

Cultivations techniques

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In Africa, most banana and plantain trees are grown in backyards or home gardens ranging in size from 0.5 to 4 hectares, where 5 to 15 varieties are grown together. Yield per area is very high due to the high density of plants and soil fertility. The high density is due to the fact that the plants are never thinned (all suckers are allowed to grow). Soil fertility is a result of the richness of the nutrient composition and organic materials deposited, as the backyard is used as a rubbish dump. Household waste and ashes from all sources are dumped there. This results in a significant increase in cation exchange capacity (CEC) from 3 to 30 meq/100 g of soil.

Since the focus is solely on natural regeneration, as all waste is used for production, the size of bunches varies (no maximum weight due to excessive competition) in the home gardens. Thus, there is no peak period of bunches unlike in plantations. There is hardly any care take off. There is no planned production. People are satisfied with what the plant yields.

The salient problems of home gardens can be classified into two categories: (1) small cultivated areas due to the presence of neighbouring dwellings and proximity to the road, etc. (2) diseases and pests.

Due to a lack of financial resources, farmers' limited technological knowledge and, above all, toxicity, the use of pesticides is not an option. Instead, preventive techniques should be used to limit the spread of diseases and pests: systematic destruction of diseased plants, use of healthy planting materials and cultivars resistant to various pests and diseases. In order to achieve self-sufficiency in banana, the first step consists of the establishment of fields outside villages, ranging in size from a few hectares to several hundred hectares, with a view to obtain high yields for 7 to 30 years. This requires the application of appropriate cultivation techniques. Unfortunately, these appropriate cultivation techniques are not applied in fields where plantains are grown, and as a result, current fields last barely 2-3 years.

Choice of land

The land must be easily accessible, given the cost of transporting fertilisers and bunches. Soil

rich in organic matter should be chosen, such as fields that have been left fallow for a long period, characterised by a water table at a depth of around 100 cm, good porosity, good aeration and good drainage. Indeed just a few hours of water logging is enough to cause damage to the roots. The banana plantation should be located in an area that is unlikely to experience strong winds; low-lying areas that are too wet or areas that are too dry are not suitable.

Site preparation

Once the land has been selected, the fallow vegetation must be destroyed either temporarily or permanently. After a long period of fallow, the vegetation can be cut manually, dried and burned. This enriches the topsoil with K, Mg and Ca, which are essential for banana growth, and on the other hand, weed seeds are destroyed by incineration. The disadvantage of incineration is the leaching of nutrients. The same situation occurs when land is cleared with tractors or bulldozers.

Ideally an old fallow is cleared without burning. Planting can then be carried out in a thick layer of cut plant biomass (which presents difficulties in terms of passage). This keeps the soil covered and allows minerals to be released gradually, which is beneficial for perennial crops such as bananas. This thick soil cover with plant biomass is also a means of controlling weeds. Once the biomass on the fallow land has undergone total mineralisation, the banana leaves are covering the soil. This extends the life span of the plantation. In both cases (clearing and burning or clearing alone), natural vegetation must be allowed to grow back between the banana plants.

When it comes to long periods of fallowing, the natural vegetation is mainly composed of dicotyledons (with many trees) that have deeper root systems than monocotyledons such as banana plants. Hence these dicotyledons cause no harm to banana plants. Pockets of monocotyledonous weeds need to be destroyed by herbicides. Forest regrowth can serve as living mulch or dead litter that protects the soil from weeds, high soil temperatures and torrential rains. This vegetation is only cut if it shades the banana trees too much or complicates field work. These advantages do not exist if cover crops (legumes) are mowed.

Field preparation with a bulldozer is unjustified because the nutrient-rich biomass of the fallow is stripped away with the topsoil. Moreover, the soil becomes compacted, which can lead to waterlogging.

After preparing the field, the planting holes are marked. Water channels are dug for drainage. Under certain conditions, good soil for banana is soil that has been ploughed and harrowed.

