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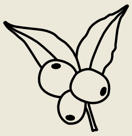

Organic COFFEE

MANUAL

Caio Vinícius Cintra Diniz
Fábio Lúcio Martins Neto
Marcelo Juliano Viviani
Constance Dorise

Caio Vinícius Cintra Diniz
Fábio Lúcio Martins Neto
Marcelo Juliano Viviani
Constance Dorise

Organic Coffee Manual

1st edition

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Caio Vinícius Cintra Diniz
Agronomic Engineer, MSc in Soils and Plant Nutrition

Fábio Lúcio Martins Neto
Agronomic Engineer, PhD in Phytotechnics

Marcelo Juliano Viviani
Zootechnist, Quality Management Specialist in Agribusiness

Constance Dorise
MSc in Food Identity

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Introduction

1.

Figure 1. Natural organic coffee.

Source: Marcelo Viviani

Global production of organic coffee has grown in recent years as a result of increased consumer demand for foods from sustainable sources and restricted pesticide use during production, as well as improved access to organic inputs and management practices by the production sector.

Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.

Source: IFOAM[1].

[1]Available in: https://www.ifoam.bio/why-organic/organic-landmarks/definition-organic

At a global level, land dedicated to organic coffee production has increased fivefold since 2004 and by 2016, approximately 8.5% of the total area used for coffee cultivation was dedicated to organic production. Mexico has the largest land area devoted to organic coffee, followed by Ethiopia and Peru.

Coffee: Development of the global organic area 2004-2016

Source: FiBL-IFOAM-SOEL-Surveys 2006-2018

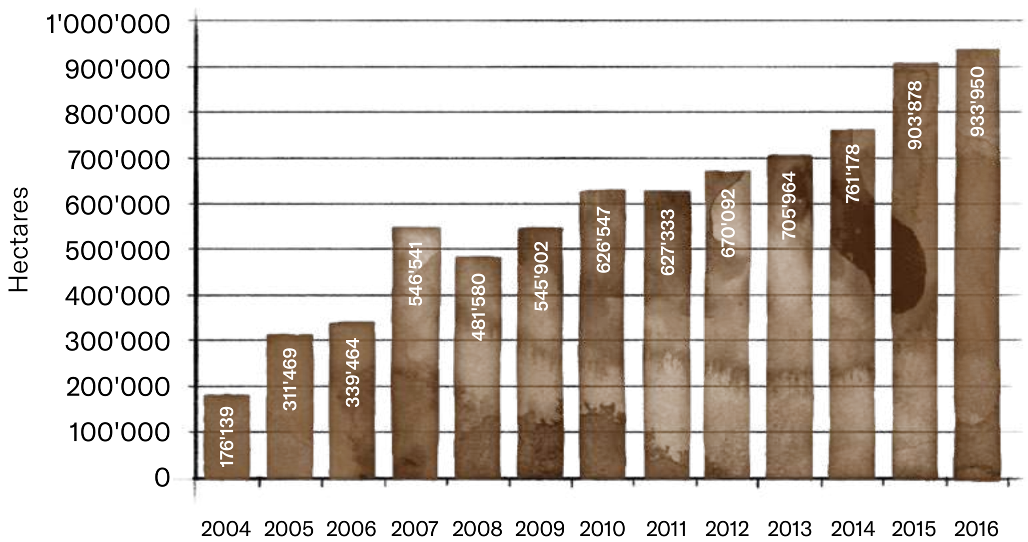


Figure 2. Development of the global organic area dedicated to organic coffee production.

Source: Willer & Lernoud (2018)

Managing any business involves planning and decision-making and coffee production is no exception. Production decisions are based on the existing coffee growing conditions (including soil suitability), potential opportunities and threats, existing infrastructure, the availability of labor and suppliers and other factors.

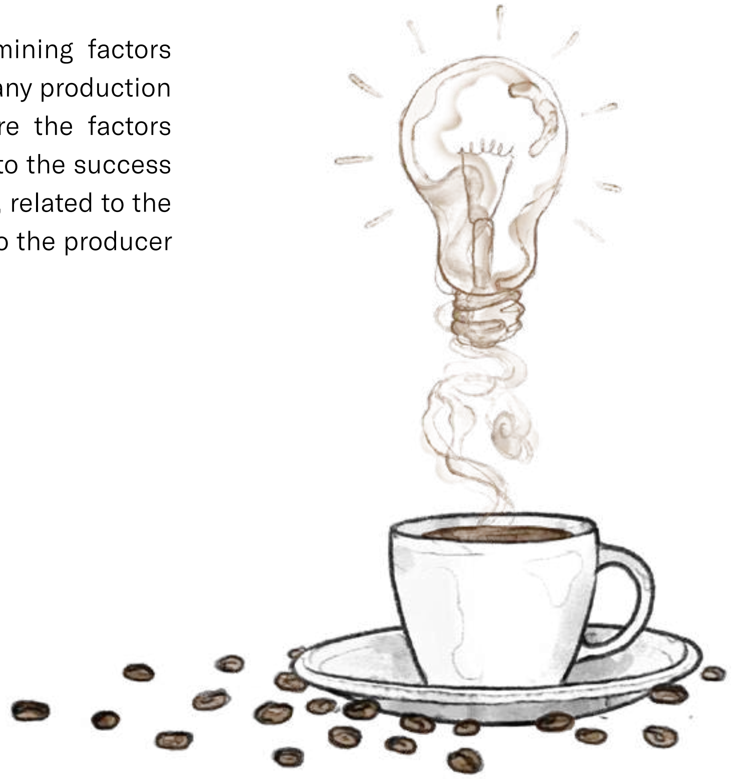
Once a decision to convert to the organic system has been reached, and depending on the scope of the business, the necessary steps must be taken to guarantee the timely availability of the inputs and services required.

In addition to management capacity, successful organic coffee production requires technical knowledge of conversion to organic production and management of an organic production system. This manual is designed to serve as a reference for producers and technicians interested in exploring the universe of organic coffee farming, and acquiring knowledge of the production, processing and certification of coffee in accordance with the principal regulations on organic production.

Enjoy reading it!

1.1. Success factors

There are several determining factors for achieving success in any production activity. The following are the factors most likely to contribute to the success of organic coffee farming, related to the production unit itself or to the producer and his team.



a. Climate, soil and varieties

The right climate conditions play a key role in producing coffee trees with high levels of productivity, low rates of pests and diseases, low production costs and improved beverage quality.

The Arabica coffee tree grows spontaneously in the understory of the mountain forests in southwestern Ethiopia, southeastern Sudan and Kenya. The climate in these regions is mild with sufficient rainfall but also a marked dry season.

The soil should foster a favorable environment for the full development of the coffee plant root system which act in collaboration with different organisms to absorb water and nutrients. Naturally fertile soils are best for organic coffee farming, but it is still possible to build chemical, physical and biological fertility of the soil with suitable management over a period of time.

Figure 3. Coffee tree soil without (left) and with (right) the use of organic compost containing beneficial microorganisms.

Source: Korin Agricultura Natural

As far as coffee varieties are concerned, coffee plantations may benefit from being established or replanted with coffee trees that are resistant to diseases such as coffee leaf rust[2].

b. Relief and water

Relief is another important aspect to evaluate as it determines the possibility of mechanizing farm work and coffee harvesting. Nutrition, plant health and inter-row vegetation management usually require a large number of operations. Mechanization is advantageous, especially in plantations where no trees, other than coffee, have been planted.

- Flat and undulated relief: suitable for mechanization

- Mountainous relief: unsuitable for mechanization

[2]Further information in module 2. Establishment of coffee plantations, item 2.1. Choice of varieties.

The availability of water (and financial resources) for irrigating organic coffee plantations is an advantage, even in regions with low climate risk, as it enables plants to develop better and increases coffee production. However, irrigation should not replace management practices that allow rainwater to be used more efficiently – such as maintaining soil cover, creating windbreaks and intercropping.

The use of irrigation in organic coffee farming can determine the activity's success, when it is properly planned and managed.

Figure 4. Drip irrigation in an organic coffee plantation. Source: Caio Diniz

c. Labor and inputs

The availability of labor in the region where the farm is located is important because organic coffee production usually requires more work (manual and/or mechanized) than conventional coffee production.

It also helps to have inputs such as organic fertilizers available at a reasonable price in the region or onsite. This has a direct impact on the cost of producing organic coffee and the success of the undertaking.

Figure 5. Manual weeding in organic coffee rows. Source: Caio Diniz

d. Production unit management

Responsible business management, whether a family or a commercial business, is another important factor as continued organic farming depends on compliance with environmental and labor legislation, but also on the financial health of the business. Therefore, the first step is to control the production cost (i.e. the cost of producing a bag of coffee).

Table 1. Percentage distribution of total operating cost items in the implementation, management and production of organic coffee in southern Minas Gerais, Brazil.

Cost items	Year 0	Year 1	Year 2	Production years 3–19 (lower productivity) ⟶ 20 bags/ha	Production years 4–20 (higher productivity) ⟶ 30,2 bags/ha
			%		
Labor	59.1	84.3	47.1	50.3	71.2
Seedlings	17.1	0.6	-	-	-
Inputs	9.2	13.3	46.3	31.9	13.4
Fuel	2.4	0.6	0.6	3.7	5.2
Machinery and equipment	11.2	1.3	6.1	14.1	10.2

Source: Turco et al. (2012)

Recording and controlling the cost of production allows producers to identify the main expenditures and make better financial investments.

To increase the likelihood of success in organic coffee farming, it is important that producers and their teams develop a systemic view of their production, taking into account the numerous interactions in a coffee agroecosystem. They also need to be willing to continue learning about organic management practices as well as the sustainable and specialty coffee market.

e. Knowledge of management practices

Organic coffee production calls for considerable technical knowledge. This is why producers and their teams must be trained in organic coffee management practices and the agricultural and agro-ecological techniques used in sustainable coffee farming. It is also important to be aware of the various country regulations applicable to organic coffee production and processing.

