planting material (mulch, compost).

Natural restoration can guarantee minimum productivity levels, but to make sure that farmers do not have to expand farming areas (at the expense of natural/ecological reserves) to achieve reasonable and sustainable income levels, external fertility inputs are often necessary in addition to good crop management.

⁴ The impact of fertilization on productivity has a minimum and a maximum. In between the minimum and the maximum there is an "optimum" effect. This is where a kilo of fertilizer results in maximum productivity increase. This is considered "favorable". When more fertilizer is applied, the effect on productivity is less. Eventually excess fertilizer will be washed out and pollute the environment.



Relation with soil characteristics:

As we learned, storage capacity is not only a matter of presence of nutrients as such: the soil structure is also important for nutrient storage. It is important that nutrients are released slowly for crop development instead of being washed out of the soil (leached) by heavy rains. This is the Cation exchange capacity (CEC). Without a good CEC much fertilizer will get lost and eventually the chemicals will pollute the surface water (eutrophication).

Soil fertility testing:

Why, when, how? In order to know how much fertilizer can best be applied to maintain productivity levels, chemical soil testing should be done frequently. Ideally this soil testing should be done at laboratory level and include the needs of micronutrients. However, in many cases these facilities are not easily available, affordable and/or accessible.

Chemical soil testing is a relative expensive activity. However, in almost all cases it pays for itself, both in economic terms (optimum applications for desired productivity) and in terms of nature conservation (avoiding excessive fertilizer applications).

In the case of annual crops, several crops are usually cultivated in one year. Often this concerns crops that extract relatively large quantities of nutrients from the soil. Meanwhile, soil preparation often implies exposure to rainfall and full sunshine, even if temporarily. This impacts the soil fertility strongly: in the first place, the affecting chemical nutrient availability; but also in the long run, soil structure aspects. For these reasons frequent checking (soil fertility testing) and planning of actions to restore fertility (including the application of organic matter) is required.

For perennial crops the extraction of nutrients is more constant and can be estimated more easily. In this case soil testing can be limited to once every three years (though once a year would be ideal). As explained above, agroforestry systems and the use of green cover-crops are beneficial, because they store nutrients in a living biomass buffer, releasing it slowly to the cropping system. In the humid tropics particularly, agroforestry is a good method to maintain the stability of both organic matter and fertility. Practices like mulching are also beneficial.

The testing itself can consist of a combination of actions. To keep fertility testing affordable for all producers, a number of different methods are described. Not all are ideal, but at least they enable a starting level in remote areas! Availability of "tools", laboratories, etc., and the accessibility and affordability of these services for producer-organizations play an important role in determining which techniques can best be used for soil testing.

- 1) One of the simplest tests is observation of crop behavior. Discoloration or necrosis of crop leaves is an effective method to determine a number of deficiencies. Many other growth and development abnormalities can easily be observed and are often caused by nutrient deficiencies. Booklets with photographs of deficiency characteristics in specific crops are available for many crops and in many countries. For the main crops coffee, tea and cocoa the deficiency characteristics are given in Recommendations for Coffee, Tea, and Cocoa.
- 2) Likewise, observations on weeds can provide indications on the soil fertility situation, e.g. predominance of persistent deficiencies (grass weeds or ferns are indicators of nutrient) and hence the need to carry out tests.
- 3) These observations do not provide information on the quantitative needs of nutrients, but can be very useful as indicator for *which* nutrients are needed.
- 4) With field observations it is also important to determine if nutrient deficiency is caused by specific physical soil conditions, e.g. waterlogging, soil texture (sand), impermeable layers (rock, hard pans), dumping of chemicals or excessive drought. It is therefore important that producers and IMS trainers have a good understanding of the physiography of the production areas, e.g. in the case of waterlogging,



fertilization doesn't make sense if nothing is done to improve drainage/oxygen availability for the roots.

- 5) In many countries, basic toolkits (boxes with some basic chemical preparation for testing) are available that can be taken to the field for testing organic matter, pH, potassium, calcium, magnesium, etc. For individual small and medium farmers, this is too costly, but IMS organizations should be able to procure these kits and use them sample-wise as a service facility for IMS members.
- 6) Gadgets are available from several sources online, e.g. Sonkir Soil MS02 3-in-1 Soil Moisture/Light/pH Tester; Covery 3 in 1 Soil Tester Moisture Meter Light and PH acidity Tester, or Gain Express Soil Ph & Moisture Meter. Cost: ≈ €10 per piece. A video with instructions for the use of these gadgets can be found here: https://youtu.be/yq_9GvZDLr8
- 7) The soil scanner from AgroCares: a recently developed scanner that can be used for professional soil testing, including recommendations for fertilizer applications to reach desired productivity level (for main crops). This scanner analyzes soil on the basis of color-light pulses. It connects via the Internet to a database where collected data are compared to a large number of tests done elsewhere. The tests consist of analyzing the solid soil segment (minerals and organic matter), which is a mixture of the top soil taken at several spots in plots with similar soil/physiographic characteristics. Based on information on available fertilizers in the country (in a database on the Internet) recommendations are automatically developed for each country.
- 8) This scanner is still in a test phase but will probably become available in a number of countries during 2020. See <https://www.agrocares.com/en/products/scanner> Cost: Investment cost in hardware (≈ €3000), recurring cost: annual license (≈ €1500) The scanner is too expensive for average farmer organizations to procure, but RA will assess the possibility to make them available on lease basis in some countries. In that case the costs of a test can probably be reduced to US\$5-\$10 per plot. The recommendation is to carry out the test sample wise per IMS (e.g. using square root method), making sure different soil/physiographic situations are covered. Sites of testing can be alternated with new test rounds.
- 9) Laboratory soil testing:
This is the most reliable method for soil testing. It requires the same method of preparation of samples as with the soil scanner, but the sample will be taken to a laboratory. Insight into the availability of micronutrients can be obtained in this way. This is often important information about the development of specific parts of crops, e.g. root development, hormones for blossom, iron for leaves (tea), fruit setting, etc. In most countries the ministry of agriculture, through a university or research institution, offers soil analysis services at a relatively low cost. Most countries nowadays also have a commercial soil analysis service provider. Soil samples can also be sent to neighboring countries, South Africa, Europe or the US for analysis. For remote regions this testing method is unfortunately not available yet.
- 10) Similar to the soil sampling, a sample of leaves can be taken in the field and analyzed at a laboratory level. This indicates directly which elements are deficient in the crop, on the basis of which information recommendations for fertilization can be given. This is the most sophisticated and most expensive fertility testing method, which may be applicable for vegetable crops and flower production in greenhouses, where the soil-substrate is strongly controlled, and nutrient availability can be fine-tuned.



In all cases, unexpected changes in nutrient availability are not necessarily caused by crop nutrient-uptake alone. Changing humidity conditions can cause erosion, lixiviation (leaching) and sometimes change the pH (water saturation) and lead to Al+++ toxicity (occupation of the CEC system) in the soils. This all affects nutrient availability and thus crop development/health. If such sudden unexpected changes are observed during testing, the IMS coordinator has to analyze what may have caused the changes and adapt the soil management plan.

For most of the individual certified farms, soil testing is rather complicated. RA therefore tries to promote the use of tools (kits) that can be taken into the field and are affordable for many farmers/farmers groups. Per IMS organization there is no need to test soils in all farms. A sample-based testing of the most typical plots may give very useful information for the entire farmer group.

REQUIREMENT 4.4.4

Core Requirement

Applicable to: *Small and Large farms part of a group, Individual certificate holders*

Requirement 4.4.4. When available, producers use by-products including organic fertilizers produced on the farm first. If more nutrients are needed, these are supplemented where possible by other organic fertilizers, or by inorganic fertilizer.

To minimize risk, animal manure is hot composted before use as a fertilizer. Producers store animal manure and compost at least 25 meters away from any water body.

Producers use organic fertilizers and by-products available at farm-level first and supplement with inorganic fertilizer if nutrients are still lacking.

Producers do not use human sewage, sludge, and sewage water for production and/or processing activities.

Producers store animal manure that is used as fertilizer at least 25 meters away from any water body. If needed, it is appropriately composted to minimize risks.

Objective of the Requirement:

Promote as much on-farm recycling of nutrients and organic matter as possible, while respecting sanitary hygiene standards and avoiding eutrophication of surface water as a result of accumulation of organic waste/composting.

Minimize the need of external inputs.

This requirement/good practice aims to encourage farmers to minimize the need for synthetic⁵ fertilizers, to ensure they will only be used as a complement when this is necessary for maintaining productivity and no feasible options for organic fertilizer are available.

⁵ Synthetically produced fertilizers are considered all fertilizers that have been obtained through industrial production from chemical components, petroleum or (mined) methane-gas, even if they have the same chemical composition as products that are available in natural organic matter.



REQUIREMENT 4.4.5

Mandatory improvement (L1)

Applicable to: *Small and Large farms part of a group, Individual certificate holders*

The soil of the production area is not left exposed, it is protected by measures such as cover crops, crop residues or mulch.

Objective of the Requirement:

Farmers have taken concrete measures to improve the on-farm recycling of nutrients and to increase benefits from natural processes that contribute to fertility and maintain soil structure, meanwhile protecting the soil against heating and erosion.

REQUIREMENT 4.4.6

Mandatory improvement (L1)

Applicable to: *Small and Large farms part of a group, Individual certificate holders*

Fertilizers are applied in such a way that nutrients become available when and where crops need them, and contamination of the environment is minimized.

Objective of the Requirement:

This requirement adds to Requirement 4.4.4 in avoiding excessive application of fertilizer and unnecessary losses that cause pollution of surface water (eutrophication,) while achieving maximum efficiency/profit of the applied fertilizers.

Some nutrients (fertilizers) are extremely useful for stimulating growth (formation of leaves and branches), while others are especially needed for blossom and/or fruit (seed) development. Depending on the to-be-harvested part of the plant and the natural growth cycle of the crop, a fertilization schedule is made, wherein the specific needs of nutrients during the crop cycle are considered.

To avoid dissolution and volatilization of nutrients (nitrogen), the fertilizer has to be incorporated in the soils and not applied superficially, so that the nutrients can be attached to the nutrient storage system and be slowly released for plant feeding. In case of phosphorus application in phosphorus-fixing soils, applications should preferably be done as organic fertilizer and/or in several small applications. Also, control of the pH can add to efficiency.