Spacing

The roots and leaves of banana plants can grow to a length of 2 to 3 metres. Therefore, for optimal land use and minimal shading and competition, the plant spacing is: 2x2m; 2x2.5m; 2.5x5m or 2x3m. For plantains, the ideal spacing is 2x3m. Plants are often planted in a rectangular pattern, except on hillsides where planting is done along contour lines to minimise erosion.

Choice of cultivars

When establishing a banana plantation, it is important to choose the cultivar best suited to your production needs. For plantations intended for export, the Cavendish cultivar has always been chosen because it combines several qualities: fruit length, taste and colour. For these plantations, the yield per bunch varies from 40 to 80 tonnes/ha/year. For plantations intended for local consumption, the criteria used are taste, length and circumference of the fruit. The yield for these local plantations varies from 5 to 15 tonnes/ha/year. When selecting a cultivar for large-scale production, the weight of the bunch alone should not be used as a criterion, but rather the production per unit of time (Table 1).

Table 1. Choice of plantain cultivars

Cultivar type	Size (m)	Cycle (months)	Weight of bunch (kg)	Production (kg/ha/year)
Giant	4.5	18	20	13.3
Medium	3.5	12	15	15.0
Small	2.5	9	10	13.3

Giant cultivars produce heavy bunches but take longer to grow. They are also susceptible to lodging. Therefore, a medium-sized cultivar would be the most profitable with the highest yield.

Rapid propagation of suckers

Banana plants can easily be produced *in vitro* to obtain not only very rapid and uniform growth but also healthy material. The starting point for *in vitro* propagation, i.e. micropropagation, is the same as used in other methods of vegetative propagation of banana plants: the corm (e.g. of a suckering shoot) which contains meristems (Figure 1a).

The corm of the banana plant is first carefully stripped of all non-meristematic tissue (Figure 1b-c). Young, healthy tissue is then taken from the heart of the corm (Figure 1d).

This is called the "explant" (Figure 1d). The "explant" is a volume of tissue composed of meristematic cells. It contains the potential for *in vitro* multiplication and therefore for micropropagation of banana plants.



Figure 1. Preparation of plant material for *in vitro* propagation of banana plants. a: Shoot selected for *in vitro* propagation; b: Cleaning of the corm; c: Removal of leaf sheaths to access the meristematic apex; d: Collection of young tissue

The explant is disinfected because the medium on which it will be cultured is conducive to the proliferation of microorganisms which can overgrow the explant. Alcohol, bleach and distilled water are used (Figure 2).

The concentrations of disinfectants in the washing baths have been selected to ensure that they do

not destroy the explant itself. It involves bleach, which, at certain pre-tested concentrations, is a disinfectant for the explant.



Figure 2. Disinfection (alcohol, bleach, sterile distilled water)