Moreover, the ability to yield high-quality, organic coffee depends on the application of good post-harvest management practices. The quality of the beverage is one of the key factors that determines access to sought after markets.

Access to knowledge is available through publications, training and/or (public or private) technical assistance.

f. Producer groups and marketing

A group of organic coffee producers can be created or producers can join an existing group. Joining a producer group is usually most beneficial for smallholders or family farms. Some of the advantages of joining a producer group include: better access to technical assistance, a lower per-producer certification cost, lower costs of production by pooling resources and a higher probability of increasing sales.

Marketing is also an important factor to consider, as production depends largely on knowing in advance to whom the organic coffee will be sold and at what price. The organic coffee market is more loyal than the conventional market, which is why the creation of associations and the promotion of good, long-lasting and reliable commercial relationships are key success factors.

1.2. Step-by-step guide to start production

Having learned about some of the main success factors for organic coffee growing, we recommend this step-by-step guide for beginning organic coffee production, whether a producer is starting a plantation or converting a conventional coffee plantation to an organic production system.

1. Knowledge of organic regulations[3]

Different regulations apply to different players in the organic coffee production chain. They vary, depending on the region of coffee production and/or processing. Unlike the social and environmental standards which are applicable to the coffee growing sector in general, the regulations on organic production are specific to each consumer market's legislation (e.g. Brazil, European Union, USA and Japan). Understanding the provisions of these regulations is the first step to successful organic coffee production.

[3]Further information in module 8. Certification, items 8.1. Organic regulations and 8.2. General requirements.

An organic production unit can obtain certification under one or more regulations, depending on the requirements of the market.

2. Compliance with the conversion period[4]

Once a decision is made to convert all or part of a production unit to the organic system, the producer must be compliant with the applicable regulation(s) during a conversion period before the following harvest can be considered organic. During this period, producers must draw up an Organic Management Plan (OMP) taking into account, among other factors, the inputs and management practices adopted in their production unit.

A producer who wishes to apply for certification must contact a certifier at the beginning or end of the conversion period. The latter is less expensive because it eliminates the cost of certification during a period when the producer is not yet able to market the coffee as organic. To ask the certifier for retroactive recognition of the conversion period, the producer must be able to produce proof of the ***start of the conversion period***, as well as documents and records of all operations involved in production.

The decision on the date which is considered to be the start of the conversion period will be based on evidence obtained from the internal inspections or oversight visits made to check that the technical regulations have been met, such as:

I - statements by official bodies related to agricultural activities;
II - statements by official environmental agencies;
III - statements by neighbors, associations and other organizations involved in the organic production network;
IV - laboratory analyses;
V - aerial photos and satellite images;
VI - in situ inspection of the area;
VII - documents pertaining to the purchase of animals, seeds, seedlings and other inputs; and
VIII - verification of the knowledge of producers and workers in the production unit about the principles, practices and regulations of organic production.

Source: Normative Instruction (NI) No. 46/2011, amended by Normative Instruction No. 17/2014, Art. 12, Sole paragraph.

[4]Further information in module 8. Certification, item 8.2. General requirements.

A case study in Espírito Santo do Pinhal, Brazil analyzed the economic feasibility of converting a production unit comprising 42.3 hectares of coffee to organic management over an eight-year period, from the partial replacement of inputs through to total conversion, based on a conversion period of 24 months for each plot. The results showed that by adopting organic management, higher profits were obtained after conversion than with the conventional system (2018/2019 and 2019/2020 harvests), with the selling price of organic coffee 30% higher than conventional coffee, taking into account a 30% increase in production costs and a fall in productivity during the conversion.

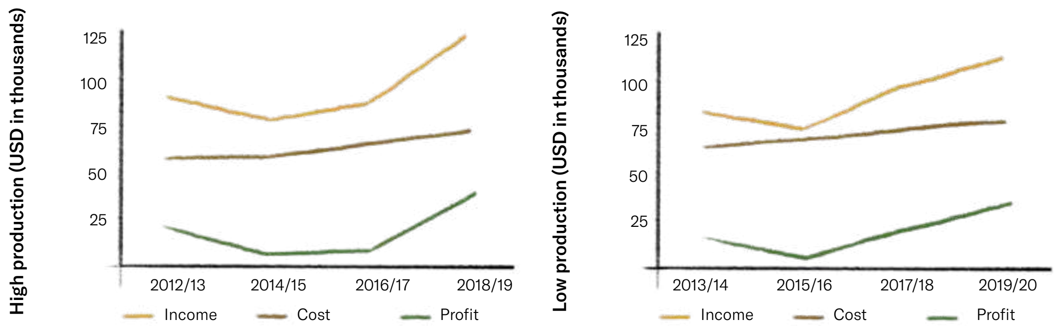


Figure 6. Evolution of income, cost and profit (in USD) for the conversion scenario, in years of high (left) and low (right) production.

Source: Oliveira (2015)

3. Applying for organic certification[5]

After choosing one or more organic production regulations and having complied with these during a conversion period (in the case of plant production), it is time to approach an accredited organic certification body and initiate the certification process[6].

It is important to find a certifier that fits the producer's particular business profile as the relationship between the production unit and the certifier is usually close-knit and long term. Once the choice has been made, the certifier must be contacted and the producer (or group of producers) must prepare the documentation needed for the initial inspection.

[5]Further information in module 8. Certification, item 8.3. Certification process.

[6]Certifications accredited according to the different organic production regulations can easily be found on the Internet.

1. Introduction

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Establishing a coffee plantation

2.

Establishing an organic coffee plantation is based on the normal recommendations for growing coffee with the addition of only chemicals and agronomic practices permitted under organic production regulations. Soil health and adaptation of the climatic conditions are fundamental considerations for establishing a successful plantation. Furthermore, special attention must be paid to the selection of suitable coffee plant varieties and ensuring only healthy, well developed seedlings are planted.

Figure 1. Establishing an organic coffee plantation.

Organic production regulations require that seeds and seedlings come from organic systems. Given that these materials are not readily available on the market, the production unit may choose to produce its own coffee seedlings, using inputs permitted under organic regulations[7].

Seeds treated with pesticides cannot be used, either in the nursery or in the field (e.g. cover crops). To grow coffee plant seedlings, the producer may use selected seeds, sourced from their own plantations or acquired from producers registered with the ministry of agriculture in the country in question.

If substances or practices that are not permitted are used to establish the coffee plantation (e.g. use of conventional seedlings), the respective area must undergo a conversion period[8].

[7]The production of organic seedlings for commercialization must comply with other requisites that will not be dealt with in this manual.

[8]For further information, see module 8. Certification, item 8.3. General requirements.

2.1. Choice of varieties

When planning a coffee plantation setup, the producer should select varieties with desirable characteristics such as resistance to diseases, pests and nematodes, drought tolerance, robustness, high productivity and acceptable cup quality. With these aspects in mind, rust-resistant varieties should be prioritized as coffee leaf rust is the main disease affecting coffee in most producing regions.

A catalogue with more than 20 rust resistant and tolerant coffee varieties is publically available on the World Coffee Research website.

Figure 2. Rust-resistant variety (left) next to the susceptible coffee tree (right). Source: Caio Diniz

Table 1. Varieties of Arabica coffee with different levels of rust resistance.

Resistant	Moderately Resistant	Moderately Susceptible
IAC 125 RN	Obatã Vermelho IAC 1669-20	Icatu Vermelho IAC 2941
IAC Catuaí SH3	Tupi IAC 1669-33	Icatu Vermelho IAC 2942
IAC Obatã Amarelo 4739		Icatu Vermelho IAC 2945
	Oeiras MG 6851	Icatu Vermelho IAC 4040
Araponga MG1		Icatu Vermelho IAC 4041
Catiguá MG1	IPR 99	Icatu Vermelho IAC 4043
Catiguá MG2	IPR 101	Icatu Vermelho IAC 4045
Catiguá MG3	IPR 105	Icatu Vermelho IAC 4046
Paraíso MG H 419-1		Icatu Vermelho IAC 4228
MGS Paraíso 2	Katipó	Icatu Amarelo IAC 2944
Pau Brasil MG1	Saíra	Icatu Amarelo IAC 3686
Sacramento MG1	Japy	Icatu Amarelo IAC 2907
MGS Aranãs	Japyam	Icatu Early IAC 3282
	IBC Palma 1	
IAPAR 59	IBC Palma 2	IPR 102
IPR 97	Sabiá 417 (Early)	IPR 103
IPR 98	Sabiá 708 (Mid)	
IPR 104	Sabiá 398 (Late)	Azulão
IPR 107	Siriema 842	Catucaiam 2015479
IPR 108	Beija-Flor	Catucaiam 24137
	Guará	Catucaiam 78515
Acauã	Siriema AS1	Rouxinol
Acauã Novo		Catucaí Vermelho 19/18
Canário	Costa Rica 95	Catucaí Vermelho 20/15
Icatu Tuiuiu		Catucaí Vermelho 24/137
Arara		Catucaí Vermelho 36/6
Asa Branca		Catucaí Vermelho
		Multilínea F5
Marsellesa		Catucaíaçu
Oro Azteca		Catucaí Amarelo 2SL
Parainema		Catucaí Amarelo 3SM
Centroamericano		Catucaí Amarelo
Colombia		Multilínea F5
		Catucaí 785-15

Observations:

Some cultivars that exhibit a degree of rust resistance are also resistant to the coffee leaf borer (Siriema AS1) and to nematodes (Catiguá MG3, Paraíso MG H 419-1 and Catucaí 785-15), as well as being drought tolerant (IAC Catuaí SH3, Acauã and IPR 103).