REQUIREMENT 4.4.7

Mandatory smart-meter

Applicable to: *Small and Large farms part of a group, Individual certificate holders*

Producers monitor and optimize the use of inorganic fertilizers.

Indicator:

- Volume of N, P and K per ha (kg/ha, per year or per cropping cycle)

In groups of small farms, the indicator can be monitored for a representative sample of farms.

Objective of the Requirement:

To enable best cost-benefit by improved productivity, while avoiding eutrophication due to overdosages of fertilizers.

When fertility of a particular nutrient increases, productivity also usually increases, up to maximum level. The best result will be when every kilo of fertilizer results in maximum increase in productivity.

Nutrients also interact. A deficiency of the one nutrient against an overdosage of the other nutrient can lead to sub-optimal productivity increase. When combined fertilizer is applied, often the result is better. It is important that farmers keep record of the application levels of fertilizers and monitor the effect on productivity. When the productivity increase diminishes, the fertilizer dosages should be reduced. More fertilizer will only lead to higher costs per kilo of production and to the washing of nutrients into surface water, causing negative effects in the environment (eutrophication).

REQUIREMENT 6.4.5

Core requirement

Applicable to: *Small and Large farms part of a group, Individual certificate holders*

Erosion by water and wind is reduced through practices such as re-vegetation of steep areas and terracing.

Clarification

This requirement was included in the environment chapter because erosion by water and wind applies to all the farm and not strictly to the farming area.



REQUIREMENT 6.4.6

Core requirement

Applicable to: *Small and Large farms part of a group, Individual certificate holders*

Fire is not used for preparing or cleaning fields, except when specifically justified in the IPM plan.

Clarification

This requirement was included in the environment chapter because the use of fire to prepare or clean soil applies to the full farm and not only for farming activities.

Objective of the Requirement:

To avoid unnecessary damage to farm plots and landscape⁶.

What is this damage?

Burning as a form of land preparation implies the burning of biomass and dead organic matter. Farmers sometimes use fire in land preparation to clean the land and to have short-term benefits of by-fire mineralized nutrients (from organic matter). That goes together with considerable CO₂ emissions, but also – and specially if the intervals between fires are short (less than 10 years) – with severe deterioration of soil organic matter component. Except from CH₂O losses, nitrogen almost totally disappears, while nutrients like potassium will temporarily become available in excess but will later be washed out and become deficient as well. This will lead to much less diverse microbiological activity in the soils and cause the appearance of persistent weeds (often grasses that appear as natural monoculture). Finally, the difficulty in eliminating the persistent grass/weeds often forces farmers to use burning more and more frequently or leads to the temptation of herbicide use.

Repeated burning will lead to loss of CEC (Cation exchange capacity; the nutrient storage capacity) of the soils, and thereby diminish productivity, etc.

Besides, burning also negatively impacts water retention capacity and of course affects the biodiversity in general.

Finally, burning strongly contributes to susceptibility to surface erosion and leaching of soil nutrients. Climate change will aggravate this even more, either in the form of drought and/or via water erosion due to heavy rain showers.

For weed control and soil protection, good alternatives exist for the practice of burning: selective weeding, use of groundcover crops (Leguminosae) and where the crop allows, agroforestry systems.

⁶ In some cases burning of vegetative rests of infected crops is necessary. This is a crop protection/phytosanitary measure, which is allowed and can be included in the IPM management plan. This is different from using fire as soil preparation meant in this requirement.



2. SOIL MATRIX: FOR SOIL ASSESSMENT AND MANAGEMENT PLAN

This appendix focuses on Requirement 2.4.1 of the Rainforest Alliance Standard and gives recommendations for Requirement 2.4.2 – the preparation of a soil (and water) Management Plan.

BASIC FACTORS TO BE CONSIDERED IN THE SOIL ASSESSMENT

The soil assessment includes:

- (a) Soil structure (and texture).
- (b) Soil depth and soil horizons.
- (c) Densification of compaction areas.
- (d) Identification of erosion-prone areas and slope.
- (e) Soil moisture and water level in the soil.
- (f) Identification of areas with visual symptoms of nutrient deficiency.

First, for a basic understanding of determining soil characteristics for assessment, we will explain the basic topics of soil texture, structure and factors that influence (potential) nutrient availability. For all other points of attention relating to the soil assessment we will provide step-by-step guidance using concrete examples of soils that frequently will be found in agricultural lands. Finally, we will provide some concrete examples for soil management interventions aimed at improving production conditions for crops.

This appendix does not include soil fertility testing methods for fertilization (Requirement 4.4.4), which is explained in the general Guidance document for the interpretation of soil requirements.

a) Soil structure and texture

The texture and structure of a soil influence infiltration rate and therefore the drainage capacity and the risk of run-off and erosion. Soil texture refers to the mixture and relative proportions of the different components (sand, silt and clay). A soil with a high content of sand is relatively porous and allows for quick infiltration of rainwater, while a clay soil is prone to compaction and run-off. The loose texture of a sandy soil, however, makes it more prone to wind erosion than a clay soil. If water infiltration into a sandy soil is impeded by a high water table or an underlying impermeable sub-soil layer (clay or rock), the risk of run-off and erosion is high due to its loose texture.



b) Soil texture

Sandy soil:

Sandy soils are made up of a large percentage of sand. Sand is basically rock that has been ground into tiny particles by weathering and earth movement. Depending on the sand particle size these soils can be coarse or fine, but they always feel gritty. They can be easily filled. Sand can neither hold water nor store nutrients. Sandy soils are therefore easy draining, loose soils of low fertility. Sandy soils do not stick together if pressed into a ball. They are usually of lighter colors, ranging from white, yellow, orange, to dark grey. Soils in arid areas are often sandy soils.

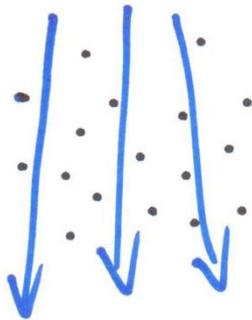


Figure 1. Free-draining sandy soil

Recommendation:

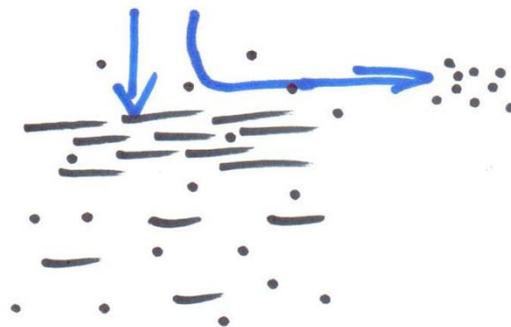
To improve the structure of a sandy soil large amounts of compost or animal manure have to be applied.

Clay soil:

Clay soils are made up of a large percentage of very fine clay minerals. Clay compacts easily, forming big lumps. Clay soils are often heavy and difficult to till. Water cannot easily penetrate heavy clay soils and waterlogging and run-off is a typical problem. However, clay soils have a good nutrient-holding capacity and are naturally rich and fertile soils. The color of clay soils can vary from light to dark grey, yellow to red.



Figure 2. Compacted clay soil



Rain cannot penetrate a compacted clay soil. Run-off carries loose soil particles (erosion).



Recommendation:

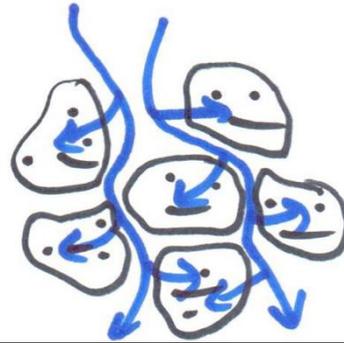
Heavy clay soil can be improved by organic matter additions or liming, both of which will improve soil structure.

Loam texture:

Soils containing a balanced amount of sand, silt and clay (and organic matter) have a Loam texture. Loam is dark and crumbly. Its particles are well aggregated and provide structure, wherein organic matter plays an important role. Water can penetrate the spaces between particles easily (drainage). It also has a good water-retention capacity in the spaces inside the aggregates. The rough surface of the soil reduces the ferocity and velocity of wind and water, thus reducing erosion. The organic matter content gives loam particles a negative electric surface charge, allowing the attachment of nutrients that can be easily exchanged with plant roots. Loam soils are the most favorable agricultural soils as they are fertile, easy to till, and provide enough soil biota to keep plants healthy.



Figure 3. Dark, crumbly loam soil



Water percolating into spaces between the soil aggregates and being soaked up into air spaces within the aggregates.



Step 1:

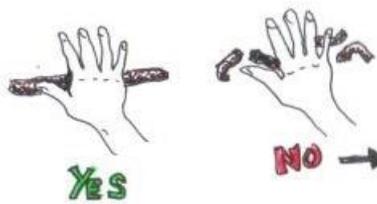
Can the soil be formed into a ball?



SANDY soil
(more than 70% sand).

Step 2:

Can the ball be rolled out into a coil?



LOAM soil
Mix of sand, silt,
organic matter
and clay
(low clay %)

Step 3:

Twist the coil into a ring.



LOAM soil
Mix of sand, silt,
organic matter
and clay
(high clay %).

CLAY soil
(more than 40%
clay).

Figure 4. Simple testing method to determine soil texture type:



C) Soil structure:

The term "soil structure" refers to the arrangement and composition of soil particles in the soil. Organic matter and calcium particles help to bind the different soil components together into bigger structural units called aggregates. A well-structured soil is characterized by air-filled spaces between and within the aggregates. These spaces allow for a high rate of water infiltration, which means good internal drainage. At the same time, they allow for aeration of the soil and the provision of oxygen, which roots need to take up nutrients.

Soil structure deteriorates when a soil has a low organic matter and a low calcium content, or when pressure is applied to a wet/soft soil by heavy machinery, animal trampling, plowing, etc. A soil with a poor soil structure has a high risk of compaction and generating water runoff due to a reduced infiltration rate.

When saturated with water over a long time – in particular clay soils and soils with a high organic matter content – no oxygen is available in the soil. This turns soils acidic (low pH). When oxygen becomes scarce, oxidized iron (Fe^{+++}) changes to a reduced stage (Fe^{++}) and a lot of aluminum ions (Al^{+++}) are released. In addition, organic matter may produce H_2S (rotten egg smell). All these elements are usually available in clay soils and in organic matter).