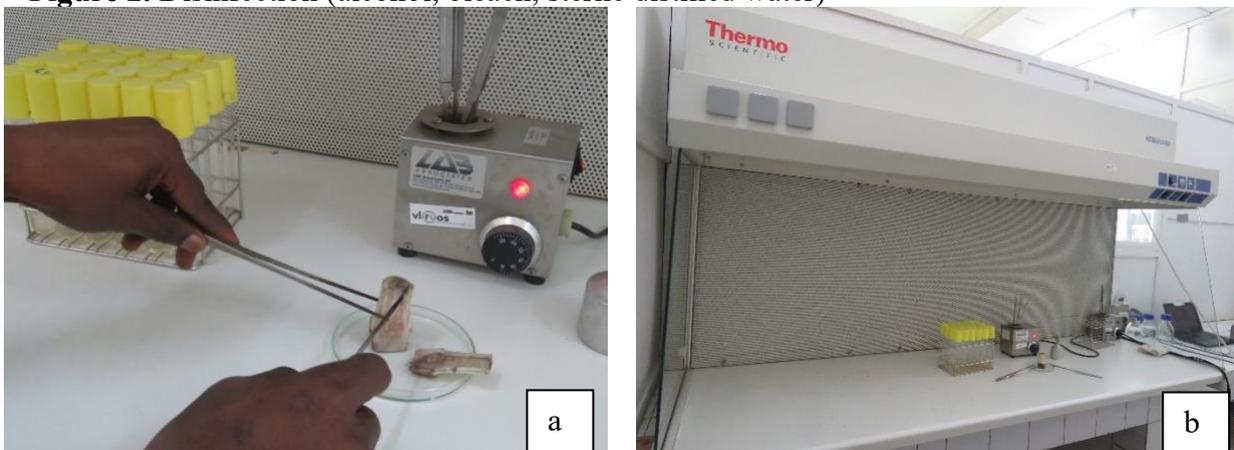


Figure 3. Dissection of the explant (a) under a laminar air flow hood (b)

All operations are performed in a sterile environment. The laminar flow table allows manipulation under air flow that is constantly filtered and disinfected (Figure 3). The plant material that has been collected and disinfected is cut into very small pieces. The containers and substrate ready to receive the plant material fragments on a medium (nutrient gel) are themselves sterilised in an autoclave, where heat acts as a disinfectant (Figure 4a).

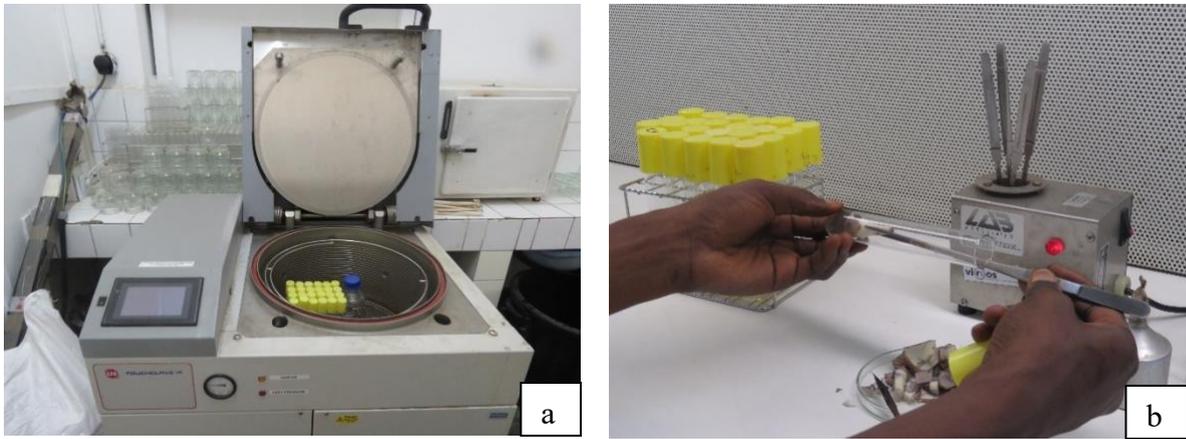


Figure 4. Autoclaving (a) and inoculation of explants onto culture medium (b)

The disinfected plant material fragments are placed in sterile containers (e.g. test tubes). These contain a culture medium that has been sterilised in an autoclave (Figure 4a). They must be sealed with a cap that prevents contamination. This is done in a sterile atmosphere under the laminar flow. The instruments are sterilised with the flame of an alcohol lamp (Figure 4b).

Growth substances have been added to the culture medium: cytokinins and auxins. These are the same substances that, in nature, cause tissue differentiation: budding, growth, flowering. The balance (cytokinins/auxins) is adjusted according to the desired outcome: either cell proliferation or differentiation into organised tissues. In other words resulting either plant multiplication or plant regeneration.

The explants are maintained in the laboratory under desired conditions of temperature, humidity and light (Figure 5). After sufficient multiplication, the explants can be transplanted (Figure 6a) to a medium where the cytokinin/auxin balance has been adjusted to cause differentiation into organised tissues. Here, foliage appears and several *in vitro* plants develop (Figure 6b).