Source: Ministério da Agricultura, Pecuária e Abastecimento (MAPA)[9], Consórcio Pesquisa Café[10], Instituto Agronômico – IAC[11], Empresa de Pesquisa Agropecuária de Minas Gerais – EPAMIG[12], Instituto Agronômico do Paraná – IAPAR[13], Fundação Procafé[14]

The varieties Sabiá 708, Catucaí Amarelo 24/137, IBC Palma 1, Paraíso MG H 419-1, Catucaí Vermelho 36/6, Catuaí Vermelho IAC 15, Oeiras MG 6851 and lineage H518 are the most suitable for the organic system in eastern Minas Gerais, Brazil.

Source: Moura et al. (2013)

[9]http://www.agricultura gov.br/guia-de-servicos -registro-nacional-de-cultivares-rnc

[10]http://www.consorciopesquisacafe.com.br/index.php/tecnologias/cultivares

[11]http://www.iac.sp.gov.br/cultivares/inicio/

[12]http://www.epamig.br/download/folder-cultivares-cafe-epamig/

[13]http://www.iapar.br/pagina-1958.html

[14]http://fundacaoprocafe.com.br/semente/

2.2. Seedling production

Planting healthy, well-developed seedlings is essential for the coffee farmer to establish a successful plantation. Given the lack of organic seedlings in the market, the producer may use conventional seedlings. However, the certifier must be informed of this and the respective plantation will have to go through a conversion period. As previously discussed, one good option is to produce organic seedlings for use in that particular production unit.

Producing coffee seedlings in the organic system does not differ much from producing them in conventional nurseries, except for minor changes needed to comply with organic production regulations.

The texture of the soil used in preparing the substrate must be just right – not too sandy and no excessive clay content. Soil must be collected from the subsurface layers to avoid problems with weeds and pathogens. Cow manure that will be used in the substrate must be well cured (composted) and if sourced from conventional systems, it must be authorized by the certifier. Composting it also helps to eliminate weeds and contaminants. If manure cannot be obtained, authorized organic fertilizers such as organic compost and vermicompost (worm humus) can be used in the same recommended dose.

As an alternative to disinfection of the substrate, solarization has been used. This consists of covering the substrate with transparent plastic film and raising the temperature to levels that are lethal to pathogens. This can be done by spreading a thin layer of substrate over a cemented patio or black plastic tarpaulin. Then a transparent plastic canvas, which must be well stretched out and fixed, is opened over the substrate and left in the sun for at least 30 days.

There are two types of coffee seedlings: six-month seedlings and one-year seedlings. Six-month seedlings are the most used as they are cheaper. They use a lower volume of substrate and remain in the nursery for a shorter time.

Coffee seedlings can be produced in polythene bags with drainage holes. They should be grown from selected seeds, have good germination capacity, and not treated with pesticides.

The recommended dimensions for the coffee seedling bags are:

- **Six-month seedlings: 11 cm wide x 22 cm height**
- **One-year seedlings: 14 cm wide x 28 cm height**

The nursery must be located on a well-drained, sunlit, ventilated site, with slightly sloping topography. It should be protected from winds, have ample good quality water available for irrigation, have easy access, and must be an acceptable distance from existing coffee fields. The site must be frost-free and must also have a system to protect against water run-off with contours, terraces or vegetation belts which will prevent erosion. An area of approximately 10 m² is required to produce 1,000 six-month seedlings. The coffee nursery must be protected with a straw cover, or preferably a black/red shade net. In both cases, natural light reduction should not exceed 50%.

To prepare 1,000 L of substrate, the following is recommended:

- **700 L of sieved subsoil**
- **300 L of sieved, cured manure (compost)**
- **1 kg of P_2O_5 (e.g. 7 kg of rock phosphate)**
- **0.6 kg of K_2O (e.g. 1.2 kg of potassium sulfate[15])**

The bags must be filled with substrate and lightly compacted to prevent the soil breaking apart when the bags are opened during the planting operation. The seeds must be sown 1 cm deep, two seeds per bag. After germination, the less vigorous of the two seedlings must be eliminated, leaving just one plant per bag.

[15]The use of potassium sulfate is permitted if it has been obtained through physical processes and is not enriched by a chemical process or chemically treated to increase its solubility.

Figure 3. Production of coffee seedlings in the producer's own nursery.

Source: Caio Diniz

Seedling nutrition can be complemented by spraying bio-fertilizers and foliar fertilizers containing micronutrients every two weeks. To prevent disease and pests during seedling formation, preventive measures should be adopted. Preventive measures include: locating the nursery on a suitable site, using good quality substrate and irrigation control and avoiding too little or too much water. If any plant health control is necessary, only substances and practices that are permitted for use in organic production systems can be used.

Damping-off, a disease caused by fungi such as *Rhizoctonia solani*, can be controlled with microbiological fungicides containing *Trichoderma harzianum* (e.g.: Trichodermil SC 1306®).

Cercospora leaf spot, a disease caused by the fungus *Cercospora coffeicola,* can be controlled with periodic application of fungicides or copper-based preparations in the form of hydroxide (e.g. Supera®), oxychloride, sulfate, oxide or octanoate.

After the third pair of true leaves forms, acclimatization of seedlings should be initiated by gradually withdrawing the cover. This allows the seedlings to adapt to the local climatic conditions before being planted in the field.

2.3. Soil preparation and planting

The main goal in preparing the soil to set up a coffee plantation is to improve its chemical, physical and biological properties in order to foster better growth of root systems (volume as well as depth). This improves the absorption of water and nutrients by the roots, resulting in healthier and more productive coffee plants.

Figure 4. Preparation of the soil for sowing organic coffee.

Source: Caio Diniz

Soil preparation should be carried out at least 60 days before planting the coffee. However, in soils with unfavorable conditions (e.g. low fertility, compaction, presence of nematodes, etc.) better results are obtained when preparation of the soil begins one or two years in advance, combined with the cultivation of green manures.

Deep soil preparation is recommended in the coffee sowing rows, thereby eliminating unfavorable conditions which restrict coffee tree root development.

Taking into account soil conservation practices that reduce erosion (e.g. minimum tillage, contour and raised bed sowing, on terracing, etc.), preparation of the soil essentially consists of plowing and harrowing the entire area (only if necessary in order to add lime), subsoiling, opening furrows or holes, distribution of lime, gypsum, preparing mineral fertilizers and organic fertilizers and adding those inputs to the furrows or sowing holes.

2.3.1 Soil correction and fertilization

In order to recommend corrective measures and fertilizers to establish the organic coffee plantation, soil analysis from soil samples (taken from the layers at depths of 0 to 20 cm and 20 to 40 cm) must be interpreted. This manual includes recommendations on the use of lime, gypsum and planting fertilization[16] while also providing information on green manures and organic fertilizers.

a. Green manuring

The choice of cover crops for green manuring must be based on a diagnosis of the soil and the climate conditions of the area to be farmed, considering the factors that limit plant development. For example, there are species that facilitate biological nitrogen fixation, others with a high nutrient cycling capacity, and some with increased ability to break up compacted or densified layers, reduce the nematode population and suppress weeds, among other characteristics. It is therefore advisable to fertilize the crop with a combination (blended mixture) of different types of green manure to achieve the desired results in the shortest possible time (Table 2).

Table 2. Suggestion for mix of cover crops (spring/summer).

Types	Seedling rate (kg/ha)
Pennisetum glaucum	5 to 8
Fagopyrum esculentum	15 to 20
Crotalaria spectabilis	6 to 8
Crotalaria breviflora	6 to 8
Crotalaria ochroleuca	6 to 8
Cajanus cajan o *Mucuna deeringiana*	10 to 15

Source: Calegari (2016)

[16]See module 3. Nutritional management, item 3.2.3. Soil correction and fertilization.

b. Organic fertilization

Organic fertilization in the rows or planting holes will encourage the seedlings to develop by improving the chemical, physical and biological properties of the soil close to the roots. It is important to point out that the benefits of adding organic matter beneath the soil surface depends on breaking up the compacted or densified layers (e.g. subsoiling) and preventing decomposition from occurring in anaerobic conditions (waterlogged soil), thereby increasing the water infiltration rate.

Organic fertilizers available on site or from elsewhere should be used, taking into account their nutritional composition, based on the recommendations below.

	Amount per hole		Amount per meter of furrow		Total amount
	(kg/hole)	(L/hole)	(kg/m)	(L/m)	(t/ha)
Cow manure	3 to 5	7 to 15	4.5 to 7.5	10.5 to 22.5	12 to 20
Poultry manure	1 to 2	1.5 to 3	1.5 to 3	2.25 to 4.5	4 to 8
Castor oil cake	0.5 to 1	1 to 2	0.75 to 1.5	1.5 to 3	2 to 4
Coffee dry parchment	1 to 2	5 to 10	1.5 to 3	7.5 to 15	4 to 8

Source: Adapted from Ribeiro Cuimarães and Alvarez (1999)

Observations:

The amount per meter of furrow and the total amount are calculated based on the recommended values per hole, considering spacing of 3.5 m x 0.70 m and an approximate density of 4,000 plants/ha.

Applying organic fertilizers in the furrow or planting hole (with the exception of cured livestock manure) requires an interval of 30 to 60 days between adding it to the soil and planting the seedlings.

2.3.2 Spacing and planting in the field

When defining the spacing for the coffee plantation, different factors must be considered including: topography, mechanization, incidence of pests and diseases, varieties (tall or dwarf). Generally speaking, in organic coffee farming the same recommendations for conventional coffee growing should be followed, prioritizing the mechanization of farming practices and management of the vegetation between the rows (or furrows) of coffee trees wherever possible.