These circumstances disturb a good granular structure, lock pores, impede movement of nutrient and/or disable roots to reach these nutrient. Al^{+++} occupies the nutrient storage system of the soil, disabling nutrients from attaching to it. Al^{+++} is toxic for most plant roots. In the case of deteriorated structures, we often talk of bad soil structure (or bad soils).

Nutrient for the crop

Where we consider good and bad characteristics in soil structure, we also distinguish poor- and rich soils.

Rich and poor versus good and bad are very much related characteristics but are not the same. Rich or poor refers to the presence of useful chemical reserves in the soil for the crop available, i.e. the fertility/nutrient content of the soil, which is very important for agriculture productivity. Where there is little nutrient storage capacity (in soils with a bad structure), the nutrient storage will by default be low. But even where there is a good structure, this does not guarantee that the storage capacity is fully used for nutrient attachment. Nutrients should also be present in the soil. That subject forms part of Requirement 4.4.4, Soil Testing, which is explained in the general Guidance document for the interpretation of soils.



STEPS IN SOIL ASSESSMENT

Step 1: Assess the organic matter content

As explained above, the nutrient content of a soil depends largely on the soil type (the minerals that are found in the soil) as well as on the organic matter content (in the upper layers) of the soil. Soil organic matter (SOM) is the amount of recycled biomass, by which nutrients are returned to the soil.

Most organic matter is found in the upper layer(s) of the soil. We call this the O-horizon and the A-horizon. The O-(zero) horizon is the layer of leaf litter that covers the soil. The A-horizon is the top layer of the soil itself, where organic matter has formed humus and is integrated into the soil structure.

These two layers are the part of the soil where most feeder-roots of plants develop; roots that often live in symbiosis with mycorrhizas (fungi) and bacteria, and which is continuously moved by a great variety of microorganisms (biodiversity!!!): the "arable layer", the most fertile layer for plant growth and the most susceptible to damage by external factors.

Organic matter has a negative (electric) surface charge to which cations (nutrients with a positive electric charge) can be attached to the soil particles and loosely held for exchange with the soil solution and fine plant roots. The organic matter content in the soil therefore plays an important role in the Cation exchange capacity (CEC) and nutrient availability in soils. Organic matter also serves as the food source for soil microorganisms that are responsible for decomposition processes, nitrogen cycling, and soil and plant health, among many other tasks. Furthermore, nitrogen availability is largely dependent on carbon availability, which is the main component of organic matter.

Therefore, the first step in assessing the nutrient availability in a soil is assessing its organic matter content. As described above, soils rich in organic matter have a crumbly/granular structure, generally darker color, good tilth and water retention capacity. The decomposition rate of organic matter depends largely on soil temperature and moisture level. Under tropical lowland conditions the decomposition of soil organic matter is accelerated, and organic matter needs to be replenished at a rate approximately three to six times higher than in cooler climates.

This SOM layer requires most attention in land-use planning. Depending on the physiographic conditions of this layer a specific combination of crops may be required along with additional measures to ensure sustainable use and productivity. If long droughts occur or excess rainwater frequently happens, what measures can be taken to avoid an unhealthy environment for the chosen crop(s)? In other words, maintenance of this top layer requires priority in all farm- and land-use plans. (See also Step 5: Identification of erosion prone areas and slope.)

⇒ **Recommendation:**

To manage adequate soil organic matter levels, crop and (dead) weed residuals should as much as possible be recycled and incorporated in the soil. When possible, composting is an effective way of recycling. Or, in case there is no danger of pathogen or pest cross-contamination, residuals can also be used as mulch, or ploughed into the soil.



Step 2: Understand organic matter behavior in the climate of the region

Decomposition processes in the soil also speed up nitrogen cycling and therefore call for nitrogen applications as well. Generally, under warm and humid tropical conditions nitrogen losses are high. In humid tropical lowlands the decomposition of soil organic matter is accelerated, and organic matter needs to be replenished at a rate approximately three to six times higher than in cooler climates. That is often difficult to achieve in agriculture. Therefore, nitrogen deficiency is the number one typical feature of tropical soils. Animal manure and nitrogen fertilizer applications need to be managed in such a way that nitrogen uptake by the crop is maximized and losses are minimized. In the first place this requires a continuous production/application of fresh organic matter, preferable of a relatively stable composition (compost/humus). When possible, compost applications can be very useful for crop performance.

⇒ Recommendation:

All organic matter sources available to the farmer should be used to recycle nutrients and to increase the organic matter content on the farm. This includes plants that grow in between the crops (weeds).

Where possible nitrogen-fixing cover crops should be planted to reduce undesired weed growth and keep the soil protected while producing organic matter. Depending on the crop, shade should be provided by trees (agroforestry). This will also contribute to an almost continuous production of fresh organic matter (leaf litter).

When available, fresh manure should be composted and not air-dried, while nitrogen fertilizers like Urea and DAP (Di-Ammonium Phosphate) are placed into the soil and not exposed on the soil surface, so they can be better attached to the SOM.

The use of herbicides is discouraged: not only does it deprive the farmer of a source of organic matter, but it is also detrimental to soil microbial life, which is critically important for soil fertility.

Step 3: Assess pH and effects on fertility for the crop

It has been explained above that the pH influences the structure of the soil. But the pH also influences the release of nutrients from the soil storage system to the crop. For the soil assessment (Requirement 4.4.1), we only consider what this influence can be, with the aim of enabling farmers to predetermine if soils are too acid or too alkaline. *Measuring* the acidity or alkalinity (pH), with the aim of taking measures for soil improvement, will be addressed under Requirement 4.4.4: Soil Testing.

- a) The Truog model below (Figure 5) shows the influence of the pH (acidity) on nutrient availability/nutrient fixation. It can be observed that both an acid and an alkaline environment have a negative effect on the availability of most essential nutrients. Only phosphorus, potassium and sulfur show good availability in alkaline circumstances. In strongly acid soils only iron is sufficiently available. In general, a pH between 5 and 7 seems to be best for the release of the ideal nutrient mixture for crops.
- b) Influence of matrix material (the underground): e.g. presence of feldspar (soil components that release nutrients when they weather), calcium, sand(stone) and in poor acid soils in excess of Al^{+++} . Sometimes there is also completely inert material (e.g. pure-white- kaolinite clay) in the underground, etc.

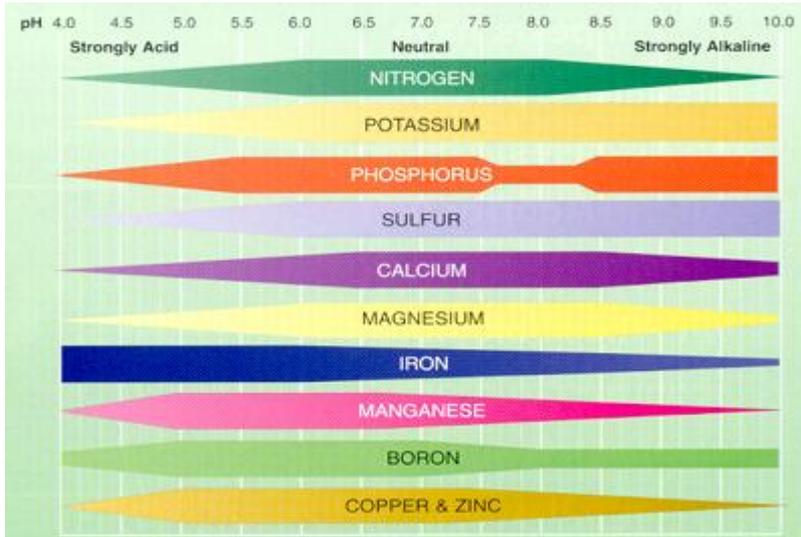


Figure 5. Truog model on the relation between pH and nutrient availability

In the following paragraphs some leads will be given on how to assess acidity using examples from typical soil profiles.

⇒ **Recommendation:**

If a deficiency of a nutrition element is observed, before applying fertilizers the pH should first be analyzed and when necessary measures taken to achieve a neutral soil situation have been made. In the text below, we give some indicators to identify the types of soils with low and high pH as well as what can be done about it.

Step 3a: Some typical characteristics soils with a low pH (acid soils)

High hydrogen (H^+/H_3O^+) levels in the soil cause soil acidity, expressed as low pH (>5). High hydrogen levels can be expected in areas with high rainfall, and on soils with low organic matter content, and after continuous use of ammonium fertilizers like Urea or DAP. In normal well-drained circumstances these soils are often bright orange-red, to yellowish-grey.

Another nutrient deficiency issue on these typically bright red and yellowish soils are connected to high iron oxide (red) and aluminum oxide (yellow to red) content. Especially in low pH soils iron and aluminium become more mobile and because of their triple positive charge (Fe^{+++} and Al^{+++}) bind up any available phosphorus, which has a triple negative charge (PO_3^-), thereby causing phosphorus fixation or a *de facto* phosphorus deficiency. (See Figure 5. Truog model).



Figure 6. Typical colors of tropical soils with high probability of low pH and phosphorus-fixation



⇒ **Recommendation:**

These types of soils are best managed with the application of lime in the case of low soil pH and additions of large amounts of organic matter.

Step 3b: Alkalinity of soils

At the other end of the pH spectrum are the alkaline soils with a high pH (>7). These are often found in drier areas and typically have a whitish color or whitish layers, caused by a high calcium carbonate content. These soils also often have a relatively high salt (sodium) content, which shows as a whitish crust on the soil surface and causes issues with the electric conductivity (EC) of the soils. A high EC causes problems with nutrient and water uptake in the root zone.



Figure 7. Typical colors of tropical soils with high probability of high pH and high EC

The pH of a soil and a potential need for liming (calcium) in the case of too low pH, or gypsum/sulfur applications in the case of too high pH can be measured by a pH test.

Simple and inexpensive tools are available to regularly measure the soil pH on the farm. Possible gadgets are available from several sources online, e.g. [Sonkir Soil MS02 3-in-1 Soil Moisture/Light/pH Tester](#); [Covery 3 in 1 Soil Tester Moisture Meter Light and PH acidity Tester](#) or [Gain Express Soil Ph & Moisture Meter](#). On problematic soils these measurements should be done regularly, and records kept to inform decision-making processes on possibly needed soil amendments.

