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Banana-coffee system cropping guide



Lydia Wairegi, Piet van Asten, Ken Giller and Thomas Fairhurst

Africa Soil Health Consortium: *Banana–coffee system cropping guide*

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When coffee and bananas are competing for nutrients and water, bananas generally suffer more. But under good management, coffee benefits from the shade and mulch from bananas. That's why Professor J.Y.K Zake (a soil scientist based in Uganda) said "...take care of your bananas, and your bananas will take care of your coffee..." as bananas seem to be the weaker link in the system.

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1. Introduction

This guide is designed for people working with smallholder farmers, including extension workers, grass-root NGOs and community-based organizations.

This version has benefited from review by potential users which highlighted the need for a simpler and more user-friendly content for use by extension workers.

The guide provides essential technical information that will help farmers to select the most appropriate methods to manage fields intercropped with banana and coffee.

The importance of banana and coffee crops in Africa cannot be overstated. From the highlands of East Africa to the humid forest zone of West Africa and the lowlands of Central Africa, banana is a key staple food and an important source of income for farmers who trade in local, national or regional markets. By contrast, coffee is a major cash crop for export, making significant contributions to national economies. About 30% of the world's banana and plantain, and 11% of the world's coffee are grown in Africa.

The vast majority of smallholder farmers in regions where these crops are grown in Africa work with less than 2 hectares (ha) of land. These smallholders need to find ways to increase yields by intensifying crop management of both banana and coffee in their limited land holdings.

In a banana–coffee cropping system, the banana provides shade for coffee that is beneficial in reducing stresses caused by extreme temperatures and strong winds. Coffee trees grow well under moderate shade (less than 50%), which can help improve and stabilize coffee yield and quality. Shade helps to reduce the occurrence of overbearing dieback in coffee and also reduce yield losses caused by drought.

The banana also provides mulch and the soil cover that benefits both crops. The mulch improves root development in both banana and coffee, and improves availability of potassium (K) in the topsoil, due to the large biomass turnover. The permanent canopy and root systems of banana reduce soil losses due to erosion and surface wash by reducing the impact of rainfall on the topsoil.

Bananas and coffee can grow well together, but optimizing conditions for both crops requires careful management in order to avoid excessive competition for light, water and nutrients between the two crops.

In several parts of East Africa, smallholder farmers have already discovered the benefits of growing bananas and coffee intercropped together in the same field. Nonetheless, the practice did not receive much attention from researchers, until recently. This prevented extension officers helping farmers to adopt the practice in a sustainable and productive manner.

This guide describes how to intercrop banana and coffee in a productive, profitable and sustainable way.

For a glossary of words and phrases used in the guide see Section 10.

2. Banana and coffee intercrop systems

2.1 Distribution of the banana-coffee system

Banana and coffee are important crops in East, Central and West Africa (Figure 1).

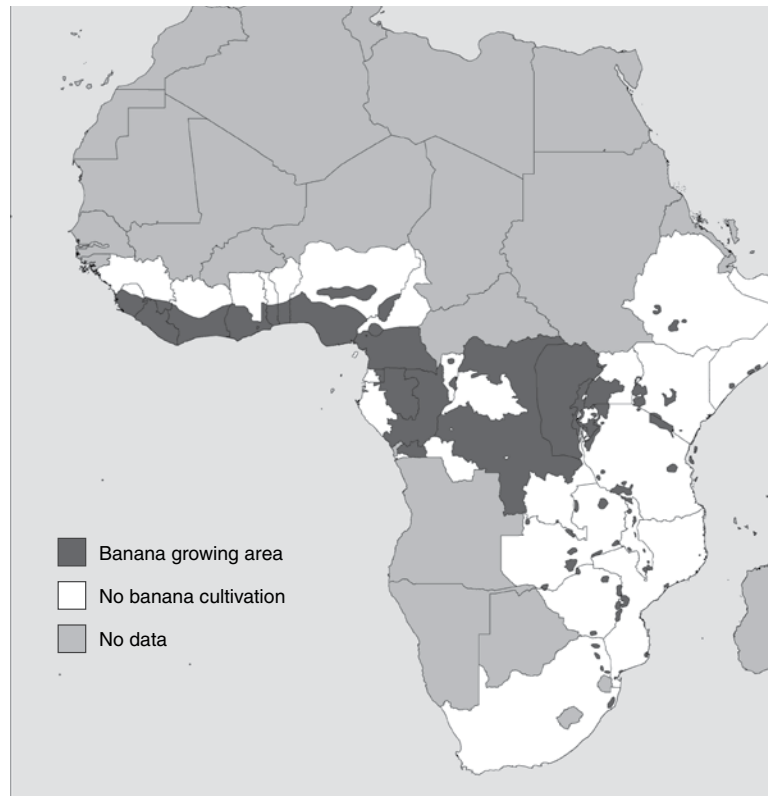


Figure 1. Map showing the distribution of banana–coffee systems in sub-Saharan Africa.

Banana and coffee are both commonly grown as monocrops, but in densely populated regions of Uganda and Tanzania more than half the farmers now grow them together in the same field as an intercrop (Photo 1).



Photo 1. Banana and coffee grown together as an intercrop. (Image: Piet Van Asten, IITA).

2.2 Advantages and disadvantages of intercropping banana and coffee

The main advantage of intercropping banana with coffee is that the system is usually more profitable and resilient than the production of either crop grown as monocrops.

Banana provides the coffee with shade, which reduces stress on coffee due to wide variation in temperature within the coffee leaf canopy and wind damage. Young coffee trees grow well when grown under shade, and shade improves coffee yield and bean quality in mature coffee when moderate amounts of mineral fertilizer are used. Shade can also prevent or at least minimize the incidence of the condition overbearing dieback in coffee. Permanent shade is particularly important for Arabica coffee, especially when fertilizer use is erratic.

The banana also provides mulch to the cropping system. The mulch supports good root development for both the banana mats and the coffee trees and can improve the availability of potassium (K) in the topsoil, due to the large biomass turnover.

The leaf canopy, root system and mulch provided by banana help to minimize soil losses and improve soil moisture conservation.

Intercropping reduces the risk faced by farmers when cultivating monocrops. For example, it is unlikely that both crops will be affected at the same time by pests, disease, or drought stress and market prices for both crops are generally unlikely to 'crash' simultaneously

Growing bananas in young coffee plantations also ensures that the farmer gets some returns from the land before the coffee reaches the productive stage.

Bananas and coffee can grow well together, but establishing the best conditions for both crops require careful management of the soil and crop leaf canopies. For example, if the shade provided by banana is too dense (more than 50%), coffee yields may also be reduced. Conversely, the yield of bananas will be small if there are only a few banana mats and coffee may be insufficiently shaded leading to overbearing dieback. Robusta may even compete with banana so aggressively that the banana population decreases until banana yields are insignificant.

There is also a strong interaction between shade and fertilizer use in coffee production (Table 1). Coffee can produce high yields without shade when large amounts of mineral fertilizer are applied. Fertilizer inputs will only have a limited effect on yield if coffee is densely shaded but if fertilizer is not applied to unshaded coffee, the trees may initially yield well but later many branches will die back. This is called 'overbearing dieback' (Table 1).

Table 1. Effect of shade and fertilizer inputs on yield and yield stability in coffee

	Yields with shade	Yields without shade
If soil is good, and fertilizer is used	Moderate and stable	Good
If soil is not good, and fertilizer is not used	Moderate and stable	Poor, unstable

The basic principles for managing the interactions between shade and fertilizer on coffee production are:

- Where soil fertility is poor, coffee grown under shade often yields better and is a more resilient system (i.e. plantation life is longer and production more stable) than coffee grown without shade.
- If shade is too dense the yield potential of coffee is reduced and the coffee will respond poorly to fertilizer. Adding fertilizers to coffee that is heavily shaded is not recommended because the increase in coffee yield may not be sufficient to cover the investment in fertilizer. Reducing the number of bananas to reduce shade can improve the benefits of fertilizer in such fields.

Overall, the major advantage of properly managed banana–coffee intercrops is that there is increased productivity and revenue per unit area of land (Table 2). Return to labour is also often higher in banana–coffee systems because less labour is required when the crops are grown together than the same area of monocrops. The advantage of intercropping compared with monocropping is greater in Arabica–banana compared with Robusta–banana system.

Table 2. Yield (fresh fruit for banana, green bean for coffee), and revenue of monocropped and intercropped banana and coffee, in Arabica and Robusta growing regions in Uganda

	Cropping system		Arabica growing region		Robusta growing region	
			Coffee	Banana	Coffee	Banana
Yield (t/ha/year)	Monocrop	Coffee	1.2		1.3	
		Banana		15		15
	Intercrop	Banana-coffee	1.2	20	1.1	9
Revenue (US dollars)	Monocrop	Coffee	2200		1300	
		Banana		1500		1000
	Intercrop	Banana-coffee	2200 + 2000 = 4200		1100 + 600 = 1700	

2.3 Banana and coffee types

The many types of banana grown in Africa can be grouped according to how the fruit is used, i.e. cooked, roasted, processed for juice or eaten as a dessert fruit (Photo 2). The cooking banana is common in the East African highlands while the roasting banana (or plantain) is more prevalent in West Africa and parts of Central Africa. In this pocket guide, the term banana is used to refer to all types of bananas and plantains, except where it is necessary to refer to a specific type.

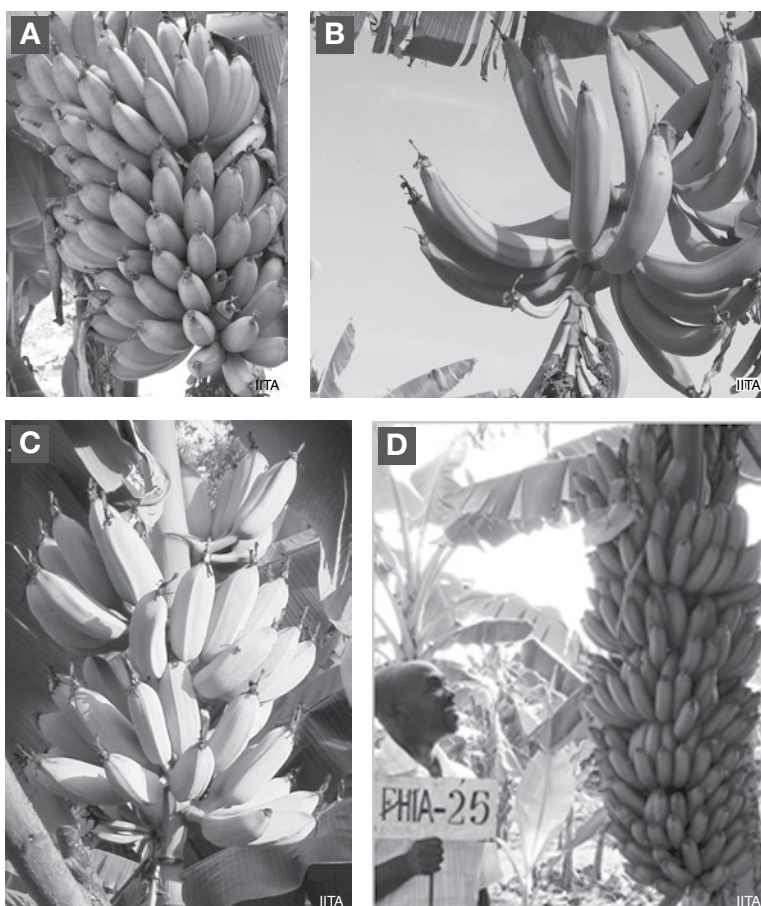


Photo 2. Banana types. **(A)** The highland cooking banana, a major food and cash crop in East Africa. Sale of bunches contributes to export of nutrients from the farm. **(B)** Plantain common in West Africa. **(C)** Beer banana used to brew beer for household consumption and the local market. **(D)** FHIA 25, a cooking banana that is highly resistant to black sigatoka and produces large bunches, produced by the Honduran foundation for Agricultural Research.

Two types of coffee are commonly grown: Arabica coffee and Robusta coffee. The market price of Arabica coffee is higher than for Robusta because it has more refined taste characteristics that give it a more favoured place in the market.

Arabica coffee requires a cooler climate and is therefore grown at higher altitudes (typically 1,000-2,000 masl) than Robusta (below 1,500 masl) (Table 3). Both Arabica and Robusta coffee can be grown in association with banana.

Table 3. Agro-ecological conditions in production areas for banana–coffee systems in sub-Saharan Africa.

System	Zone	Percentage of cultivated area used for banana–coffee systems			Rainfall mm	Altitude masl	Length of growing period days
		West	Central	East			
Banana-Robusta	Sub-humid	16	29	16	1000-1500	<1500	180-270
	Humid	10	59	2	>1500	<1500	>270
Banana-Arabica	Highlands*	0	4	12	>1000	>1500	-

*Defined as those areas in the semi-arid, sub-humid and humid zones of SSA where, because of higher altitude, mean daily temperature during the growing period is <20°C.

2.4 Banana and coffee plants

Banana plants

Although the banana plants grow very large they are actually monocotyledonous (i.e. like maize, sugarcane and grasses) and have no woody parts. They have an underground stem called a corm at the base of the plant. What looks like the stem is actually a pseudostem or ‘false stem’, made up of overlapping leaf sheaths.

Bananas generally flower between 8–16 months after sucker planting and the first harvest matures 3–4 months later (Table 4). Farmers must therefore wait 11–20 months from planting suckers until the first harvest of banana fruit. The banana crop cycle duration is generally longer for taller varieties and in cooler climates found at higher altitude.

Table 4. Timing of key physiological events in banana–coffee intercrops.

	Description	Timing	Duration
Banana			
Flowering	Production of leaves stops, flowering stalk emerges.	8–18 months after the sucker is planted.	
Bunch filling	Finger length increases, then finger diameter expands.		3–4 months
Coffee			
Flowering	Flower buds open.	2–3 years after planting.	
Pinhead	Minimal growth of fruit.		2–3 months
Soft green	Expansion, rapid swelling of fruit.		2–4 months
Hard green	Filling of beans, beans reach maturity.		4–7 months
Ripening	Pulp swells and turns from green to red colour.		Berries ready for harvest 6–8 (Arabica) and 9–11 (Robusta) months after flowering.

Only one bunch of bananas is produced on each pseudostem, after which the mother plant dies. It should be cut back at soil level and the pseudostem cut into pieces and spread over the soil surface to provide a mulch layer and prevent proliferation of banana weevils.

As the planted sucker grows to become the mother plant, other suckers develop from its corm to form a 'banana mat' (or family of banana plants) (Figure 2). The best daughter sucker must be selected in each mat and is retained to replace the mother plant that is felled at harvest. Other suckers are removed to prevent overcrowding.

A sucker that is growing from a mother plant gets some nutrients from the mother, especially if the mother has not yet flowered. After flowering, however, the flow of sugars and nutrients from the mother plant to the sucker is reduced because the mother starts to divert all the products of photosynthesis to feed the developing fruit bunch.

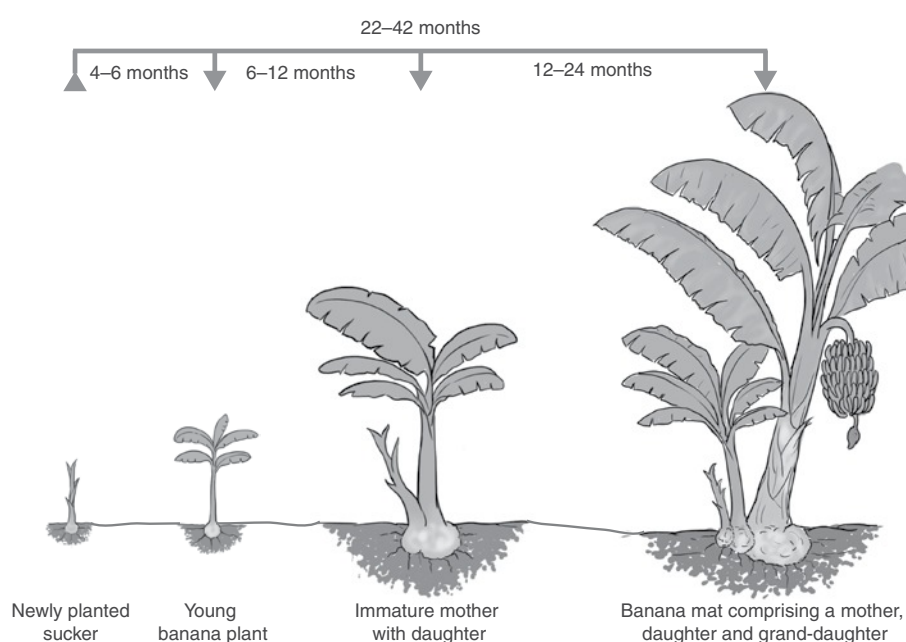


Figure 2. Evolution of banana mats from planted suckers to mature mats.

By the time the bunch from the 'mother' stem is ready for harvesting, the mat should have two other young plants of different ages, i.e. a 'daughter' and a 'granddaughter' (Figure 2; Photo 3). After the mother has been harvested, another sucker is selected from the granddaughter, so that three plants of different ages are maintained on each mat at any time.



Photo 3. Each banana mat should have three generations of plants i.e. mother, daughter and granddaughter to ensure bunch harvests are regular, the mats do not die-out the desired banana population is maintained.

The period between harvests within a mat depends on the speed with which follower suckers develop and mature and is influenced by the timing of sucker selection, rainfall and soil fertility status, among other factors. With good soil and crop management, a mat can produce a bunch in 10-12 months. With a population of 740 mats/ha, intercropped bananas have a yield potential of about 960 bunches/ha/year. Bunch weight ranges from 30–50 kg so the yield potential from bananas in an intercropped field ranges from 29–48 t/ha/year.

In a new banana field, the first generation of planted bananas will reach maturity and harvest at about the same time. After three to four cycles (i.e. after about three years), however, plants mature at different times during the year and, as a result, crop production is a continuous process.

Bananas flower more and initiate larger bunches in the wet season compared with the dry season and this explains pronounced seasonality of production in areas where there is a distinct wet season.

Not surprisingly, banana prices are lowest during the peak production period, when there is a glut in the market, and highest when bunches are scarce during the low crop period. So, selection of follower suckers should depend on farmer's objectives:

- If production is for the market, suckers that will mature during peak price periods should be selected.
- If production is for household food, focus should be to make sure that the plantation produces bunches throughout the year.

Roots of banana grow from the corm and vary from 50–200 cm in length. Most of the roots are found in the surface of the soil up to a depth of 30 cm (Photo 4) and a dense network of roots develops directly under the mulch.



Photo 4. Fertilizer should be placed close to the soil surface where most roots and care should be taken when carrying out management practices like weeding so as not to damage the roots.

Coffee plants

Generally, coffee produces the first crop 3-4 years after planting although some of the new selections start producing about a year earlier (Table 4). For example, clonal Robusta coffee established from cuttings produces the first yield about two years after field planting.

Coffee plants flower about a week after the start of the rainy season, resulting in two harvests in regions close to the equator with bimodal rainfall. For example, in west Uganda, where rains occur in April-May and September-November, the main crop is harvested in April-June and the fly-crop in October-January

Coffee berries are harvested 6-8 months after flowering in Arabica coffee and 9-12 months after flowering in Robusta coffee (Figure 3). Yield increases with each harvest and stabilizes at about the fifth year after planting, provided proper pruning is carried out each year.

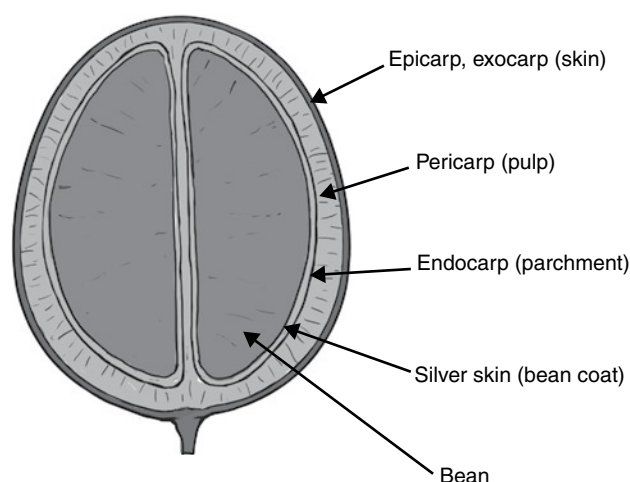


Figure 3. Coffee green beans are enclosed in several layers that comprise the harvested berry.

Like banana, coffee has a shallow root system with most of the feeder roots found in the surface 20 cm of soil. Most of the roots of coffee bushes are found around 60-90 cm (Arabica) and 150 cm (Robusta) from the base of each coffee bush.

In contrast with plants raised by vegetative propagation (clonal), coffee grown from seed develops a central tap root, which penetrates to a depth of 0.5–1.0 m, and sometimes reaches a depth of >4 m. Plants with a tap root can scavenge for water more effectively when the water table drops during the dry season. For this reason, when planting seedlings (particularly where the tap root has bent upwards in seedlings raised in polybags) the tap root should be straightened gently so that the tap root grows downwards. The tap root will not penetrate deep into the soil if the seedling is planted with a ‘hooked’ tap root. Do not cut the tap root – it is not replaced!

Robusta has more above-ground biomass and a denser root system, and therefore competes more strongly with banana than Arabica coffee. For this reason, the plant population of Robusta coffee in banana–coffee intercroops is smaller at about 1100 trees/ha compared with Arabica which is planted at about 2200 trees/ha in intercroops).

As we shall see, to maintain banana yields in banana–coffee systems, the coffee must be correctly spaced and pruned to minimize competition from the coffee trees. Insufficient and incorrect pruning is a very common problem in banana–coffee intercroops.

Correct timing, frequency, and sequencing of operations (e.g. pruning coffee trees after the harvesting season) are crucial for successful management of banana–coffee systems (Figure 4).

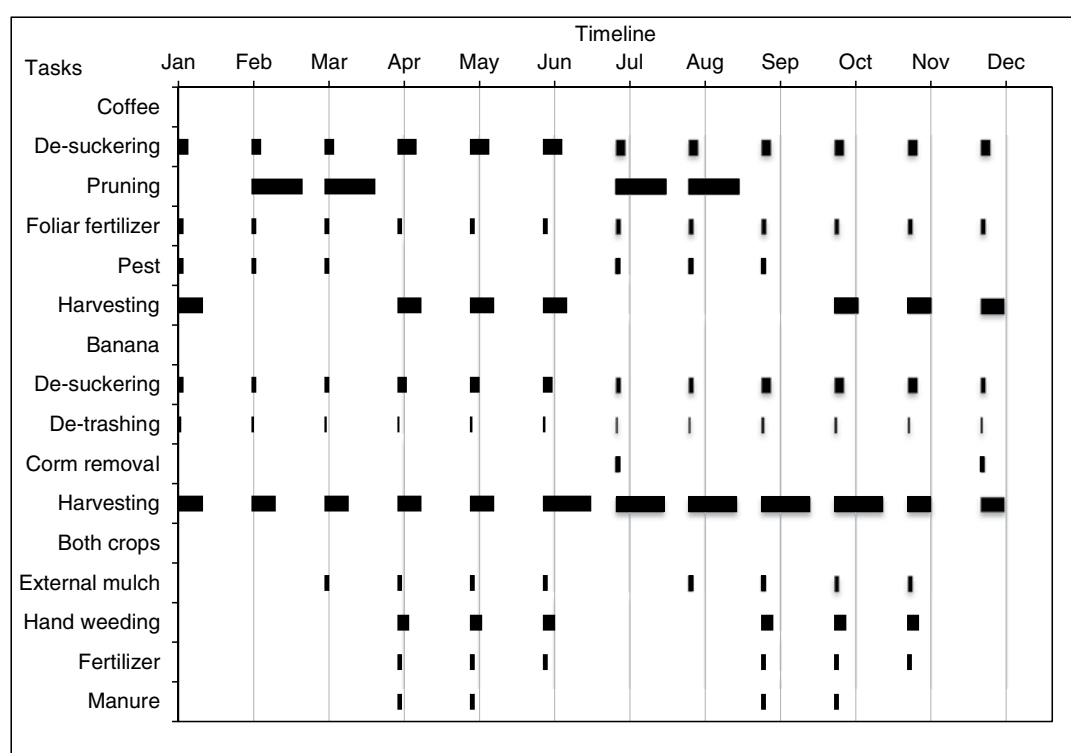


Figure 4. Annual cropping calendar of banana–coffee system in West Uganda.

2.5 Yield gaps

In perennial cropping systems, mistakes made during crop establishment mean that there is a yield gap between site-specific attainable yield and actual yield (Figure 5). Such yield gaps persist throughout the life span of the inter-crop but can be minimized by careful establishment

of the system. Common causes of yield gaps include the following:

- Use of inferior planting materials
- Off-types of banana and coffee planted in the field
- Incorrect plant spacing.

Yield gaps between site-specific attainable yield and actual yields can be reduced by the following practices (Figure 5):

- Planting carefully selected coffee and banana plants at the right spacing
- Use of crop residues as mulch
- Application of mineral fertilizers to supply nutrients
- Control of pests and diseases
- Proper agronomic management (i.e. pruning, weed control, drainage) of the crops.

This will ensure that the nutrients applied are taken up and used efficiently by the plant and recycled back to the soil in crop residues.

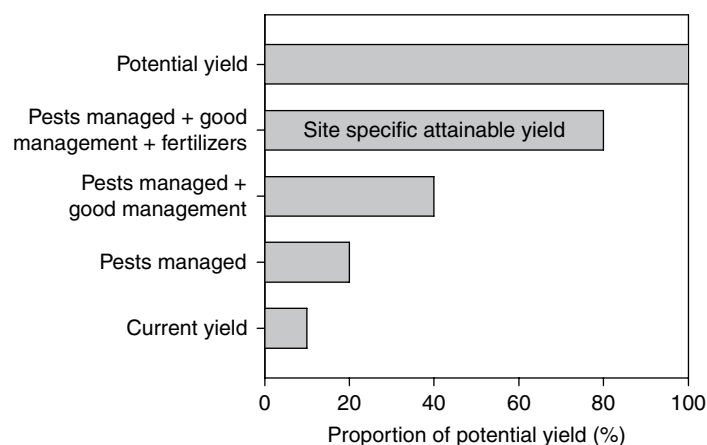


Figure 5. Contribution of selected agronomic constraints to yield in banana-coffee systems.

The farmer should always aim for yields that give the best economic returns. Aiming for the highest possible yield may not give the greatest profit and therefore, as a rule of thumb, farmers should aim for 60–80% of the site specific attainable yield in order to achieve efficient use of inputs and good economic returns.

The maximum yields recorded in monocrops in Uganda are above 70 t/ha/year for banana, above 3 t/ha/year for Robusta coffee (ripe cherries) and above 2 t/ha/year for Arabica coffee (green bean). In most farms, actual yields of banana and coffee tend to be less than 30% of these maximum yields.