	Mechanized systems	Coffee plant population/ hectare in mechanized systems	Non-mechanized systems	Coffee plant population/ hectare in non- mechanized systems
Dwarf type varieties	3.5 to 4.0 x 0.50 to 0.70 m	From 3571 to 5714	2.5 to 3.0 m x 0.50 to 0.70 m	From 8000 to 4761
Tall type varieties	3.5 to 4.0 m x 0.70 to 0.90 m	From 2777 to 4081	3.0 to 3.5 m x 0.70 to 0.90 m	From 4761 to 3174

Source: Adapted from Mesquita et al. (2016)

Organic coffee growing can also follow the recommendations for the conventional system when it comes to the formation of mulch on coffee tree rows. Adaptation of the cultivation area to the climatic conditions, attenuating solar radiation, excessive heat and wind, is particularly important during the plantation's establishment phase, taking into account the increased susceptibility of the newly planted seedlings to lack of water. This is why mulching, intercropping, tree planting and the use of windbreaks are all beneficial[17].

[17]For further information, see module 6. Adaptation of climatic conditions.

Figure 5. Mulch in the coffee rows. Source: Bruno Souza Maciel

An example of the process to establish an organic plantation:

A Brazilian coffee producer decides to produce organic coffee crop on his farm. He takes soil samples and sends them to the laboratory for fertility analysis. The results of the analysis are interpreted by an expert who visits the area and recommends various soil preparation practices. A dwarf type, rust-resistant variety with additional desirable characteristics is selected. As the topography of the area is conducive to mechanization, a spacing of 3.5 m x 0.70 m is defined.

Chemical fertility is evaluated, and a penetrometer is used to assess the soil's level of compaction or densification. In order to improve root development conditions, the recommendation is to prepare the soil over the entire area in the year prior to planting the coffee seedlings. Soil preparation includes plowing and harrowing before adding lime, followed by a green manure mix. After a few months, the cover crops are cut and the rows are marked out according to the spacing and slope of the land. In September, subsoiling is carried out, the planting rows opened, and the required amounts of lime, rock phosphate, ulexite and livestock manure are added. Lastly, in mid-November, the six-month seedlings that were grown in the same production unit are planted.

2. Establishing a coffee plantation

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Nutritional management

3.

The coffee tree, like any plant, needs to absorb a certain amount of mineral nutrients in order to develop healthily and reach its full productive potential.

Macronutrients		Micronutrientes	
Nitrogen (N)	Calcium (Ca)	Boron (B)	Manganese (Mn)
Phosphorus (P)	Magnesium (Mg)	Chlorine (Cl)	Molybdenum (Mb)
Potassium (K)	Sulfur (S)	Copper (Cu)	Nickel (Ni)
		Iron (Fe)	Zinc (Zn)

Source: Kirkby (2012)

In conventional agriculture, those nutrients are obtained mainly by applying chemical fertilizers – mineral fertilizers which dissolve in the water and, through various processes, nourish the plants. In addition, lime is used to supply some nutrients and to correct the soil's acidity.

"To fertilize means to replenish nutrients taken from the soil".
Justus von Liebig

Source: Scheller (2001)

However, in organic agriculture and other long-term sustainable production systems, nutrient supply is based on practices that promote soil health, taking into account the chemical, physical and biological properties of the soil (Figure 1).

Soil health is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans18.

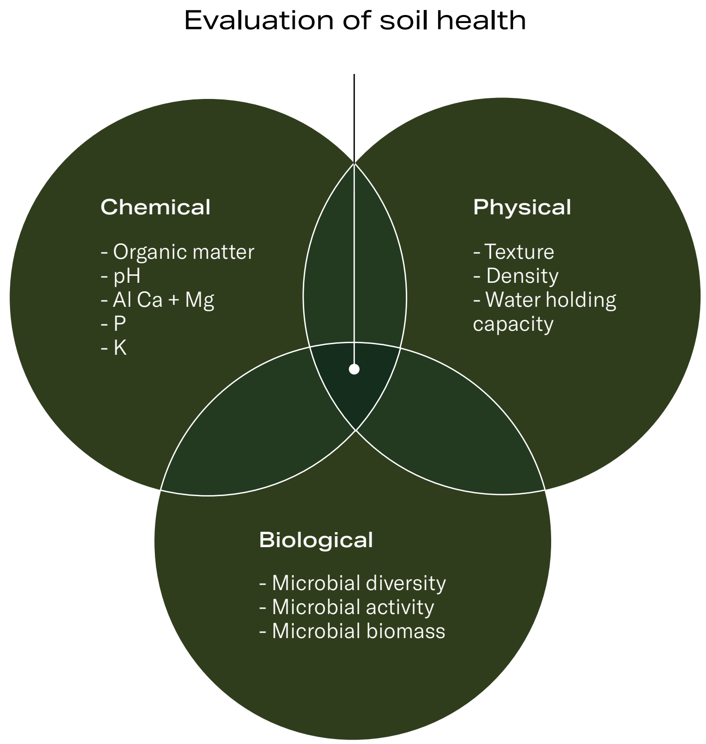

Figure 1. Soil health can be evaluated on its chemical, physical and biological properties.
Source: Adapted from Mendes, Souza & Reis Junior (2015)

[18]Source: https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

Organic fertilization provides nutrients for plants through the decomposition process, but its greatest benefit is to feed the soil organisms involved in forming aggregates and pores (Figure 2), improving water infiltration, air circulation and root penetration. Another benefit of this practice is to increase the content of organic matter in the soil, which improves the soil's ability to retain water and nutrients.

"To fertilize means to breathe vitality and new life into the earth."
Rudolf Steiner

Source: Scheller (2001)

Figure 2. Soil aggregate made up of sand, silt, clay, organic matter, roots, organisms and their secretions.

Source: Nature Education[19]

Under such conditions, the root systems of plants expand into a larger volume of soil and, through interaction with different organisms, the roots absorb more water and access the nutrients contained in the organic matter and in the mineral fraction of soil, as well as in low-solubility rock dust or mineral fertilizers applied in the plantation.

In other words, the management of soil fertility in organic coffee growing is based on the increase of biological processes through the recycling of organic matter, be it produced in the cultivation area itself or applied as an organic fertilizer. In addition, tools are used to evaluate soil fertility and the nutritional state of plants to be able to determine the need for corrective measures and fertilizers permitted under organic production regulations.

[19]Available at: https://www.nature.com/scitable/knowledge/library/the-soil-biota-84078125

3.1. Practices to improve soil health

"There are more organisms in one tablespoon of healthy soil than there are people on earth".

Source: FAO[20]

The health of the soil of any coffee plantation depends on the constant production or application of diversified organic matter upon which diverse living organisms rely for food. Whenever possible, it is also necessary to keep the soil covered by plants or mulch to protect it from the sun, rain and wind.

Figure 3. A healthy soil is a living soil. Source: A. Odoul / FAO

[20]Available at: http://www.fao.org/soils-2015/resources/information-material/en/

The production of organic matter in the cultivation area itself is advantageous, as it minimizes the labor and costs involved in transporting and applying organic fertilizer. An example of this is weed management and/or cover crops in the coffee plantation's inter-rows (grasses, leguminous plants, etc.) which are cut periodically and used as biomass placed under the crown of the coffee tree. The residues of the crop itself (e.g. leaves and branches) are also important. Plant roots can also contribute to the uptake of soil organic matter, including the release of root exudates that feed the microorganisms of the rhizosphere (Figure 4).

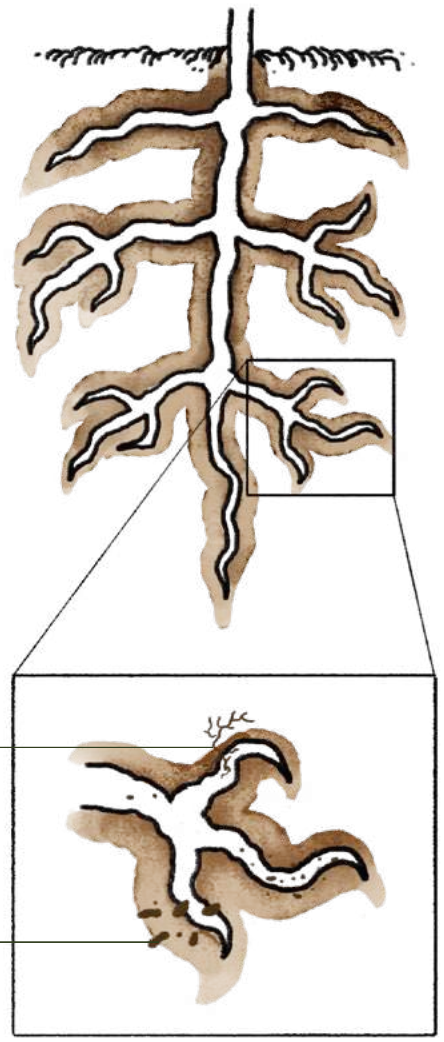

Figure 4. Microorganisms that live in the rhizosphere and play a role in plant nutrition.

If available, the producer can apply organic fertilizers produced on their own property or purchased elsewhere such as cow manure, poultry litter, coffee dry parchment, organic compost, plant-based fertilizer in cake form and other residues of animal or plant origin.

3.2. Organic fertilizers

An organic fertilizer, in the majority of cases, can be a solid or liquid plant-, animal-, or fungus-based fertilizer capable of improving soil nutrient availability.

Organic fertilizers are made from inputs that are available on the farm and are sources of beneficial microorganisms that decompose the organic matter through two processes: aerobic (compost) and anaerobic (biol, bokashi).

3.2.1 Decomposition process of organic matter

a. Organisms involved in the organic matter decomposition process

Microorganisms are responsible for transforming, metabolizing and making nutrients available to plants. There are three main groups of organisms involved in the decomposition of organic matter:

- **Primary consumers**
- **Secondary consumers**
- **Tertiary consumers**

Primary consumers are microorganisms that belong to five groups of phototrophic bacteria (*Rhodopseudomonas* spp), lactic acid bacteria (*Lactobacillus* spp), yeasts (*Saccharomyces* spp), actinomycetes (*Actinomyces* spp) and fungi (*Aspergillus* spp) which have the following respective characteristics:

- Phototrophic bacteria synthesize nucleic acids, amino acids and sugars, fostering plant development.
- Lactic acid bacteria produce acids from sugars and hydrocarbons derived from phototrophic bacteria. The lactic acid produced by the bacteria attacks the harmful microorganisms and stimulates the decomposition of organic matter, favoring the fermentation of materials such as cellulose.
- Yeasts transform sugars and carbohydrates and produce hormones and enzymes which activate cell production and stimulate root growth.
- Actinomycetes are beneficial fungi that control fungi and pathogenic bacteria by producing antimicrobial substances.
- The fungi rapidly decompose organic matter, producing antimicrobial substances such as esters.