Step 4: Check on limitations due to flooding and drainage conditions

Waterlogging and saturation with water occurs when a compacted or impenetrable layer is formed in the soil, which prevents water from percolating into deeper layers at the same rate as it collects on the surface, and where the landscape does not allow drainage through runoff. Flooding and waterlogging cause a particular condition under which the usually air-filled spaces in the soil are filled with water and the soil is devoid of oxygen. Few plants can survive under such conditions (an exception is paddy. For irrigated paddy cultivation impermeable layers are often purposely clogged in volcanic Andosols). In most cases temporary waterlogging will lead to root rot and damping off (fungus diseases).

Gley soils:

When saturation occurs frequently, often in naturally waterlogged conditions, soil Iron will shift from Fe⁺⁺⁺ to Fe⁺⁺ (reduced). This is often observed as grey and bluish-grey colored mottling together with orange, yellow or rusty mottling. These colors are due to a lack of air and the reduction of iron compounds. This is called gley. When saturation is permanent all soil clay will become entirely blue-grey (e.g. the groundwater layer). This is called the G-horizon (layer). These wet soils have a greater risk of runoff because they cannot take up more water in their saturated state.



Figure 8. A typical gley soil. Below the top horizon (with some organic matter) we observe a grey soil with yellow and grey patches indicating fluctuating water levels. Where the ground water is permanent the soil is entirely blue (G-horizon)

⇒ **Recommendation:**

Adequately drained gley soils can be used for arable cropping, dairy farming or horticulture. The soil structure will be destroyed for a long time if soils that are too wet are cultivated. Gley soils in depression areas with unsatisfactory drainage possibilities are best kept under a permanent grass cover or swamp forest. Alternatively, trees can be planted on ridges that alternate with shallow depressions. Liming of drained gley soils with a low pH value might be necessary once drainage is assured. In the tropics, rice is most often grown in this type of soil by making inundated depressions between ridges.

Peaty soil:

Peaty soils are a particular form of gley soil that are characterized by their high organic matter content of more than 20% (sometimes even more than 75% organic matter, i.e. real peat). Peaty soils can be found in lowland bogs and river valleys or wet uplands. They are saturated soils and have little capacity to accept rainfall, which causes a high risk of runoff and soil erosion because of their low density and loose soil structure. When drained peaty soils are vulnerable to oxidation, which means the carbon in the organic matter is mineralized releasing nitrogen and CO₂ gas. This initially makes draining peat land interesting for agricultural use. The devastating negative effects, however, are the subsequent loss of organic matter (peat 'wastage'), irreversible compaction of the soil when drained too deep (in real peat), the contribution to climate change through CO₂ emissions, and loss of habitat for many species of plants and animals. Peaty soils have a low pH (acid).

⇒ **Recommendation:**

Peat lands are best kept wet and used for cropping and afforesting with crops adapted to the wet soil conditions. This is known as paludi-culture, which may maintain the organic matter content of peat lands (e.g. the Açai palms – *Euterpe oleracea* – in the Amazon flood plains). To keep groundwater levels high and conserve peat land areas they can also be used as grassland for livestock.

⇒ **General recommendation for flooded and water saturated soils:**

If flooding, waterlogging and saturation only occurs infrequently, temporary drainage conditions may need to be improved. Depending on the cause for flooding and waterlogging several different management options can be employed:



- Improve soil structure to increase the soil's potential to take up water: organic matter, deep-rooting plants, etc.
- Break through hardpans to allow water to percolate into deeper layers. This can be done with trees and/or mechanic interventions.
- Water management measures. Retention: dig trenches and raise dams, collecting excessive water in reservoirs to avoid it from flooding into the area.
- Evacuation or deviation of water: dig drainage trenches to channel excess water from the area to lower areas.
- Crop on raised beds.

A special case: black cotton soil:

Black cotton soil is a special form of clay soil with very particular drainage and flooding problems related to its texture. It is made up of extremely fine black clayey material (called Montmorillonite). Black cotton soil is known for its capacity to soak up water. During the rainy season, black cotton soil becomes sticky, heavy, extremely slippery, and is difficult to till. It has the characteristic of retaining water unless it is almost saturated, which limits the growth of many crops. For cotton this is not a problem, which explains the name.

When absorbing water, its volume expands considerably. During the dry season it shrinks, becomes very hard and develops cracks. This swell and shrink is harmful for infrastructure constructions (roads, bridges). The internal drainage is imperfect. After heavy rains superficial waterlogging occurs frequently.

If tillage is necessary (zero tillage is recommendable), this can best be done immediately after the first rains as the soil loosens. Working the soil later will increase compaction (plow-soles). Black cotton soils usually have a high pH, but are low in phosphorus and organic matter. They are mostly found in the savanna areas in Africa, in Gujarat, Madhya Pradesh and Maharashtra in India, Queensland in NS Wales (Australia), Parana region South America and Mexico/Texas. Despite the name, they are not always black; sometimes they are deep red.



Figure 9. Typical cracking on black cotton soil and waterlogging on the surface after rains

⇒ **Recommendation:**

Heavy applications of compost manure/organic matter are necessary to improve the soil structure and to improve internal drainage. Black cotton soil is used for producing cotton, wheat, linseed, millets and oilseeds and some savanna-adapted tree crops (Acacias). Under proper irrigation, this soil can also produce rice and sugar cane.

⇒ **Recommendation:**

Avoid drying out of the soil by maintaining high organic matter levels, minimum till, mulching and the use of cover crops.

To manage nutrient levels avoid leaching, which will lead to a lowering of the pH and increased phosphorus fixation. Apply lime if necessary. Apply boron foliar feeds (spraying).



Step 5: Identification of erosion prone areas and slope

The processes that lead to the formation of the topsoil layer are countered by erosion. Soil erosion is broadly defined as the – often-accelerated – removal of the topmost layer through water, wind or tillage. The heavy loss of topsoil through erosion caused by poor human agriculture practices is recognized as an utmost threat to the world's soil resources, as the soil in many areas is eroding at a much faster rate than it is replaced by soil formation processes. Recognizing areas that are susceptible to soil erosion is necessary to develop and implement the best management measures for soil conservation.

Factors that lead to increased erosion are those that accelerate the rate at which soil particles are detached and transported from the soil layer. These are namely:

- Ferocity, meaning the force at which water (rain) and/or wind hits the area.
- Velocity, meaning the speed at which water or wind moves over the area.
- Holding capacity (sheer strength) of the soil, meaning the soil's ability to withstand the forces of wind and water.

Erosion increases where raindrops hit unprotected soil (splash erosion).

Slopes increase the speed at which rainwater flows off (hill erosion and gully erosion).

Torrential rains cause flooding of rivers (stream bank erosion).

Saturated soils cannot hold onto underlying layers and slip off due to their increased weight (landslide and sheet erosion), and erosion increases where small and loose soil particles are exposed to strong winds (wind erosion).

To avoid soil erosion it is important to identify any areas that might be prone to increased erosion due to the above-mentioned factors. These are namely:

- Exposed topsoil (uncovered by vegetation or organic matter layer).
- Slopes.
- Sealed areas where water percolation is reduced, and larger amounts of water run off.
- Seasonal high rainfall, or strong differences between dry and rainy seasons.
- Fast-flowing rivers and streams.
- (limited soil depth:)A relatively thin layer of topsoil on base rock or other impermeable underground.
- Unaggregated soils.
- Areas open to strong winds.
- Soil types particularly prone to erosion (explained below).

⇒ **Recommendation:**

Areas that exhibit any of these characteristics should be identified on a farm map to guide decisions regarding land use and soil management practices. This can be done on a hand-drawn map that indicates all manmade and natural key features and landmarks (water bodies, roads and tracks, buildings, protruding rocks, etc.), slopes and sloping level (%), altitude and/or GPS readings, vegetation or crop type, variations in soil type, areas showing signs of/or at risk of erosion or landslides, gullies, etc., problematic areas (low fertility, pest/disease issues, etc.), areas prone to flooding or waterlogging, and possibly soil sampling locations. These features can also be entered in an official area map or satellite image, if available. This area map should be used for management planning and decisions and updated regularly.

The factors leading to increased erosion can be mitigated by good agricultural practices:

- Trees provide a canopy cover that reduces the ferocity and the number of raindrops that hit the soil directly. They also contribute greatly to the holding capacity of a soil through their strong roots, which keep the soil in place. The planting of trees with different root systems, like *Leucaena leucocephala*, *Peltophorum pterocarpum*, *Melastoma malabathricum* and



Acacia mangium, can provide considerable soil protection, especially on slopes. Leaf litter from the trees should not be removed or burned but remain as a mulch cover that keeps the soil surface protected.

- Tilled land should not be left exposed to the forces of wind and rain but protected with a layer of vegetation (cover crop, grass, etc.) or an adequate mulch layer. Minimum till greatly reduces soil exposure.
- Vegetation slows down the water run-off and thereby increases the time for infiltration into the soil. The root system of vegetation also makes the soil more porous further aiding faster infiltration of water into the soil.
- Deforestation of and erosion promoting practices (over-grazing) in neighboring areas, especially at a higher altitude and along water streams, must be avoided.
- Up-and-down-slope plowing should be avoided. Even gentle slopes (3°) can accumulate significant amounts of run-off water and gather momentum if the slope is long and the infiltration rate is slow because of the soil type. Water will concentrate in lower lying areas/ridges along the slope and cause channel erosion.
- On significant slopes (slope >math>7^{\circ}</math>/15%), contour strip farming is advisable. If contour lines are secured through perennial plants (e.g. grass barriers) they need to be regularly inspected for possible breaks in the contour line through which run-off water would be funneled.
- Access roads should not be constructed in areas prone to erosion, as run-off speed will be increased and lead to gully formation.
- Before building construction and sealing off land through concrete surfaces, the danger for increased water collection, run-off, and river swelling for lower or down-stream lying areas should be assessed and – if necessary – mitigated through construction of drainage areas.
- Allowing rivers and streams to meander instead of straightening the riverbed will reduce their velocity. Planted banks have a higher holding capacity and also break the speed and force with which water floods surrounding areas. Vulnerable areas might need constructed barriers to protect newly planted banks.
- Gullies that have already started to form need to be secured by the construction of barriers and dams at the outflow end, and the planting of trees on the areas surrounding the gully edge.
- Crop rotation, fallowing, mulching and management of organic matter content in the soil will aid better aggregation of the soil and increase the soil's holding capacity.
- Lines of trees or hedges provide windbreaks and protect soils from wind erosion.