Recent field surveys show that yields obtained by most farmers in Uganda are about 10–20 t/ha/year of fresh banana but the best farmers achieve more than 30 t/ha/year.

According to FAO, coffee yields in Uganda average about 0.6 t/ha/year of green beans but the best yields are about 2 t/ha/year for both Arabica and Robusta coffee. The yields in many farms

are obtained with little or no use of fertilizers, less than optimal management and little attention to pest and disease control.

In each production zone it is helpful to collate available information to determine site yield potential and maximum economic yields for bananas and coffee grown as intercroops and monocrops.

For example, in east Uganda we estimate that the site yield potential for banana is 66 t/ha/year in monocrops and 44 t/ha/year in intercroops, and for coffee about 2.5 t/ha/year in both monocrops and intercroops. By contrast, in west Uganda, the yield potential for banana is 66 t/ha/year in monocrops but 30 t/ha/year in intercroops, and the yield for coffee is about 3 t/ha/year in both intercroops and monocrops (Table 5).

The substantially reduced yields in banana intercropped with Robusta could be partly because Robusta can form a more extensive root system than Arabica and hence could be more competitive.

Table 5. Example of site yield potential and target yield of monocrop and intercropped banana and coffee in east and west Uganda.

Crop		Yield (t/ha/year)	
		Site potential	Target yield
Banana-Arabica	Mono-crop banana	>66	40
	Mono-crop coffee	>2.5	2
	Intercrop banana	>44	30
	Intercrop coffee	>2.5	2
Banana-Robusta	Mono-crop banana	>66	40
	Mono-crop coffee	>3.0	2.5
	Intercrop banana	>30	25
	Intercrop coffee	>3.0	2.5

Pest and disease pressure on banana tends to be localized and the incidence of pests and diseases in coffee depends mainly on the variety grown. Often, pest and disease pressure decrease with an increase in altitude. For example, banana weevils are a greater problem in central than in southwest Uganda. Robusta coffee is hardly affected by coffee rust, which can reduce yields in Arabica coffee very significantly and coffee rust damage is often more severe in Arabica coffee with poor nutritional status.

It is therefore possible to improve yields and achieve good economic returns to investments in improved crop management by using moderate amounts of fertilizers, proper pruning and mulch management, and appropriate investments in pest and disease control.

Key messages

- Intercropping banana with coffee is usually more profitable and resilient than the production of either crop grown as monocrops.
- Banana provides the coffee with shade, reducing stress on coffee due to wide variation in temperature within the coffee leaf canopy and wind damage.
 - Banana also provides mulch to the cropping system, supporting good root development for both crops.
- The leaf canopy, root system and mulch provided by banana help to minimize soil losses and improve soil moisture conservation.
- Intercropping banana and coffee reduces the risk faced by farmers; it is unlikely that both crops will be affected at the same time by pests, disease, or drought stress and market prices for both crops are unlikely to ‘crash’ simultaneously.
- Intercropped bananas and coffee require an adequate supply of nutrients from the soil, recycled crop residues that also provide mulch and mineral fertilizers.
- Banana and coffee need to be carefully managed by pruning the coffee trees and desuckering the banana plants to maintain an optimal crop leaf canopy of both plants.
- Above 1500 masl, banana can be intercropped with Arabica coffee; at lower altitudes banana can be intercropped with Robusta coffee.
- Yield gaps between site-specific attainable yield and actual yields can be reduced by:
 - Planting carefully selected coffee and banana plants at the right spacing
 - Use of crop residues as mulch
 - Application of mineral fertilizers to supply nutrients
 - Control of pests and diseases
 - Proper agronomic management (i.e. pruning, weed control, drainage) of the crops.

Aim for yields that give the best economic returns: farmers should aim for 60–80% of the site specific attainable yield in order to achieve efficient use of inputs and good economic returns.

3. Ideal conditions for banana-coffee systems

Essential growth conditions required for the cultivation of banana-coffee include: fertile soils, suitable climate, topography and shade.

3.1 Soils

Soil is among the most important growth factors related with coffee and banana productivity. Knowledge of the soil physical and chemical properties is essential for sustainable coffee-banana production; hence farmers need to know the characteristic of their soils prior to establishing a plantation. Soil physical properties include texture, structure and water holding capacity.

Soil texture and depth

Both banana and coffee grow best on loamy soils with good surface drainage and water-holding capacity, not compacted or stony, and at least 2 m deep. Deeper soils (more than 3 m) that allow coffee plants to develop a taproot and both crops to develop a more extensive root system are preferred.

Large inputs of crop residues and animal manure will be required to improve the water holding capacity of light textured soils (e.g. sandy loams and loamy sands) and to improve nutrient storage and reduce leaching losses.

Soil pH

Coffee grows well in moderately acid soils (pH less than 5) but banana prefers soils with higher pH (pH above 5.5).

However, acidity in soil may build-up due to continuous application of ammonium based fertilizers (for example ammonium sulphate, di-ammonium phosphate (DAP) and ammonium chloride), and from the continuous leaching of calcium and magnesium elements. Soil analysis can give an indication if soils are too acidic. The laboratory report usually includes recommendations on amount of lime to apply and frequency of application, based on the soil pH. For example, lime can be applied every 2-3 years. For best results, the lime should be applied when soil moisture is adequate.

The most accurate method of determining soil pH is by pH meter but local indicators, e.g. presence of bracken fern, (Table 6) can be useful.

Table 6. Examples of indicators of soil fertility that farmers can use

Soil Status	Criteria	Indicators
Poor soil	Crop growth	Stunted plant growth
	Soil characteristics	Soil has light (yellow, red) colour, rocky outcrops
	Type of weeds present	<i>Digitaria</i> sp.; <i>Cytopogon afronardus</i> (Ettete)
Moderate soil	Type of weeds present	<i>Bidens pilosa</i>
Good soil	Crop growth	Good plant growth
	Soil characteristics	Soil has dark colour
	Type of weeds present	<i>Cyperus distaus</i> (Katabuteme); <i>Crassocephalum crepidioides</i> (Sekoteka); <i>Conyza sumatrensis</i> (Kafumbe); <i>Imperata cylindrica</i> (Lusenke); <i>Commelina benghalensis</i> (Nanda); <i>Galinsoga parviflora</i> (Mukasa).
Low pH	Types of weeds present	Bracken ferns (<i>Pteridium</i> spp.)
	Crops	Tea does well

Soil fertility

Both coffee and banana grow well in soils with high soil exchangeable potassium (above 0.3 cmol/kg) and total nitrogen (above 0.15%) status (Table 7).

Table 7. Ideal soil characteristics for banana and coffee production for Central, South and Southwest Regions in Uganda.

Property	Units	Ideal	Central	South	West	East
pH	soil/water	>5	6.4	6.7	5.6	6.3
Soil Organic Matter*	%	>3	3.6	3.7	3.1	3.5
Soil Organic Carbon**	%	>1.7	2.1	2.1	1.8	2.0
Total N	%	>0.15	0.2	0.2	0.2	0.2
Available P	mg/kg	>15	50	87	47	39
Exchangeable K	cmol/kg	>0.3	1.7	2.5	1.5	3.8
Exchangeable Ca	cmol/kg	>2	7.7	11.1	5.6	8.2
Exchangeable Mg	cmol/kg	>2	1.5	2.5	1.3	1.8
K/(Ca+Mg) ratio	-		0.2	0.2	0.3	0.4
Clay	%	20≤45	29	31	25	43

*Soil organic matter = soil organic carbon x 1.72. **Soil organic carbon = soil organic matter x 0.58

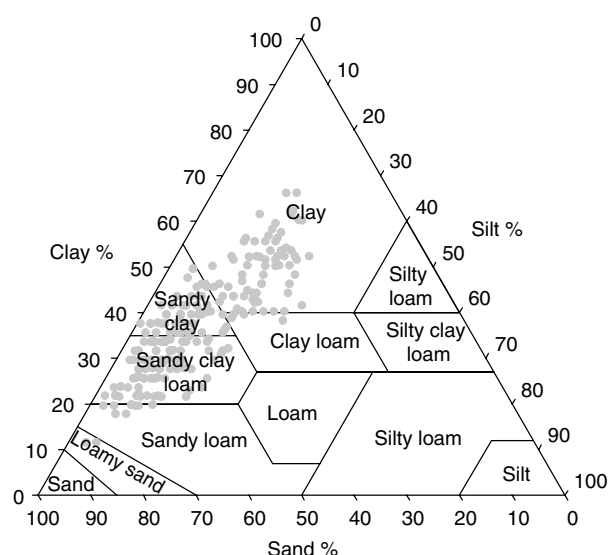


Figure 6. Soil texture in major banana–coffee regions in Uganda.

Soils under the banana–coffee system in Uganda generally contain quite large amounts of soil organic matter (more than 3%) and are slightly acid (pH less than 7) (Table 7). Based on soil analysis, the soils seem to have large amounts of nutrients but fertilizer trials, foliar analysis and visual observations have shown that deficiencies exist. A nutrient deficiency map can be constructed based on soil and foliar analysis, and calculated nutrient imbalances in plants (Figure 7).

Extensive trials in farmers’ fields in Uganda and other parts of East Africa have shown that poor soil fertility limits production of banana and coffee in the vast majority of cases. Nitrogen, phosphorus, potassium and magnesium are the nutrients most commonly found to be limiting, but the relative importance of each nutrient deficiency varies between regions. For example, whilst many soils in Uganda are N and P deficient, the low nutrient status Ferralsols of central Uganda are also deficient in K and plants on the volcanic areas in east Uganda are often affected by Mg imbalances (Figure 7).

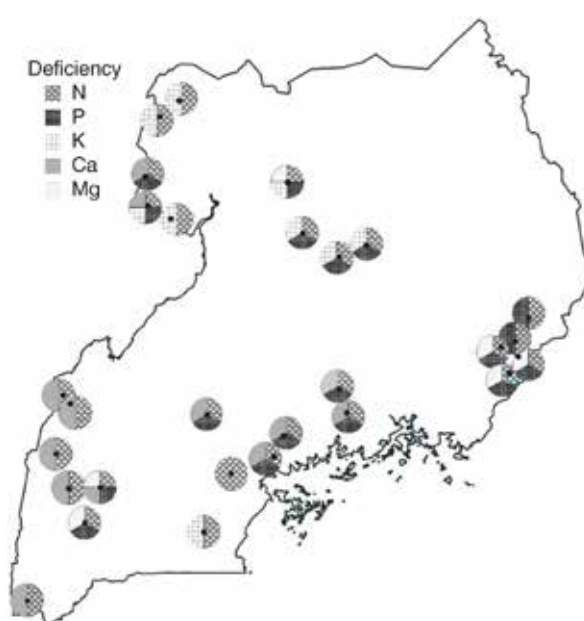


Figure 11. Nutrient deficiency map for banana–coffee regions of Uganda.

At the farm scale, fields near to the farm homestead are generally more fertile than more distant fields because household waste (e.g. banana peelings, sweepings), crop residues and animal manure are generally applied to fields close to the farm homestead.

On less favourable soils, bananas can be grown at higher densities (i.e. more than 740 mats/ha) without affecting coffee yields because the banana plants are smaller and less competitive for light, nutrients and water.

3.2 Agro-ecological environment

Banana-Arabica systems are more profitable than banana-Robusta systems when at higher altitudes (above 1,500 masl). However, some lowland varieties of Arabica (e.g. Catimor) yield well at lower altitudes (i.e. above 600 masl), though their coffee quality profile is often considered to be inferior to the traditional coffee varieties.

Temperature, altitude

The ideal optimal temperature for banana-Arabica is 18-21°C while that for banana-Robusta is 22-26°C (Table 8). High temperatures (above 32°C) before and during flowering often result in abnormal coffee flowering and poor fruit set. Bright sunshine and warm weather are necessary for the harvesting. Growth is most rapid during hot rainy season and during cool dry season berries ripen and ready for picking.

Temperature decreases by 0.5–0.7°C for every 100 m increase in altitude. Therefore, at higher altitudes (typically 1,000–2,000 masl), where the weather is cooler and wetter, banana can be intercropped with Arabica coffee whilst at lower altitudes (below 1,500 masl) banana can be intercropped with Robusta coffee.

However, some lowland varieties of Arabica (e.g. Catimor) yield well at lower altitudes (i.e. above 600 masl) primarily because such varieties are resistant to coffee leaf rust (CLR) but at this altitude the quality tends to be impaired and shade must always be used to prevent overbearing dieback. However, several 'traditional' Arabica varieties do not perform very well at low altitudes (below 1400m) due to the less favourable weather and higher pest and disease pressure.

Relative humidity

Robusta successfully grows under high air humidity while Arabica coffee requires less humidity (Table 8).

Rainfall

Both banana-Arabica and banana-Robusta systems require abundant rainfall (about 1200 and 2000 mm annually).

Insufficient rainfall (i.e. less than 900 mm/year) and soil moisture deficits can be major limitations leading to a reduction in the size and number of banana bunches produced. The mulch cover provided by banana pseudostems and leaves and coffee prunings is therefore particularly valuable in areas with marginal rainfall.

Table 8. Optimal conditions for banana-Arabica and banana-Robusta systems.

Parameter	Units	Banana-Arabica coffee	Banana-Robusta coffee
Altitude	masl	600-2000	200-800 (but does well up to 1500 in Uganda).
Slope	%	Level to gently sloping. Soil conservation required where slope greater than 15%.	
Rainfall	mm/yr	1200-1800	1200-1800 but can tolerate >2000.
Annual mean temperature	°C	18-21	22-26 but cannot tolerate temperatures below 5-6 or long periods below 15.
Frost		Arabica coffee affected by frost.	Frost does not occur.
Average annual humidity	%	70-80	80-90
Wind and hail		Banana plants are damaged by strong winds and wind combined with hail.	
Shade in banana		Banana prefers full sunlight but tolerates light shade.	
Shade in coffee		Arabica coffee requires moderate shade.	Robusta coffee requires moderate shade and is hardier than Arabica.

3.3 Shade

Full sunlight and drought stress are very harmful for coffee, causing yellowing and death of leaves in young coffee plants, and overbearing and dieback in older trees. Permanent shade is particularly important for Arabica coffee, particularly when fertilizer use is erratic.

Key messages

- Select deep, well-drained fertile soil with good water holding capacity, with pH above 5.
- Deeper soils (more than 3 m) that allow coffee plants to develop a taproot and both crops to develop a more extensive root system are preferred in areas affected by seasonal drought.
- Poor soil fertility limits production of banana and coffee in most cases: N, P, K and Mg are the nutrients most commonly found to be limiting.
- Establish system where rainfall is more than 900 mm/year.
- Install soil conservation measures, such as terraces and grass strips, on land with slopes.
- On less favourable soils, bananas can be grown at higher densities (i.e. greater than 740 mats/ha) without affecting coffee yields: the banana plants are smaller and less competitive for light, nutrients and water.
- Mulch, provided by banana pseudostems and leaves and coffee prunings, is particularly valuable in areas with marginal rainfall.
- If strong winds are a frequent occurrence, a windbreak of trees should be planted around the field before planting banana-coffee systems.

4. Establishing banana–coffee systems

4.1 Introduction

To avoid frequent replanting it is best to select a banana type that can produce bunches over many cycles, even when intercropped with coffee. For example, suckers of plantains are slow to establish, by comparison with the East African highland banana, until after the plantain mother stem has flowered.

Farmers in Uganda prefer taller banana varieties for intercropping because the banana canopy is well above that of coffee and therefore does not compete for space with the lower-storey coffee trees. The choice will depend on the production objectives of the farmer, such as whether the banana is grown for staple food, beer making or as a cash crop.

Nurseries should be established or planting material suppliers identified so that banana plants and coffee seedlings are available at the onset of the planting season. Banana suckers require about 2-6 months and coffee seedlings about 12-18 months in the nursery.

4.2 Plant spacing

The plant spacing for both banana and coffee must be selected so that both crops can continue to yield well over the long term. If the bananas are spaced too close together they will shade and reduce the yield in the coffee; if coffee trees are planted too close to the banana they may shade out young suckers on adjacent banana mats.

Aim for about 700-800 banana mats/ha, 2000–2400 trees/ha for Arabica or 1000-1200 trees/ha for Robusta (Table 9). Optimal density will depend on the local soil type, water and nutrient availability, plant stature, commodity prices and production objectives.

To achieve a population of about 740 banana mats and 2222 Arabica coffee plants per hectare, banana can be spaced at 4.5 m × 3 m, and coffee at 3 m × 1.5 m (Figure 8).

The plant spacing and arrangement for coffee should be modified according to the stature and growth habit of a particular variety, topography (i.e. flat versus contour planting) and if weeding and other practices are carried out using tractors. Spacing is generally wider (lower plant population) on more fertile soils with better rainfall because the trees will be larger compared with trees grown on poor soils with low rainfall.

Closer spacing can be used with small statured varieties and wider spacing for varieties with longer branches and larger stature. The seed producer can usually provide advice on suitable tree spacing.

For example, in Kenya, the general recommended spacing for Arabica is 2 m by 2 m to allow sufficient space between rows for chemical weed control. By contrast, a smaller within row spacing of 1.5 m is recommended for the Arabica varieties Ruiru and Batian on flat land, giving a slightly larger plant population.

Because the position of the mother banana stem moves about 0.3–0.5 m per generation, distinct rows of banana mats disappear after a few years. At this point it is important to check that the banana population remains between 700-800 mats/ha by carrying out a census.

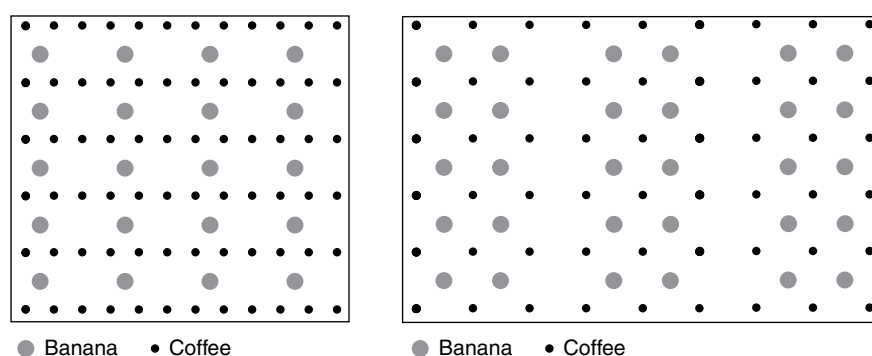


Figure 8. Examples of spacing and plant arrangements for Arabica (a) and Robusta (b) based banana–coffee systems.

Table 9. Suggested plant spacing and planting densities for banana–coffee systems.

System	Crop	Spacing		Density
		Between row	Within row	
		m	m	plants/ha
Mono–crop	Arabica	3	1.5	2222
	Robusta	3	3	1111
	Banana	3	3	1111
Intercropped	Arabica coffee	3	1.5	2222
	Banana	3	4.5	740
	Robusta coffee	3	3	1111
	Banana*	3,6*	3	740

*Double rows, 3 m between the two rows, 6 m between double rows

When banana–coffee crops are immature, they can be intercropped with short stature annual crops, which should be planted 0.5–1.0 m away from the banana and coffee plants. The annual crops provide some food and income for the farmer before the banana and coffee reach maturity.

Legume crop species that fix nitrogen, such as common bush beans, are preferred because their crop residues provide nitrogen to the banana and coffee when returned to the soil.

In addition, annual crops help to suppress growth of weeds and provide an incentive to the farmer to weed around the young banana and coffee plants before the perennial crops start to yield.

4.3 Planting coffee in existing banana fields

The first step is to make an assessment of the density of banana mats and their distribution to determine whether or not the bananas need to be thinned before intercropping with coffee. The mat population can be estimated by counting the number of mother plants within the radius (measured with a piece of cord) of a central mother plant. For example:

- If the number of mats within a 9 m radius circle is 15, the mat population is $15 \times 40 = 600$ mats/ha.
- If the number of mats within a 9 m radius circle is 20, the mat population is $20 \times 40 = 800$ mats/ha.

As a rule of thumb, there should be around 740 banana mats per ha in the area to be intercropped with coffee (see Table 9 and Figure 8). If thinning is required, remove the least productive or diseased mats first.

About three months before the planned planting time (i.e. the start of the rains), mark holes for planting coffee in the banana plantation (suggested plant spacings are given in Table 9).

In an old banana field the mats are no longer found in rows because the position of the mother stem moves each time a mat is harvested (Figure 2). Marking rows for coffee planting inevitably involves some compromises to fit the coffee between banana mats. The important point is to try to maintain, as far as possible, the ideal coffee spacing (Figure 8). Holes for planting coffee should be 0.4 m in diameter and 0.4 m deep.

One month before the rains, fill the hole with top soil mixed with organic manures (e.g. equal parts of soil, animal manure and compost), 0.1 kg triple superphosphate (TSP), nematicide or insecticide (if pests such as root nematodes or termites are known to be a problem) and 0.1 kg lime (if the soil pH is below 4). Heap the soil over the hole to allow for settling and top-up with the soil after one month, as required.

Plant the coffee seedlings when rains have started and the ground is moist to about 60 cm depth.

The space between the banana and coffee can be intercropped with non-climbing annual crops such as tomato and bush beans.

If the shade from banana is not sufficient, shade the coffee seedlings for the first six months after planting using leaves, or other plant materials. During the first two years (Figure 9), manage the banana mats carefully to ensure that they continue to provide shade but do not 'move' to within 1 m of the young coffee trees.

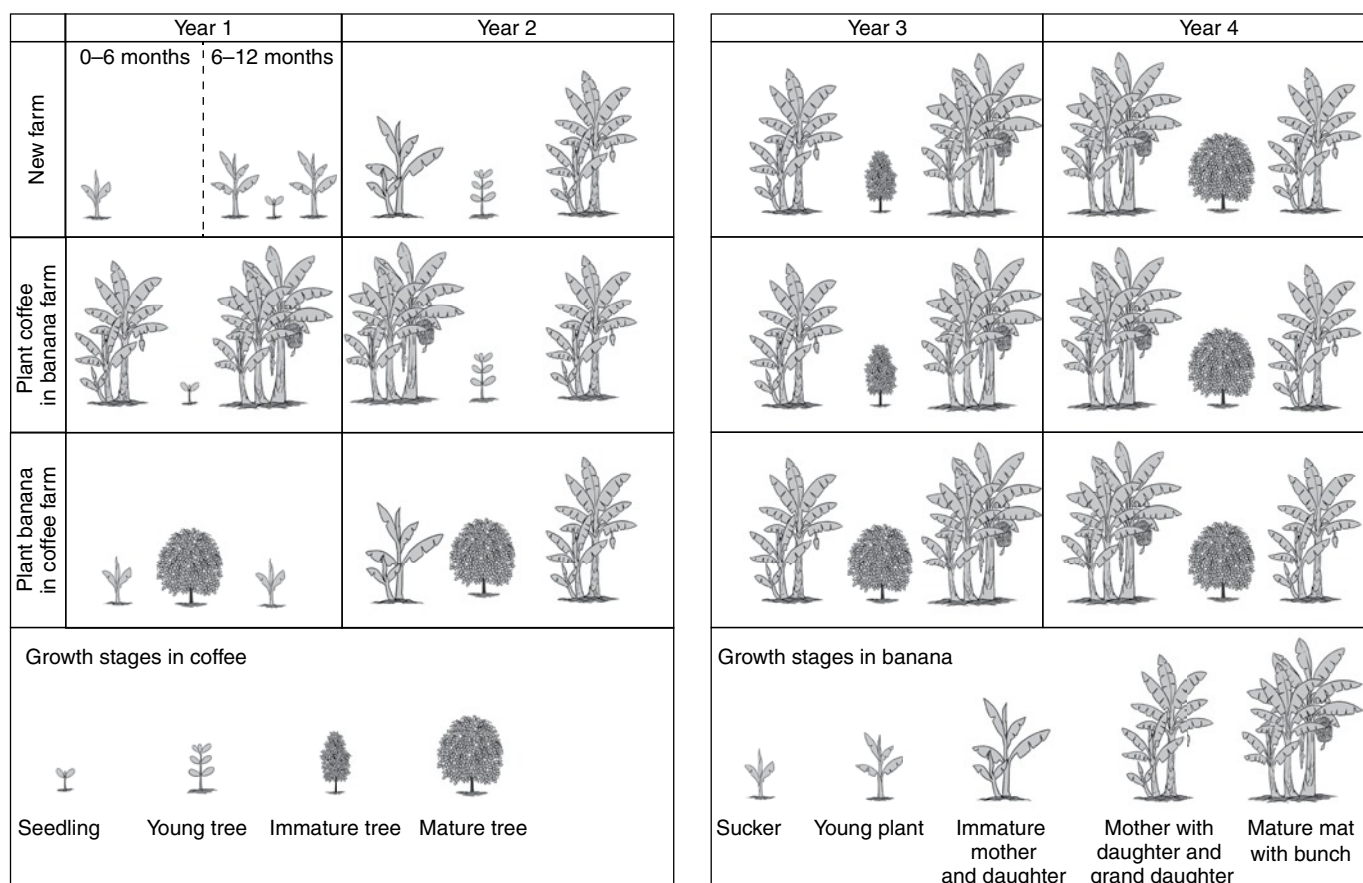


Figure 9. Stages in the development of banana–coffee systems from planting to harvest.

Growth of banana suckers can be affected by coffee as the trees grow taller and bushier. Therefore, manage the canopy of coffee by pruning, especially by the third year after coffee planting, to make sure that emerging banana suckers receive adequate light.

4.4 Planting banana in existing coffee fields

Make an assessment of the density of coffee trees and their distribution to check whether the coffee needs to be thinned before intercropping with bananas.

As a rule of thumb, there should be about 1 100 (Robusta) and 2 200 (Arabica) trees per ha in the area to be intercropped with banana (Figure 8).

It may be necessary to remove whole rows of coffee to create sufficient space to interplant the coffee with bananas. Where possible, the least productive coffee trees should be removed first.

Over-shading of banana by mature coffee can be a serious problem for newly planted suckers. To avoid over-shading of young banana plants, the best time to introduce banana would be when changing the cycle of coffee (i.e. rejuvenating coffee trees through stumping or heavy pruning). The change takes about two years (Figure 9) and this would provide the banana plants with sufficient time to reach maturity before the coffee returns to production.

Banana plant establishment can also be carried out when improved coffee tree varieties are

introduced in an old coffee plantation, particularly where the new coffee varieties are introduced by top working (i.e. grafting new varieties on to old coffee stems) or uprooting and replacing the existing trees. It may also be possible to convert a field of coffee over several years by intercropping a portion of the coffee farm with bananas each year.