Figure 5. Culture chamber in a banana micropropagation laboratory



Figure 6. Transplanting (a) and regeneration (b) of banana and plantain plants

After separation from each other, individual plantlets are allowed to develop. Thereafter the plantlets are weaned from the aseptic laboratory environment and gently accustomed to a more natural environment called acclimatisation in the nursery (Figure 7). All plants obtained are

identical to the original mother plant. Variant plants are plants that do not conform to the original plant due to mutation or somaclonal variation and should be discarded. The rate of propagation by *in vitro* micropropagation is very high. From a single shoot, a thousand or more plants can be obtained, ready for use within a year (Figure 7).



Figure 7. Shaded nursery of banana and plantain plants ready for transplanting to the field

The *in vitro* plants are grown for 4 to 6 weeks in bags filled with fertile soil mixed with organic matter in a ratio of 7:2. When the plants reach a height of 50 cm, they are transplanted to the field. Growth is very uniform, resulting in synchronised flowering over a period of 2 to 3 weeks during the first cycle. This is ideal for harvesting if that coincides with high market prices. However in the second crop cycle harvesting lasts over a long period.

While *in vitro* culture allows several thousand plants to be propagated from a single plant, only 10 shoots can be obtained from a plant in the field after harvesting. However, many seedlings can be produced from treated corms. This is known as macropropagation. The corm is planted and completely covered in a nursery, and the apical meristem is destroyed either by incision (Figure 8a) or by cutting (Figure 8b).

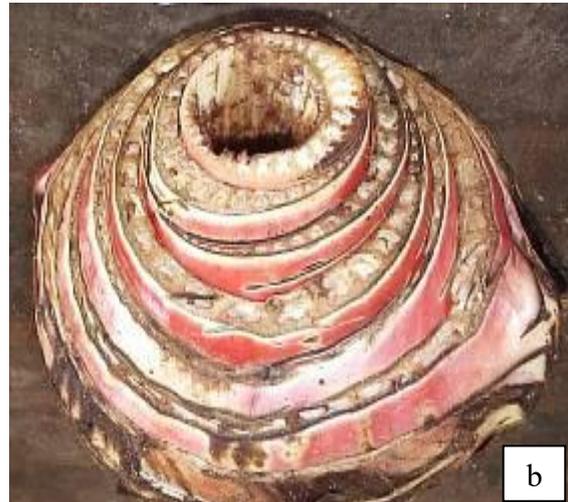
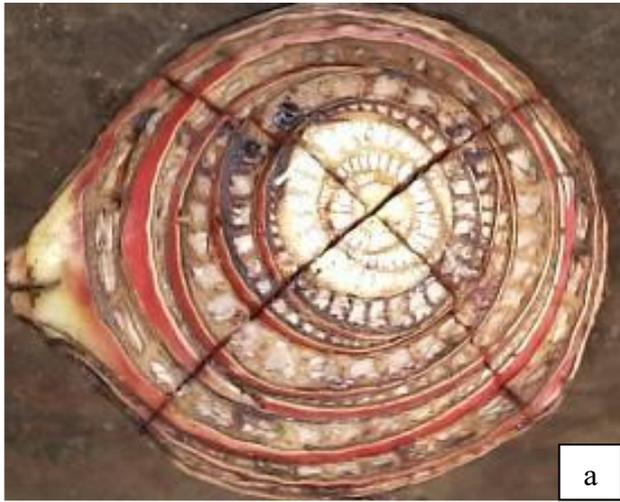


Figure 8. Cross incision (a) and removal of the apical meristem (b)



Figure 9. Formation of rooted shoots from bulb fragments in macropropagation (a) and weaning of seedlings (b, c, d)

The rootstock cutting will produce one or more shoots (Figure 9a) two to three months after being placed in the propagator. These products of vegetative propagation, or clones, are genetically and physically identical to the plant from which the rootstock was taken. The plants produced in this way are removed from their substrate (Figure 9b). They are separated and weaned from the rootstock from which they originate (Figure 9c). Each separated plant will be transplanted into a container and then grown in a nursery (Figure 9d).