Andosols



Figure 10. Andosol

Andosols (sometimes called Andisols) are soils that are typically found in humid regions around the world on the slopes of mountains of volcanic origin. They are relatively young soils and rich in volcanic ashes. They are usually fertile, rich in potassium and other minerals (feldspars) and have a porous, crumbly topsoil layer often with a high organic matter content. But they are often low in phosphorus and boron. Phosphorus fixation is worsened by low pH and high aluminum and iron- levels.

Despite the high organic matter content these soils can still be very susceptible to erosion. On sloping terrain drainage is not an issue. However, where the groundwater table is high, they form gley layers. The erosion risk is very high where the soil has dried out after deforestation and has been dispersed into small particles. These are easily carried off with run-off water and wind.

⇒ Recommendation:

Andosols are often used for coffee (arabica varieties), tea and vegetables. The susceptibility to erosion means that cultivation on steep slopes requires well planned Sloping Agriculture Land use Techniques (SALT): contour planting, establishment of living barriers and use of deep-rooting trees for shade and extra care for areas where surface and/or ground water accumulates; protective vegetation along streams, etc.



Soil management plan

Based on the soil assessment, soil management measures are identified and included in the farm Management Plan to build up soil organic matter, prevent erosion, increase on-farm nutrient recycling and optimize soil moisture.

The Soil Assessment Matrix provided by RA can be used as guidance for these measures.

To be effective and successful, farm management decisions must be based on accurate information. It is necessary to inspect the farm regularly and to record any findings or changes to be able to make use of this information for future decision-making. To maintain soil fertility, it is necessary to avoid erosion and organic matter loss. It is also important to ensure the right kinds of nutrients are available in the needed amounts to grow a crop. The nutrient needs of the crop can best be established through a soil test, which provides information on the nutrient status of the soil as well as a recommendation for the input need (lime and fertilizer; see soil and fertility guidance document, 2.4.4).

⇒ **Recommendation:**

Farmers are strongly recommended to regularly assess the status of their soil, including the status of erosion or waterlogging-prone areas, the nutrient status as well as influences of climate change. To gain a better understanding of their soil, farmers are encouraged to investigate the nature of their soil through simple assessment methods. Soil pH can be measured regularly using simple and inexpensive on-farm gadgets. To ensure seasonal nutrient availability, soil tests need to be conducted preferably every three years.

References for more in-depth soil assessment methods:

Several different methods for soil assessment have been described and can be used by farmers without the need for expensive equipment. These include: Willamette Valley – Soil Quality Card; Shelley McGuinness – Soil Structure Assessment Kit; FAO – Visual Soil Assessment, VSA, etc. A video with instructions on how to test for soil type can be found here:

<https://youtu.be/GWZwbVJCNec>



Soil Assessment Matrix

The matrix below can be used as a quick and simple assessment tool for a soil's status. It provides short descriptions of three different states (poor, moderate, good) of a soil for various aspects that determine a soil's fertility/health status and the possible need for soil fertility/health management actions. Recommended action is described in the last column and can be used as guidance for the farmer to improve his or her soil's fertility status as well as a guidance for an inspector/auditor to assess the soil fertility management at farm level.

Indicator	Criteria for Rating			Recommended action for improvement
	1 (poor)	2 (moderate)	3 (good)	
Does the soil have good structure and tilth?	Compacted, massive clods or very powdery soil, no visible pores.	Some visible crumb structure, mix of small and big clumps.	Friable, crumbly, well aggregated into nut-sized particles showing visible pores.	Increase organic matter content by planting and incorporating cover crops, use of animal or compost manure, mulching, reducing cultivation.
Is the soil free of compacted layers/hard pans?	Plants show bent roots, probe inserted into the soil resists and/or bends.	Some difficulty to insert probe into the soil.	Probe can easily be inserted into the soil beyond 20cm.	Avoid cultivation with heavy equipment or cut the soil at the same level every year. Use minimum till and use ripper instead of plow. If possible, cover the soil with deeply rooted plants like alfalfa (<i>Medicago sativa</i>).
Has the soil the adequate pH for the crop?	Soil pH is 1 point or more below or above the ideal crop pH range.	Soil pH is within ± 0.5 point from the ideal pH range.	Soil pH matches the crop requirements.	50kg of lime is applied for every 50kg of ammonium-based fertilizer to maintain a stable pH. Adjust low pH soils with liming. Apply widespread and incorporate into the soil. Adjust high pH soils with use of ammonium and sulfate-based fertilizers.
Is the soil surface free of crusting?	Visible salt crust or lichens. Very smooth surface with no pores.	Crumbs have a smooth appearance; loose organic matter is washed up on the surface.	No visible crust. Crumbly surface with visible pores and integrated organic matter.	Conduct an EC test to determine salt levels in the soil. Amend saline soils with higher irrigation rates and gypsum applications. Increase soil organic matter content/mulch.
Are earthworms (and other microorganisms) present?	None.	1–5 per square meter of topsoil.	>5 per square meter of topsoil.	Increase Soil Organic Matter content, apply mulch, use green cover crops.



Soil Fertility Management Plan

Success in farming depends to a large degree on the soil fertility status of the farm. It is of utmost importance that a farmer is able to assess his or her soil's fertility status, can identify problematic areas, and lays out a plan not only to avert soil fertility loss through erosion and waterlogging, but also to improve soil fertility in problematic areas and to maintain soil fertility long-term through adequate soil fertility management measures and on-farm nutrient recycling.

⇒ Recommendation:

Farmers should be enabled to assess their soils' fertility status and know which soil fertility management measures will maintain and improve soil fertility. Ideally the soil or landscape particularities are recorded on a farm map and records kept on soil tests and soil fertility management actions (liming, compost or animal manure applications, fertilizer applications, mulching, etc.). However, where this is not possible the farmer should at least be aware of the status of his soils, and in particular any problematic areas, and should be able to narrate his mode of action to maintain or improve soil fertility.

Increase of soil organic matter (SOM) and on-farm nutrient recycling

The single most important soil fertility management action is the maintenance of soil organic matter (SOM) levels in the soil, as this improves the physical, chemical as well as biological features of the soil. It aids in erosion as well as waterlogging prevention and also improves plant health due to microorganism activity. Decomposition of organic matter is also the way in which nutrients are naturally returned to the soil. With every harvest, nutrients are exported from the soil and need to be replenished. Increased nutrient losses through burning or removal of organic matter must be avoided.

⇒ Recommendation:

All available organic matter sources on-farm should be used and recycled in the form of compost, animal manure, liquid manure or mulch. Organic matter should only be burned if diseased and unsuitable for recycling.



Mucuna pruriens (velvet bean) as cover crop, produces organic matter and fixes nitrogen



Mulch of *Mucuna pruriens* in dry season.



Alley cropping. Tree lines produce organic matter and reduce wind erosion.



Live barriers on slopes produce organic matter and reduce run-off erosion.



Agroforestry in coffee: leguminous trees and cover crop (*Arachis pintoj*).



Diversified agroforestry system in coffee.



Large-scale compost-making in a pineapple plantation.



Diversified agroforestry system in cocoa.

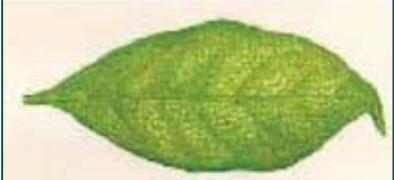


3. CROP SPECIFIC RECOMMENDATIONS

3.1 COFFEE RECOMMENDATIONS

Arabica and Robusta Coffee		
pH (H₂O) range	5.5-6.0	
Erosion control measures	Up to 15% slope: rows are planted across the slope. Ground covers are planted. Slope greater than 15%, contour planting must be undertaken. Areas prone to landslides or gulying are protected by planting trees like <i>Leucaena leucocephala</i> , <i>Peltophorum pterocarpum</i> , <i>Melastoma malabathricum</i> and <i>Acacia mangium</i> .	
Wind control measures	Planting of windbreaks along the boundaries only in areas exposed to strong winds, where natural forest is inadequate.	
Soil moisture control	Coffee trees are mulched with suitable materials. Mulch is kept away from the base of the plant to reduce the risk of disease. Mulch is re-applied at the end of each rainy season. Legume soil cover is planted between the trees. To increase water retention capacity of the soil organic matter levels of 1-3% are maintained.	
Waterlogging control	Soils are free draining with a minimum depth of 1m (preferably sandy-loam soils. Soils with a high silt content and heavy clay soils are avoided). Soil drainage capacity is maintained by regular organic matter applications.	
Growing conditions for arabica	Altitude	Above 1000m up to 2000m (frost line).
	Temperature	Optimum daily temperature: 15° - 24°C.
	Rainfall	>1200 to 1500mm annually evenly distributed over 7 months per year, with a dry, stress period afterwards to induce a uniform flowering.
	Slope	>15%.
Growing conditions for robusta	Altitude	200 – 900m.
	Temperature	24 to 30°C.
	Rainfall	1500-3000mm annually distributed over 9 months per year.
	Slope	Minimal slope > 7% slope.
Nutrient control	Ideally soils are tested once per year before flowering and the recommended type and amount of inputs is applied. For every 1t of green bean removed from the plants, appr. 40kg N, 2.2kg P and 53kg K must be replaced annually. Organic manure applications alongside inorganic fertilizer applications increase the uptake rate for nutrients.	
Threshold levels to avoid toxicities and EC disruptions: Na < 1.0 meq/100g Cl 250mg/kg EC <0.2dsm. Al < 0.04mmol dm ⁻³ (A problem especially under low pH conditions. Countered by lime applications.)		