For example, to change the cycle of coffee over a three-year period, the coffee field can be partitioned into three blocks, and the change can be carried out in one block each year.

About three months before planting time, mark positions for banana plants and prepare planting holes (0.6 m deep by 0.6 m diameter). One month before the rains, fill the hole with topsoil mixed with organic manures (e.g. equal parts of soil, animal manure and compost), 0.2 kg triple superphosphate (TSP) (or other fertilizers like 0.2 kg diammonium phosphate (DAP), or 0.4 kg of NPK 17:17:17), nematicide or insecticide (if pests such as root nematodes or termites are known to be a problem) and 0.2 kg lime (if the soil is below pH 4). Heap the soil over the hole to allow for settling and top-up with the soil after one month, as required.

When rains start, plant banana suckers in the holes and then sow annual crops in remaining open spaces. Banana plants will be shorter than coffee in the first year. This means that the canopy of coffee needs to be reduced periodically by pruning to optimize the amount of shade over the newly planted banana suckers.

4.5 Establishment of new banana–coffee farms

Prepare land six months before the start of the rainy season by removing any stumps of trees and woody weeds.

Mark the position of planting holes for both banana and coffee (see Table 9 and Figure 8) and prepare the holes for banana three months before the start of the minor rains and for coffee three months before the start of the major rains. Bananas should be planted at least six months before the coffee (Figure 9) so that banana mats provide sufficient shade when coffee seedlings are planted out.

It may be beneficial to establish some temporary shade one year before planting coffee seedlings using legume tree species, such as tephrosia (*Tephrosia vogelii*) or pigeon peas (*Cajanus cajan*). The temporary shade can be removed gradually during the first 18 months after coffee planting. Over this period, the tephrosia prunings provide mulch material with high N content that benefits both coffee and banana plants.

Sometimes the temporary shade trees are retained after the coffee has reached maturity. For example, in banana–coffee systems around the base of Mount Kilimanjaro in Tanzania, shade and mulch in immature and mature phase is provided by grevillea (*Grevillea robusta*), a non-legume timber tree.

In case of occurrence of strong winds, multipurpose trees such as *Terminalia ivorensis* (Muyati) or *Croton megalocarpus* (Nkulumire) should be planted in rows at 5–10 m intervals around the field as windbreaks. This protects the young plants from being damaged by winds that may shred and tear leaves or even uproot plants. Suitability of windbreak tree species is determined by its height,

i.e. taller trees have better impact. Therefore, it is advisable to choose a tree that has foliage right from the ground. In this case, a mixture of trees and bushes planted at 5-10 m intervals will be more effective than a windbreak consisting of only trees.

4.6 Choice of planting material: banana

Choice of planting material is an important part of developing a productive and profitable banana–coffee system because of the different economic uses and adaptation to different environments.

Types and varieties

The East African highland banana (cooking/brewing) is common in the highlands of East and Central Africa, while plantains are more popular in the lowlands of central Africa and humid forest zone of West Africa.

It is generally best to select banana types/cultivars for intercropping that have the following characteristics:

- Tall at maturity.
- Tolerant of stress (e.g. poor soil fertility, competition) but not excessively competitive.
- Robust enough to be harvested for many cycles.
- Tolerant of shade, especially when the suckers are young.
- Erect leaves, especially when young, but provide shade when mature.

The following varieties are used commonly in East and West Africa:

- The East African highland banana can be found in most banana growing areas in East Africa.
- Pisang Awak or Kayinja (an exotic beer banana) is grown on less fertile soils in Rwanda and Uganda
- Yangambi km5 is popular in Eastern DRC, Western Rwanda, and the Rusizi Valley on the border with Burundi.

Varieties that have a very vigorous suckering habit (i.e. produce many suckers per mother plant) are generally not preferred because they require more rigorous and labour intensive de-suckering in order to avoid excessive competition.

Planting materials

Banana planting material for traditional varieties and hybrids is usually available as suckers, tissue cultured (TC) and macro-propagated plants (Photo 5). Other planting materials that are not very commonly used are maiden suckers with tops cut off and corms with sword suckers attached.

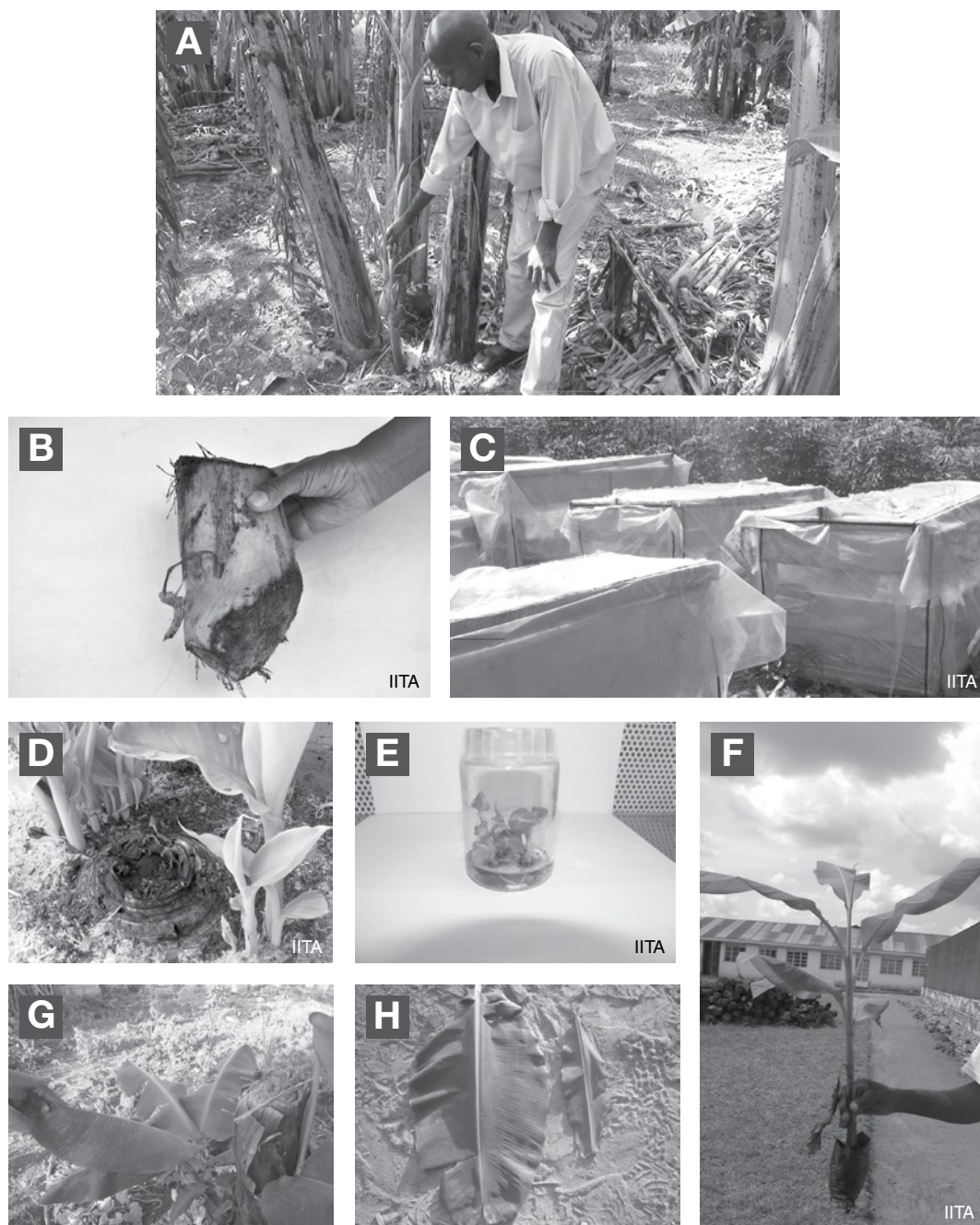


Photo 5. Banana planting materials. **(A)** Sword suckers, unlike water suckers, are closely attached to the mother, have a well-developed corm and are good planting material. **(B)** To control nematodes and weevils, the sucker is prepared by removing all roots, peeling the corm, dipping the corm in boiling water for 30 seconds. **(C)** Macro-propagation, which can be done by famers, is a way of multiplying plants rapidly, and can be very useful in meeting farmer demand for newly introduced cultivars. **(D)** One corm can produce many plantlets at the same time. **(E)** Micropropagation, done in laboratories, produces plantlets that are free from pests and diseases, uniform in size, and have vigorous growth. **(F)** Macro-propagated plantlets need more careful management than sword suckers to establish well and give good yields. **(G)** Water sucker, more superficially attached to a stem from which the mother was harvested, are not good planting material. **(H)** Water and sword suckers are easy to tell apart because leaves of water suckers are large and wide and those of sword suckers are small and sharp.

When using suckers, use sword suckers and not water suckers. Sword suckers have narrow leaves and produce large bunches. Water suckers have broad leaves, are not well attached to the corm and produce smaller bunches (Photo 5).

Banana suckers can be uprooted from an established plantation, a neighbour's field, commercial nursery or research station and transplanted to a new farm. Farmers can carry out macro-propagation but tissue culture is carried out in laboratories by trained personnel.

Preparing suckers for planting

The basic steps are as follows:

- Dig up selected healthy suckers from selected mother plants.
- Remove roots from the sucker.
- Peel the corm.
- Sterilize the peeled corm, preferably in boiling water for 20-30 seconds, or alternatively in a solution containing a pesticide (e.g. ethoprophos) to kill nematodes and weevil larvae.

Uniform, pest and disease-free banana plants that are easily transportable and more vigorous than suckers and can be produced in large numbers by macro-propagation or tissue culture (Photo 5).

Preparing plants by macro-propagation

The basic steps are as follows:

- Dig up selected healthy and disease-free sword suckers from mother plants. Mats that are healthy, disease free and have desirable traits can be labeled and suckers for propagation retained during routine management of field.
- Remove roots from sucker, peel and sterilize the corm (see above). Peel leaf sheaths off to expose buds.
- Cross-cut each exposed bud in centre to encourage growth of many plantlets from one bud.
- Kill of main growing point on corm by cross cutting in the middle or removing the soft tissue in the middle.
- Sterilize rooting substrate (e.g. sawdust, soil, coffee husks), for about 2-4 hours, then place substrate in humidity chamber.
- Place corms in a high-humidity chamber and water. The humidity chamber can be a simple wooden box on which a frame is raised and covered with clear polythene sheeting.
- Plantlets start to sprout after 1–2 months. Detach plantlets that have three leaves.
- If only one plant sprouts from a bud, cut off the plant, then cut across the centre of the bud to stimulate sprouting of multiple plantlets.
- Pot detached plantlets with at least three roots in polybags containing potting mix (equal parts of soil and well-rotted animal manure). Plantlets with less than three roots should be planted back in humidity chamber

- Harden plantlets for one month in a nursery under shade and keep them well watered.
- Discard abnormal plants before planting out in the field.

Preparing plants by micro-propagation

Micro-propagated plants (or tissue cultured plants) are first grown in a laboratory then moved to a nursery for hardening. The main advantage of micro-propagated plants is that they are uniform, disease free and can be produced in large numbers and at low cost.

Farmers can carry out the hardening process or can acquire plants after hardening when they are ready for planting.

If hardening is required:

- Place plants in humidity chamber for 3-6 weeks.
- Remove from humidity chamber and place in shade for up to two months.
- The plants are then planted in field.

Plantlets from macro-propagation and tissue culture are more fragile than plants established from suckers and require careful management (i.e. careful transplanting, watering, fertilizer application) for the first six months after field planting.

4.7 Choice of planting material: coffee

Types and varieties

Consider planting the most recently released varieties (e.g. Ruiru 11 and Batian in Kenya, TaCRI Arabica coffee hybrids in Tanzania) as they are often not only more resistant to pests and diseases but also have higher yield potential.

For example, in Uganda, seven Robusta coffee lines that are resistant to Fusarium wilt have been released and in Kenya some Arabica varieties (e.g. Ruiru 11, a dwarf hybrid) have been released that are more resistant to leaf rust and coffee berry disease than the commonly cultivated varieties such as Bourbon.

It is generally best to select types/cultivars for intercropping that are:

- Tolerant of competition but not too competitive.
- Not too tall at maturity to avoid shading banana (i.e. about 1-2 m shorter than banana at maturity).
- Compact in stature to allow space for banana.

Apart from selecting coffee with these characteristics, manage the canopy of banana and coffee well to reduce competition between the two crops.

Planting materials

Arabica coffee is self-pollinated, highly uniform and invariably grown from seed whilst Robusta coffee, which is cross-pollinated, is usually propagated vegetatively (Photo 6).

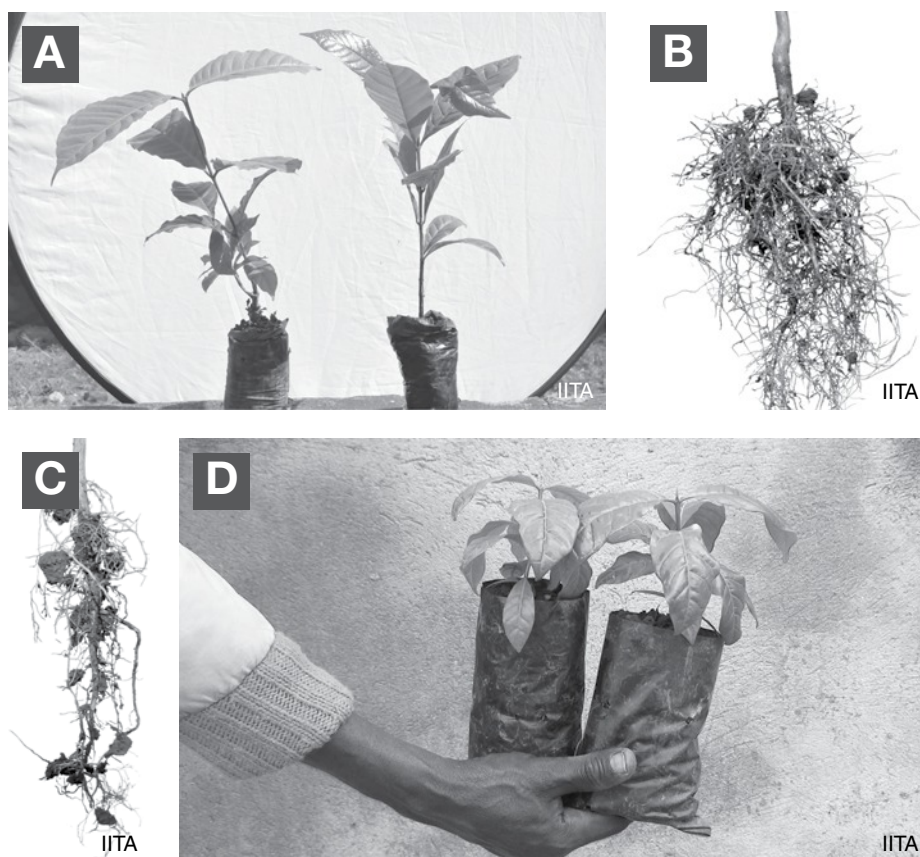


Photo 6. Coffee planting materials. **(A)** Robusta seedling grown from cutting (left) and Arabica seedling grown from seed (right). The Robusta seedling is more vigorous. **(B)** Roots of Robusta seedling propagated vegetatively. The roots of Robusta propagated vegetatively are more fibrous and entwine with those of banana more than those of Arabica. **(C)** Roots of Arabica seedling propagated from seed. Arabica grown from seed has a tap-root and can get nutrients from greater soil depth. **(D)** Tissue culture is carried out in laboratories to multiply clean planting materials rapidly.

Arabica coffee plants grown from seed have a deep taproot and can scavenge for water from a greater soil depth. It is also convenient to produce large numbers of plants from seed. Because Arabica coffee is self pollinated, seedlings are very uniform.

Uniformity in Robusta coffee is achieved by propagating cuttings from carefully selective and highly productive individual mother trees. Vegetatively propagated plants are identical to and have same characteristics as the mother tree.

Vegetatively propagated plants are referred to as ‘clonal’ coffee. The immature phase is shorter in trees raised from cuttings compared with trees raised from seed.

Alternatively, high yielding scion material from selected mother trees can be grafted onto old Arabica and Robusta coffee stumps to upgrade an existing plantation. The advantage here is that a new variety can be introduced rapidly without removing and replanting the existing coffee. Whatever the technique used, it is advisable to plant Robusta coffee plants produced from a range of mother trees to encourage pollination of flowers and subsequently enhanced fruit set, and also to reduce the risk of a single variety being affected by a particular pest or disease.

Farmers should use planting materials from recognized nurseries.

Arabica seedlings can be raised from seed by the farmer or purchased ‘ready to plant’ from a recognized nursery. In some countries (e.g. Kenya, Uganda), nurseries can only be established after consultation with mandated institutions that maintain populations of coffee and supply planting materials to the seedling producers.

To produce seedlings from cuttings, producers establish mother gardens to provide material for cuttings.

4.8 Agroforestry shade trees in banana-coffee

Farmers traditionally grow coffee under agroforestry shade trees. Leguminous shade trees like *Leucaena* spp., *Calliandra* spp., *Sesbania* spp.) are suited for middle storey and can provide temporary shade before permanent and taller trees like *Albizia* spp. reach maturity.

Leguminous shade trees enrich the soil through biological nitrogen fixation. Generally shade trees improve soil health by providing organic matter and nutrients from leaf fall and prunings. Agroforestry trees can also be a source of fruits, fuel wood, timber, building poles, herbal medicines and livestock fodder among other purposes (Table 10).

Choice of trees should depend on local ecological conditions and expected benefits from the trees. Care should be taken to optimize tree composition in order to maximize benefits, and minimize negative effects, which could include competition for water and nutrients, and increased incidence of certain pests and diseases.

It is recommended to maintain shade cover of not more than 50% in coffee for optimum benefits. This can be attained by keeping the appropriate number of trees, and pruning overgrown tree branches.

Table 10 Examples of agroforestry shade trees that can be grown in banana-coffee systems

Type of canopy	Name (Luganda name)	Description	Other uses
Medium storey	<i>Albizia chinensis</i> (mugavu)	legume	fuel wood, fodder
	<i>Albizia coriaria</i> (mugavu)	legume	fuel wood, timber,
	<i>Calliandra calothyrsus</i> (Kaliyandula)	legume	fuel wood, fodder, timber
	<i>Leucaena</i> spp.,	legume	fodder
	<i>Sesbania</i> spp.)	legume	fodder
	<i>Gliricidia sepium</i>	Legume, can reach 10-12m	Fodder, fuel wood, staking material, fencing
Upper storey	<i>Grevillea robusta</i> (Kalwenda)	None legume	fuel wood, building
	<i>Mesiopsis eminii</i> (Musizi)	Not a legume, can reach 10-30m tall	fodder, fuel wood, timber
	<i>Cordia africana</i> (Mukebu)	Not a legume	food, fodder, fuel wood, Timber,
	<i>Acacia</i> (Kasaana)	legume	fuel, fencing and stakes

Key messages

- Banana and coffee can be planted at the same time in a banana–coffee intercrop system, or coffee can be introduced in existing banana plantations (the banana population may need to be thinned to provide sufficient space for the coffee trees), or banana can be planted in an existing coffee plantation (the coffee trees may need to be pruned and thinned to create space for the banana plants).
- Select banana and coffee types that are not greatly affected by intercropping.
- Dig planting holes three months before rains; circular holes of 60 cm diameter and 60 cm depth are preferred for banana and 40 cm diameter and 40 cm depth for coffee; when digging holes ensure to separate topsoil from subsoil.
- Planting holes should be in straight lines, spaced at 10 ft x 10 ft (3 m x 3 m) for Robusta coffee, and 8 ft x 8 ft (2.4 m x 2.4 m) for Arabica coffee; 10 ft x 10 ft (3 m x 3 m) for banana.
- Refill the planting hole one month before rains with topsoil mixed with a basin of manure and a handful of DAP or SSP fertilizer.
- Obtain all planting material from a certified nursery; plant at on-set of rains when ground is moist to at least 60 cm depth.
- Plant short annual crops 0.5-1.0 m away from immature banana mats and coffee plants.
- Manage your coffee well so that it is shorter than banana.
- Plant clean banana suckers and seedlings of coffee varieties recommended for your area.
- Aim for 700-800 banana mats/ha, 2000–2400 Arabica trees/ha or 1000-1200 Robusta trees/ha.

5. Managing banana-coffee systems

5.1 Integrated soil fertility management practices for banana-coffee systems

Integrated soil fertility management (ISFM) can be defined as:

‘A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic and economic principles.’

More simply, ISFM is ‘improved seed plus fertilizer plus manure (or organic matter) and better crop care and management’. The goal is to combine all the agronomic components necessary for optimal crop growth and yield, including the use of high yielding and healthy planting material, plant nutrients (whether supplied as organic materials or mineral fertilizers) and other soil amendments. The previous section has dealt with ‘improved seed’. In this section we discuss the steps that need to be taken to ensure the best yield of banana and coffee, starting with simple agronomic management practices.

5.2 Canopy management

Canopy management means establishing the correct number of banana and coffee plants within the field and then adjusting the leaf area of the bananas, coffee trees and temporary and permanent shade by pruning, training and thinning to achieve the following:

- Bananas provide the right amount of shade to the coffee trees.
- Coffee trees are pruned so that banana suckers receive sufficient sunlight to develop properly.
- Coffee trees are pruned so that stems are replaced continuously and sufficient light penetrates each tree to stimulate flowering.
- The mature banana leaf canopy is well above the coffee canopy (e.g. 1 m above) and provides dispersed shade.
- Competition between plants is reduced, pest and disease attack are reduced and application of agrochemicals using knapsack sprayers is convenient.

Banana canopy management

Replacement banana suckers must grow up through the coffee canopy. Therefore, the coffee should be pruned to ensure that emerging suckers receive sufficient light.

Etiolated banana suckers are a sign that newly emerged suckers have been excessively shaded by the coffee during the first six months of banana sucker growth. As a result, the banana stem population may decrease and the coffee



Photo 7. Removal of dead leaves from banana plants allows good light penetration for the growing banana suckers and the coffee trees.

becomes more exposed to full sunlight, which may lead to coffee die-back.

Each fully developed banana mat should at any time contain (see Photo 3, Figure 2):

- a mother plant that is fruiting
- a large daughter
- a small granddaughter.

If the mat has too many suckers, they should be removed. Suckers draw on the carbohydrate supplied by the mother stem and excessive sucker retention reduces the amount of carbohydrate available for bunch growth. Desuckering should be carried out very carefully to avoid damaging bunches.

Dried leaves should be removed from the banana plants and used to mulch the inter-row space (Photo 7).

Coffee canopy management

Both Robusta and Arabica coffee are usually grown as multi-stem trees to increase the amount of yield bearing wood. Three to four stems should be established on each tree by 'arching' (sometimes called agobiado training) or 'capping' young coffee trees (Photos 8).

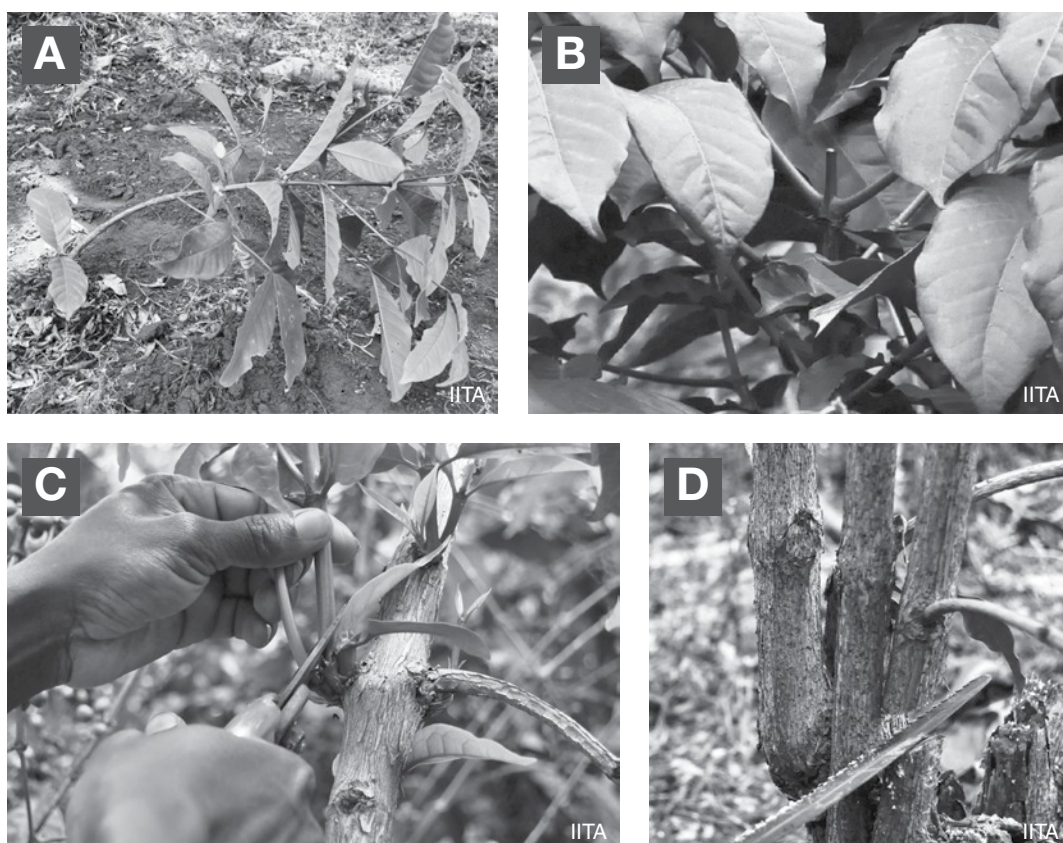


Photo 8. Coffee canopy management. (A) Young Robusta plant bent over by pegging to encourage growth of multiple stems. (B) Capped stem of Arabica coffee to control height. Crop is mainly borne on secondary and tertiary branches. (C) unwanted suckers are continuously removed throughout the year. (D) Coffee trees age with time and production declines, and the main stems are cut-off to rejuvenate tree and improve production.

Young coffee plants need to be trained so as to provide proper shape to the bushes, and improve the efficiency of management operations. Training basically involves restricting plant height by decapitating the terminal portion of the main stem by providing an slant cut at a prescribed height (topping).

Mature coffee trees are partly self-shading and require less shade than immature trees. In general, Arabica needs more pruning than Robusta.

There are many different pruning systems for coffee but an overarching basic principle is that coffee berries are produced in greater quantity on 'young wood'. Therefore, each year, starting in the second or third year of bearing, one stem is removed and a sucker retained that will become a replacement stem. In this way, the tree always contains three to four stems that are less than 4 years old.

Each year all trees should be 'skirted' to remove lateral branches up to a height of 0.5 m. This makes it easier to recover berries that fall on the ground during and between harvests. Removing branches that touch the ground stops insect pests from using these branches to climb onto the tree.