There are two other propagation techniques: decapitation (D) and false decapitation (FD), respectively when the apical meristem of the mother plant is destroyed 5 months (FD) or 6 months (D) after planting. Banana plants intended for sucker production must be planted at a high density, for example at a spacing of 1.5 x 1.5 m. Decapitation involves cutting the mother plant at ground level and destroying the apical meristem with a disinfected machete (Figure 10).



Figure 10. Removal of apical meristem from the mother plant

Once the apical meristem is removed, suckers can emerge freely. After a short period, the most developed sucker begins to inhibit other suckers and grows significantly. This sucker is removed when it reaches 50 cm in height and is used as planting material.

Removing suckers as they appear when they reach 50 cm in height encourages the production of new suckers. The other suckers are then not inhibited until another sucker emerges and inhibits the others. This sucker is also removed and used as planting material, and so on. Between 5 and 10 well-developed suckers are obtained per corm.

As soon as the reserve materials present in the corm of the mother plant are exhausted, all but one of the shoots are destroyed. The selected shoot is allowed to grow for six months to produce a large corm. The procedure is then repeated. In false decapitation (FD), an opening is made in the pseudo-pseudostem of the mother plant (Figure 11) at ground level, allowing the apical meristem to be destroyed using a disinfected machete.



Figure 11. False decapitation

For their growth, the suckers use not only the nutrients from the corm of the mother plant but also its photosynthetic assimilates from the leaves. Thus, FD can be applied one month earlier than D. FD is not always effective, as the terminal bud is not always completely destroyed and hence apical dominance is not always removed. However, this technique is appropriate if, taking advantage of the rainy season, you want to obtain suckers one month earlier.

The suckers must be carefully extracted to avoid damaging the mother corm and the corm of the sucker itself. First, the roots are cut with a sharp spade, then the soil around the mother corm and the shoot is dug up and partially cleared, and finally the connection between the mother plant and

the shoot is broken using a sharp blade. Using the pseudostem of the shoot as a lever, the rest of the connection is completed by removing the shoot. The resulting hole is filled with soil.

Subsequently, to accelerate leaf initiation and to avoid transporting a large volumes of material, the pseudostem of the collected sucker is cut a few centimetres above the apical meristem and hence above the corm of the sucker.

The corm of the sucker is then carefully peeled with a machete to remove any roots that may contain nematodes, as well as any nematodes present in the outer layer of the corm. A peeled corm should be white in colour. Brown-black marks indicate that the banana plant is infested with weevils and/or nematodes and must be removed. When a large part of the corm has been removed, it should be discarded. The corm of the suckers must be cleaned in the field where the suckers were harvested. Harvested suckers should be planted within a week. They are often soaked for 20 minutes in water at a temperature of 55°C to kill nematodes and weevils.

Planting

Immediately after clearing the fallow land, planting holes (50x50x50cm) are dug in specific locations, taking care to separate the black layer of the topsoil from the rest of the soil. The sucker is then placed straight into the planting hole. The side of the shoot that was connected to the mother corm is placed against the planthole so that the axial shoot appears on the opposite side. This axial shoot is the best shoot for the next cycle because it is well anchored and well developed. The axial shoot will then occupy later a large space in the planting hole. When planting on a slope, the axial shoot will be oriented towards the slope (Figure 12).