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 <p data-bbox="204 629 603 678">Uniform yellowing over whole tree or light yellowing between the leaf veins.</p>	<p data-bbox="635 365 930 394"><u>Phosphorus deficiency</u></p> <p data-bbox="635 398 1038 622">Lower leaves (older) exhibiting slight yellowing, young leaves remaining darker green; faint yellowing between the veins of older leaves at advanced stages; small dead spots may be present.</p>	<p data-bbox="1070 271 1257 300">P 60-80mg/kg.</p> <p data-bbox="1070 331 1358 689">P-fixation is commonly found on red or yellow soils under low pH conditions. In that case slow-release P fertilizer (rock-phosphate) and lime applications are more efficient than DAP applications.</p>
 <p data-bbox="204 1055 563 1126">Localized dead tissue or yellowing between the veins on older/lower leaves.</p>	<p data-bbox="635 797 914 826"><u>Potassium deficiency</u></p> <p data-bbox="635 831 1023 1055">Initial yellowing on the leaf edges followed by development of dead spots. Dead tissue increases until the whole leaf edge is covered. The veins and midrib remain green.</p>	<p data-bbox="1070 909 1262 938">K > 0.75mg/kg.</p>
	<p data-bbox="635 1205 938 1234"><u>Magnesium deficiency</u></p> <p data-bbox="635 1238 1007 1503">Faint yellowing on older leaf edges with sunken, yellow-brown to light brown dead spots developing in a wide band along leaf edges; yellowing between veins evident in affected leaves, particularly along the midrib.</p>	<p data-bbox="1070 1323 1326 1352">Mg > 1.6meq/100g.</p>
	<p data-bbox="635 1547 938 1576"><u>Manganese deficiency</u></p> <p data-bbox="635 1581 1007 1727">Yellowing in older/lower or middle leaves; mottling, stippling between veins; necrotic spotting along main vein.</p>	<p data-bbox="1070 1603 1257 1632">Mn <50mg/kg.</p>
	<p data-bbox="635 1742 954 1771"><u>Molybdenum deficiency</u></p> <p data-bbox="635 1776 1038 1933">Bright yellow mottling between veins; leaves wither, curl and margins collapse; leaves distorted and narrow; older leaves affected first.</p>	<p data-bbox="1070 1760 1358 1951">Rare deficiency. Usually caused by low pH conditions. Recommended action: increase pH and SOM levels.</p>



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 <p>Uniform yellowing over whole leaf starting from the top.</p>	<p><u>Nitrogen deficiency</u> Leaves rapidly becoming pale green starting with the younger leaves and shoots. New leaves uniformly pale yellow-green with a dull green sheen. Entire plant becoming pale green, with sparse vegetative growth; whitish veins may be present in lower leaves.</p>	<p>N > 20mg/kg.</p>
	<p><u>Sulfur deficiency</u> Leaves light green to yellow-green, with faint yellowing between veins; deficient leaves retaining shiny luster. Whole plant may show symptoms.</p>	<p>S > 20mg/kg. Usually not a deficient nutrient on rain forest soils.</p>
 <p>Sharp yellowing between veins of youngest leaves.</p>	<p><u>Iron deficiency</u> Leaves expanding normally, with veins remaining green and clearly visible against the light green to yellow-green background; background becoming nearly creamy white at acute stages.</p>	<p>Fe 2 -20mg/kg.</p>
	<p><u>Zinc deficiency</u> Leaves not expanding normally; narrow, often strap-shaped; veins visible against a yellow-green background; failure of inter-node to elongate properly, giving plants a compact appearance.</p>	<p>Zn 2-10mg/kg.</p>
 <p>Bronzing, mottling or death of youngest leaves; dieback of terminal buds.</p>	<p><u>Calcium deficiency</u> Leaves bronzed along edges, cupped downward; new leaves dead; eventual dieback of shoot tips.</p>	<p>Ca 3-5 meq/100g.</p>



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
	<p><u>Boron deficiency</u> Youngest leaves light green, mottled, with uneven edges and asymmetric shape; new leaves with dead spots or tips.</p>	<p>B 0.5-1.0mg/kg. Boron deficiency is typical on volcanic soils, often found in coffee growing areas.</p>
 <p>Coffee trees with a wilting, drooping appearance.</p>	<p><u>Copper deficiency</u> Young leaves die back, chlorosis sets in; leaves curl and roll into S-shape, curving downward, starting from the bottom. Shoots are weak and restricted; may be rosetted.</p>	<p>Cu 0.3-10mg/kg Not a common deficiency if copper sprays are used for control of mildew, leaf rust or <i>Cercospora</i> leaf spot.</p>



3.2 TEA RECOMMENDATIONS

Tea (<i>Camellia sinensis</i> var. <i>sinensis</i> and <i>C. sinensis</i> var. <i>assamica</i>)		
pH (H₂O) range	4.5-5.0 (tea prefers acidic soil).	
Soil type	Tea does also well on any fertile soil, especially red soils as it tolerates high aluminum levels well. Soils should be free draining with a depth of about 1.0 to 1.5m, which nevertheless provides sufficient moisture throughout the year. Often established on cleared forest soil, which is naturally rich in humus. Maintenance of high soil organic matter levels is key to long-term productivity.	
Soil moisture control	Tea is sensitive to drought. To maintain water retention capacity soil organic matter levels of >3% are necessary. The space between trees must be mulched with suitable materials. Mulch is kept away from the base of the bushes to reduce the risk of disease. Pruning materials are used as mulch unless diseased. Instead of mulch, legume soil cover can be planted between the bushes for as long as the tea doesn't cast too much shade.	
Waterlogging control	Tea is sensitive to waterlogging. Fungal diseases are more prevalent on soils that have insufficient draining capacity. Planting on slopes to allow for easy drainage is common practice. Soil organic matter content is key for good drainage. Leaf fall from shade trees can provide sufficient levels of mulch, otherwise animal or compost manure applications are necessary.	
Shade control	Preferably established in close proximity to natural rainforest for a healthy microclimate and protection from strong winds. Tea is a forest plant and needs up to 50% shade. Interplanting with shade trees is recommended for healthy and high-quality crops. Smaller leguminous trees are established at 4 x 4 to 6 x 6m, while taller timber trees are planted at 10 x 10 to 12 x 12m in between the tea rows. During the establishment of a new plantation it is a must to protect plants from sun damage.	
Growing conditions for cocoa	altitude	800 - 2000masl
	slope	Some slope is needed to allow for good drainage. 15-25° = very highly suitable. Gentle slope (>5-7°) = highly suitable. Very steep slope" (>35°) unsuitable.
	temperature	16-30°C with an average temperature of 21-22°C during the growing season.
	rainfall	1250-2000 mm, well distributed over 8-9 months/year.
Nutrient control	Ideally soils are tested once per year before the main rainy season, and the recommended type and amount of inputs is applied. Depending on yield/ha for every ton of marketable tea produced on an average 178.3kg nitrogen, 3.5kg phosphorus and 115.1kg potash, 10kg sulfur, 41.4kg calcium and 11.5kg magnesium must be replaced annually ⁷ , split into 4-6 applications. Additional applications of @ 6-8kg zinc sulfate per ha are recommended. Organic manure applications alongside inorganic fertilizer applications increase the uptake rate for nutrients. From a yield of 3t/ha of marketable tea, CEC capacity (SOM) becomes a limiting factor.	

⁷ Fertilization rates need to be calculated by taking soil type, SOM levels, soil nutrient base levels and average loss rates into account. Average loss estimate: N = 30-70% (higher at higher temperatures, and if exposed to O₂ and H₂O), P = 50-100% (higher at low pH and high Al or Fe levels in the soil), K = 30%, Ca = 10%, Mg, Cu, Fe, Zn, B = 25%.



Threshold levels to avoid toxicities and EC disruptions:

EC <0.2dsm.

Tea is tolerant to high levels of Al in the soil. High Al levels in the soil even prevent Fe-toxicity.

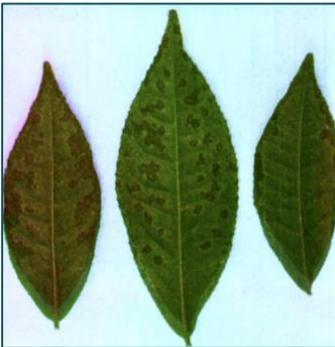
Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 <p>P-deficiency symptoms</p>	<p>Phosphorus deficiency Stunted plant growth and purple coloration on older leaves.</p>	<p>P 17mg/kg.</p> <p>Rock-phosphate applications are more efficient on soils with low pH.</p>
 <p>K-deficiency symptoms</p>	<p>Potassium deficiency Scorching due to chlorosis and necrosis occurring at the tip of the mature tea leaves and extends along the margin. Dominant purple/brown color and reduced leaf size are the common symptoms.</p> <p>Increases sensitivity to drought stress.</p>	<p>K > 0.4-0.6meq/100g.</p> <p>In soils with pH <4.0, the H⁺ and Al₃⁺ ions interfere with K uptake.</p> <p>K-deficiency is less acute where tea-pruning residuals are used as mulch.</p>
 <p>Mg-deficiency symptoms</p>	<p>Magnesium deficiency Yellowing of mature leaves followed by premature leaf fall.</p> <p>Mg-uptake is reduced under high N- and K-fertilization.</p> <p>Mg-uptake is also reduced on low-pH soils with a high Al-content.</p>	<p>Mg > 4-8meq/100g.</p> <p>N- and K-fertilization should be combined with Mg-fertilization.</p> <p>Sufficient Mg is needed under low shade conditions, e.g. during the years of tree establishment.</p> <p>Two applications of 100-150kg/ha magnesium sulfate are recommended per year.</p>



Symptoms first appearing on the younger leaves (upper part of the tree):

Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
	<p><u>Nitrogen deficiency</u> Yellowing of younger leaves. The leaves become rough, hard and reduce in size.</p>	<p>N >18mg/kg.</p> <p>Can occur after periods of drought or waterlogging.</p> <p>If ammonium fertilizer is used it needs to be covered with mulch to avoid losses. Raking in is only recommended if surface roots are not disturbed.</p>
	<p><u>Sulfur deficiency</u> Called "tea yellows".</p> <p>Leaves turn a bright yellow color while veins remain dark green.</p> <p>Entire plant appears shrunken. Under severe deficiency leaves may curl-up, edges and tips turn brown.</p>	<p>S <30mg/kg.</p> <p>Application of 20% of annual nitrogen in the form of ammonium sulfate.</p>
	<p><u>Iron deficiency</u> Young leaves become yellow in color; interveinal chlorosis.</p> <p>Can be induced by high Zn fertilization.</p>	<p>Fe >30 mg/kg.</p> <p>More likely on high pH soils.</p>



	<p>Zinc deficiency Plants show very short internodes. Young leaves become chlorotic, small and sickle shaped. Side shoots are stunted.</p> <p>May inhibit growth and decreases shoots production.</p> <p>Can be induced by a build-up of phosphorus after excessive phosphate fertilizer applications.</p>	<p>Zn 4-8mg/kg.</p> <p>Relatively frequent deficiency, especially on red soils.</p> <p>Zinc sulfate foliar application after plucking.</p>
 <p>Zn-deficiency symptoms</p>		
	<p>Calcium deficiency Downward curling followed by appearance of small spots on the lower surface of young leaves.</p>	<p>Ca 5-10 meq/100g.</p>
	<p>Boron deficiency New growth stunted, distorted and bunched up. Sometimes followed by necrosis on tips and margins.</p>	<p>B >0.5-1.0ppm (0.1 – 0.5ppm in leaf).</p> <p>Boron is best tested through leaf analysis as it is highly mobile in soil and the range between deficiency and toxicity is small.</p> <p>Boric acid foliar application.</p>



	<p><u>Copper deficiency</u> Young leaves become pale yellow.</p> <p>High levels of iron in the soil can lead to copper deficiency.</p>	<p>Cu 1-2mg/kg.</p> <p>Cu-deficiencies may occur after excessive N-applications.</p> <p>Copper sulfate foliar application.</p>
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Photo credit:

Royal Tasmanian Botanical Gardens in Hobart.