These microorganisms generate heat as a product of their work and are classified according to the temperature range within which they operate:

- **Psychrophilic: between -18ºC and 18ºC**
- **Mesophilic: between 5ºC and 43ºC**
- **Thermophilic: between 40ºC and 93ºC**

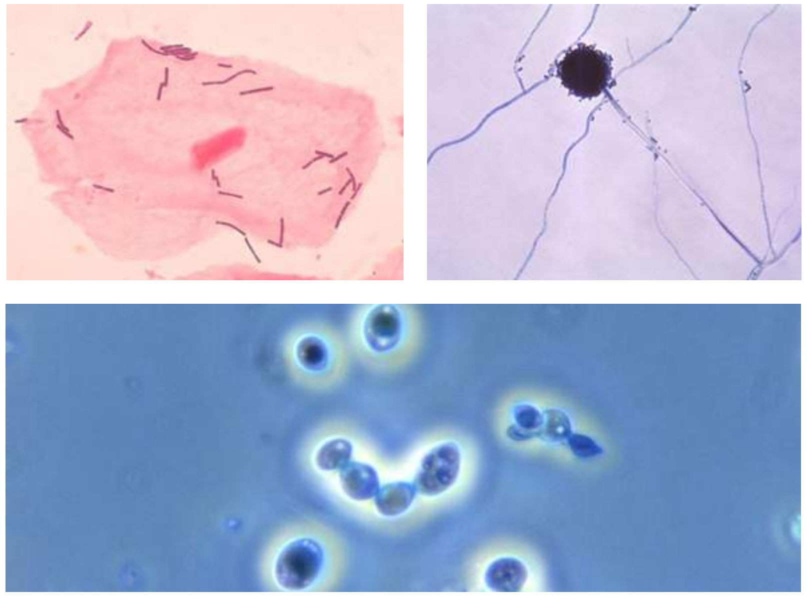

Figure 5. Lactic acid bacteria, fungi and yeasts. Source: CDC

Secondary consumers, such as nematodes and arthropods consume other organisms such as bacteria and protozoans, and also carry out different interactions among themselves (competition, predation, synergism, commensalism, etc.)

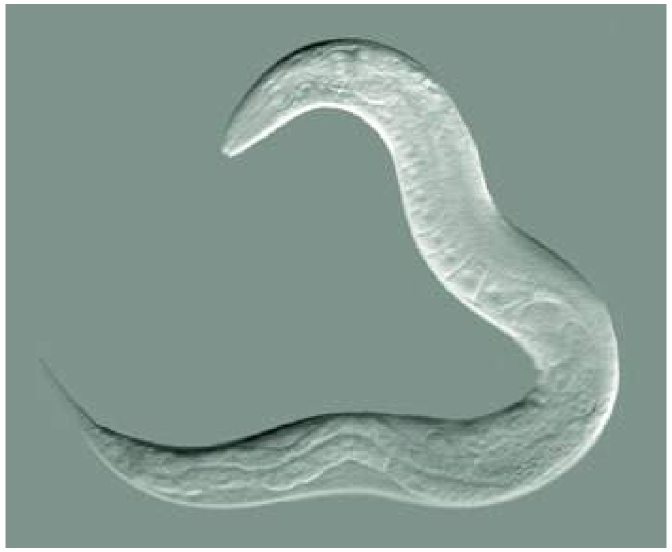

Figure 6. Predatory nematode. Source: Bob Goldstein

Tertiary consumers such as arachnids and coleoptera feed on secondary organisms and also control nematode populations.

Figure 7. Predatory mite. Source: Koppert

b. Aerobic and anaerobic organic matter degradation processes

• The aerobic process

The aerobic organic matter degradation process occurs in four fundamental phases and lasts on average three to six months, depending on climate, inputs and the farmer's degree of involvement. Throughout the degradation process of the main components, carbon (C) and nitrogen (N), the composting blend produced by the microbial activity undergoes temperature changes. These temperature changes facilitate identification of the process taking place:

The mesophilic phase:

Psychrophilic bacteria and fungi begin the decomposition process by generating sufficient heat for mesophilic organisms to appear. The mesophilic organisms composting process starts at 25°C and reaches 45°C after several hours. Soluble components such as simple sugars and complex proteins convert organic acids and amino acids, resulting in a 4.0 and 4.5 respective decrease in the pH of the mass. Under optimum conditions, this phase takes two to eight days.

Direct observation criteria:

- **Smell of the blend: fruit, green matter**
- **Color of the blend: initial color**
- **Particle size: original size**

The thermophilic phase:

The communities of mesophilic microorganisms which developed in the previous phase decrease and the thermophilic communities, which withstand higher temperatures, increase. These are mainly bacteria that decompose cellulose or lignin. In this phase, temperatures can reach between 60°C and 70°C, which makes it possible to pasteurize the blend, eliminating any pathogens, parasites or seeds present.

Direct observation criteria:

- **Smell of the blend: slightly acidic**
- **Color of the blend: darker brown**
- **Particle size: reduced**
- **Dehydration of the system**

The cooling phase:

C and N sources decrease, as does temperature (40 and 45°C). During this phase, and in the absence of optimum conditions, the thermophilic microorganisms disappear while the mesophilic microorganisms develop again. This phase takes several weeks.

Direct observation criteria:

- **Smell of the blend: damp earth**
- **Color of the blend: black**
- **Particle size: blends of still-decomposing particles and finer particles**

The maturation phase:

The temperature continues to decrease, reaching ambient temperature, or even cooler. The humus undergoes secondary polymerization and condensation reactions, forming fulvic and humic compounds. During this phase the pH tends to be neutralized.

Direct observation criteria:

- **Smell of the blend: damp earth**
- **Color of the blend: black**
- **Particle size: less than 2 cm**

• Anaerobic process

Anaerobic decomposition is a biological process causing the degradation of organic matter, with which two by-products are obtained: biogas and stabilized organic matter (or bio-fertilizer) in either liquid or solid form.

There are four phases to the aerobic process in which the organic matter decomposes. The entire process takes an average of three to four months, depending on the climate. It is a process in which several groups of bacteria successively work to decompose organic matter. In order for the process to be effective, the rate of degradation must be similar in each of the four phases to produce the substrates needed for the next phase as the products of one phase serve as substrate for the next. If the process is inhibited, the result is toxic conditions for the bacteria.
The different phases of the process are described below with color and odor indicators for each phase. However, they tend to vary quite considerably, depending on the source of the organic matter present in the bio-digester.

The hydrolysis phase:

Hydrolysis is the initial phase of anaerobic degradation of organic substrates. Particles and complex organic molecules like carbohydrates, lipids and proteins are transformed into simple sugars, fatty acids and amino acids through the action of enzymes produced by microorganisms such as *Bacteroides, Lactobacillus, Propionibacterium, Sphingomonas*.

During this phase the temperature, chemical composition of the substrate, particle size and pH must be considered, as these are factors that can limit the overall speed of the process.

For the first 15 days of the process, the temperature rises to around 24°C, maintaining the original pH of the blend.

Direct observation criteria:

- **Odor of the blend: very unpleasant (putrid)**
- **Color of the preparation: green, light olive brown**

The fermentative or acidogenic phase:

This phase is dominated by acid-forming bacteria such as *Clostridium*, *Paenibacillus* and *Ruminococcus* which transform simple sugars, fatty acids and amino acids into organic acids and alcohols. These compounds will subsequently be used by methanogenic bacteria. Additionally, dissolved oxygen in the system is eliminated.

This phase occurs 15 days after the start of the process and lasts approximately 60 days. It is identified by an average temperature of 24°C and a pH stabilization of between 5.5 and 6.5.

30 days from the start of the whole process, the temperature reaches 25°C, a temperature range where the mesophile microorganisms can thrive and the digestion process begins.

Direct observation criteria:

- **Odor of the blend: unpleasant (fresh guano)**
- **Color of the preparation: green, olive brown**

The acetogenic phase:

This phase is dominated by acetogenic bacteria that transform fatty acids and ethanol into acetate and hydrogen.

This phase begins after 60 days; temperature rises to 30°C at 90 days and the pH starts to become alkaline (between 6.6 and 7.3).

Direct observation criteria:

- **Odor of the blend: normal (decomposed manure and compost)**
- **Color of the preparation: light olive brown, olive brown, green**

The methanogenic phase:

Methanogenic bacteria such as *Methanobacterium*, *Methanospirillum hungatii* and *Methanosarcina* metabolizan acetato, hidrógeno y dióxido de carbono y metanol en metano.

This phase is identified after 90 days; temperature falls again and the pH is above 6.2.

Direct observation criteria:

- **Odor of the blend: damp earth, herbal maceration**
- **Color of the preparation: green, light olive brown, olive brown**

It is necessary to take control of the anaerobic digestion process as it can be inhibited by the presence of toxic substances in the system. These substances can form part of the raw materials that enter the bio-digester or by-product of the metabolic activity of the anaerobic microorganisms.

The most common toxicities are due to an excess of ammonium, hydrogen sulfate, or heavy metals, but can also be due to the presence of sulfur, ammonia, fatty acids or alkali metal salts such as sodium, potassium and calcium.

c. Control of degradation processes

In order to obtain a quality organic fertilizer, variables which guarantee the correct development and termination of the process are controlled. There are seven potential control measures, depending on the type of organic fertilizer produced:

- Temperature

Temperature is an essential control measure which makes it possible to corroborate the efficiency and degree of stabilization of the mixture. It can be measured with a digital thermometer or a metal stick (in the case of compost). A metal bar or pipe is inserted and withdrawn, and the end introduced is touched in order to gauge the approximate temperature and corresponding phase. This action is repeated in at various stages of the process.