On mature coffee trees, stem height can be managed by capping each stem 2 m from ground level or removing inner branches on each stem to encourage the stems to bend outwards.

Unwanted suckers are removed from both Arabica and Robusta at three to four month intervals throughout the year.

A common problem occurs where old coffee trees need to be rejuvenated because annual pruning operations have not been carried out and the stems are old and unproductive. In such situations the trees can be stumped or the best stem is retained and all other stems removed. Three to four suckers are then retained from amongst the suckers that develop on the stump and allowed to develop into stems. After one year the remaining old stem is removed and the tree is effectively rejuvenated.

5.3 Residue management

In mature plantations, some of the nutrients taken up by plants are returned or recycled to the soil through leaf-fall, coffee pruning, unwanted suckers and banana pseudostems felled at bunch harvest and corms from banana. In addition, there may be prunings from shade trees, banana peels from locally consumed bananas and plantains, and coffee husks and pulp from the coffee pulper.

In addition to providing mulch cover, retaining these plant materials in the plantation means that less external inputs are required to replace nutrients removed in harvested products (coffee berries, banana bunches) and to increase yields of coffee and bananas.

The amount of nutrients contained in suckers, pseudostems, trash and leaves of banana and leaves and husks of coffee in a plantation yielding 10 t/ha/year fresh banana and 0.5 t/ha/year green beans of coffee, is about 90 kg N, 10 kg P and 190 kg K per ha (Figure 10), equivalent to about 200 kg urea, 50 kg triple superphosphate and 370 kg potassium chloride fertilizer.

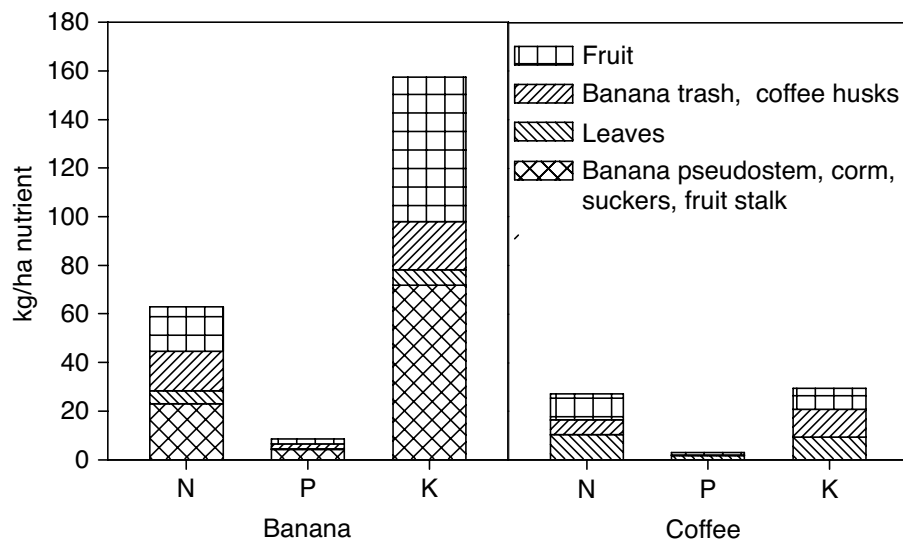


Figure 10. Nutrient removal in banana–coffee systems.

If banana residues are removed from the farm and fed to livestock, animal manure collected from the livestock pens can be returned to the field. Nutrients released by decomposition of soil organic matter or weathering from the soil mineral fraction is only a small part (less than 10%) of what is recycled every year with crop residues and is insufficient to meet the crops' requirements for good yields. For this reason, mineral fertilizers are required.

Always keep in mind that:

- Removal of plant parts from the fields depletes the nutrient capital contained in the banana–coffee system.
- Returning crop residues to the system, or feeding such residues to livestock and then applying manure from these livestock to the system, recycles but does not add nutrients to the system (Photo 9).
- Applying residues of crops/plants that have been grown elsewhere to the field/farm adds nutrients to the system (photo 9).
- Grazing livestock in other fields (e.g. grazing lands on hillsides) and using manure from such livestock on the farm adds nutrients to the system.

Apart from supplying nutrients, applying crop residues to the soil also provides benefits including the following:

- Conservation of soil moisture.
- Mulch layer helps to reduce soil erosion on sloping land.
- Weed suppression and reduced requirement for weeding operations and therefore reduced soil disturbance and damage to banana and coffee feeder roots that lie close to the soil surface (Photo 10).
- Increased root development in the surface soil.
- Replenishment of soil organic matter.



Photo 9. Crop residues. (A) If crop residues are fed to animals, recycling nutrients back to the soil by applying manure can reduce on costs of fertilizer. (B) Both banana and coffee benefit from self and external mulch like grass.

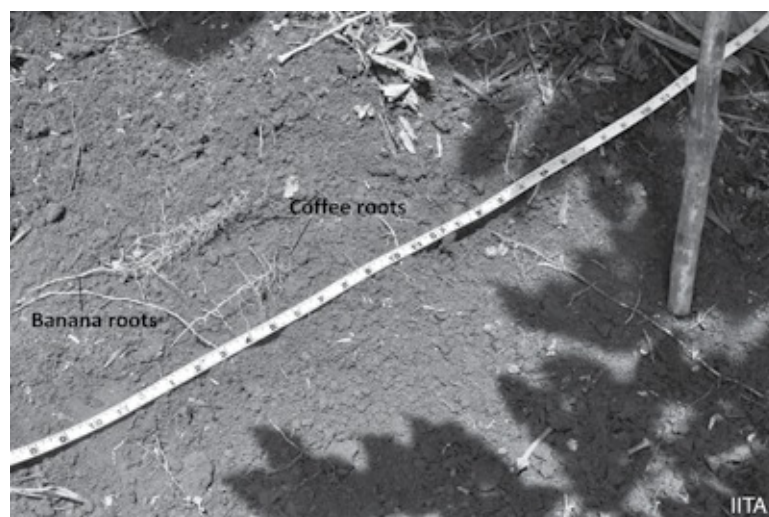


Photo 10. Banana benefits from fertilizer applied to coffee and coffee benefits from nutrients applied to banana as roots of both crops crisscross.

5.4 Soil and water conservation practices

Whilst the broad canopy of banana can reduce the impact of rain on the soil and therefore reduce soil losses, terraces and should be used to minimize soil erosion where banana–coffee systems are planted on land with slopes steeper than 15%. Other soil and water conservation measures that can be used include bunds, trenches and cut-off drains. In addition, mulch cover from banana residues (pseudostems and leaves) and coffee pruning are valuable in areas with marginal annual rainfall (i.e. less than 900 mm) whereby soil moisture deficits are major limitations leading to a reduction in size and number of banana bunches produced (Figure 11).

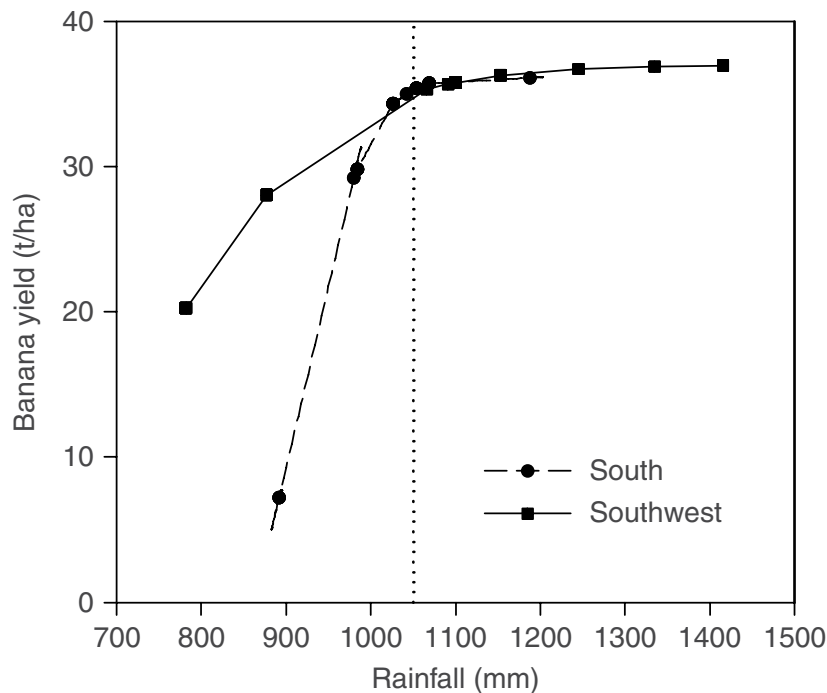


Figure 11. Effect of rainfall on banana yield in two regions in Uganda.

5.5. Organic inputs and mineral fertilizers

All plants require an adequate supply of nutrients to grow and yield well and banana and coffee are no exception. For example, young plants require phosphorus for good root establishment and growth, and mature plants require potassium for effective flowering and fruit filling.

If the supply of nutrients is insufficient, production decreases and coffee may be affected by die back. Unlike legumes, which require phosphorus (P), and cereals, which require nitrogen (N) and phosphorus, both banana and coffee need large amounts of potassium (K) as well as phosphorus and nitrogen.

Deficiencies of the macronutrients nitrogen, phosphorus and potassium, and also sulphur, magnesium and calcium, and the micronutrients zinc, boron and iron lead to the appearance of leaf nutrient deficiency symptoms in banana (see Photo 11) and coffee (Photo 12) that can be detected in the field.

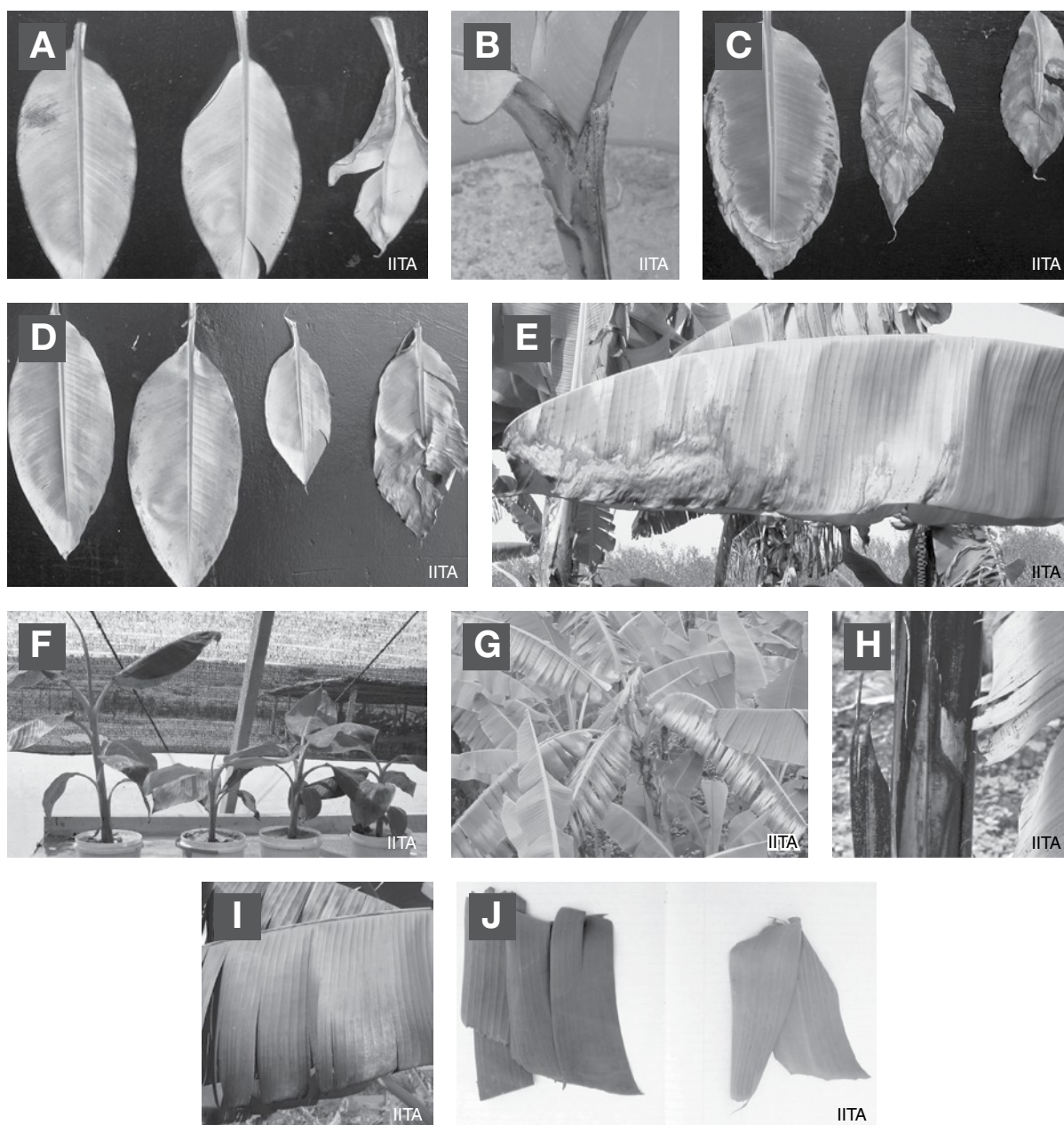


Photo 11. Nutrient deficiencies in banana. **(A)** N deficiency, leaves turn green, then yellow. **(B)** Leaf petioles and sheath turn pink in N deficient banana. **(C)** P deficiency, leaf margins turn scorched brown. **(D)** K deficiency, leaf margins and tips turn yellow from tip, then orange, scorching along margins hangs. **(E)** As scorching on leaves of K deficient plants progress, mid-rib is unable to support leaf, mid-rib breaks and half of leaf close to tip hangs downwards. **(F)** Plants supplied with adequate nutrient have more vigorous growth (e.g. plant on extreme left) than plant deficient in N (second from left), P (third from left) or K (extreme right). **(G)** Mg deficiency, light yellow band along leaf. **(H)** In Mg deficient plants, leaf sheaths can separate from the pseudostem. **(I)** Dark color along leaf margin observed in East African highland banana growing in soil with low pH. **(J)** without micronutrients leaves are yellow (right) instead of green (left).

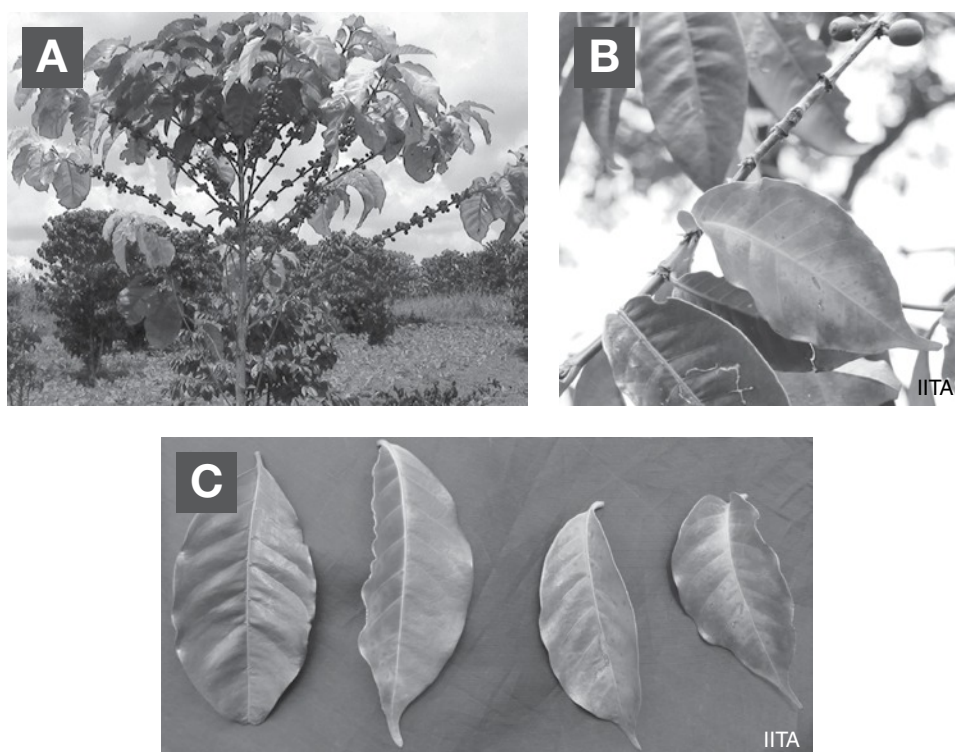


Photo 12. Nutrient deficiencies in coffee. **(A)** Yellowing of leaves caused by withdrawal of N from leaves to maturing crop. The symptom is common during the dry weather. **(B)** P deficiency, older leaves go yellow, then red-bronze (red-purple). **(C)** Normal Leaf (left) and progression of P deficiency symptoms.

Nutrient requirements can be supplied as organic inputs (i.e. crop residues or animal manure), mineral fertilizers or a combination of both.

Using organic inputs in combination with fertilizers may increase the efficiency of fertilizer use: when fertilizers are applied in the presence of organic residues, more of the nutrients contained in the fertilizer are taken up by the crops.

Unlike fertilizer nutrients, which are readily available to plants, organic inputs need time to decompose and release nutrients and are therefore a 'slow release' source of nutrients to plants.

Legume crop residues decompose and release their nutrient content more rapidly than cereal straw.

The concentration of nutrients in organic resources is low and therefore much larger quantities of organic matter are required to supply a given quantity of nutrients by comparison with mineral fertilizers.

For example, fresh goat manure on average contains 7 kg P per tonne (equivalent to 16 kg per tonne P_2O_5 ¹). By comparison, one tonne of triple superphosphate (TSP) fertilizer contains 200 kg P or 460 kg P_2O_5 . If the goal is to apply 50 kg/ha P_2O_5 this could be delivered in about 3 tonnes of goat manure but just 109 kg TSP.

If the farmer does not have livestock and plans to buy animal manures it is worthwhile to compare

¹ Fertilizers are labelled to show the amount of N, P and K in them, for example 15-15-15. The first number shows the % of N in the fertilizer. The second number shows the % of P expressed as the equivalent amount of the salt P_2O_5 (P_2O_5 contains 43% P). The third number shows the % of K expressed as the equivalent amount of the salt K_2O (K_2O contains 83% K).

the cost of nutrients in fertilizers and animal manures and then select the least costly source.

Mineral fertilizer

The four 'rights' help farmers get the most benefit from fertilizers:

- apply the right fertilizer
- at the right rate
- at the right time
- in the right place.

Newly established banana-coffee systems

During the first few years of a newly established banana-coffee system, fertilizers can be applied separately to each immature crop.

In mature banana-coffee intercrops, however, it is not really practicable to target fertilizers to one or other of the two crops; by the time the system has started to yield, root systems of both crops will have formed an overlapping, continuous web of roots.

The right fertilizer at the right rate: Tables 11 provides suggested ranges of fertilizer suitable for applying to immature banana trees during the first 2 years and Table 12 does the same for immature coffee trees during the first 3 years.

All three fertilizers need to be applied: urea supplies N, TSP supplies P and MOP supplies K.

The lower end of the range is most suited to relatively fertile soils and the higher end for soils which are relatively low fertility; for example, if a farmer has a relatively fertile soil then 130 g urea, 45 g TSP and 335 g MOP would be suitable.

Farmers who have applied little or no mineral fertilizers and little or no organic matter to continually cropped plots during the past few years are likely to have low fertility soils. Other indications of soil fertility include yields achieved over the past few seasons – were these similar to the best neighbouring farmers or were they much lower? Stunted plants and abnormal colour leaves, combined with low yields also suggest nutrient deficiencies. If possible, it is a good idea for banana-coffee farmers to have a soil and leaf test done to determine the nutrient status of the soil.

Table 11. Suggested fertilizer rates for immature banana in sub-Saharan Africa

Year	Urea	and TSP	and MOP
	g per plant		
1	130-150	45-65	335-435

2	150-200	90-175	420-500
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Table 12. Suggested fertilizer rates for immature coffee in sub-Saharan Africa

Coffee type	Urea	and TSP	and MOP
	g per tree		
Arabica year 1	45-65	10-20	35-50
Arabica year 2	65-110	20-35	50-85
Arabica year 3	110-200	35-55	85-150
Robusta year 1	90-130	20-45	70-100
Robusta year 2	130-220	45-65	100-170
Robusta year 3	260-390	65-110	170-300

Farmer friendly fertilizer measurements

It is difficult for farmers to know what 45 g of urea or 10 g TSP fertilizer looks like and few will have access to weighing scales.

The solution to this problem is to identify a locally available container, such as discarded plastic water bottle. By cutting the neck off the water bottle, the resulting cylinder can be used as a handy scoop for measuring fertilizer.

Different fertilizers have different densities, so a cut-down plastic bottle full of one fertilizer will not contain the same weight as the same measure full of another type of fertilizer.

For those with access to the internet, a tool (the OFRA fertilizer calibration tool) is available at CABI-ASHC website (www.africasoilhealth.cabi.org). This tool enables the user to calibrate any circular or rectangular container filled with a range of fertilizers.

For smaller amounts of fertilizer the plastic lids from water bottles or beer or soda metal crown cork bottle-tops¹ may be suitable.

Fertilizer type	Weight of fertilizer (g) per metal beer or soda bottle-top full
TSP	7
Urea	4
MOP	6

² The standard metal crown cork bottle-top has a 2.8 cm diameter and a depth of 0.5 cm, giving a volume of 3 ml (3 cm³). It has 21 'teeth'.

The right time: Apply fertilizer when soil is moist, during the rainy seasons.

To minimise losses, N fertilizer (such as urea) should be applied in two split applications –at the beginning and then in the middle of the rainy season (about 2 months after the first application).

It is not necessary to apply phosphate (such as TSP) and potash (such as MOP) fertilizers in split applications as they are released more slowly.

The right place: Fertilizer should be applied over the soil surface where feeder roots are found. Most of the roots of banana are found in the surface of the soil up to a depth of 30 cm (Photo 13) and a dense network of roots develops directly under the mulch.

Like banana, coffee has a shallow root system with most of the feeder roots found in the surface 20 cm of soil. Most of the roots of coffee bushes are found around 60-90 cm for Arabica and 150 cm for Robusta from the base of each coffee bush.

Remove trash on the surface where fertilizer is to be applied, apply fertilizer and then replace the trash.

For young banana mats, make a furrow about 30 cm from the mat. Place fertilizer in the furrow and cover with soil. If the mother plant has a bunch approaching maturity, apply fertilizer to the daughter and granddaughter. Do not work the fertilizer into the soil using a hoe as you may damage roots of the crops.

For fertilizer N (e.g. urea) in young coffee plants, apply under the leaf canopy, extending up to 20 cm beyond the drip-line.

Mature banana-coffee systems

In mature banana-coffee intercrops it is not practicable to target fertilizers to one or other of the two crops; by the time the system has started to yield, root systems of both crops will have formed an overlapping, continuous web of roots.

The right fertilizer products at the right rate: Table 13 provides ranges of fertilizer suitable for applying to mature banana-coffee systems trees during the first year and in the second and subsequent years. The lower end of the range is most suited to relatively fertile soils and the higher end for soils which are relatively low fertility; for example, if a farmer has a relatively fertile soil, for first year banana-Arabica, 370 kg urea and 110 kg TSP and 635 kg MOP per hectare would be suitable. Recommended amounts of fertilizer are given as both kg per hectare and the equivalent expressed

as kg per 100 coffee trees – farmers often know how many coffee trees they have and may find this easier than kg per hectare.

Table 13. Suggested fertilizer application rates for mature banana-coffee systems in sub-Saharan Africa

Year	Crop	Target yield increase Tonnes/hectare (green bean for coffee)		Urea	and TSP	and MOP
		Banana	Coffee	kg per hectare (kg per area with 100 coffee trees)		
First year	Banana-Arabica	10	0.5	370-435 (17-20)	110-140 (5-6)	635-770 (29-35)
	Banana-Robusta	10	1	500-610 (45-55)	130-175 (12-16)	750-920 (68-83)
Second year onwards	Banana-Arabica	10	0.5	220-250 (10-11)	55-75 (2-3)	385-450 (17-20)
	Banana-Robusta	10	1	300-350 (27-31)	75-100 (7-9)	470-550 (42-50)

The right time: Apply fertilizer when soil is moist, during the rainy seasons. To minimize losses, fertilizer N application should be applied in two split applications – for example at the beginning and then in the middle of the rainy season (about 2 months after the first application). It is not necessary to apply phosphate and potash fertilizers in split applications as they are released more slowly.

The right place: Fertilizer should be applied over the soil surface where feeder roots are found (Photo 13). Remove trash on the surface where fertilizer is to be applied, apply fertilizer and then replace the trash. The best approach is to broadcast fertilizers over the soil surface under the banana–coffee system.

Shade and fertilizer use

There is also a strong interaction between shade and fertilizer use in coffee production.

Where soil fertility is poor, coffee grown under shade often yields better and is a more resilient system (i.e. plantation life is longer and production more stable) than coffee grown without shade.

If shade is too dense the yield potential of coffee is reduced and the coffee will respond poorly to fertilizer. Adding fertilizers to coffee that is heavily shaded is not recommended because the increase in coffee yield may not be sufficient to cover the investment in fertilizer. Reducing the number of bananas to reduce shade can improve the benefits of fertilizer in such fields.

Additional tips on fertilizer use

To get good and profitable response from fertilizers, competition for fertilizer should be reduced by

careful weeding, water should be managed well and there should also be appropriate investments in pest and disease management.

Key messages

- Prune banana and coffee to ensure that the coffee canopy remains below the banana canopy.
- Replace old coffee stems with new suckers so that bearing stems are always less than 4 years old.
- Leave prunings on the ground and return non-edible plant materials to the plantation.
- Apply fertilizers to address nutrient deficiencies and meet targeted yields, as recommended.

6. What can go wrong?

6.1 Pest and disease management

Pests and diseases can damage roots, stem and leaves of plants thereby affecting uptake of nutrients and water from the soil, movement within the plant and photosynthesis. Pests and diseases can also damage the fruits directly.

Pests

The most important pests for banana are weevils, which damage the corm, and nematodes which damage the roots (Photo 14).