Directorate of Plant Protection Quarantine and Storage; N. H. IV, Faridabad, Haryana.

National Institute of Plant Health Management; Rajendranagar, Hyderabad, Telangana.

Department of Agriculture and Cooperation; Ministry of Agriculture, Government of India

U. Pethiyagoda & S. Krishnapillai.



3.3 COCOA RECOMMENDATIONS

Cocoa Recommendations		
pH (H₂O) range	6.5- 7.0. but can tolerate pH 4.5- 8.0.	
Soil type	<p>Predominantly grown on red laterite soils but can be grown successfully on a large variety of soils, but they must be hardpan and stone free to at least a depth of 1.5m to allow the cocoa's taproot to penetrate sufficiently deep.</p> <p>Often established on cleared forest soil, which is naturally rich in humus. Maintenance of high soil organic matter levels is key to long-term productivity.</p>	
Soil moisture control	<p>Cocoa plants are sensitive to drought and soil moisture deficiency. To maintain water retention capacity of the soil organic matter levels of >3% are necessary. The space between trees must be mulched with suitable materials. Weeds must not be burned but can be used as mulch. Mulch is kept away from the base of the plant to reduce the risk of disease. Mulch is re-applied regularly.</p> <p>Instead of mulch, legume soil cover can be planted between the trees for as long as the trees don't cast too much shade.</p>	
Waterlogging control	Cocoa will only withstand waterlogging for short periods. Soil organic matter content is key for drainage. Before leaf fall reaches sufficient levels, mulching and animal or compost manure applications are necessary.	
Shade control	Naturally cocoa grows in the understory of evergreen rainforest, where tall trees provide shade. Shading is necessary during the years of establishment. Cocoa can be interplanted with other commercial trees like papaya and banana. Shade can be reduced after three to four years. Windbreaks are often beneficial.	
Growing conditions for cocoa	Altitude	<1200masl.
	Temperature	Optimum daily average: 24°C. min. 15°C; max. 35°C, but fluctuation reduces yield.
	Rainfall	>1500 to 2000mm annually evenly distributed. Dry spells (<100mm/month) should not exceed three months otherwise irrigation is necessary. Cocoa yield is affected more by rainfall than by any other climatic factor.
	Relative humidity	80%-100% A hot and humid atmosphere is essential for the optimum development of cocoa trees.



Nutrient control	<ul style="list-style-type: none">• Ideally soils are tested once per year before the main rainy season, and the recommended type and amount of inputs is applied.• Depending on yield/ha for every 1t of dry bean harvested, 25kg N, 4-10kg P, 40-60kg K, 8-11kg Mg, and 5-9kg Ca must be replaced annually. The K-need can be lowered considerably if husks are composted and returned to the field. Generally, organic manure applications alongside inorganic fertilizer applications increase the uptake rate for nutrients.• Fertilizer applications should be split in 2-3 (before and after the main rainy season, or P before flowering, ½K plus other nutrients during flowering, and ½K during pod development).• In cocoa, leaves develop in “flushes”. Leaves from one flush will mature before the next flush occurs and nutrients for a flush of growth are moved up from the older leaves. In the case of low soil fertility, this can lead to defoliation of the lower part of the tree. Therefore, the degree of defoliation during flush growth can be used as an indicator for the soil fertility status.•
<p><u>Threshold levels to avoid toxicities and EC disruptions:</u> Cocoa has low tolerance to Cl and salinity. EC <0.2dsm. Al <0.7 mmol/kg (A problem especially under low pH conditions in acidic soils. Al toxicity reduces yield. Countered by lime applications.)</p>	



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
	<p><u>Phosphorus deficiency</u> Everything about the tree appears stunted, compressed and narrow.</p> <p>Paling starts from the tip and margins of older leaves, followed by interveinal paling of all leaves, sometimes with a red tint. Later tip and margins become necrotic and leaves might drop.</p> <p>Witches Broom disease seems to occur more often on P-deficient soils.</p>	<p>P 20-60mg/kg.</p> <p>P-deficiency leads to underdeveloped roots, leading to an aggravation of P-deficiency in the tree.</p> <p>P-fixation is commonly found on red or yellow soils under low pH conditions. In that case slow-release P fertilizer (rock-phosphate) and lime applications are more efficient than DAP applications.</p>
	<p><u>Potassium deficiency</u> The tree appears to have stopped growing.</p> <p>Yellowing starts from the tip and margins moving toward the leaf base with increased interveinal yellowing and necrosis on the edge. Later brown or necrotic spots appear. Old leaves drop with terminal dieback.</p>	<p>K >0.3 meq/100g.</p> <p>K-deficiency is common on newly cleared soils and requires high-level K-fertilization.</p> <p>K-deficiency is less acute where husks are composted and returned to the field.</p>
	<p><u>Manganese deficiency</u> Symptoms show all over the tree. Light green to yellow interveinal chlorosis, with veins remaining dark green.</p>	<p>Mn 4-20mg/kg.</p> <p>Manganese fertilization has shown to also increase molybdenum uptake.</p>



Symptoms first appearing on the older leaves (lower parts of the tree)

Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
	<p><u>Magnesium deficiency</u> Interveinal yellowing in stark contrast to the veins that remain green. Later yellow areas turn brown. Symptoms can be confused with K-deficiency, but leaves are not dropped as in K-deficiency.</p>	<p>Mg >1.5 meq/100g.</p> <p>High K-fertilization (which might be necessary on K-deficient soils), can suppress Mg-uptake. Therefore K-fertilization should be combined with Mg-fertilization.</p> <p>Sufficient Mg is needed under low shade conditions, e.g. during the years of tree establishment.</p>
	<p><u>Molybdenum deficiency</u> Bright yellow mottling between veins; leaves wither, curl and margins collapse; leaves distorted and narrow; older leaves affected first.</p>	<p>Rare deficiency. Usually caused by low pH conditions. Recommended action: increase pH and SOM levels.</p> <p>Manganese fertilization has shown to also increase molybdenum uptake.</p> <p>Depending on the crop species, the critical deficiency levels of Mo vary from 0.1 to 1 mg/kg.</p>



Symptoms first appearing on the younger leaves (upper part of the tree)

Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
	<p><u>Nitrogen deficiency</u></p> <p>Tree appears to be drooping and stunted.</p> <p>Leaves uniformly pale or yellow including the veins and smaller in size, later showing signs of necrosis.</p>	<p>N >20mg/kg.</p> <p>Can occur after periods of drought or waterlogging.</p> <p>If ammonium fertilizer is used it needs to be covered with mulch to avoid losses. Raking in is only recommended if surface roots are not disturbed.</p>
	<p><u>Sulfur deficiency</u></p> <p>Entire tree appears pale, but not stunted.</p> <p>All leaves become blotchy with pale or yellow spots, Veins appear pale.</p>	<p>S 30-50mg/kg.</p> <p>Usually not a deficient nutrient on rainforest soils. Rather rare deficiency in cocoa.</p>
	<p><u>Iron deficiency</u></p> <p>Young leaves turn whitish pale with veins remaining dark green.</p>	<p>Fe >30 mg/kg.</p> <p>More likely on high pH soils.</p>
	<p><u>Zinc deficiency</u></p> <p>Younger leaves appear narrow and wavy, called "little leaf" symptom.</p> <p>Leaves might show chlorosis and mottling, remaining green only along the veins, which might take on a reddish tint.</p> <p>Leaves might show crinkling; shortening of internodes causes a</p>	<p>Zn 2.5-4mg/kg.</p> <p>Relatively frequent deficiency, especially on red soils.</p>



	rosette type of growth, twigs might die back.	
	<p>Calcium deficiency Younger leaves appear striped and wavy.</p> <p>Starting from the margins, then developing into uniform yellowing of younger leaves, with areas between the veins becoming necrotic.</p> <p>Leaves and pods eventually drop, shoot tips and buds die.</p>	<p>Ca >7.5 meq/100g</p> <p>Adequate Ca reduces susceptibility to diseases.</p>
	<p>Boron deficiency New growth distorted and bunched up. Sometimes followed by necrosis on tips and margins.</p>	<p>B >25ppm (in leaf).</p> <p>Boron is best tested through leaf analysis as it is highly mobile in soil and the range between deficiency and toxicity is small. Boron is best applied as a foliar spray.</p> <p>Boron deficiency is typical on volcanic soils, often found in coffee growing areas.</p>
	<p>Copper deficiency Leaf tips appear chlorotic, scorched and distorted.</p> <p>Younger leaves are generally smaller with no apparent yellowing.</p>	<p>Cu 0.3-10mg/kg</p> <p>Cu deficiencies may occur after excessive N-applications.</p>