Figure 8. Measurement of the temperature in the compost with a digital thermometer.

Source: GroundGrocer

- Moisture

Microorganisms use water as a transport medium for soluble substances and waste products from process reactions. The optimum moisture content must be such that the water does not fully occupy the pores of the blend, in order to allow air and other volatile substances produced during the process to circulate. In order to identify the moisture content of the mass as a percentage, a fist test is carried out, taking a fistful of substrate and pressing it. If it drips, there is too much water. However, if this variable needs to be more accurate, the sample should be weighed, then dried (through heating or aeration) and weighed again. The difference in weight is the retained moisture.

Figure 9. The squeeze test to determine moisture content.

Source: SPOSEL

- pH

The pH level has an impact on microbial activity, indicating how acid or basic the dynamics of the composting process are. This variable can be regulated by incorporating acids or bases so that the microorganism communities present increase or decrease, regulating the process by altering which organic matter degrades.
The pH is measured directly in the substrate using a pH gauge (strips or digital gauge) or producing a 1:1 aqueous extract of the mass, 1:2 depending on the characteristics of the substrate or compost to be made.

- Aeration

The presence of oxygen is essential for aerobic microorganisms. However, the tools for measuring oxygen concentration are costly. It can be measured directly when there is too much water or not enough heat. On the other hand, the presence of oxygen for anaerobic microorganisms alters the good development of fermentation.

- C/N ratio

Carbon and nitrogen are the main sources of nutrition for the bacteria. Bacteria consume 30 times more carbon than nitrogen. Carbon constitutes the source of energy and nitrogen is used to form new cells.
The C/N ratio affects the speed and loss of ammonium during the composting process. A good C/N ratio ensures good decomposition of organic matter.

- Particle size

Grinding the material facilitates the activity of the microorganisms and increases the speed of the process. The greater the exposed surface of the microorganisms, the faster and more effective are their actions.

- Odor and color

Odor and color are two indicators of the good development of the process. Each organic fertilizer has its own particular characteristics. Unpleasant odors indicate a problem in the process and the color will vary depending on the type of process.

3.2.2 Types of organic fertilizers

a. Inputs in organic fertilizers

The ingredients in organic fertilizer depend on the type of fertilizer the farmer is going to produce. Each input has a function in the blend. An input can supply energy to activate microbial metabolism, provide the right means of reproduction for the microorganisms or provide microbial diversity. There are seven basic ingredients to be found in the key organic fertilizers:

Table 1. Basic ingredients of organic fertilizers and their functions.

Input	Function
Manure	• Provides the microorganisms needed for fermentation: yeasts, fungi, protozoa and bacteria.
Chlorine-free water	• Facilitates the fluid medium of all anaerobic fermentation reactions.
Milk	• Provides proteins, vitamins, fats and amino acids to generate other organic compounds formed during fermentation. • Ideal medium for the reproduction of microorganisms of fermentation.
Molasses	• Provide the energy needed to activate the microbiological metabolism. • Provide minerals such as calcium, potassium, phosphorus, boron, etc.
Green, dry plant residue	• Sources of N and C.
Common soil	• Makes fertilizer physically homogeneous and distributes moisture. • Increases the volume required to facilitate biological activity. • Retains, filters and gradually releases the nutrients.
Litter	• Principal source of microbial inoculation. • Speeds up the fermentation process.

In addition to the basic inputs, additional materials can be added to the blend depending on the nutritional requirements of the soil and the availability of these materials on the farm.

Table 2. Additional ingredients in organic fertilizers and their functions.

Input	Function
Ash / charcoal	• Provides minerals to activate and enrich fermentation. • Improves the physical characteristics of the soil. • Highly porous, favoring the macro and microbiological activity of the soil.
Rice husk	• Improves the physical characteristics of the soil. • Source of silicon.
Rice bran / wheat bran / flour	• Promotes the fermentation of fertilizers. • Provides hormone activation.
Beneficial microorganisms	• Activates the compost. • Provides types of microorganisms not present in the original mass and increases the original population of microorganisms.

Should certain inputs not be available in the area or only available at a high cost, they can be substituted by others, such as sugar cane juice or syrup, coffee pulp or sugar in place of molasses. Powdered milk can be replaced with milk or whey, and the litter can be replaced with yeast.

b. Composting

Composting is a biological process whereby organic matter is degraded by aerobic microorganisms which act successively on original organic matter, depending on certain factors. Intensive microbial activity, created by generating high temperatures, results in pasteurization of the mixture, and it reduces the weight and volume of the processed matter, until it is converted into humic substrate.

Ingredients

The original blend from the composting process varies according to the ingredients available to the farmer at the site, which in turn will affect the nutritional properties of the finished product. The basic raw materials for making compost are fresh and dry organic matter, agricultural soil, litter, manure. Additional materials can be added, such as beneficial microorganisms (through inoculation), and mineral complements such as phosphate rock.

Figure 10. Superimposition of inputs for producing vermicompost.

Techniques

The composting method chosen by the farmer depends on the available area and the volume needed by the farm.

Pile composting
The aerobic technique used to produce piled compost consists of stacking basic inputs and additional layers in piles, maintaining the 25 to 40 C/N ratio.
The blend is kept under a roof and turned once a week for the purpose of ventilation and to release water vapor.

In-vessel composting
The anaerobic method of confining the composting materials in layers within an enclosed, roofed area.

Vermicomposting
Vermicomposting is a technique that uses Red Californian Worms (*Eisenia foetida foetida* and *Eisenia foetida andrei*), or other species of worm such as *Eudrilus eugeniae*, *Lomricus rabellus*, *Perionyx excavatus*, to carry out the process of decomposing organic matter. Vermicompost is prepared in vessels or beds.

Figure 11. Preparation of vermicompost.

Monitoring

A surplus of any key components in compost will foster the growth of phytopathogenic agents. Thus, it is essential to have the right balance of composting elements, as well as the correct process of forming organic inputs.
Monitoring the composting process is undertaken through observations (particle size, C/N ratio) and by logging temperature, moisture and pH regularly throughout the process.

Table 3. Quality parameters to be maintained during the compost making process (FAO, 2013).

Parameters	Ideal range in mesophilic phase (2–5 days)	Ideal range in thermophilic phase (2–5 weeks)	Ideal range in maturation phase (3–6 months)
C/N ratio	25 - 35	15 - 20	10 - 15
Moisture (%)	50 - 60%	45 - 55%	30 - 40%
Particle size (cm)	< 25 cm	15 cm	< 1.6 cm
pH	6.5 - 8.0	6.0 – 8.5	6.5 - 8.5
Temperature (°C)	45–60%	45 °C	Ambient temperature

A moisture content of 80% must be maintained in the worm bin for vermicompost and the physical state of the worms and predator populations should be checked.

Controls

Table 4. Identification of problems and consequences of temperature deviations, and controls to be applied to restore the blend's conditions.

• Temperature

Temperature	Problem	Outcome	Controls
< 35 °C	Insufficient moisture	Microorganisms reduce their metabolic activity which in turn causes the temperature to drop.	• Moisten the substrate a little. • Add fresh organic matter (e.g. banana leaves).
	Insufficient material in the pile	Microorganisms reduce their metabolic activity which in turn causes the temperature to drop.	• Add raw materials.
	C/N ratio too high	Diminution of the amount of N available for the microorganisms, reducing microbial activity and therefore generating heat.	• Add materials with a high N content (manure, pulp, inoculation of microorganisms).
> 70 °C	Temperature too high	Inhibition of the decomposition of organic matter due to high temperatures; the microorganisms die.	• Aeration of the blend. • Add sources of C, such as dead leaves, grass clippings, vegetable trimmings and plant cuttings.

• Moisture

Table 5. Identification of problems and consequences of moisture deviations, and controls to be applied to restore the blend's conditions.

Moisture	Problem	Outcome	Controls
> 70%	The process becomes anaerobic	The holes between particles fill with water, oxygen concentration decreases producing bad smells and lixiviates.	• Add dry materials. • Increase aerations.
< 30%	Insufficient moisture	Decrease in microbial activity.	• Aeration of the blend. • Turning.

• pH

Table 6. Identification of problems and consequences of pH deviations, and controls to be applied to restore the blend's conditions.

pH	Problem	Outcome	Controls
< 4.5	The process becomes anaerobic	A surplus of organic acids is produced, inhibiting degradation processes.	• Add materials with a high N content. • Turn the blend to introduce air.
> 8.5	Too alkaline	Fosters the production of ammonia which in excessive quantities inhibits microbial growth.	Add sources of C.

• Aeration

Table 7. Identification of problems and consequences of aeration deviations, and controls to be applied to restore the blend's conditions.

Aeration	Problem	Outcome	Controls
Insufficient aeration	The process becomes anaerobic	Replacement of aerobic microorganisms with anaerobic ones. The decomposition process is delayed, hydrogen sulfate is produced, causing bad smells.	• Watch out for smells. • Make sure humidity and turning are not excessive.
Too much ventilation	Drop in temperature	Cooling of the mass and decrease in microbial activity.	• Turn the mass less often.

• C/N ratio

Table 8. Identification of problems and consequences of C/N ratio deviations, and controls to be applied to restore the blend's conditions.

C/N ratio	Problem	Outcome	Controls
> 35	Too much C	Too much carbon which reduces the blend's biological activity. The multiplication and development of bacteria is slower due to insufficient nitrogen.	• Add sources of N.
< 15	Too much N	Foul smells are caused by excess N released in ammoniacal form. Bacterial activity is inhibited due to the excess ammonium, which in large quantities is toxic and inhibits the process.	• Add materials with a high C content.