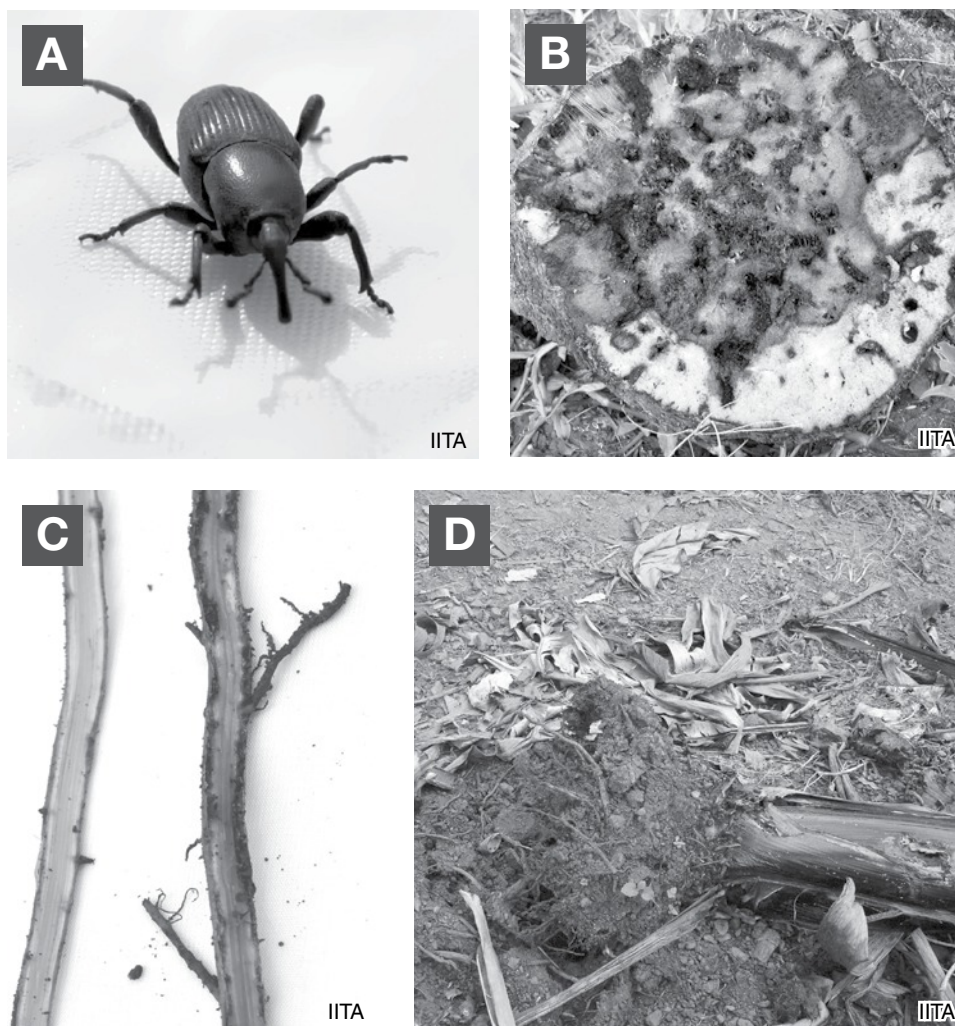


Photo 14. Pests of banana. **(A)** The banana weevil whose larvae bore into the corm causing damage and subsequently affecting movement of nutrients in the plant. **(B)** Corm damaged extensively by the banana weevil larvae. **(C)** Root nematodes damage roots affecting uptake of water and nutrients (left- healthy root, right - damaged root). **(D)** Serious root damage by nematodes can cause plants to topple.

For coffee, some of the most important pests are coffee berry borer, antestia bugs, twig borers, scales, stem borers and mealybugs, which can attack aerial parts of the plant or roots (Photo 15).

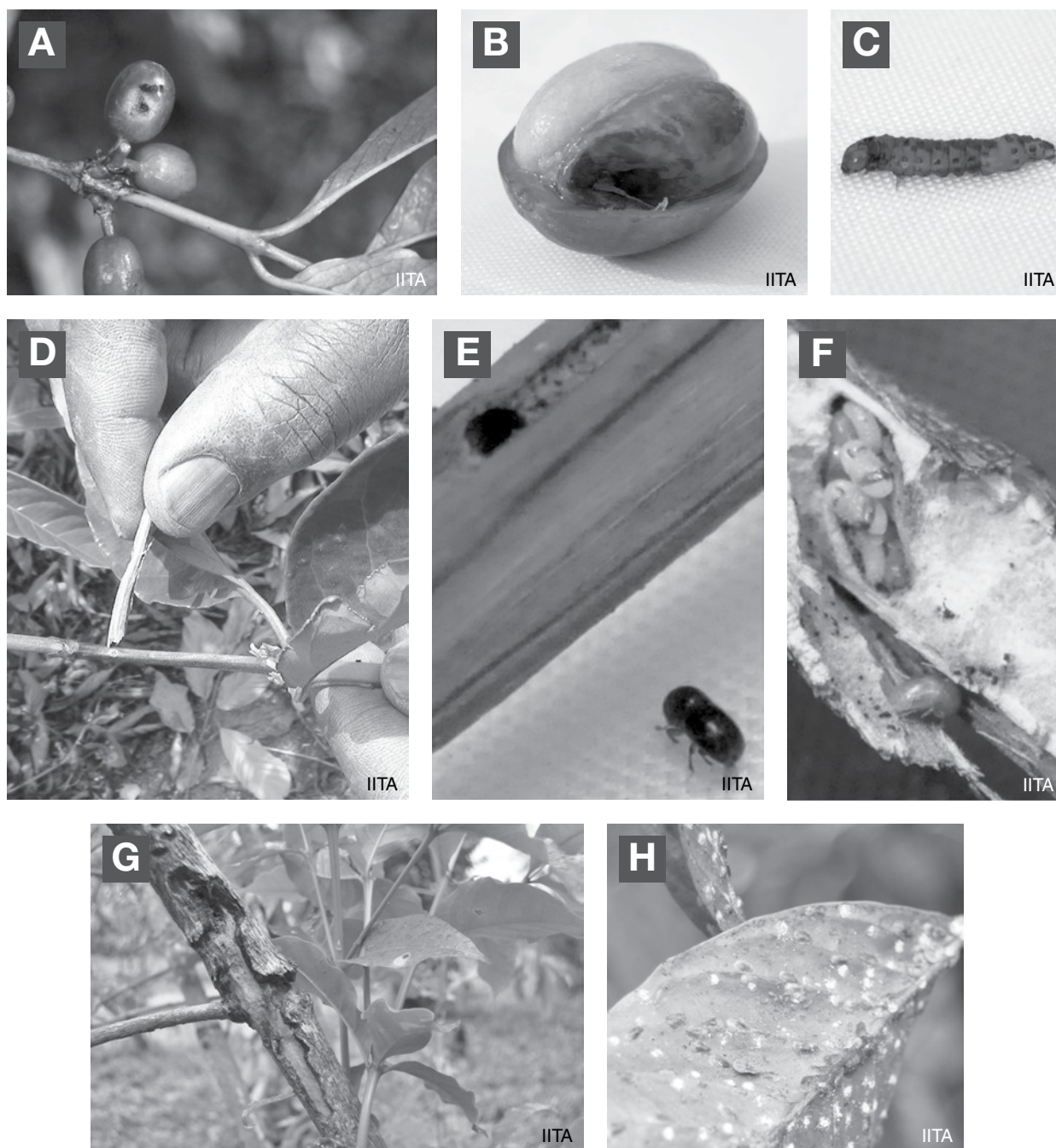


Photo 15. Pests of coffee. **(A)** Female berry borers make holes on berries and lay eggs inside. The eggs hatch into larvae inside the berries, larvae feed on berry causing damage. **(B)** Berry damaged by berry borer. **(C)** Larvae of the berry borer. **(D)** A small hole made by the female coffee twig borer. **(E)** The twig borer is a small flying insect that spreads fast and is difficult to control. **(F)** The borer lays eggs inside a twig, and the eggs hatch into larvae. The infected twig starts drying up from the damaged part towards the tip of the twig. **(G)** Damaged by the stem borer, can cause leaf yellowing, and drying of young plants. **(H)** Scales suck moisture from plants and produce honeydew. The honeydew encourages growth of sooty mould, which reduces the photosynthetic area on leaves.

Diseases

There are two new diseases which have become major threats to banana production.

The banana *Xanthomonas* wilt (BXW) (Photo 16), which is caused by a bacterium, has been spreading in East and Central African region. The disease has been reported in Ethiopia, Uganda, Kenya, Rwanda, DRC and Tanzania.

Banana bunchy top disease (BBTD) (Photo 16), which is caused by a virus, has been reported in Central, south and North Africa.

Other important diseases of banana are bunchy-top, fusarium wilt (Panama disease), banana streak disease, banana mosaic disease, yellow Sigatoka and black Sigatoka (Photo 16).

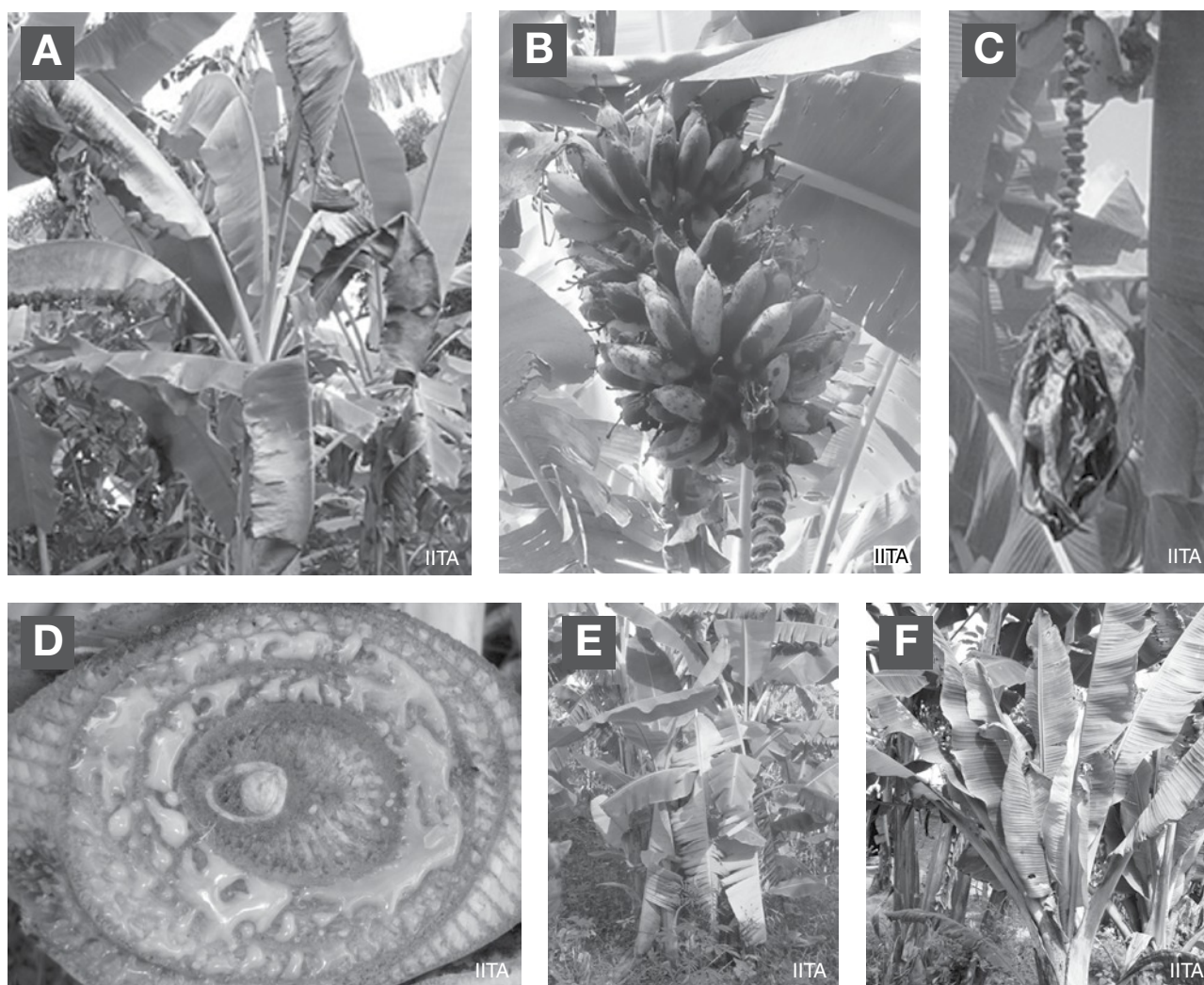


Photo 16. Diseases of banana. (A) BXW attacks highland and exotic banana causing yellowing of leaves. (B) Premature ripening of fruit due to BXW. (C) Wilting of male bud due to BXW. (D) and yellow ooze in stem due to BXW. (E) Fusarium wilt attacks exotic bananas causing yellowing of leaves, and collapsing of leaves to form a “skirt” around the pseudostem. (F) Bunchy top due to banana bunchy top virus. If severe, plants do not fruit or can form fruits with deformed fingers.

For coffee, some of the common diseases are coffee berry disease (CBD, a fungal disease mainly in high, wet and cool altitudes), coffee leaf rust (CLR, fungal, low altitude), bacterial blight of coffee (BBC) and coffee wilt disease (CWD, also known as Fusarium wilt or Tracheomycosis, which affects both Arabica and Robusta coffee) (see Photo 17 for examples). Coffee wilt disease has increasingly become a major constraint to Robusta production in DRC, Tanzania and Uganda. However, care should be taken to carefully diagnose diseases since water stress in coffee fields can be easily mistaken for disease.

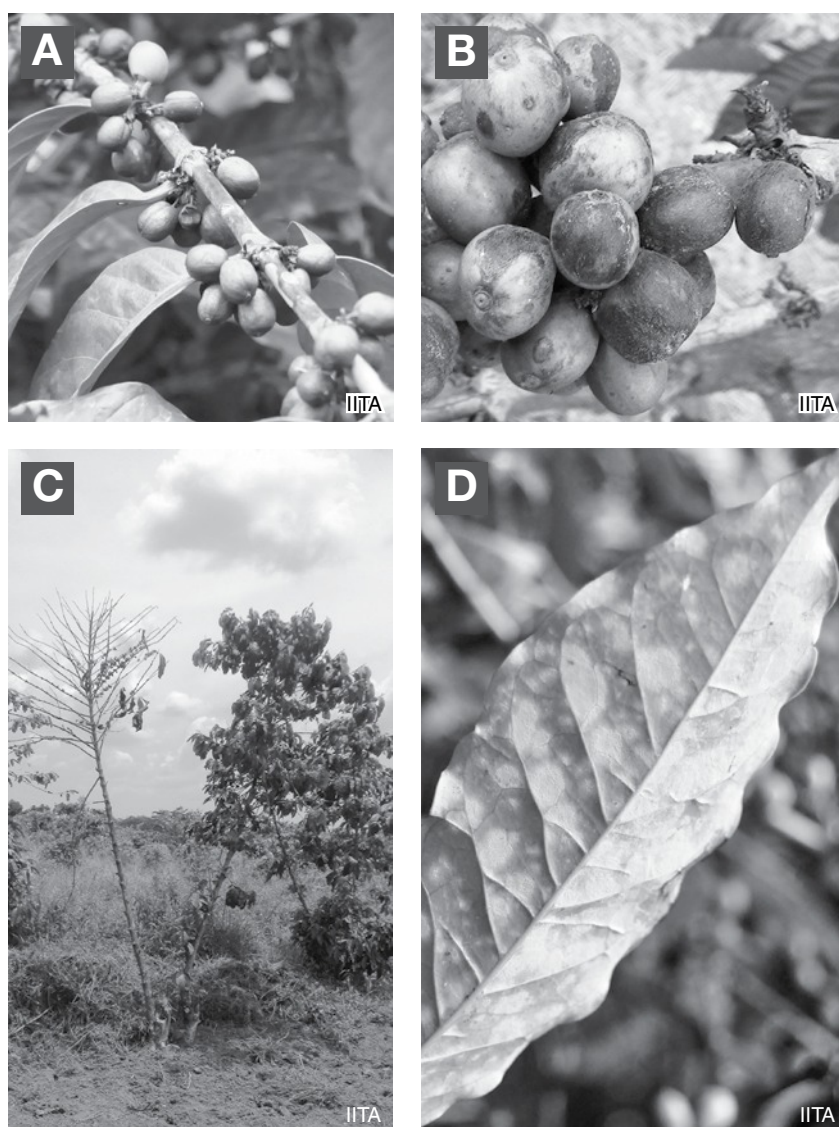


Photo 17. Diseases of coffee. **(A)** Berries infected with coffee berry disease become dark, and may fall off. The fungus lives in the bark of the tree. Disease is more commonly found in Arabica. **(B)** Red spots on green and ripe berries, caused by the “red blister disease” (*Cercospora coffeicola*). The disease can cause premature fall of berries and leaf defoliation. The disease is more commonly found in Robusta coffee. **(C)** A two-stem coffee tree infected by coffee wilt disease. The stem on the left has dried up due to disease while that on the right is yet to show symptoms. **(D)** coffee leaf rust, more common in low altitudes (e.g. serious in Arabica grown in warm humid conditions below 1500), can cause shedding of leaves and lead to reduces yield.

6.2 Control of diseases and pests (IPM)

The best way of controlling pests and diseases is by use of a combination of management practices together with the use of resistant varieties, referred to as 'integrated pest management' (IPM).

At planting, use pest- and disease-free planting materials and, if possible, use resistant planting materials. For example, some banana hybrids (e.g. FHIA 17 and FHIA in East Africa and PITA14 and PITA17 in West Africa) are available that are more resistant to black Sigatoka disease and produce larger bunches than traditional varieties.

After crop establishment, monitor the crop closely for the presence of pests and diseases by carrying out regular crop inspections. When pests and diseases are detected early, control measures may only be required over small areas and economic damage to the crop is small.

Also be on the lookout for diseases and pests in the neighbouring fields or in the surrounding area. Farmers should desist from tethering livestock within or in proximity of the coffee or bananas fields suspected to be diseased or infested with pests.

Control diseases and pests using the recommended methods (see Appendix 1-8 for farmer-friendly extension materials).

Some pests transmit disease from plant to plant. For example, banana streak disease is spread by mealy bugs and banana mosaic disease can be spread by aphids. Therefore, control of pests can often reduce the spread of diseases.

Remove the male bud from bananas when flowering has completed (Photo 18). This stops insects that transmit diseases like cigar end rot (a fruit disease) and BXW from visiting the flowers.

If using chemicals, apply insecticides and fungicides that are recommended (see examples of insecticides (Table 14) and fungicides (Table 15) for use in coffee and follow instructions on pack for their use. Use the chemicals safely (see Photo 19 and box).



IITA

Photo 18. Cutting the male bud after flowering controls spread of diseases like BXW.

Box: Guidelines for safe use of agricultural chemicals**1. Place of purchase**

- Purchase chemicals from licensed/registered dealers
- Pesticide should be accompanied by an information leaflet on guidelines on proper use and handling of chemical
- Do not use banned or prohibited chemicals. If unsure, consult your local agricultural agent, or buyers of your produce

2. Choice of chemical

- Use the correct chemical for crop and pest. Follow information leaflet on pest and crop
- Use recommended chemicals that are accepted in the market. Confirm with your local extension agent or buyer of coffee

3. Correct timing

- Follow guidelines. Check how many days you must allow between spraying and harvesting

4. Correct quantity

- Apply the recommended quantities

5. Correct mixing

- Follow guidelines on compatibilities

6. Correct application

- Follow guidelines on correct application method

7. Correct handling

- Wear protective clothing covering body, head and face to prevent contact with skin, eyes, or inhaling. Do not face into the wind when spraying.
- Keep materials for handling spillages ready for use if needed
- Wash off chemical that comes into contact with body with water and soap
- Wash your hands with soap and water before eating, smoking or going to the toilet
- Bathe and change clothes after spraying
- Wash containers used to mix and spray chemicals
- Visit doctor if sick after spraying. Provide doctor with name of chemical and the information leaflet for chemical to read.

8. Disposal of chemicals and containers

- Dispose excess diluted chemical as per manufactures' guidelines
- Do not leave empty containers lying around
- Follow manufacturers' instructions on disposal

9. Storage and storage period

- Store pesticides away from human and animal food, away from children, in locked place, with warning signs
- Keep chemicals in their original containers
- Storage for period recommended by manufacture. Do not use after expiry date

10. Records

- Keep records of chemicals used, when used, where used

Table 14. Examples of insecticides that can be used to control insect pests in coffee.

Insect pest	Chemical	Additional management practices
Coffee berry borer	Endosulfan, Chlorpyrifos, Fenitrothion, Fenthion	Timely harvesting of ripe berries, placing tarpaulin on ground at harvesting to catch berries that fall, removing and destroying old dried berries left on trees and on ground after harvest period.
Stem borer	Fipronil	Good crop management, uprooting and destroying infested trees.
Twig borer*	Imidacloprid	Pruning and destroying of infected plant parts, good canopy management, keeping fields weed-free.

*The adult twig borer can fly. So, control should be in all coffee fields in an infested area to avoid re-infestation from neighboring fields.

Table 15. Examples of fungicides that can be used to control coffee berry disease (CBD), coffee leaf rust (CLR), bacterial blight of coffee (BBC) and coffee wilt disease (CWD).

Disease	Chemicals	Other management practices
CBD	Azoxystrobin + Chlorothalonil, Pyraclostrobin, Chlorothalonil, Fluazinam	For CBD, CLR and BBC, good canopy management through regular pruning and desuckering, regular change of cycle, planting resistant varieties if available.
CBD, CLR	Dithianon, Cupric chloride (green copper)	
CBD, CLR, BBC	Cuprous oxide (red copper), Cupric hydroxide (blue copper)	
CWD*	-	For CWD, planting disease-free materials, uprooting and burning infected plants, planting resistant varieties. In addition, farmers should desist from tethering livestock within or in proximity of the coffee field.

*Pathogen lives in soil, difficult to control using chemicals

**Photo 19.** Herbicide damage on leaves can be confused with nutrient deficiencies.

6.3 Nutrition and pest and disease pressure

Although research findings on the relationship between nutrients and pest pressure are not always conclusive, plants are better able to withstand pest and disease attacks when supplied with an adequate supply of nutrients.

Pests and diseases have often been thought to be the major constraints to production of banana and coffee, but an increasing body of evidence suggests that pests and diseases are largely secondary problems.

The primary constraints to production are deficiencies of nutrients that render the crops weak and susceptible to damage. In the case of banana, weevil and nematode damage can be very apparent on weak plants, but may not be the main cause of poor growth. In addition, it is important to maintain a well ventilated canopy by proper pruning of both coffee and banana.

In the case of coffee, leaf rust is less prevalent in plants grown on moderately acidic soils with adequate fertilizer inputs compared with crops grown on more acid soils with insufficient fertilizer.

6.4 General management

Weed control

Keep the fields weed-free to reduce competition. Weeds can be controlled by mulching, hand-pulling or spraying with herbicides (Table 16). Farmer knowledge of the type, application time and recommended rates is vital for effective weed kill and cost reduction. Rate of application will be dependent on the type of weed and size of the weed. The knapsack sprayer should be well calibrated (see Box below on how to do the calibration) to ensure that spraying is effective and efficient. In order to avoid inadvertent damage, herbicides should be sprayed directly on the target weed and should not come in contact with the foliage of coffee or banana. Ring weeding with a hand-hoe is recommended for weeds that are in close proximity of coffee or banana.

Table 16. Examples of herbicides that can be used to control weeds in banana–coffee system.

Chemical	Types of weeds controlled	When to apply
Glyphosate	Non-selective, controls grasses and broad-leafed plants	Applied to weeds after they emerge
Sulfosate	Non-selective, controls grasses and broad-leafed plants	Applied to weeds after they emerge
Glufosinate-ammonium	Non-selective, controls grasses and broad-leafed plants	Can be applied to soil to prevent emergence of weeds, and also be applied to weeds after they emerge

*Avoid herbicide drift to banana and coffee plants

Other management issues

The banana–coffee system does well in soils with adequate drainage (i.e. soils that allow movement of air and water). Ensure that sufficient drains (0.5–1.0 m deep) have been installed

to provide adequate soil drainage and to prevent water standing in the field after major rainfall events. During dry spell it is recommended to de-leaf instead of de-trashing.

Use stakes or twine to support banana pseudostems that are carrying bunches and prevent them from toppling over before the fruits are ready for harvesting (Photo 20).

In large plantations, bananas are bagged to prevent damage by animals before harvesting. Smallholder farmers do not bag their produce because they target the local market. But if producing for export, they too need to bag banana bunches to meet export quality requirements.

In mature plantations, roots of Robusta can form a thick mass close to the banana and interfere with growth of banana roots leading to excessive competition between the two crops. If the mat is too thick, disturb the soil around the banana to damage some of the coffee roots. For example, in Uganda it has been found that loosening the soil around banana mats using a forked-hoe helps to control the growth of coffee roots.



Photo 20. Bunch bearing plants, can be supported using pegs, to prevent them from toppling.

Box: How to calibrate a knapsack sprayer

The main determinant of effective pesticide application is a correctly calibrated knapsack sprayer. Calibration of your sprayer ensures that the correct amount of the chemicals active ingredient is mixed with the correct amount of water, and applied to the recommended area of coverage to guarantee good results.

The basic principles of sprayer calibration are: i) walking speed of the operator (kilometres per hour), ii) output per minute of the sprayer (litres), iii) swath width of each pass of the sprayer (metres).

1) Assessing the walking speed of the operator

- Fill the knapsack with clean water. Load the knapsack on your back.
- Measure a distance of 100 meters. Walk at steady pace while spraying.
- Take a stride per pump stroke. Spray with the nozzle at knee height.
- Take average time (seconds) needed to travel two passes of 100 meters each.
- Calculate the walking speed by dividing 360 by the time to travel 100 meters.

2) Measuring the output of the sprayer

- Fill the knapsack with clean water. Pump stroke the knapsack until it is up to pressure.
- Release the trigger and hold the nozzle directly into a calibrated vessel for 1 minute.
- Make steady pump strokes following your heartbeat rhythm until 1 minute elapses.
- Determine the amount of water (litres) that has been discharged by the sprayer in the collection vessel.

3) Determining the swath width of the sprayer

- Fill the knapsack with clean water. Load the knapsack on your back.
- Pump stroke the knapsack until it is up to pressure. Start walking at steady pace.
- Take a stride per pump stroke. Spray with the nozzle at knee height.
- After spraying a distance of 20 strides, measure the width of footprint of the spray on the ground (m).

4) Overall output of the single nozzle knapsack sprayer can be calculated using the following formula:

$$\text{Litres per hectare} = \frac{600 \times \text{nozzle output}}{\text{operator speed} \times \text{swath width}}$$

For example: An operator walking at 5 kph, using a knapsack sprayer with nozzle output of 1.4 litres and swath width of 0.8 metres.

$$\text{Overall output} = \frac{600 \times 1.4}{5 \times 0.8} = \frac{840}{4} = 210 \text{ litres per hectare}$$

*Therefore, if you need 5 litres of the chemical per hectare, then actual spray volume per hectare will be 5 litres of chemical plus 205 litres of water to make up 210 litres per hectare.