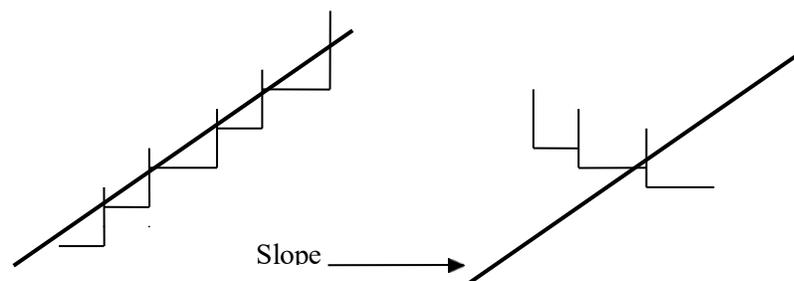


Figure 12. Tiered arrangement of axial suckers in the rows and between the rows of banana planting holes (left: good example; right: bad example).

The planting holes are first filled with soil from the more fertile topsoil layer, then with soil from the deeper layer (Figure 13).

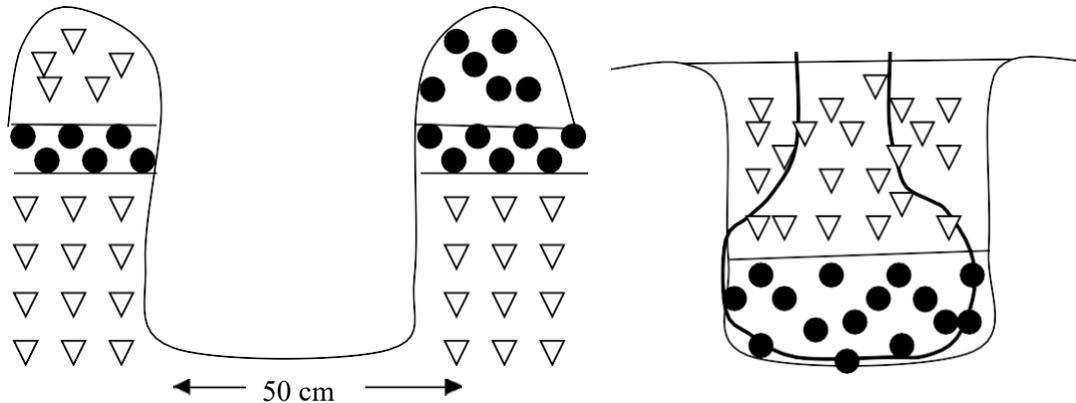


Figure 13. Filling of banana planting holes (left: separation of top and bottom soil after digging; right: topsoil is put first in the plant hole).

This allows the roots to branch out into the fertile part of the soil. The first leaf above the ground is visible after 3 to 4 weeks and then the check before replanting should start.

Planting time

Banana trees can be planted throughout the rainy season. However, for optimal production, the best time is when the planted suckers can grow for 3 to 4 months without water stress. Most small farmers plant banana plants at the beginning of the rainy season, but the peak harvest occurs a year later, with serious socio-economic consequences (low prices). It is therefore recommended to plant banana plants two months after the start of the rainy season so that the peak harvest coincides with peak market prices. With irrigation, planting is possible in all seasons, even during the dry season.

Amendments

Banana trees export a large amount of nutrients (especially K_2O and N, but also P_2O_5 , CaO and MgO). Per kg of fruit, 1 g N, 3 g K, 0.1 g P, 0.05 g Ca and 0.2 g Mg are exported. Thus, K_2O requirements are the highest.

Chemical fertilisers are placed at the soil surface within a radius of 50 cm around the main plant. They are not incorporated into the topsoil to avoid root damage. Fertiliser should be applied when it is not sunny to prevent nitrogen volatilisation, for example. Due to the low retention capacity of tropical soils, doses of fertiliser, especially nitrogen and potassium, should be split to prevent leaching. Phosphorus, calcium and magnesium can be applied in one or two doses. The number of applications depends on the cost of labour. As a rule, fertiliser should not be applied in the dry season or under excessively wet conditions.