• Particle size

Table 9: Identification of problems and consequences of particle size, and controls to be applied to restore the blend's conditions.

Particle size	Problem	Outcome	Controls
> 30 cm	Too big	If particles are too large, too many aeration channels are created and the temperature of the blend decreases.	• Particle size reduced to 10–20 cm.
< 5 cm	Too small	If particles are too small, the mass becomes compacted, reducing air circulation and causing anaerobic conditions.	• Turn the blend. • Add materials that are larger in size.

• Health and safety

The provisions of national and international regulations state that pathogens must fall within certain ranges according to the applicable regulation and type of fertilizer. For example, fecal coliform counts, *Salmonella* spp, *Escherichia coli* and viable helminth eggs (all on a dry weight basis) must not exceed ranges stipulated in applicable regulation.

c. Bioferments

Bioferments are liquid substances that aid plant nutrition and play an important role in reducing the incidence of pests and diseases in crops, by colonizing the surfaces of plants. The microorganisms present in fermented fertilizers have a competitive antagonist relationship with different phytopathogenic organisms, helping to prevent and combat disease in plants.

Inputs

The basic ingredients are fresh manure, chopped green residue, molasses, milk, soil from virgin forests and non-chlorinated water. Additional inputs include the inoculation of beneficial microorganisms, rumen, yeasts, introduction of mineral supplements, the remnants of biofertilizers used in previous productions, eggshell, nettles, vermicompost, fish entrails, etc.

Techniques

Inoculation of mountain microorganisms (MM)
Introduction of microorganisms naturally (mountain microorganisms) or artificially (commercial products known as efficient microorganisms) in order to improve soil conditions by activating microbial activity in the soil, diversifying and increasing microorganism populations, speeding up organic matter decomposition processes, creating competition with pest and disease-causing microorganisms, and increasing the viability and availability of nutrients in the soil.

Biol
A liquid substances containing hormone precursors that stimulate the pest and disease resistance of coffee plants.

Supermagro
Supermagro is a fertilizer that is similar to biol but with a more complex mechanism. Mineral salts are added as zinc sulfate, magnesium sulfate, copper sulfate, calcium sulfate and Borax at regular intervals during the manufacturing process.

Monitoring

The progress made in the production of bio-fertilizers is monitored to ensure that fermentation progresses correctly. As bio-fertilizers are produced in a hermetic environment, they tend not to be subject to major problems during their production phases, though it is important to have a fully hermetic gas output system so that air is unable to escape and contaminate the blend.

For biol and supermagro, it is recommended that a second hose be added to the fermentation drum before beginning, in order to take samples of the liquid (through a syringe-like suction device). This way, progress can be monitored and temperature, pH, color and odor can be checked. This technique also prevents air entering the preparation.

Controls

Should the preparation develop a putrid smell, discard it.

3.3. Nutritional management of coffee plants

The coffee plant requires the right proportion of nutrients for fruit formation and vegetative growth. When this demand is not satisfied, the plant is unable to form all the substances it needs to fully develop, which leads to losses in productivity and quality as well as problems with pests and diseases. It is, therefore, fundamental to achieve the right balance of corrective measures and fertilizers, without causing a deficiency or excess of nutrients.

Nutritional balance

Various interactions between nutrients take place, both positive and negative. In the latter case, an excess of one element can lead to a deficiency of another, reducing its use by the plant. Examples:

Nitrogen (N) ↔ Copper (Cu)

Phosphorus (P) ↔ Zinc (Zn)

Potassium (K) ↔ Boron (B)

Calcium (Ca) ↔ Manganese (Mn)

Source: Primavesi (2016)

Each consumer market (e.g. Brazil, European Union, USA and Japan) has its own legislation regulating organic production. This is the reason why organic farmers can only use substances and practices authorized by the respective regulations.

3.3.1 Soil analysis

Soil analysis is a tool used to evaluate the chemical fertility of the soil, as well as its texture (particle size). It is recommended that the result of any soil analysis be interpreted by an expert, according to the methods used in the laboratory.

In the case of producing coffee plantations, soil samples should be taken once a year, and at least every two years, normally in months of low rainfall.

How to take soil samples

First, the cultivated area of the farm has to be divided into sampling plots which will depend on the size of the plantation. They must be uniform in terms of topography, color and soil texture, farming activities and coffee variety.
Subsamples will be taken from each of these plots at 10 to 25 different sampling points, from the layer 0 to 20 cm deep, and from the strip of soil where the fertilizers are applied, using an auger, a probe, or a hoe.
Samples can also be taken from the layer 20 to 40 cm deep, to ascertain whether gypsum needs to be applied.

The subsamples from a same plot are mixed in a clean bucket to make a one uniform 300g sample.
This sample must be put into a clean plastic bag and sent to a competent laboratory. Each sample must be identified with the name of the producer, the property, the plot and the sampling date. See Figure 12.

Figure 12. Taking and preparing soil samples.

3.3.2 Foliar analysis

Leaf analysis is a tool for assessing the nutritional state of plants and should be used in conjunction with soil analysis. The result of the foliar analysis should be interpreted based on the critical range of the nutrient content in the leaves of the coffee plant (Table 10). The plant is to be considered well-nourished when the content of each nutrient is within the interval covered by the critical range. Values above that range indicate a surplus, and values below the range indicate a deficiency of the respective nutrients.

It is important to note that the result of the foliar analysis is influenced by a series of factors and that a low foliar content of a nutrient does not necessarily mean that its availability in the soil is low. The availability of water, the interaction of nutrients and problems with the development of the coffee leaves are some of the factors that may be associated with the result of the foliar analysis. Furthermore, foliar spraying of nutrients and substances used for pest and disease control may affect the result.

Table 10. Critical ranges for nutrient contents in coffee leaves, according to the respective authors.

Nutrient	Malavolta (1993)	Matiello et al. (2010)
	%	
N	27.0 - 32.0	30.0 - 35.0
P	2.0 - 2.1	1.2 - 1.5
K	19.0 - 24.0	18.0 - 23.0
Ca	10.0 - 14.0	10.0 - 15.0
Mg	3.1 - 3.6	3.5 - 5.0
S	1.5 - 2.0	1.5 - 2.0
	mg/kg	
B	59 - 80	40 - 80
Cu	8 - 16	8 - 30
Fe	90 - 180	70 - 200
Mn	120 - 210	50 - 200
Zn	8 - 16	10 - 20

For coffee trees, samples should be taken from leaves between the flowering phase and the rapid growth phase of the fruits, waiting at least 30 days after each application of fertilizer to the soil or leaves.

In the case of nitrogen fertilizations, expected productivity is deemed to be the main reference point recommended for this. The foliar analysis, carried out after the first part of the nitrogenated fertilization, can serve as the basis for re-assessing the amount of nitrogen to be applied to the remaining parts. With regards to the other nutrients, the result of the foliar analysis can be used to gauge whether fertilizations are proving to be adequate, enabling adjustments to be made to subsequent fertilizations.

How to take leaf samples

Much like the uniform plots from which soil samples are taken, walk in a zigzag within the plantation, taking the 3rd or 4th pair of leaves from 25 plants at random, from the middle third and both sides of the plants (Figure 13), totaling 50 pairs of leaves per plot. Avoid leaves covered with dust, damaged by insects or with signs of disease. The samples should be placed in paper bags and sent to the laboratory to arrive no later than three days after being taken. Each sample must be identified with the name of the producer, the plot and the date.

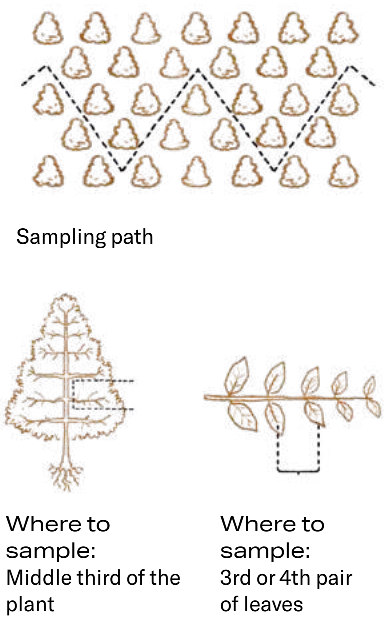

Figure 13. Diagram of foliar sampling from the coffee tree.

3.3.3 Soil correction and fertilization

To make a recommendation on corrective measures and fertilizers in organic coffee growing, it is important to first make a diagnosis of the production system. There are specific fertilization recommendations for the planting, formation (2nd year) and production (after the 3rd year), as the nutritional requirements of the coffee tree are different in each circumstance. In the case of producing coffee plantations, the expected productivity (bags/ha) should be considered, based on historic production and crop load on the trees which will give rise to the next crop. Moreover, for a good diagnosis, the following information should be obtained for each plot:

- Spacing
- Area (ha)
- Varieties
- Crop association or green manuring
- Degree of shade and nutrient cycling provided by tree-planting
- Obstacles to root development (e.g. soil compaction)

Figure 14. Distribution of organic compost under the canopy of the coffee tree.

Source: Caio Diniz

The next step is to interpret the results of the soil analysis. The following example shows the determinations made by a laboratory[21].

[21]Macronutrients (Basic), Micronutrients and Sulfur.

Soil analysis results

pH pH	OM Organic matter	P Phosphorus	K Potassium	Ca Calcium	Mg Magnesium
	g/dm^3	mg/dm^3	$mmol_c/dm^3$	$mmol_c/dm^3$	$mmol_c/dm^3$

H+Al Potential acidity	Al Aluminum	CEC Cation exchange capacity	V Base saturation	S Sulfur	B Boron
$mmol_c/dm^3$	$mmol_c/dm^3$	$mmol_c/dm^3$	%	mg/dm^3	mg/dm^3

Cu Copper	Fe Iron	Mn Manganese	Zn Zinc
mg/dm^3	mg/dm^3	mg/dm^3	mg/dm^3

Extraction methods:
pH: Calcium chloride;
P, K, Ca, Mg, Na: Ammonium acetate;
H+Al: SMP buffer;
Al: Potassium chloride;
S: Calcium phosphate;
B: Calcium chloride;
Cu, Fe, Mn, Zn, Mo: DTPA.