5) Determining the amount of chemical concentrate (i.e. at label dose rate per hectare) to put in a full knapsack sprayer

For example: If the capacity of your knapsack sprayer is 20 Litres, and the label dose rate for Roundup® is 5 Litres per hectare, and our calibrated spray volume is 210 Litres.

- Amount of concentrate is calculated by the formula:

$$\frac{\text{Tank capacity} \times \text{dose rate}}{\text{Calibrated spray volume}} = \frac{20 \times 5}{210} = \frac{100}{210} = 0.476 \text{ litres}$$

- Number of full tanks per hectare is calculated by:

$$\frac{\text{Calibrated spray volume}}{\text{Tank capacity}} = \frac{210}{20} = 10.5 \text{ knapsacks per hectare}$$

- Area covered by one single full knapsack sprayer will be:

$$\frac{\text{Square metres per hectare}}{\text{Knapsacks per hectare}} = \frac{10000}{10.5} = 952.4 \text{ square metres}$$

In summary, the overall efficiency of spraying coffee-banana system will depend on i) condition of the sprayer (i.e. leakages), ii) walking speed of the operator, iii) stage of weed growth and density, iv) field area to be sprayed. Other factors are time of day, slope inclination, and wind direction. It is recommended to spray mid-morning when the dew has thawed and along the wind current.

Harvest

A substantial amount of the crop yield produced can be lost if harvesting is not done correctly. To make sure that losses at harvest are minimal, harvest at the right time, using the right method and handle the harvest carefully.

Banana cannot be stored for long periods after harvesting because ripening is rapid following bunch harvest. Most mats will produce bunches at about the same time at the first harvest after sucker planting. In subsequent years, as 'daughter' replace 'mother' plants, bunches are harvested throughout the year with a peak crop season following flowering in the rainy season.

Coffee, on the other hand, is harvested during flushes and the berries are either sold to the processing plant or dried on a tarpaulin and stored for sale at a later date.

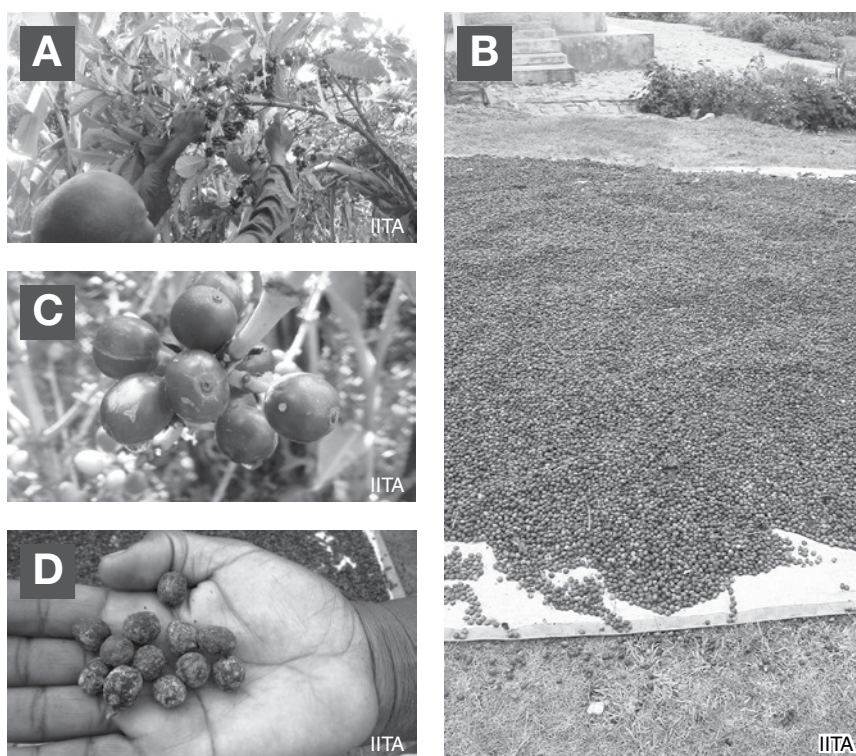


Photo 21. Coffee harvesting and drying. **(A)** Harvest ripe berries carefully and place in a dry container. **(B)** For dry processing, dry berries in the sun on clean surface (e.g. tarpaulin) before delivery to the collection point. **(C)** Sometimes harvesting is in the rainy season (e.g. in parts of Uganda), drying can be a challenge. Berries harvested on different days should be dried separately to avoid re-wetting. **(D)** Berries go mouldy and lose quality if they are contaminated with soil or are not dried properly.

Harvest coffee once per week to avoid losses of over ripe berries. Bananas are harvested green but only when the fingers have filled properly. If bunches are to be sold, check the field once each week to determine the amount of crop that will be ready each week so that harvest and crop collection can be arranged in good time.

To reduce harvest losses of banana:

- Harvest when fingers are full but still green.
- Cut the peduncle (i.e. the stalk connecting the bunch to the pseudostem) carefully above the last hand. If the bunch is cut off above the hooked part of the peduncle, the hook can serve as a handle when lifting the bunch. Where this is not necessary, leave as much of the stalk in the field to reduce nutrient removal and the weight of material to be transported.
- Lower the cut bunch to the ground carefully, avoid bruising after harvest and store in a cool place.

To reduce harvest losses in coffee:

- Pick only ripe, red berries. Leave green berries on the tree to ripen.
- Avoid dropping berries onto the soil surface by careful picking and harvesting the field every seven days. Harvesting is much easier when coffee trees are properly pruned.
- If coffee is to be sold as dried berries, dry the ripe berries soon after harvesting. Dry about for 3-5 weeks on a good quality canvas tarpaulin, turn the coffee as it dries and store dried beans in a cool dry environment. If rains fall when the coffee has been spread out to dry, cover the coffee with a tarpaulin or move to shade to avoid re-wetting. Berries become mouldy if they are not dried properly. Moulds cause taints to the taste of coffee, discolour or even form poisons in the beans and therefore lower the quality of coffee
- If the coffee is sold to a pulper make sure the quality of berries meets the required criteria (i.e. limits on dirt content, number of green berries).

Key messages

- Use pest- and disease-free planting materials and, if possible, use resistant planting materials.
- Monitor the crop closely for the presence of pests and diseases by carrying out regular crop inspections: when pests and diseases are detected early, control measures may only be required over small areas and economic damage to the crop is small.
- Be on the lookout for diseases and pests in the neighbouring fields or in the surrounding area.
- If using chemicals, apply insecticides and fungicides that are recommended for use in coffee and always follow instructions on pack.
- Keep fields weed-free to reduce competition by mulching, hand-pulling or spraying with recommended herbicides.
- In mature plantations of Robusta, if the mass of roots is too thick, disturb the soil around the banana to damage some of the coffee roots.
- Harvest banana bunches when fingers are full but still green, and coffee berries when ripe and red.
- Handle harvested banana bunches and coffee berries as required by the market.

7. Economic analysis

Before introducing new farming practices, it is important to have an idea of the kind of benefits that will be obtained. Once the technology has been introduced, actual benefits obtained can then be calculated. The benefits can be in terms of yield increase, reduction in investments (e.g. on time and labour) and increased profitability.

The likely benefits of a new technology are calculated based on estimated data while actual benefits are based on actual data collected on introduction of the new farming practice.

Below are some simple calculations that can provide useful insights into the likely costs and benefits while needing only a minimal amount of data/information.

7.1 Agronomic benefits

The *agronomic efficiency* (AE) of fertilizer, which is the effect of a unit of nutrient applied on yield, can be calculated as:

$$\text{Agronomic Efficiency} = \frac{(\text{Yield with fertilizer} - \text{Yield without fertilizer})}{\text{Amount of nutrient applied}}$$

For example, if yield with fertilizer was 2217 kg per hectare and yield without fertilizer was 1249 kg per hectare for monocropped coffee, and 200 kg per hectare of urea was applied to supply nitrogen (urea has 46% nitrogen), then

$$\text{Amount of nitrogen applied} = \frac{200 \times 46}{100} = 92$$

and

$$\text{Agronomic Efficiency} = \frac{(2217 - 1249)}{92} = 10.5$$

So, for every kg of N applied, an additional 10.5 kg coffee was produced.

7.2 Economic benefits

The economic returns from investments in fertilizer can be estimated by calculating the amount of yield required to buy one kilogram of fertilizer. This is called the *input/output price ratio* and is calculated as:

$$\text{input/output price ratio} = \frac{\text{Price of fertilizer}}{\text{Price of yield}}$$

‘Price of fertilizer’ is price of one kg of fertilizer and ‘Price of yield’ is price of one kg of yield. For example if ‘Price of fertilizer’ was USD 1.2 and ‘Price of yield’ was USD 0.07 for banana, then

$$\text{input/output price} = \frac{1.2}{0.07} = 17.1$$

To estimate the return on investments in fertilizer, the value of additional yield with fertilizer can

be compared with the cost of fertilizer. The value/cost ratio (VCR), also known as the benefit cost ratio, is calculated as:

Step 1:

Value of additional in yield = (Yield with fertilizer- Yield without fertilizer) × Price of yield

Step 2:

Cost of fertilizer = Amount of fertilizer applied × Price of fertilizer

Step 3:

$$\text{Value/Cost Ratio} = \frac{\text{Value of additional Yield}}{\text{Cost of fertilizer}}$$

Yields and amount of fertilizer can be in kg/ha or kg/acre, and price per kg.

In the intercrop system, the returns to money invested in fertilizer can be calculated as:

$$\text{Value/Cost Ratio} = \frac{\text{Value of additional Yield of banana} + \text{Value of additional yield of cofee}}{\text{Cost of fertilizer}}$$

(Value of additional Yield of banana+Value of additional yield of cofee)/(Cost of fertilizer)

As a rule of thumb, a value/cost ratio greater than 2 is needed for an investment to be economically attractive to farmers.

If additional information, for example on costs of labour, weeding, pruning, de-suckering and pest control is available, more detailed calculations can be carried out. (See Table 17, below for example on use of fertilizer in monocrops and inter-crops).

Table 17. Economic benefits of fertilizer use in coffee mono-crops and banana-coffee intercropping in Robusta system.

	Mono-crop		Intercrop	
	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer
Price of coffee (\$/kg)	1.03	1.03	1.03	1.03
Price of banana (\$/kg)	0.07	0.07	0.07	0.07
Yield of coffee (kg/ha/year)	1249	2217	1088	2197
Yield of banana (kg/ha/year)			9271	11071
Cost of fertilizer				
Purchase		243		193
Transport		4		3
Labor for application		3		3
Calculations:				
Value of coffee	$1249 \times 1.03 = 1286$	$2217 \times 1.03 = 2283$	$1088 \times 1.03 = 1120$	$2197 \times 1.03 = 2262$
Value of banana			$9271 \times 0.07 = 649$	$11071 \times 0.07 = 775$
Total value of system	1286	2283	$1120 + 649 = 1769$	$2262 + 775 = 3037$
Total cost of using fertilizer		$243 + 4 + 3 = 250$		$193 + 3 + 3 = 199$
Change in value of yield(s) with fertilizer use	$2283 - 1286 = 998$		$3037 - 1769 = 1268$	
Value cost ratio (VCR) for fertilizer use	$998 \div 250 = 4.0$		$1268 \div 199 = 6.4$	

7.3 Opportunities for improving economic benefits

Certification schemes

Certification and verification schemes for coffee can help improve quality and therefore the price of produce sold. Find out if such schemes exist in your location and join. If none exist, explore with neighbouring farmers the possibility of joining such schemes. Coffee certification schemes currently found in sub-Saharan Africa include 'Fairtrade, 'Rain forest alliance' and 'UTZ certified'.

Choose certification schemes that contribute to increased productivity as well as sustainability!

Integration into the farming system

Whilst farmers can get better returns by growing banana–coffee together, the system can have impacts on other enterprises or activities on the farm. There are several issues that should be taken into consideration when tailoring the cropping system into the farming system:

Nutrient use efficiency

Very few farmers apply mineral fertilizers to banana, despite clear evidence that moderate applications can double yields. By contrast, farmers recognise the need for fertilizers on coffee. When intercropped with coffee, the banana can scavenge fertilizer nutrients that are not taken up by the coffee crop. The efficient use of the applied nutrients that results contributes to both cash income from coffee and enhanced banana production.

Labour

Unlike annual crops, the banana–coffee cropping system requires labour throughout the year. It is therefore more labour demanding and can compete with other activities on the farm. It is important to plan the activities on the farm well so that the available labour is used efficiently.

Livestock and nutrient cycling

Banana–coffee intercrops perform well in regions that are also suitable for livestock. Often, farms are small and farmers cannot grow sufficient fodder for livestock. In such cases, crop residues from the bananas may be fed to livestock rather than retained in field as mulch. Where banana residues are fed to livestock, most of the nutrients contained in the residues can be returned to the banana–coffee system as animal manure. Coarse grasses that are not suitable for feeding of livestock or old thatch can be used as an alternative source of mulch material.

Risk

Before introducing the banana–coffee system, remember that unlike annual cropping system, the banana–coffee system is permanent. Once established, it is not easy to change to another cropping system.

When faced with poor prices of coffee, some farmers let their coffee grow wild, then rehabilitate when prices improve. But in the banana–coffee system, it may be best to cut back the coffee trees to rejuvenate the trees when coffee prices are poor.

Synergy

The system can be introduced without necessarily affecting production of annual crops in the first year. When banana and coffee are young, farmers can continue to plant other crops in the field as before. The banana–coffee system can also benefit from the annual crops.

For example, if coffee seedlings are planted within a tomato field, copper sprayed on tomatoes also controls diseases in the young coffee. If the annual crop is a legume that fixes nitrogen, banana and coffee can benefit from the improved soil fertility.

Key messages

- Keep good records for use in calculation of benefits and costs.
- A value/cost ratio greater than 2 is needed for an investment to be economically attractive to farmers.
- Choose certification schemes that contribute to increased productivity as well as sustainability!
- Before introducing the banana–coffee system, remember that unlike annual cropping system, the banana–coffee system is permanent. Once established, it is not easy to change to another cropping system.
- When faced with poor prices of coffee, it may be best to cut back the coffee trees to rejuvenate the trees when coffee prices are poor.
- When banana and coffee are young, farmers can continue to plant other crops in the field as before. The banana–coffee system can also benefit from the annual crops.

8. Conclusion

In this guide we have described the characteristics, use, advantages and disadvantages, and soil and climate requirements of banana–coffee intercropping systems in Africa.

Yield gap is a useful way to investigate the potential for yield improvement at a particular site.

We reviewed the field practices for establishing banana–coffee systems either as new farms or by introducing banana in coffee farms or vice versa.

We have described the use of integrated soil fertility management to improve the productivity of banana–coffee systems by focusing on the use of suitable high quality germplasm, proper plant spacing to achieve a balanced canopy of banana and coffee plants, crop residue and pest and disease management.

We then consider methods to assess the economics of introducing banana–coffee systems and how they can be integrated into a farm system.

We hope that extension workers and others will find this guide useful in their work to improve the productivity of banana–coffee systems in Africa.

9. References

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Source of Figure 1

CIALCA, Banana tissue culture. Banana extension materials.

CIALCA, Bananamacropropagation. Banana extension materials.

CIALCA, Banana soil fertility problems 1/2. Banana extension materials.

CIALCA, Banana soil fertility problems 2/2. Banana extension materials.

CIALCA, Zero tillage mulch banana system. Banana extension materials.

CIALCA, Damage to bananas caused by nematodes. Banana extension materials.

CIALCA, Banana weevil *Cosmopolites sordidus*. Banana extension materials.

CIALCA, Banana *Xanthomonas* wilt (BXW) factsheet. Banana extension materials.

CIALCA, Banana bunchy top disease. Banana extension materials.

CIALCA, Fusarium disease of banana (Panama disease). Banana extension materials.

CIALCA, Banana streak disease and banana mosaic disease. Banana extension materials.

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Source of Figure 7: map of nutrient deficiencies in Uganda.

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Source of data used in Figure 5.

11. Glossary

Arching: Young plants are bent over, string is tied to bent stem, then tied to stake pushed into the ground to hold stem in position.

Bi-modal rainfall: Rainfall that comes in two seasons in a year.

Bunch: Fruit of banana plant

Capping: The tip of stem is cut-off

Compound fertilizers: A fertilizer that has contains more than one nutrient.

Corm: A short vertical underground stem.

Cross-pollination: Pollen from one flower pollinates another flower

Cuttings: Single-node sections are cut from suckers. The suckers are harvested from a mother plant

Desuckering: Removing twigs that grow from the main stem in coffee, and small plants growing at the base of a banana stem.

Dieback: Leaves fall off, branches die. Caused by having more coffee cherries than the plant can sustain.

Drip-line: The line around the coffee tree where most of the rain that falls on the tree is shed.

Etiolated: Plants that are weak and yellow due to lack of sufficient light.

Fly crop: When coffee is harvested twice a year, one harvest tends to be smaller and is called the fly crop.

Fruit set: Change from flower to fruit

Grafting: A sucker is cut-off from a plant, placed in cleft made on a root stock, and the union is tied to facilitate joining.

Hybrids: Made by crossing two different varieties

Main crop: The larger harvest in coffee harvested twice in a year.

Mat: A family of banana plants with interconnected living corms. Ideally should be a single mother plant, daughter and granddaughter.

Monocrops: growing single crops

Monocotyledonous: Plants whose seeds have one cotyledon. The plants have leaves with parallel veins.

Mother plant: The oldest plant in a mat. Can be flowering or bearing a banana bunch In coffee, plant from which materials for propagation (e.g. suckers for cuttings, seeds) are got.

Phenology: For banana and coffee, the growth stages from planting to maturity

Pruning: Cutting off selected branches

Pseudostem: A false stem made up of rolled leaf sheaths

Self-pollination: flower pollinates itself

Straight fertilizers: A fertilizer that has contains one nutrient

Stumping: In coffee, cutting off most of the main stem and leaving a small part above the soil surface

Suckers: Twigs growing upwards from the main stem in coffee.

Sword suckers: suckers that are closely attached to the mother plant. They have small leaves that are sword-shaped.

Tap root: Usually a single root that grows downwards, from which small roots grow.

Top-working: Cuttings of improved coffee are grafted on old trees.

Overbearing: Coffee trees has more fruit than it can support sustainably.

Overcrowding: Presence of too many plants in a given area. The plants compete for nutrients, water and light.

Propagated vegetatively: Produced from cuttings and not from seed.

Water suckers: Suckers loosely attached to mother plant. The suckers have large broad leaves.

Weed-free: Without weeds

12. Acronyms and abbreviations

Al	aluminium
ASHC	African Soil Health Consortium
B	Boron
BBC	bacterial blight of coffee
BBTD	banana bunchy top disease
BXW	banana Xanthomonas wilt
C	Centigrade
C:N	carbon to nitrogen ratio
Ca	Calcium
CBD	coffee berry disease
Cl	Chlorine
CLR	coffee leaf rust
CLR	coffee leaf rust
cm	centimetre
Cu	Copper
CWD	coffee wilt disease
DAP	diammonium phosphate
DRC	Democratic Republic of the Congo
FAO	Food and Agriculture Organisation of the United Nations
Fe	Iron
G	Gram
ha	hectare (1 ha = 2.47 acres)
IITA	International Institute of Tropical Agriculture
ISFM	integrated soil fertility management
K	potassium
K ₂ O	potassium oxide
KCl	potassium chloride
kg	kilogram
LER	land equivalent ratio
m	metre
masl	metres above sea level
Mg	magnesium
MgO	magnesium oxide
mm	millimetre

Mn	manganese
N	nitrogen
Na	sodium
NGO	non-governmental organisations
P	phosphorus
P ₂ O ₅	phosphoric acid
SSA	sub-Saharan Africa
Si	silica
t	tonne
TSP	triple superphosphate
VCR	value/cost ratio
WUR	Wageningen University
Zn	Zinc

Appendices

Appendix 1. Nutrient and water content of manures and residues commonly available in sub-Saharan Africa.

Material	N	P	K	Ca	Water content
	kg/t material				%
Human faeces	10	2	3		
Cattle faeces	3	1	1		
Pig faeces	5	2	4		
Fresh cattle manure	4.0–6.0	1.0–2.0	4.0–6.0	2.0–4.0	60
Composted cattle manure	15	12	21	20	35
Farmyard manure	10	8	12	8	50
Goat manure	8	7	15	8	50
Sheep manure	10	7	15	17	80
Pig manure	7.0–10.0	2.0–3.0	5.0–7.0	12	80
Poultry manure	14–16	2.5–8	7.0–8.0	23	55
Garbage compost	6	2	23	11	40
Sewage sludge	16	8	2	16	50
Sugarcane filter cake	3	2	0.6	5	75–80
Castor bean cake	45	7	11	18	10

Appendix 2. Nutrient conversion factors.

From	Multiply by	To get/From	Multiply by	To get
NO ₃	0.226	N	4.426	NO ₃
NH ₃	0.823	N	1.216	NH ₃
NH ₄	0.777	N	1.288	NH ₄
P ₂ O ₅	0.436	P	2.292	P ₂ O ₅
K ₂ O	0.83	K	1.205	K ₂ O
SO ₂	0.500	S	1.998	SO ₂
SO ₄	0.334	S	2.996	SO ₄
SiO ₂	0.468	Si	2.139	SiO ₂
MgO	0.603	Mg	1.658	MgO
CaO	0.715	Ca	1.399	CaO
CaCO ₃	0.560	CaO	1.785	CaCO ₃

Appendix 3. Banana pests and diseases extension materials

These farmer-friendly extension materials have been produced by CIALCA – the consortium for improving agriculture-based livelihoods in Central Africa (cialca.org). They are reproduced here with kind permission from the consortium.

Appendix 3.1: Banana tissue culture

http://www.cialca.org/files/files/extension_materials/tissue-culture_english.pdf

BANANA TISSUE CULTURE

Get PEST AND DISEASE-FREE plantlets



Tissue culture (TC) is one way of producing thousands of new banana plantlets rapidly (in 4 to 6 months) that are:

- pest and disease-free
- uniform
- more vigorous than suckers
- easily transportable, which means easily marketable.

Farmers can obtain TC plants directly from the laboratory, but also from a TC nursery in their neighborhood. TC plant generally costs 1 \$ or less.

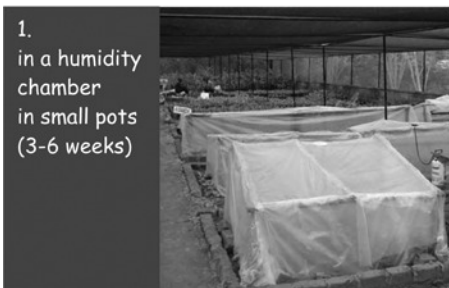
Start in the LABORATORY, harden LOCALLY



TC plants are made in a sterile environment in specialized laboratories.

1. Banana plant pieces are taken from healthy mother plants to the laboratory, where they are disinfected, and
2. multiplied on multiplication medium (4 weeks), and
3. rooted on rooting medium (4 weeks)

Then, the small plantlets are moved to a nursery for hardening, in two steps:



These two steps of hardening can be organised by the TC company, by an independent privately run nursery or by farmers through community-managed nurseries.

IMPORTANT TO FARMERS: good management !

Both plantlets from macro propagation and tissue culture are more fragile than suckers. They need extra care, especially during establishment: watering, good husbandry, manure...

"Without the extra care, the benefits will be lost."



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For more information, visit our websites. Questions ? Thomas DUBOIS (IITA): t.dubois@cgiar.org

Appendix 3.2: Banana macropropagation

http://www.cialca.org/files/files/extension_materials/macro-propagation_english.pdf

BANANA MACROPROPAGATION

Bananas do not produce planting material readily. Tissue culture is one way of producing new and clean plantlets rapidly but it requires expensive laboratory equipment, electricity and technical skills. Macropropagation is another cost effective way that can be done locally.

A good way to be aware of plant health concepts

Why macropropagation ?

- It can rapidly multiply plantlets to distribute a new variety or replace plants in disease-affected fields.
- It gives relatively healthy plants if source suckers are from healthy mother plants and contamination is minimized during the process.
- It can be done locally at low cost and with little training: a private person or a farmers' organisation can launch this activity.
- It can teach awareness of principles of plant health.

Be very careful: even if not showing symptoms at first, a sucker from an infected mother will generate diseased plantlets at the end. Never use it, neither for macropropagation, nor as conventional planting material.



One healthy sucker at first gives 8 to 25 healthy plantlets in 12 to 18 weeks

Multiply affordable plantlets locally

1. select sword suckers from healthy mother plants to not multiply disease



- First step: select healthy sword suckers.
- Next steps: sanitize the corm and cut buds to give many healthy new shoots.
- New shoots must be rooted in sterilized soil in the humidity chamber.



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The only means needed:

- A drum to sterilize corms and potting soil (with organic matter)
- A rustic propagation chamber with sawdust, plastic, shade: e.g. a small unit (2 x 1 x 0,75 m) can take 80 corms and produce 1000 rooted plantlets in 3-5 months.



For more information, visit our websites. Questions ? Jim Lorenzen (IITA): j.lorenzen@cgiar.org

Appendix 3.3: Banana soil fertility problems 1/2.

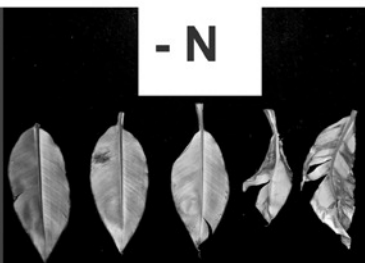
http://www.cialca.org/files/files/extension_materials/fertilite_nutrients1_english.pdf

BANANA SOIL FERTILITY PROBLEMS (1/2)

Poor soil fertility leads to nutrient deficiencies. These are common everywhere, particularly when no nutrients have been applied. The deficiencies most often encountered are Nitrogen (N), Phosphorus (P), Potassium (K) and Magnesium (Mg). If only one of these nutrients is lacking, then yields will be low. Applying nutrients other than the deficient one will not help.

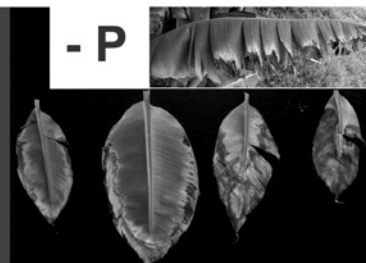


N deficiency: leaves turn light green, then yellow patches appear. Midrib often turns pink.



Nitrogen is vital in chlorophyll production (for green leaves), DNA and proteins.

P deficiency: leaf margins often turn scorched brown, not too much yellowing.



Phosphorus is important for roots growth, and flower and seed formation.

K deficiency: leaf margins and tip turn yellow, then scorched brown.



Potassium is vital for strong cells, transpiration and fruit filling. It induces disease resistance.

Mg deficiency: interveinal chlorosis causes a light (yellow) band along the leaf.



Magnesium is also vital to chlorophyll production and in most enzyme reactions.