Three weeks after planting, chemical fertiliser can be applied for the first time, followed by applications every 6 to 10 weeks. Mineral elements can also be supplied by ash, green manure and mulch (Figure 14). There is a positive interaction between organic amendments and mineral fertilisers (Table 2).

Table 2. Plantain production (t/ha) with or without mulch (M) and with or without mineral fertiliser (F)

Cycle	-P, -F	-P, +F	+P, -F	+P, +F
1	0.6	12	14	19
2	0.6	3	10	10

Mulch has the added advantage of covering the soil and controlling weeds. It reduces soil temperature and increases porosity, promoting biological activity in the soil. In banana cultivation, mulch plays an important specific role in that it increases yield by promoting root density and therefore nutrient absorption.



Figure 14. Mulch under plantains

Due to excessive temperatures and humidity in the tropics, mulch decomposes quickly and should therefore be replaced regularly with, for example, more than 80 tonnes of fresh *Pennisetum purpureum* material. Given that mulching is costly and that dessert bananas have good root branching even without mulch, mulch is best used for plantain cultivation (which has a poorly developed root system) for sustainable production.

Mulching is expensive because of (1) off-site production of mulch; (2) the cost of mowing; (3) transport; and (4) the cost of spreading.

Techniques have therefore been developed to produce mulch *in situ* (on site) between banana plants. Due to less competition, trees and shrubs are preferably used in the inter-rows of banana plants. *Flemingia congesta*, a legume, has interesting characteristics (good growth in shade, deep root system) as a source of mulch (Figure 15) for banana plants. It can be pruned more than four times a year above a height of 1 m and its prunings decompose slowly. In addition, due to its deep root system, *Flemingia congesta* effectively contributes to the recycling of leached nutrients.



Figure 15. *Flemingia congesta* alley to be used as mulch

Weed control

Banana plants have a shallow root system like most monocotyledons. Weeds (monocotyledons) that exploit the same soil depth as banana roots are undesirable because they compete for nutrients. Dicotyledonous weeds are less problematic because they have deeper roots. In general, trees and shrubs are not weeds for banana plants.

Weed control can be carried out chemically, manually or by spreading mulch. However, manual control (using a hoe) is not recommended as pulling up weeds can damage the roots of the banana plants. A field covered with mulch does not generally have a weed problem, but mulching is expensive. In most fields, weed control is chemical. It begins immediately after planting with the application of herbicides every 6 to 8 weeks. For up to 4 months after planting, care must be taken not to touch the banana plants with herbicides to prevent them from dying. Once the plantation is 5 to 6 months old, the banana leaves cover each other, reducing the growth and spread of weeds by depriving them of light.

Crop association

There is plenty of space between the rows of banana plants to intercrop food crops during the first 5 to 6 months after planting, especially when the spacing is 3x2m. Intercropping is

beneficial because it can generate income during the first year. In addition, weed problems are less of an issue when crops are intercropped. Crops that do not compete with banana plants are preferable, but this is not always possible.

Yams, taro and peanuts are good choices. There are fewer weed problems, particularly with taro and peanuts. Maize can be grown but prolongs the banana cycle by two months. It should therefore be sown before the banana. Cassava and cowpeas are not suitable because they cannot tolerate shade: cassava does not produce large tubers anymore, while cowpeas do not flower. Banana plants can be grown in association with coffee and cocoa trees to provide the shade for their young plants.

Support

Banana and plantain plants are not woody and have a shallow root system. However, they have to bear heavy fruit (15 to 70 kg). They can therefore break in the middle of the pseudostem or at the base of the corm and topple easily. The pseudostem and corm can also break in healthy plants because of strong winds, while the entire plant can be uprooted even by a light breeze when it is attacked by nematodes or weevils.