3.4 BANANA RECOMMENDATIONS

Banna (Musa cultivars)		
pH (H₂O) range	5.5-6.5 but tolerate ph of 4.5-7.5	
Soil type	Can be grown successfully on a large variety of soils, but soils should be fertile, well-draining with good water retention capacity. Soils should also be rich in K and Mg. Soil depth should be >60cm.	
Soil moisture control	Bananas are very sensitive to drought and soil moisture fluctuations. To maintain water retention capacity of the soil organic matter levels of >3% are necessary. The planting pit around the plant must be mulched with suitable materials. Mulch is re-applied regularly. During weekly pruning withering leaves are cut off and added to the mulch cover. Soil moisture content should never fall below 60-70%.	
Waterlogging control	Bananas can withstand waterlogging for up to 48 hours. Prolonged stagnant water especially if coupled with full sun however kills the plants. To ensure sufficient drainage high levels of soil organic matter or coarse soil particles (like sand, gravel) are important. On heavy clay soils additions of organic manure and mulch are mandatory.	
Wind control	Bananas are susceptible to wind damage and therefore should not be grown in exposed sites. Otherwise windbreaks have to be established for protection. If bamboo is used for windbreaks the poles can also be used as support stakes. At wind speed >40km/h severe crop damage occurs.	
Growing conditions for cocoa	altitude	<1 600 masl.
	temperature	Optimum daily average for foliar growth: 27°C with a minimum temperature of 15°C and a maximum temperature of 38°C. Some cultivars can withstand temperatures near 0°C. Optimum temperature for fruit development: 29-30°C. Flower emergence is negatively affected by low temperature. Bananas can be grown in full sun if grown in an area protected from wind. High light intensity combined with high temperatures can cause sunburn.
	rainfall	>2,500mm annually evenly distributed. If steady water supply of at least 200-220mm/month cannot be guaranteed irrigation is necessary.
	relative humidity	60-90%.



Nutrient control	<p>Ideally soils are tested once per year before the main rainy season, and the recommended type and amount of inputs is applied.</p> <p>Nutrient levels can also be monitored through leaf analysis, sampling the third youngest leaf. The following levels in DM% are considered adequate: N 2.6, P₂O₅ 0.45, K₂O 4.0, CaO 1.40, and MgO 0.60.</p> <p>Depending on yield/ha for every 1t of banana harvested, 4-7 kg N, 0.9-1.6kg P, 18-30kg K, 1.2-3.6kg Mg, and 3-7.5kg Ca and 0.4-0.8kg S must be replaced annually for Cavendish bananas; up to 10 kg N, 3.5kg P, 60kg K, 1.2-3.6kg Mg, 12kg Ca and 0.4-0.8kg S must be replaced annually for other types of bananas.</p> <p>The K-need can be lowered considerably, if after harvest remaining plant material is chopped up and applied as mulch in the planting pit. Generally organic manure applications alongside inorganic fertilizer applications increase the uptake rate for nutrients.</p> <p>N-fertilizer should be applied monthly to ensure sufficient continuous supply. 80% of the K-fertilizer should be applied before flowering. The N:K ratio as established by leaf analysis should be 1:1 to avoid "finger drop".</p> <p>To provide sufficient nutrients supply to the main stem, suckers have to be removed every 6-12 weeks, leaving not more than 3-4 stems per planting pit.</p>
<u>Threshold levels to avoid toxicities and EC disruptions:</u> EC <1.5dsm. Na 100ppm; Cl <1%	



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 	<p><u>Phosphorus deficiency</u></p> <p>Extremely stunted growth. Leaves appear bluish-green with older leaves showing necrosis along the midrib and margins. Flowers turn purple-brown.</p> <p>Under severe deficiency leaves curl and petioles break. Eventually it can lead to premature plant death.</p>	<p>P 25 mg/kg (80ppm).</p> <p>P-fixation is commonly found on red or yellow soils under low pH conditions. In that case slow-release P fertilizer (rock-phosphate) and lime applications are more efficient than DAP applications.</p> <p>In case of deficiency apply 50g of rock-phosphate per planting pit.</p>
  	<p><u>Potassium deficiency</u></p> <p>Growth is reduced. Margins become necrotic and leaves tear easily in the wind. Eventually the entire leaf dries up. Leaf tips seem to be hanging down with the midrib appearing to be broken. The corm becomes less firm.</p> <p>Fruits are small and yellow prematurely. Bunches have a bad shape and are poorly filled.</p>	<p>K 200-350mg/kg (0.5meq/100g).</p> <p>K-deficiency is common on newly cleared soils and requires high-level K-fertilization. K is considered the most important nutrient in banana production.</p> <p>K-deficiency is less acute if after harvest the remaining plant parts are chopped up and used as mulch around the plant.</p> <p>Estimated annual soil losses through fruit removal per ha: 480 kg of K₂O (with a production of 70 tons of fruit).</p> <p>In case of deficiency apply weekly foliar feed of 2% potassium chloride (KCl).</p>



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 	<p><u>Phosphorus deficiency</u></p> <p>Extremely stunted growth. Leaves appear bluish-green with older leaves showing necrosis along the midrib and margins. Flowers turn purple-brown.</p> <p>Under severe deficiency leaves curl and petioles break. Eventually it can lead to premature plant death.</p>	<p>P 25 mg/kg (80ppm).</p> <p>P-fixation is commonly found on red or yellow soils under low pH conditions. In that case slow-release P fertilizer (rock-phosphate) and lime applications are more efficient than DAP applications.</p> <p>In case of deficiency apply 50g of rock-phosphate per planting pit.</p>
 	<p><u>Magnesium deficiency</u></p> <p>Leaf chlorosis with typical "banding" along the leaf margin and the midrib. Petioles show purple mottling.</p> <p>Fruits do not ripen well and are tasteless.</p>	<p>Mg 1-3 meq/100g.</p> <p>(In heavy soils values of 5meq/100g are considered adequate.)</p> <p>Apply small amounts of dolomitic lime throughout the growth period.</p> <p>In case of deficiency apply 3t/ha dolomitic lime.</p>



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 	<p><u>Phosphorus deficiency</u></p> <p>Extremely stunted growth. Leaves appear bluish-green with older leaves showing necrosis along the midrib and margins. Flowers turn purple-brown.</p> <p>Under severe deficiency leaves curl and petioles break. Eventually it can lead to premature plant death.</p>	<p>P 25 mg/kg (80ppm).</p> <p>P-fixation is commonly found on red or yellow soils under low pH conditions. In that case slow-release P fertilizer (rock-phosphate) and lime applications are more efficient than DAP applications.</p> <p>In case of deficiency apply 50g of rock-phosphate per planting pit.</p>
  <p>Manganese deficiency</p>	<p><u>Manganese deficiency</u></p> <p>Young leaves show chlorosis around the margins, later turning necrotic. Overall pale and striated appearance.</p> <p>Fruits show raised black/brown spots.</p>	<p>Mn 160-2500 ppm.</p> <p>In case of deficiency apply weekly foliar feed of 2% manganese sulfate (MnSO₄).</p>
<p><u>Molybdenum deficiency</u></p>	<p>Rare deficiency. Usually caused by low pH conditions. Recommended action: increase pH and SOM levels.</p>	



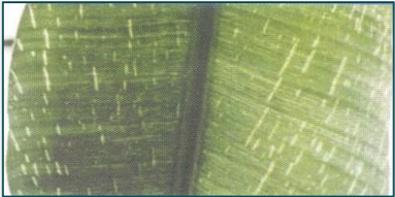
Symptoms first appearing on the younger leaves (upper part of the tree):

Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 	<p><u>Nitrogen deficiency</u> Reduced and slow growth and fewer and smaller leaves. Petioles are thin, short and purple. Entire plant appears pale and yellowish. Reduced sucker production and smaller bunch size due to reduced leaf surface. Excess N (due to high rates of urea application) leads to scorching of the petioles.</p>	<p>N 3.3-3.7 mg/kg.</p> <p>Constant supply of sufficient N is needed to promote healthy plant and leaf growth. Bunch size largely depends on the number and size of leaves produced during the first six months.</p> <p>In case of deficiency apply weekly foliar feed of 2% urea.</p>
 	<p><u>Sulfur deficiency</u></p> <p>Entire plant appears pale yellow and wrinkled. The leaf center turns white. Leaf tissue is very soft and tears easily.</p>	<p>S >0.25 mg/kg.</p> <p>In case of deficiency apply 100g ammonium sulfate (NH₄)₂SO₄ per planting pit.</p>



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 	<p><u>Iron deficiency</u></p> <p>Young leaves turn pale with dark green stripes (interveinal chlorosis).</p>	<p>Fe >100ppm</p> <p>More likely on high pH soils.</p> <p>In case of deficiency apply weekly foliar feed of 0.5% iron sulfate (FeSO₄).</p>
 	<p><u>Zinc deficiency</u></p> <p>Deficiency appears in young plants. Leaves remain short, are pale, narrow and pointed.</p>	<p>Zn >20ppm</p> <p>Relatively frequent deficiency, especially on red soils.</p> <p>Apply 50g of zinc sulfate (ZnSO₄) per plant at planting.</p>



Deficiency symptoms	Deficient nutrient	Optimum nutrient level in the soil
 	<p><u>Calcium deficiency</u></p> <p>Growth is stunted. Young leaves show thickened veins and chlorosis. Margins eventually necrotic. Leaves split and curl from the tip.</p>	<p>Ca 4-15meq/100g</p> <p>In case of deficiency apply 250kg/ha agricultural lime.</p>
 	 <p><u>Boron deficiency</u></p> <p>New growth distorted and bunched up. Leaf formation is incomplete and leaves don't unfold fully. Leaves may display white stripes. Flowering and fruiting is reduced. Fruits may also be distorted and split.</p> <p>B 1 ppm</p> <p>Boron is best applied as a foliar spray.</p>	 <p>Boron deficiency is typical on volcanic soils.</p> <p>In case of deficiency apply foliar feed of 20g borax (boric acid) per banana plant four and five months after planting.</p>



 A photograph of a plant showing signs of molybdenum deficiency. The leaves are drooping and appear smaller and more yellowish-green compared to healthy plants.	<p><u>Molybdenum deficiency</u> Plants have a droopy appearance with smaller leaves and shorter petioles.</p>	<p>Cu 9ppm</p> <p>Cu deficiencies may occur after excessive N-applications.</p> <p>In case of deficiency apply foliar feed of 2% copper sulfate (CuSO₄).</p>
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Photo credits:

Haifa Group.
Mauli Agro, Maharashtra, India.