Banana must have a balanced diet !

Uptake	N	P	K	Mg
1. Average uptake by bunch with 50 T ha ⁻¹ yield (in kg ha ⁻¹)	104	10	285	13
2. Average uptake by whole plant with 50 T ha ⁻¹ yield (in kg ha ⁻¹)	309	37	1018	55

Bananas are huge potassium (K) consumers.



Leaving the plant residues in the field after harvest is very important to minimize soil fertility losses.
Applying 2cm mulch on 1 ha can bring 300 kg of potassium.



Appendix 3.4: Banana soil fertility problems 2/2.

http://www.cialca.org/files/files/extension_materials/fertilite_nutrients2_english.pdf

BANANA SOIL FERTILITY PROBLEMS (2/2)

What to do ?

Add ORGANIC inputs : mulch, manure, compost, urine

Mulch, manure, compost and urine all contain plant nutrients, such as N, P, K, Mg and other useful nutrients (such as Calcium, Sulphur, Boron, Zinc, Molybdenum, Copper).

- Mulch can be made of bananas residues but any plant residue helps (e.g. weeds, grasses, wild sunflower, coffee husks). Mulch especially contains a lot of Potassium (K) and other cations.
- Wood ashes are also good to bring Potassium (K).
- Poultry manure is particularly rich in Nitrogen (N).
- For bananas, manure is preferably applied fresh. It is the best organic source of Phosphorus (P).
- Compost is also good but, for bananas, not much better than mulch and requires more labour.

Animal and human urine is a complete NPK fertilizer, especially N-rich (1 litre of urine contains 3 to 7 g N). All nutrients are directly available to the plant.

Store urine in any kind of closed* container and apply diluted, up to 10 litres urine per mat per year in two or more applications. Best is to apply mulch after urine. * to avoid N gaz losses and smells

Complete with chemical FERTILIZERS

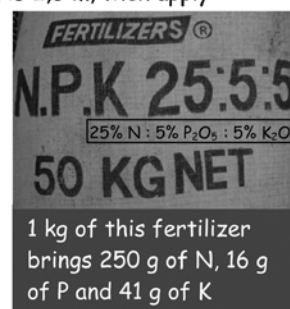
If you wish to increase your yield by 10 ton/ha/yr, and your plant spacing is 2,5 m, then apply nutrients twice a year at the start of wet season as follows:

- 60 g K per mat
- 5 g P per mat
- 30 g N per mat
- 3 g Mg per mat

Preferably apply the fertilizer dissolved in a bottle of water and pour 30 - 50 cm around the mat. Examples of fertilizers:

Fertilizer	% N	% P ₂ O ₅ ⁽¹⁾	% K ₂ O ⁽²⁾
NPK	Varies	Varies	Varies
MOP (Muriate Of Potash)	0	0	60
Potassium nitrate	13	0	38
Urea	46	0	0
Diammonium Phosphate (DAP)	18	46	0
Triple Super Phosphate (TSP)	0	46	0

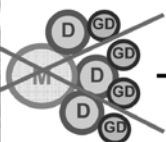
Magnesium sulfates and oxides, dolomite, magnetite and high magnesium limestone can be used as magnesium fertilizer.



Always look at the tag on the bag to know how much of each nutrient your fertilizer contains.

(1): P₂O₅ contains 32% P
(2): K₂O contains 83% K

DESUCKER regularly to maintain the correct density



Too many suckers drain resources from the mother plant, especially nutrients and water.

So desucker regularly to only leave:

- 1 mother (M)
- 1 daughter (D)
- 1 granddaughter (GD)

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For more information, visit our websites.
Questions ? Piet van Asten (IITA): p.vanasten@cgiar.org

IITA
www.iita.org

Appendix 3.5: Zero tillage mulch banana system.

http://www.cialca.org/files/files/extension_materials/zerotillage_english.pdf

ZERO TILLAGE MULCH BANANA SYSTEM

MULCH : MORE NUTRIENTS AND WATER

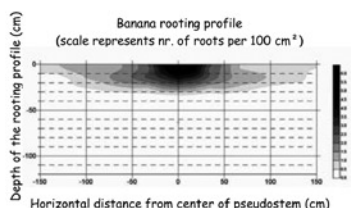


Mulch with banana trash, dried weeds, grasses: 2 cm is already great !

Mulching helps to :

- Add nutrients, especially K and other cations.
Example: 2 cm mulch per ha can bring 300 kg K.
- Conserve water: by avoiding evaporation and improving infiltration rates. Bananas require a lot of water (1500 mm/yr): when rainfall is only 1000 mm/yr, you will already experience some 50% yield loss. So, especially when rainfall is low, it is very important to increase water availability.
- Prevent erosion: do not lose rich topsoil, where banana roots feed.
- Suppress weeds: a closed mulch cover (≥ 2 cm) suppresses almost all weeds.

ZERO TILLAGE : DO NOT DISTURB ROOTS !



Usually, most banana roots do not go deep (≤ 30 cm depth), but they spread out far from the mat (up to 1,50m) : by not damaging the roots through tillage, you improve the capacity of the bananas to take up nutrients and water.

Mulch and zero tillage work together: by increasing organic matter in the soil and minimizing soil disturbance, you improve the soil structure and the health of the bananas roots. Thereby, you improve nutrients and water uptake.

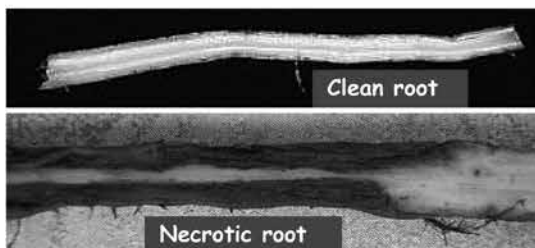
Especially, if you intercrop bananas with beans, try to plant beans without tillage and with mulch (by making small holes with a stick): banana and beans' yields will be the winners !



Appendix 3.6: Damage to bananas caused by nematodes.

http://www.cialca.org/files/files/extension_materials/sheet_degatsnematode_english.pdf

DAMAGE TO BANANA caused by NEMATODES

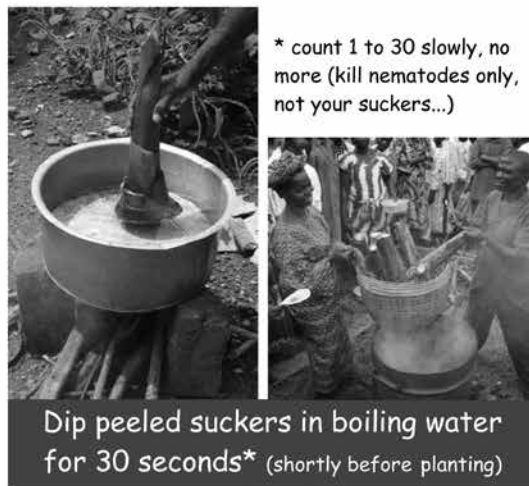


Nematodes are microscopic, which feed on banana roots. This destroys them, which reduces uptake of water and nutrients. When damage to roots is severe, it will cause toppling. New fields become infested by using infected suckers. Nearly all suckers will be infected with nematodes.



What to do ?

ALWAYS CLEAN your suckers



USE MULCH, THE MORE THE BETTER

When mulched regularly, plants better cope with nematodes.

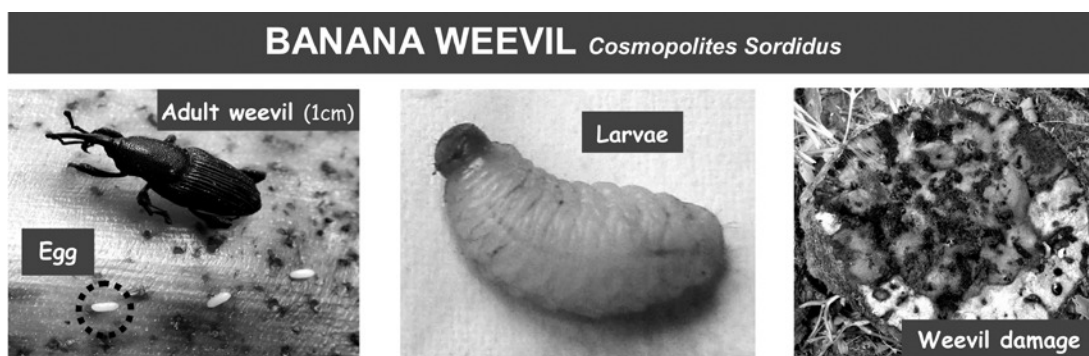
Yangambi Km5, FHIA 17 and FHIA 23 are relatively tolerant varieties of nematodes. Where nematode damage is high, if possible, rotate first with non host break crops* before replanting banana, or plant bananas in a new field, using clean suckers or tissue culture plants. Place manure or organic mulch in the planting hole and then mulch regularly.

* at least for 2 years, for instance with cassava, sweet potatoe



Appendix 3.7: Banana weevil *Cosmopolites sordidus*.

http://www.cialca.org/files/files/extension_materials/sheet_weevil_english.pdf



- A mature weevil is a black insect with clearly pronounced snout and hard fore wings.
- Adult female weevil lays eggs on pseudostem area near the collar.
- The eggs hatch into larvae which tunnel into the corm causing damage.

The larval stage is the most destructive. It leads to:

- snapping of pseudostem just above the ground under a mild wind. Snapping mostly occurs on flowered plants.
- stunted growth, reduced suckering and death of suckers.
- yield losses can exceed 40%.

What to do ?

TRAP the weevils



Split pseudostem and cut in 25cm long pieces. Put the pseudostem pieces (= traps) with the flat side down at the base of the plant. Weevils are attracted and will hide under the trap. Collect and kill the adult weevils after 2-3 days.

CLEAN your field after harvest



Weevils multiply in old corms and pseudostems after harvest. Therefore, chop and spread banana residues after harvest.

Pesticides

1. Are very effective but relatively expensive (≥ 10 USD per liter)

2. Example of commonly used pesticides:

- Dursban** (Chlorpyrifos active ingredient) contact pesticide (liquid formulation) used as drench around the banana mat.
- Furadan** (Carbofuran active ingredient) systemic and in granular form which is applied around the mat. Apply Dursban or Furadan 2 to 4 times per year depending on the level of infestation.


Note: Only apply pesticide during rainy season.

Appendix 3.8: Banana Xanthomonas wilt (BXW).

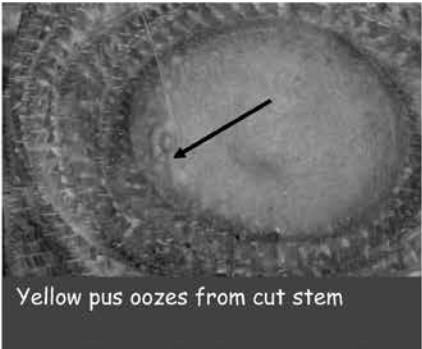
http://www.cialca.org/files/files/extension_materials/bxw_english.pdf

BANANA XANTHOMONAS WILT (BXW)


Usually known as Banana bacterial wilt



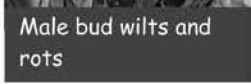
Premature yellow wilting leaves




Yellow pus oozes from cut stem




Fruits ripen when the bunch is still young



Male bud wilts and rots



Bee on a male flower that may pick up and give BXW



Cut fruits show brown stains

BXW is a bacterial disease affecting all types of bananas. How does it spread?

- **Insects** like stingless bees pick up BXW when they visit the male flower parts of an infected plant. Later when they go to the male flower parts of a healthy plant, it becomes infected.
- **Tools** like knives and hoes pick up BXW when cutting an infected plant. Later, when the tools are used on healthy plants, they will become sick.
- BXW spreads when infected **suckers** are planted in new gardens.

What to do ?

BREAK OFF the male bud

Remove the male bud with a forked stick immediately after the last cluster forms. Do not chop.

DESTROY sick plants and their suckers

Uproot infected plants and their suckers: heap/bury them in a section of the farm without bananas. Or, you can apply 2,4-D herbicide into sick plants. **Do not move any sucker from infected farms.**

Use CLEAN SUCKERS and CLEAN TOOLS



Use suckers from clean fields.
If available, use certified tissue culture plants.
Desinfect tools with fire or bleach.

Report new BXW outbreaks.




For more information, visit our websites and <http://platforms.inibap.org/xanthomonaswilt/>
Questions ? Guy Blomme (Bioversity): g.blomme@cgiar.org or Fen Beed (IITA): f.beed@cgiar.org


Appendix 3.9: Banana bunchy top disease.

http://www.cialca.org/files/files/extension_materials/BBTV_english.pdf

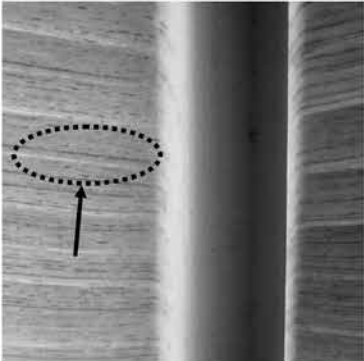
BANANA BUNCHY TOP DISEASE




On heavily infected plants, narrow upright leaves are tightly bunched



dark green dots and dashes on petiole



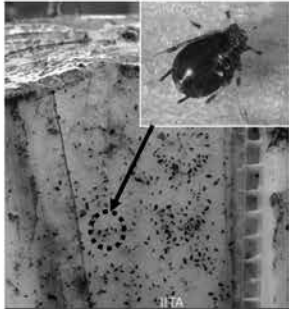
Dark green dots and dashes on leaf veins



Leaf margins appear yellow or bleached (chlorotic)

Bunchy top disease is caused by Banana bunchy top virus. Plants infected at later stages may not show the characteristic 'bunchy top' symptoms. But suckers from such plants show distinctive symptoms: yellowing of leaf margins and dark streaks on leaves and pseudostem.

The BBTV is transmitted by aphids and by planting materials derived from the diseased plants.



Aphids = virus carriers

What to do ?

DESTROY all infected plants and their suckers

Uproot and immediately bury infected plants and their suckers.
Do not move any planting material from infected farms.

CHECK all your plants

Carefully examine banana plants in your field, especially within 5 meter of infected plants.
They may be infected but may not show symptoms until later.

ONLY use HEALTHY planting material

Never use suckers from diseased plants or fields, **even if suckers appear healthy**.
Use suckers from clean fields. If available, use certified tissue culture plants.



Is Bunchy top new to you region? Immediately notify official agriculture and extension authorities, to help eradicate the infected plants. Do not propagate and distribute material from infected farms.



For more information, visit our websites. Questions ? Lava Kumar (IITA): L.kumar@cgiar.org

Appendix 3.10: Fusarium disease of banana (Panama disease).

FUSARIUM WILT OF BANANA (Panama Disease)



External symptoms

- Yellowing of oldest leaves (spreads from leaf margins)
- Oldest leaves then collapse at the petiole: it gives the appearance of a skirt around the plant.
- In young plants, dwarfing or stunting may occur.

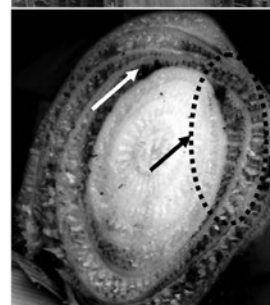
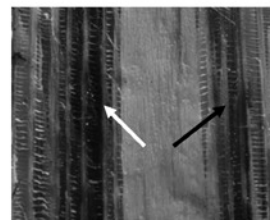
Fusarium wilt disease kills banana plants. It is caused by the soil borne fungus *Fusarium oxysporum f.sp cubense* (Foc). It spreads mostly through infected suckers, which look initially healthy but later become diseased.

Infected plants fail to produce fruit. It causes yield losses of up to 100% to susceptible cultivars, such as:

- Plantains (Gonja),
- exotic beer bananas (Kisubi, Kayinja),
- Kamaramasenge (Sukali Ndizi, apple banana, Calole),
- Bogoya (Gros Michel).

Cultivars of the Cavendish group are resistant to the races of Foc currently occurring in Africa.

The fungus can survive in the soil for over 30 years and will re-infect any susceptible banana plants that are planted: there is no existing cure...



Internal symptoms

typical discoloration of vascular tissues (in roots, corm, pseudostem, fruit stalk): from pale to dark red to

What to do ?

DESTROY infected plants and their suckers



Uproot and destroy infected plants. Also uproot their suckers, even if no symptoms are visible, as there is a high risk they are also infected. Do not spread infected plant residues. Do not move suckers from infested to clean areas, even though they may appear healthy. Measures to prevent disease establishment in new areas is one of the most effective means of control.

Be careful: Fusarium spreads in soil attached to tools, shoes, plants.

Grow RESISTANT varieties

Using resistant varieties is the most cost-effective and sustainable method of controlling Fusarium wilt in your field. Resistant varieties include: Cavendish, FHIA 17, FHIA 23, highland cooking and beer bananas, and IITA/NARO hybrids.

If you want to grow susceptible cultivars, plant bananas in a clean field with good drainage, using clean suckers from an area free from symptoms and preferably use disease-free certified tissue culture plants.




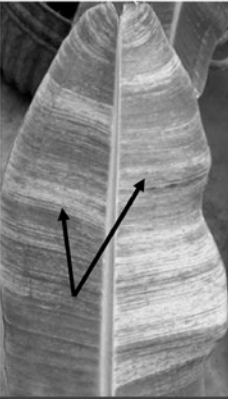
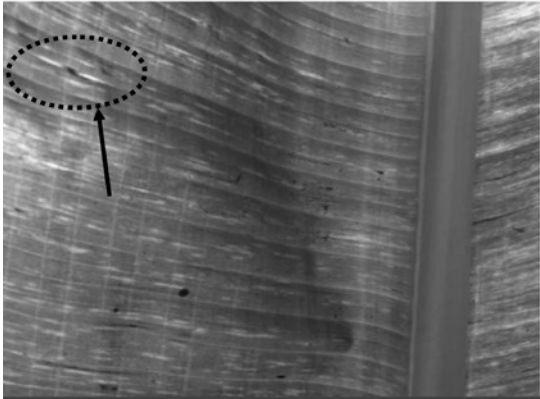
For more information, visit our websites.
Questions ? Fen Beed (IITA): f.beed@cgiar.org
Guy Blomme (Bioversity): g.blomme@cgiar.org



Appendix 3.11: Banana streak disease and banana mosaic disease.

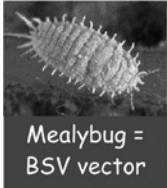
http://www.cialca.org/files/files/extension_materials/BSV-CMV_english.pdf

BANANA STREAK DISEASE & BANANA MOSAIC DISEASE




'Golden yellow' (chlorotic) streaks on leaves, which on occasions turns dark brown and necrotic

Mild chlorotic streaks on pseudostem



Mealybug =
BSV vector



aphid =
CMV vector

Banana Streak disease is caused by Banana Streak Virus (BSV).
Banana Mosaic disease is caused by Cucumber Mosaic Virus (CMV).
Symptoms caused by these two viruses look similar:

- Chlorotic streaks can be continuous, discontinuous or spindle shaped.
- Infected plants may not show symptoms on all leaves.
- Symptoms disappear and reappear periodically.
- Severe infection causes necrosis of the cigar leaf and central cylinder.

These two diseases reduce plant growth and bunch weight, but good yields can still be achieved if the crop is well managed (i.e. ample water and nutrients).
Our studies in Africa indicated that BSV incidence is usually higher than CMV.

BSV is transmitted by mealybugs. CMV is transmitted by aphids.
Both are propagated by planting materials derived from the infected plants.

What to do ?

MULCH regularly

Banana plants can tolerate BSV and CMV infections better with good crop management, specially through regular mulching and removing weeds (which can be used as mulch).
In these conditions, yield losses reduce to less than 20%.

ONLY use HEALTHY planting material

After harvest, uproot infected plants and their suckers.
Do not select planting material from infected mats, even though suckers may appear healthy.
If available, use certified tissue culture plants for cultivation.

Appendix 3.12 **Appendix 3.12:** Banana fungal diseases.

http://www.cialca.org/files/files/extension_materials/fruit_fungal_diseases_english.pdf

BANANA FRUIT FUNGAL DISEASES

Cigar end rot



The necrotic tissue on the fruit tips becomes covered with the mycelia of fungi and resembles the greyish ash of a cigar end (see picture above and below)



Two fungi are responsible for Cigar end rot. The rot spreads slowly and seldom affects more than the first 2 cm of the fruit tip.

The fruit pulp undergoes a dry rot. Mainly occurs during the rainy season

Fruit Peel disease



First tiny black spots appear on the peel (left). They enlarge to, diamond-shaped lesions that eventually cover the entire fruit and make it rot (right).

This disease has been in Central Africa for over 50 years. High altitude areas (>1700m) have noted increasing attacks recently. Insects probably make the initial damage to the fruit peel, creating opportunities for fungal infections (e.g. *Colletotrichum musa*) to colonize these wounds

The symptoms are most severe during the rainy season and severely affected fruit becomes unsuitable for human consumption, but small lesions leave the fruit pulp unaffected



What to do?

Keep your banana plants as clean as possible

Collapsing, dying and dead leaves, the upper leaf during bunch formation and bracts need to be removed from plants at regular intervals during the rainy season to reduce inoculum levels.

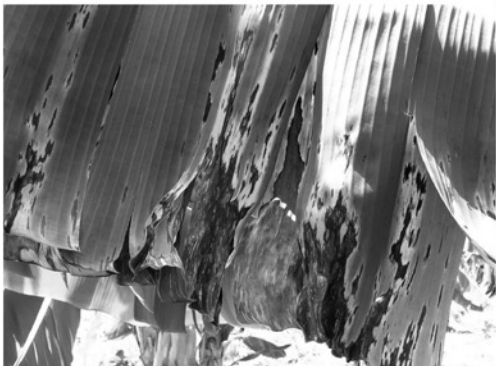
Heap and preferably bury the removed infected plant parts in banana-free field

Appendix 3.13: Banana leaf spot diseases: Yellow Sigatoka (*Mycosphaerellamusicola*) and Black Sigatoka (*Mycosphaerellafijiensis*).

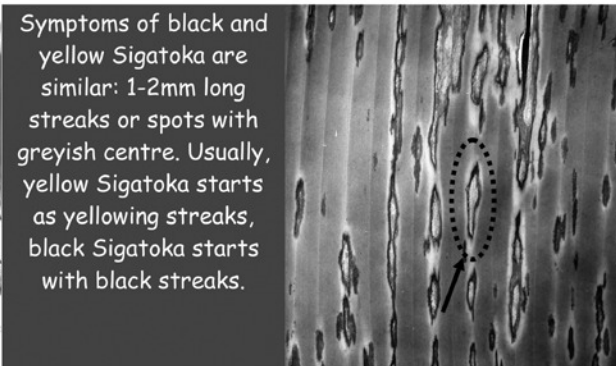
http://www.cialca.org/files/files/extension_materials/sheet_leafspots_english.pdf

BANANA LEAF SPOT DISEASES

Yellow Sigatoka (Mycosphaerella musicola) and Black Sigatoka (Mycosphaerella fijiensis)



Symptoms of black and yellow Sigatoka are similar: 1-2mm long streaks or spots with greyish centre. Usually, yellow Sigatoka starts as yellowing streaks, black Sigatoka starts with black streaks.



Banana leaf spot diseases :

- are air borne fungal diseases,
- spread very fast during wet and warm conditions.

Many leaf spot diseases exist but black Sigatoka and yellow Sigatoka are the most devastating. Black Sigatoka is more widespread in lowlands, while yellow Sigatoka is more widespread in highlands.

Effects on production

- Leaf spot diseases kill banana leaves, reduce bunch weight and fruit quality.
- Leaf spots also cause premature ripening of fruits.
- Affected field-ripened bunches harbour fruit flies that further reduce marketability.

What to do ?

REMOVE SICK LEAVES

Try to identify symptoms at an early stage - when the disease is present:

1. Remove diseased leaves (and preferably burn them)
2. Encourage low humidity banana plantations by reducing planting density for plentiful air flow, avoid water logged areas, and reduce weeds

USE RESISTANT VARIETIES

Yangambi Km 5, Mysore, Pelipita, Saba, Kayinja, FHIA lines (01, 03, 17, 21, 23, 25) and NSH are resistant. Cultivars of Cavendish are susceptible.

Regular fungicide applications are justified for large plantations (that are systemic and in oil emulsion) and can control foliar diseases (e.g. benomyl).

Appendix 4: Fertilizer recommendations

This section is a more complicated version of the text that appears in the main document (see 5.5). It is targeted at more experienced extension workers who are comfortable doing calculations to convert nutrient rates to amounts of fertilizer and who have access to laboratories which can analyse leaf and soil samples. Whereas section 5.x provides some examples of fertilizer options, this appendix aims to equip extension workers to develop their own fertilizer recommendations based on the nutrient requirements of banana-coffee systems.

All plants require an adequate supply of nutrients to grow and yield well and banana and coffee are no exception. For example, young plants require phosphorus for root establishment and growth, and mature plants require potassium for flowering and fruit filling (Table 18).

If the supply of nutrients is insufficient, production decreases and coffee may be affected by die back. Unlike legumes, which require phosphorus, and cereals, which require nitrogen and phosphorus, both banana and coffee need large amounts of potassium as well as phosphorus and nitrogen (Table 18 & 19).

Table 18. Role of major nutrients in banana and coffee.

	All plants	Banana	Coffee
N	Vegetative growth	Size of bunch, frequency of harvesting.	Crop bearing capacity, size of beans.
P	Root development, energy reactions, flowering, seed and fruit development.	Size of bunch, amount of sugar in fruits, strength of stem.	Wood development, flowering, ripening, fruit size, sucker development.
K	Translocation of products of photosynthesis, water balance, disease resistance.	Number of fingers/bunch, fruit filling, fruit quality.	Fruit development, mucilage formation, fruit quality.
Ca	Growth of terminal buds, flower formation, root and leaf development.	Yield, fruit quality.	Fruit ripening and quality.
Mg	Photosynthesis, plant growth	Hands per bunch, quality of fruit.	Bean color.
S	Formation of plant proteins	Size of bunch.	Bean color and aroma.
Bo	Growth, metabolism of carbohydrates, growth of new shoots and roots		Flowering, fruit set and development.
Cu	Photosynthesis, development of pigments that influence color	Resistance to fungal diseases.	
Cl	Water balance, ionic balance, photosynthesis		
Fe	Chlorophyll formation	Bunch size.	Bean color and aroma.
Mn	Chlorophyll formation		
Mo	Nitrogen metabolism		
Zn	Plant height, leaf size, flower initiation and formation	Finger development.	

Table 19. Amount of nitrogen (N), phosphorus (P) and potassium (K) contained in different plant parts for production of 1 t of banana and 1 t coffee (green bean).