Therefore, mature banana trees require support. There are two types of support:

1. two crossed bamboo poles or a V-shaped stick to support the rachis when it appears between the leaves
2. one vertical bamboo stick tied to the pseudostem

Harvest

The timing of the harvest is independent of the market demand due to a lack of flexibility. For local production, the bunch is harvested as soon as two fingers begin to turn yellow. For long-distance production, the fruit is not allowed to turn yellow for fear that it will rot during transport. Since the apical meristem that produces the leaves and later the bunch is removed with the bunch at harvest, no regrowth can take place from the remaining plant

parts of the mother plant. Thus, the entire plant should be cut except for one shoot (preferably the axial shoot) for the next cycle. Other suckers are destroyed by cutting above the ground, and their meristem destroyed with the tip of the machete.

To prevent bunches from hitting the soil during harvesting, the pseudostem is partly cut above the middle. With a slow hinge movement, the upper part of the pseudostem slowly bends over so that the bunch can be easily cut and transported. After harvesting, the pseudostem, leaves and thinned suckers are cut into small pieces to speed up the drying of their biomass. This technique controls the proliferation of weevils.

Extraction of shoots

As mentioned above, one suckering shoot will be selected at harvest for the next cycle. The other suckering shoots will be destroyed. In several cultivars, such as dessert bananas, several suckering shoots develop from the fourth and fifth months during vegetative growth. Therefore, one should not wait until harvest to destroy those suckers, as they will compete with the mother plant and the bunch.

The best sucker has to be selected as soon as possible, while the other suckers are to be destroyed. Under the best growing conditions, three generations (cycles) of banana plants can be found together (Figure 16): (1) the flowering mother plant; (2) the "daughter" suckering plant (with mature leaves) ready to replace the mother plant after harvesting; and (3) the axial suckering plant attached to the "daughter" suckering plant

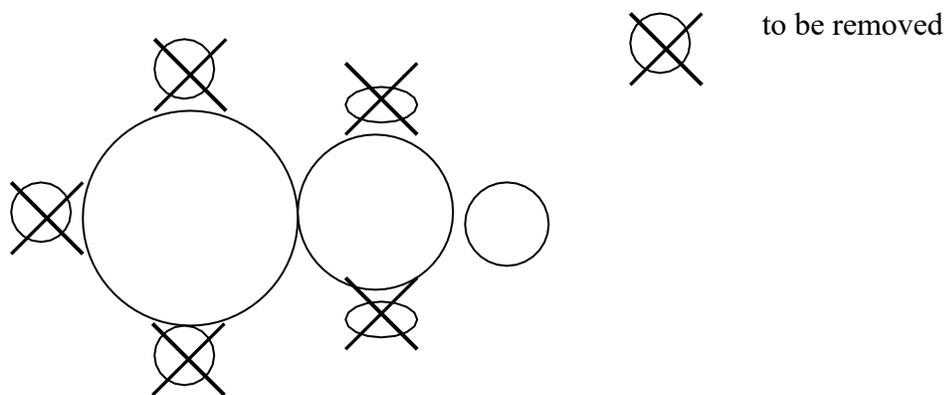


Figure 16. Selection of axial sucker (smallest sucker at the right) developing at the daughter plant (middle circle) coming from the mother plant (far left circle)

High mat

After a few cycles, the corm of the mother plant emerges from the ground exposing part of its corm. This is because each new cycle develops its axial sucker less deep than the previous cycle. In the case of plantains, this causes lodging and low yield. In dessert bananas, the phenomenon is barely noticeable. The practice of planting deeper than 50 cm or bringing soil over the exposed part is not recommended because there is a risk of damaging the roots.

Establishing a fallow field

As soon as production begins to decline to a certain threshold, mainly caused by plant loss, the field must be abandoned and left fallow. If the soil is to be reused for banana production soon, a fallow period with a fast-growing vegetation (trees and shrubs) should be established in order to eradicate grasses. A legume fallow is recommended during the last months of banana cultivation. In this case, the soil becomes partially covered with legumes before all the banana plants are removed. Spontaneous banana plants should not be left in fallow land, as they provide a refuge for pests and diseases. The fallow period can last at least three years.