Crop and plant part	Nitrogen	Phosphorus	Potassium
	kg		
Banana			
Pseudostem, corm, suckers, fruit stalk	2.3	0.4	7.2
Leaves	0.5	0.1	0.6
Trash	1.6	0.2	2.0
Fruit	1.8	0.2	5.5
Total	6.2	0.8	15.3
Coffee			
Leaves, stems	20.6	3.4	18.6
Green bean, parchment, pulp	33.9	2.5	40.5
Green bean	21.5	1.7	17.5
Total	76.0	7.6	76.6

Deficiencies of macronutrients nitrogen, phosphorus, potassium, sulphur, magnesium and calcium, and the micronutrients zinc, boron or iron, lead to the appearance of leaf nutrient deficiency symptoms in banana (Photo 22) and coffee (Photo 23) that can be detected in the field.

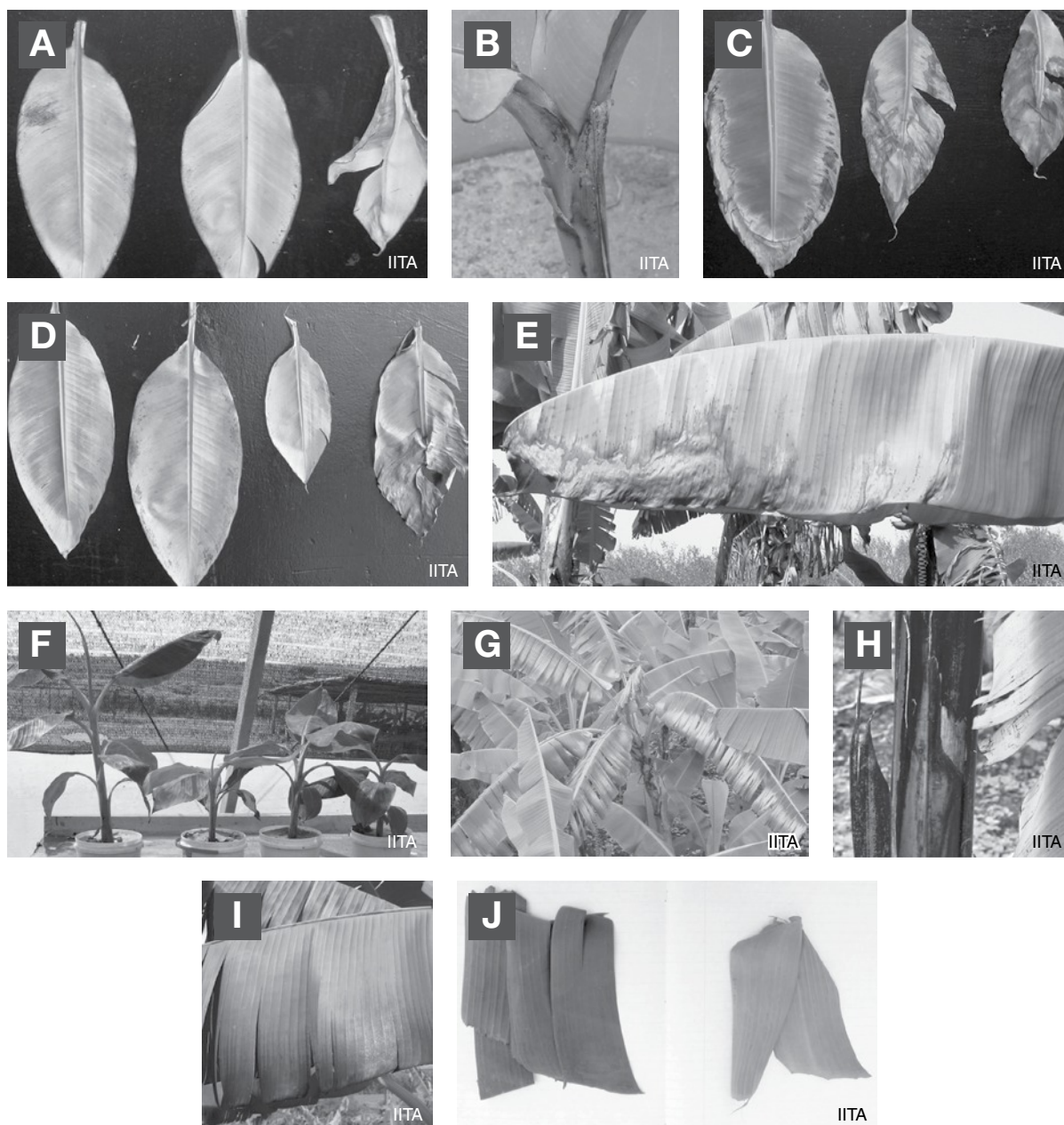


Photo 22. Nutrient deficiencies in banana. **(A)** N deficiency, leaves turn green, then yellow. **(B)** Leaf petioles and sheath turn pink in N deficient banana. **(C)** P deficiency, leaf margins turn scorched brown. **(D)** K deficiency, leaf margins and tips turn yellow from tip, then orange, scorching along margins hangs. **(E)** As scorching on leaves of K deficient plants progress, mid-rib is unable to support leaf, mid-rib breaks and half of leaf close to tip hangs downwards. **(F)** Plants supplied with adequate nutrient have more vigorous growth (e.g. plant on extreme left) than plant deficient in N (second from left), P (third from left) or K (extreme right). **(G)** Mg deficiency, light yellow band along leaf. **(H)** In Mg deficient plants, leaf sheaths can separate from the pseudostem. **(I)** Dark color along leaf margin observed in East African highland banana growing in soil with low pH. **(J)** without micronutrients leaves are yellow (right) instead of green (left).

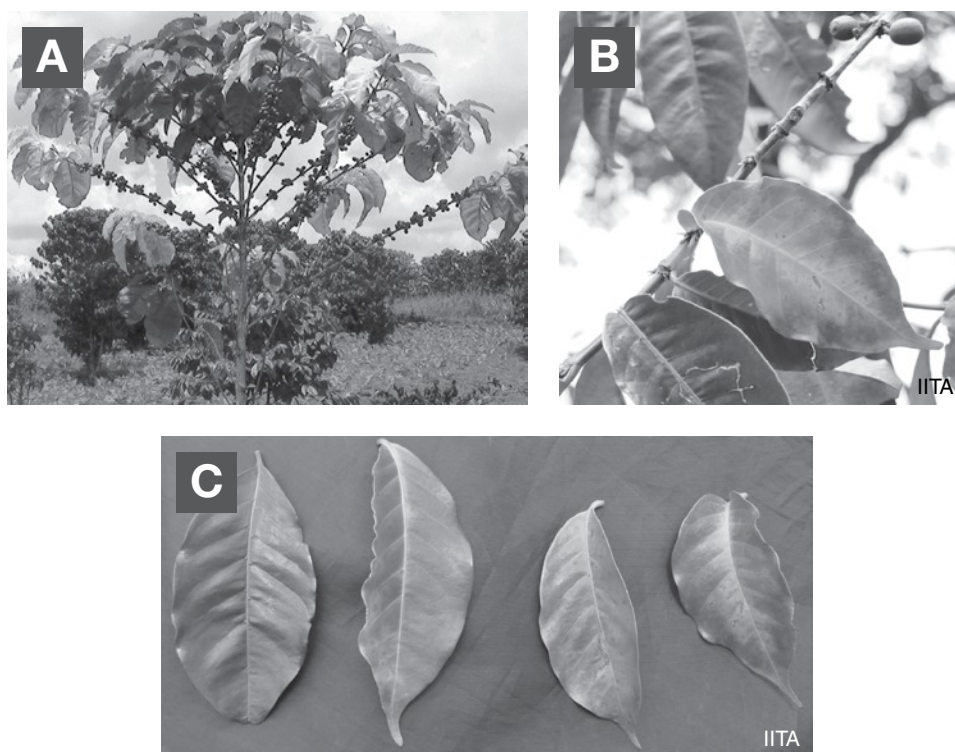


Photo 23. Nutrient deficiencies in coffee. **(A)** Yellowing of leaves caused by withdrawal of N from leaves to maturing crop. The symptom is common during the dry weather. **(B)** P deficiency, older leaves go yellow, then red-bronze (red-purple). **(C)** Normal Leaf (left) and progression of P deficiency symptoms.

Nutrient requirements can be supplied as organic inputs (i.e. crop residues or animal manure), fertilizers or a combination of both. Using organic inputs in combination with fertilizers may increase the efficiency of fertilizer use. In other words, when fertilizers are applied in the presence of organic residues, more of the nutrients contained in the fertilizer are taken up by the crops.

Unlike fertilizer nutrients, which are readily available to plants, organic inputs need time to decompose and release nutrients and are therefore a 'slow release' source of nutrients to plants. Residues with a narrow C:N ratio (e.g. legume crop residues) decompose and release their nutrient content more rapidly than materials with a wide C:N ratio (e.g. cereal straw).

The concentration of nutrients in organic resources is low and therefore much larger quantities of organic resources are required to supply a given quantity of nutrients by comparison with mineral fertilizers.

For example, fresh goat manure on average has the potential to supply 7 kg/t P or 16 kg/t P_2O_5 (see Appendix 1 for nutrient content in manures and crop residues, and Appendix 2 for nutrient conversion factors). By comparison, one tonne of triple superphosphate (TSP) fertilizer contains 200 kg P or 460 kg P_2O_5 .

If the farmer does not have livestock and plans to buy animal manures it is worthwhile to compare the cost of nutrients in fertilizers and animal manures and then select the least costly source.

The 4Rs + 1R for effective use of fertilizer

There are four 'rights' that help the farmer to get the most benefit from fertilizers, and avoid toxicity and nutrient imbalances in the soil environment:

- apply the right fertilizer product(s)
- at the right rate
- at the right time
- in the right place.

Because fertilizers are costly inputs it is important also to prioritize the use of scarce fertilizers on the crop that will deliver the greatest return on fertilizer inputs.

We now review the four rights in detail.

The right fertilizer type

- If you are not sure which nutrients your crops need, inspect the crop for the presence of nutrient deficiency symptoms (Photos 11 and 12). You can also take soil and leaf samples for analysis at reputable laboratory (see box for guidelines on how to collect soil and foliar samples).
- Use fertilizers that are suitable for the soil conditions, that have nutrients in available forms and that have the right combinations of nutrients required.

Suitable compound fertilizers for mature banana–coffee system should contain more K_2O than N and P_2O_5 (i.e. about 10% N, 3% P_2O_5 and 23% K_2O).

Unfortunately, the most common fertilizers available in local stores contain 20:10:10 and 17:17:17 of N:P $2O_5$: K_2O , which are clearly not the most suitable fertilizers for the banana–coffee systems. It may therefore be necessary to apply 'straight' fertilizers or a compound fertilizer together with additional straight fertilizer. Alternatively, farmers can buy straight fertilizers and prepare their own mixtures immediately prior to field application.

Box 1. How to take soil and foliar samples in banana coffee systems

How to take soil samples in banana coffee systems

1. Before taking samples consider the heterogeneity of the field with respect to slope and crop vigour.
2. Decide on a sampling pattern (e.g. every 30 m by 30 m) that will deliver about 10 subsamples per ha.
3. At each sampling point remove litter from the soil surface. Sample poor and better performing areas separately.
4. Use an Edleman soil auger to sample soil from 0-30 cm depth. In case of lack of auger a hand hoe can suffice.
5. Mix the sub-samples thoroughly to produce a composite sample.
6. Place samples in clean, labeled plastic bag.
7. Deliver the samples to the laboratory.

How to take foliar samples

Banana

1. A composite sample is prepared for each field.
2. Intercropped banana-coffee fields contain 700–800 banana plants per ha.
3. Decide on a sampling grid (e.g. every 5th plant in every 5th row in newly established plantations) to provide about 15–20 sub-samples per ha.
4. Samples are only taken from flowering plants.
5. Select the 3rd fully opened leaf.
6. Remove a strip of tissue 20cm long by 10 cm wide on both sides of the central vein in the middle of the leaf. The long side of the strip should be parallel to the central vein.
7. Place samples in clean, labeled paper bag.
8. Deliver the samples to the laboratory.

Coffee

1. A composite sample is prepared for each field.
2. Intercropped banana-coffee fields contain about 1000 Robusta and 2–2500 Arabica coffee trees per ha.
3. Decide on a sampling grid (e.g. every 10th plant in every 5th row in newly established plantations) to provide about 15–20 sub-samples per ha.
4. Select four bearing lateral branches at mid-height of the tree.
5. Select the 3rd or 4th pair of newly matured leaves counting from the branch tip from each of the four selected branches.
6. Place samples in clean, labeled paper bag.
7. Deliver the samples to the laboratory.

The right fertilizer rates

It is difficult to make fertilizer recommendations without information on soil fertility and crop nutrient status:

- The essential soil test parameters are soil organic carbon, total nitrogen, available P, exchangeable K and Mg, and soil pH. Ideally soil samples should be taken at each farm site or at least at a representative farm site and analysed at a reputable laboratory. Soils can then be classified in terms of soil fertility status.
- The essential foliar analysis parameters are nitrogen, phosphorus, potassium and magnesium. Information on micronutrients is useful but not essential because nutrient deficiencies can be detected by crop inspection.

Compare site soil and leaf analysis values with Table 20 and Table 21 respectively, to determine whether the site is 'low fertility status' or 'high fertility status'. Suggested ranges for fertilizer nutrient application rates for immature coffee and banana and mature banana–coffee systems on 'low fertility status' and 'high fertility status soils' are provided in Tables 23-26. Note that different recommendations are provided for different yield targets for each soil fertility status category. If the farmer plans to apply large quantities of organic resources (i.e. more than 5 t/ha) estimate the nutrient inputs provided in the organic resources from the table in Appendix 1 and adjust the recommended fertilizer rates accordingly.

Table 20. Critical and adequate leaf nutrient concentrations for banana and coffee.

Element	Units	Banana		Arabica coffee	
		Critical	Adequate	Critical	Adequate
N	%	>2.6	2.8-4.0	>2.2	2.5-3.0
P	%	>0.13	0.2-0.25	>0.1	0.15-0.20
K	%	>2.5	3.1-4.0	>1.5	2.1-2.6
Ca	%	>0.5	0.8-1.2	>0.4	0.75-1.5
Mg	%	>0.2	0.3-0.46	>0.1	0.25-0.4
Cu	mg/kg		7-20	>10	16-20
Zn	mg/kg	>14	21-35	>10	15-30
Mn	mg/kg	>10	100-2200	>25	50-100
Fe	mg/kg		70-200	>40	70-200
B	mg/kg	>10	20-80	>25	40-100

Worked hypothetical example: Soil analysis and banana leaf analysis data is available for a mature banana–Robusta coffee farm in Southwest Uganda. The present yield is 20 t/ha banana and 1.5 t/ha green bean with both crop products sold as a cash crop. The farmer purchases and applies 5 t/ha farmyard manure to her banana–coffee farm. Results of soil analysis show that the soils are poor in all nutrients except potassium (Table 21). Leaf analysis shows that bananas are deficient in nitrogen and phosphorus but leaf potassium status is above the critical value (Table 21).

Table 21. Soil and leaf analysis data from a farm in southwest Uganda compared with critical values for soil parameters and adequate ranges for leaf analysis data.

Parameter	Units	Site value	Critical value	Adequate range	Soil fertility status
Available P	mg/kg	3	15		Low
Exchangeable K	cmol/kg	0.4	0.3		High
Soil organic carbon	%	1.3	1.7		Low
Total nitrogen	%	0.12	0.15		Low
Leaf N banana	%	2.3	>2.6	2.8-4.0	Low
Leaf P banana	%	0.10	>0.13	0.2-0.25	Low
Leaf K banana	%	3.3	>2.5	3.1-4.0	High

The farmer's target is to increase banana and coffee yields. As already mentioned, soil fertility status for nitrogen and phosphorus is poor. Therefore, for a target yield of 30 t /ha/year banana and 2.5 t/ha/year coffee, the recommendation is 230-280 kg/ha N and 60-80 kg/ha P_2O_5 (Table 21) in the first year.

Soil potassium status is good and the recommendation for potassium is 230-270 kg K_2O /ha. Nutrient application rates are then converted into amounts of fertilizer (Table 22). In this case straight fertilizers have been used but a combination of compound and straight fertilizer could also be used.

Table 22. Worked example fertilizer recommendations for a banana–Robusta coffee farm in Southwest Uganda.

		Units	N	P_2O_5	K_2O
Recommended rate	First year	kg/ha	230–280	60–80	230–270
	From second year	kg/ha	140–160	35–45	140–170
Fertilizer material		–	Urea	TSP	KCl
Nutrient concentration		%	46	46	60
Fertilizer amount	First year	kg/ha	500–610	130–175	380–450
	From second year	kg/ha	300–350	75–100	230–280

TSP is triple superphosphate, KCl is potassium chloride also known as muriate of potash

Fertilizer inputs could be reduced by about 50 kg N, 90 kg P_2O_5 and 70 kg K_2O to allow for the nutrients supplied in 5 t/ha farmyard manure applied to the banana–coffee field.

The ratio of $N:P_2O_5:K_2O$ is equivalent to 10:3:23 and a compound with similar nutrient content could be used instead of straight fertilizers. If the farmer lacks the resources to implement the recommendation in full, the agronomist could reduce the recommended rate to an amount considered affordable by the farmer whilst maintaining the same ratio between nutrients.

Table 23. Suggested fertilizer application rates for immature banana in sub-Saharan Africa.

Soil fertility	Year	N	P ₂ O ₅	K ₂ O	MgO
		g/tree			
High	1	60	20	200	20
	2	70	40	250	25
Low	1	70	30	260	25
	2	90	80	300	35

Table 24. Suggested fertilizer rates for immature coffee in sub-Saharan Africa.

Crop	Soil fertility status	Year	N	P ₂ O ₅	K ₂ O	MgO
			g/tree			
Arabica coffee	High	1	20	5	20	5
		2	30	10	30	10
		3	50	15	50	15
	Low	1	30	10	30	10
		2	50	15	50	15
		3	90	25	90	25
Robusta coffee	High	1	40	10	40	10
		2	60	20	60	20
		3	120	30	100	30
	Low	1	60	20	60	20
		2	100	30	100	30
		3	180	50	180	50

Table 25. Suggested fertilizer application rates for mature banana–coffee systems in sub-Saharan Africa.

	Deficiencies	Crop	Yield increase (t/ha)		N	P ₂ O ₅	K ₂ O	MgO
			Banana	Coffee	kg/ha			
First year	N, P, K	Banana-Arabica	10	0.5	170-200	50-65	380-460	30-35
		Banana-Robusta	10	1	230-280	60-80	450-550	40-45
	P	Banana-Arabica	10	0.5	170-200	50-65	190-230	30-35
		Banana-Robusta	10	1	230-280	60-80	230-270	40-45
	K	Banana-Arabica	10	0.5	170-200	25-30	380-460	30-35
		Banana-Robusta	10	1	230-280	30-40	450-540	40-45
From the second year	N, P, K	Banana-Arabica	10	0.5	100-115	25-35	230-270	14-17
		Banana-Robusta	10	1	140-160	35-45	280-330	18-21
	P	Banana-Arabica	10	0.5	100-110	25-35	110-140	14-17
		Banana-Robusta	10	1	140-160	35-45	140-170	18-21
	K	Banana-Arabica	10	0.5	100-110	11-20	230-270	14-17
		Banana-Robusta	10	1	140-160	15-25	280-330	18-21

Table 26. Suggested fertilizer application rates for targeted yield increase in mature banana intercropped with young coffee, and mature coffee (Arabica or Robusta) intercropped with young banana. The fertilizer rates for immature crops remain as suggested in Tables 23 for banana and Table 24 for coffee.

	Deficiencies	Mature crop	Yield increase (t/ha)	N	P ₂ O ₅	K ₂ O	MgO
				kg/ha			
First year	N, P, K	Banana-Arabica	10	100-125	35-50	305-370	25-30
		Banana-Robusta	1	125-155	25-35	145-175	15-20
	P	Banana-Arabica	10	100-125	35-50	155-185	25-30
		Banana-Robusta	1	125-155	25-35	75-95	15-20
	K	Banana-Arabica	10	100-125	20-25	305-370	25-30
		Banana-Robusta	1	125-155	10-15	145-175	15-20
From the second year	N, P, K	Banana-Arabica	10	55-65	20-25	175-210	10-12
		Banana-Robusta	1	80-100	15-20	100-125	8-9
	P	Banana-Arabica	10	55-65	20-25	85-105	10-12
		Banana-Robusta	1	80-100	15-20	50-60	8-9
	K	Banana-Arabica	10	55-65	9-11	175-210	10-12
		Banana-Robusta	1	80-100	8-10	100-125	8-9

Example: Calculation for straight and compound fertilizers

The nutrients can be from straight fertilizers (i.e. that supply one nutrient) or from compound fertilizers (i.e. that supply more than one nutrient).

For example, if the goal is to apply 232 kg/ha of N, 62 kg/ha of P₂O₅ and 226 kg/ha of K₂O.

If using straight fertilizers, N can be supplied as urea (46 N%), P as triple superphosphate (TSP) (46% P₂O₅), and K as potassium chloride (KCl) (60% K₂O). The amount of fertilizer required would be:

$$\text{Amount of urea} = \frac{(232 \times 100)}{46} = 503 \text{ kg/ha}$$

$$\text{Amount of TSP} = \frac{(62 \times 100)}{46} = 136 \text{ kg/ha}$$

$$\text{Amount of KCl} = \frac{(226 \times 100)}{60} = 376 \text{ kg/ha}$$

If using compound fertilizers, a fertilizer that contains nutrients in the proportions close to those that are required should be selected. For example, if the nutrients required above are to be supplied by a compound fertilizer, a good choice would be NPK 18:4:12, containing 18% N, 4% P_2O_5 and 12% K_2O , which is among the 'coffee fertilizers' recommended in Kenya. The calculation would be:

$$\text{Amount of NPK 18:4:12} = \frac{(232 \times 100)}{18} = 1289 \text{ kg/ha}$$

This would provide about 232 kg N, 52 kg P_2O_5 and 155 kg K_2O . The shortfall of 10 kg P_2O_5 and 70 kg K_2O can be provided by applying 22 kg TSP and 117 kg KCl per ha.

In general, first determine the amounts of nutrients required, then check which of the fertilizers available on the market can supply the nutrients that your crop needs and finally select fertilizers that provide the required nutrients at the lowest cost.

A calibrated measure should be used to apply fertilizer accurately to each plant. For example, a soda-bottle cap contains 4 g urea, 6 g MOP or 7 g TSP fertilizer. Calibrated cups can also be made from tins and washing powder containers. Such measures can be calibrated roughly by counting the number of soda-caps of fertilizer that are required to fill the receptacle.

When applying fertilizer in a mature banana plantation, newly intercropped with young coffee, or mature coffee newly intercropped with young banana, fertilizer can be applied to the two crops separately in the first two years of the intercrop (see Table 25 and 26 for proposed recommendation for the mature crop and Tables 23 and 24 for immature crop). In mature banana-coffee intercrops fertilizers can be applied to both crops at once by broadcasting the fertilizers over the soil surface.

The right time for application

Apply fertilizer when soil is moist, during the rainy seasons. To minimise losses, fertilizer N application should be applied in two split applications – for example at the beginning, then in the middle of the rainy season (about 2 months after the first application). It is not usually necessary to apply phosphate and potash fertilizers in split applications as they are released more slowly.

The right placement of fertilizer

Fertilizer should be applied over the soil surface where feeder roots are found (Photo 24). Remove trash on the surface where fertilizer is to be applied, apply fertilizer and then replace the trash.

For young banana mats, make a furrow about 30 cm from the mat. Place fertilizer in the furrow and cover with soil. If the mother plant has a bunch approaching



Photo 24. Nitrogen fertilizer applied in a furrow around the coffee tree, then covered with soil, can be accessed by roots of banana.

maturity, apply fertilizer to the daughter and granddaughter. Do not work the fertilizer into the soil using a hoe as you may damage roots of the crops.

For fertilizer N in young coffee plants, apply under the leaf canopy, extending up to 20 cm beyond the drip-line.

In mature plantations where canopies of banana and coffee overlap, apply under and between banana mats and coffee plants. Do not apply fertilizer too close to banana mats (i.e. at least 30 cm from the mat).

All fertilizers should be spread evenly over the target zone – fertilizers applied in lumps may burn the crop's roots.

The right crop for fertilizer

Farmers with limited cash to invest in fertilizers must decide which crop will give the greatest return on fertilizer application. Fertilizers can be applied separately to each crop during the immature growth phase (Table 22 and 23).

In mature banana–coffee intercrops, however, it is not really practicable to target fertilizers to one or other of the two crops because by the time the system has started to yield, root systems of both crops will have formed an overlapping continuous web of roots. Therefore, as with mulch and animal manure, the best approach is to broadcast fertilizers over the soil surface under the banana–coffee system.

Note that although generally applying fertilizer makes crops healthier, applying excessive amounts of nutrients can make plants unhealthy (Table 27). Monitor your crop closely and seek advice when necessary.

Table 27. Effect of excessive application of nutrients on banana and coffee.

	Banana	Coffee
N	Bunches are smaller, break before maturation and have reduced green life after harvest.	Excessive vegetative growth, poor yields
P	May induce Mg, Zn deficiency.	May induce Zn or Fe deficiency.
K	May induce Ca, Mg deficiency.	May induce Mg deficiency.
Mn	Reduces uptake of Ca, Mg and Zn, may predispose condition of 'mixed ripe' i.e. harvested fruit ripen prematurely.	Scorching of older leaves.
Cl	Fruit not filled	Scorching of older leaves.
Cu	Stunted roots	Fe chlorosis, stunted roots.
Fe	Black margins of leaf lamina.	Mn deficiency.
Mn	Black margins of leaf lamina	Leaf chlorosis, brown spots.
Zn		Fe deficiency.
Al		Leaf chlorosis.
Na	Marginal chlorosis and necrosis of leaves.	
B	Marginal paling of leaves with necrosis.	Mottled leaf margin and chlorosis near leaf margins. Purple base of leaf midrib.

Timing of operations

Correct timing, frequency, and sequencing of operations (e.g. pruning coffee trees after the harvesting season) are crucial for successful management of banana–coffee systems.

Africa Soil Health Consortium – improving soil fertility, improving food production, improving livelihoods

ASHC works with initiatives in sub-Saharan Africa to encourage the uptake of integrated soil fertility management (ISFM) practices. It does this primarily by supporting the development of down to earth information and materials designed to improve understanding of ISFM approaches.

ASHC works through multidisciplinary teams including soil scientists and experts on cropping systems; communication specialists, technical writers and editors; economists; monitoring & evaluation and gender specialists. This approach is helping the ASHC to facilitate the production of innovative, practical information resources.

ASHC defines ISFM as: A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs & improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic and economic principles.

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