To ensure balanced fertilization, the process begins with soil correction, if necessary. Fertilizers will not be efficient or enable the root system to develop well if the soil has the wrong pH, toxic levels of aluminum (Al), or low levels of calcium (Ca) and magnesium (Mg).

a. Liming

Lime is used to correct acidity and increases the pH of the soil, in addition to neutralizing aluminum (Al) toxicity and providing some calcium (Ca) and magnesium (Mg). Liming is recommended to raise base saturation (V) to 50% and magnesium (Mg) content to a minimum of 5 $mmol_c/dm^3$ in the arable layer of the soil (0 to 20 cm deep).

Calculation of lime requirement through the base saturation method:

$$LR\ (t/ha) = \frac{CEC\ (Ve - Va)}{10\ TRNP}$$

Observations:
LR is the lime requirement in t/ha: CEC is the cation exchange capacity of the soil expressed in $mmol_c/dm^3$; Ve is the expected base saturation; Va is the actual base saturation determined by the soil analysis; TRNP is the total relative neutralizing power of the liming material that will be used.

The recognized recommendation is that the expected base saturation (Ve) is 50%. In addition, a more recent paper published by INCAPER recommends the following Ve values for the coffee tree, in accordance with the class of CEC at pH 7.0 of the soil:

Class of CEC at pH 7.0 ($mmol_c/dm^3$)		Ve (%)
Low	Under 43	90
Medium	43 to 86	70
Good	86 to 150	60

Source: Guarçoni (2017)

It is important to choose a type of lime able to provide adequate proportions of calcium (Ca) and magnesium (Mg). As a general recommendation, dolomite lime is used in soils with low and medium levels of Mg (up to 9 $mmol_c/dm^3$) and agricultural lime in the case of soils with high levels of Mg (above 9 $mmol_c/dm^3$).

In the case of coffee plantations under formation or in production, lime should be spread on the ground at the start of the rainy season and a larger amount should be applied to the strip of soil to which fertilizer is normally added.

In addition to liming, calcium (Ca) contents should be considered in other sources used in fertilization, such as rock phosphate (46% of CaO) and meat and bone meal (18% of CaO), as well as gypsum (22% of CaO).

b. Gypsum

Gypsum is a soil conditioner used to promote better development of deep root systems, enabling plants to improve their absorption of water and nutrients, even in periods of drought. Its application delivers calcium (Ca) to the deepest layers of the soil and reduces aluminum (Al) toxicity at depth, which enables deeper root growth in soils with unfavorable conditions. Moreover, gypsum provides calcium (Ca) and sulfur (S), without raising the pH of the soil.

The IAC Technical Bulletin 100 recommends applying gypsum based on the soil analysis of the layer at a depth of 20 to 40 cm, if calcium (Ca) levels fall below 4 $mmol_c/dm^3$ and and/or aluminum saturation (m) above 50%.

Gypsum can be applied on a surface level and does not need to be incorporated at depth, due to its high mobility in the soil profile. The amount of gypsum can be determined according to the soil's clay content, so it is necessary to carry out a physical (granulometric) analysis.

Calculation of gypsum requirement based on soil texture:

$$GR\ (kg/ha) = 6 \times clay\ content\ (g/kg)$$

Observations:
GR is the gypsum requirement in kg/ha; clay content in g/kg in the soil analysis.

International regulations on organic production (European Union, USA and Japan) only allow the use of natural gypsum.

c. Planting fertilization[22]

When preparing the planting furrows, apply the following amounts of nutrient in accordance with the soil analysis from 0 to 20 cm deep.

Soil P (mg/dm³)				Soil K ($mmol_c/dm^3$)				Soil B (mg/dm³)		
0-5	6-12	13-30	>30	0-0.7	0.8-1.5	1,5-3.0	>3.0	0-0.20	0.21-0.60	>0.60
P_2O_5 (g/m)				K_2O (g/m)				B (g/m)		
60	45	30	15	30	20	10	0	2	1	0

Soil Cu (mg/dm³)		Soil Mn (mg/dm³)		Soil Zn (mg/dm³)		
0-0.20	>0.20	0-1.5	>1.5	0-0.5	0.6-1.2	>1.2
Cu (g/m)		Mn (g/m)		Zn (g/m)		
1	0	2	0	2	1	0

P, K: Resin; B: Hot water; Cu, Mn, Zn: DTPA.

Source: Technical Bulletin 100 (Raij et al., 1997)

After fixation of the plantlets, carry out organic fertilization using the equivalent of 20 g of nitrogen (N)/plant, spreading the fertilizer over the soil, around the plants.

[22]See more information in module 2. Establishment of coffee plantations, item 2.3. Preparation of the soil and planting.

d. Formation fertilization

In the second cultivation year, apply organic fertilizers to the soil on a basis of 40 g/plant of nitrogen (N) applied in two parts – the first at the beginning of the rainy season and the second 90 days later. In addition, apply the same amount of potassium (K) recommended for the plants onto the soil, dividing the applications along with organic fertilization to supply N.

e. Production fertilization

For production fertilization, fertilizers should be applied according to estimated productivity (60 kg bags of green coffee per hectare) as well as the phosphorus (P), potassium (K), boron (B), manganese (Mn) and zinc (Zn) content shown in the soil analysis of the 0 to 20 cm-deep. A foliar analysis can also be carried out, at least 30 days after the first fertilization, to reassess the amount of nitrogen (N) to be applied in the following part(s).

Observations:
The results of the analyses must be compared with the values shown in the upper part of the recommendation tables (g/kg, mg/dm³ or $mmol_c/dm^3$) to determine the nutrient doses that need to be applied (kg / ha).

Expected productivity	Foliar N (g/kg)			Soil P (mg/dm³)				Soil K ($mmol_c/dm^3$)			
	<26	26-30	>30	0-5	6-12	13-30	>30	0-0.7	0.8-1.5	1.6-3.0	>3.0
bags/ha	N (kg/ha)			P_2O_5 (kg/ha)				K_2O (kg/ha)			
<10	150	100	50	40	20	20	0	150	100	50	20
10-20	180	120	70	50	30	20	0	180	120	70	30
20-30	210	140	90	60	40	20	0	210	140	90	40
30-40	240	160	110	70	50	30	0	240	160	110	50
40-60	300	200	140	80	60	40	20	300	200	140	80
60-80	360	250	170	90	70	50	30	360	250	170	100
>80	450	300	200	100	80	60	40	450	300	200	120

P, K: Resin.

Source: Technical Bulletin 100 (Raij et al., 1997)

Soil B (mg/dm³)			Soil Mn (mg/dm³)		Soil Zn (mg/dm³)		
0-0.20	0.21 - 0.60	>0.60	0-1.5	>1.5	0-0.5	0.6 - 1.2	>1.2
B (kg/ha)			Mn (kg/ha)		Zn (kg/ha)		
2	1	0	2	0	2	1	0

B: Hot water; Mn, Zn: DTPA.

Source: Technical Bulletin 100 (Raij et al., 1997)

The recommendation for calculating fertilization requirements is to start with **nitrogen (N)**, the nutrient that the coffee tree require in the largest amounts and whose supply has a significant impact on the cost of production. Nitrogen's main sources in organic coffee growing are green manures planted in between coffee tree rows and different organic fertilizers containing varying levels of N (Tables 11 to 13). In addition to the chemical composition, the moisture content of the organic fertilizer and the time required for nutrient mineralization should be considered. Generally speaking, the lower the C/N ratio is, the higher the rate at which organic matter decomposes, hence, the faster the mineralization of nutrients and their absorption by the plants.

Important:

The nutritional composition of organic fertilizers varies quite considerably, depending on the raw materials used and the production process, as well as the type of storage. Materials that are initially nutrient-rich, like manure, slaughterhouse residues, castor oil cake, dry coffee parchment, etc. which are stored in the open air, lose large amounts of nutrients with time.

Hence the importance of using reliably sourced raw materials and storing organic fertilizers under cover, in bags or under a plastic tarpaulin. Moreover, composting is a good way to make use of organic residues of plant and animal origin to produce stabilized organic fertilizers, thereby minimizing nutrient loss.

Figure 15. Organic compost stored under plastic tarpaulin.

Table 11. Accumulation of mass and nutrients from green manure associated with coffee plantations.

Source: Santos et al. (2014)

	Mass	N	P	K
	kg/ha			
Crotalaria juncea	1,040	137.5	10.4	58.3
Cajanus cajan	790	105.8	8.3	52.2
Dolichos lablab	810	91.8	8.6	65.5
Arachis pintoi	360	33.5	3.2	26.6

Observation:
Green manure should be cut down before flowering; based on an area planted with coffee trees at a spacing of 2.8 to 3.0 m x 0.5 to 0.8 m.

Table 12. C/N ratio, moisture and nutritional composition of organic fertilizers of animal, plant and agro-industrial origin (elements constituting the dry matter).

	C/N	Moisture	C	N	P_2O_5	K_2O	Ca
		%	%				
Cow manure	16	62	26	1.6	1.6	1.8	0.5
Cured cow manure	21	34	48	2.3	4.1	3.2	3.0
Poultry litter	22	28	48	2.2	2.4	2.7	2.3
Hen manure	11	54	34	3.0	4.8	2.4	5.1
Pig manure	10	78	27	2.8	4.1	2.9	3.5
Horse manure	25	61	35	1.4	1.3	1.7	1.1
Dry coffee parchment	28	11	50	1.8	0.3	3.6	0.4
Bone meal	4	6	16	4.1	27.3	4.3	23,2
Hoof and horn meal	3	6	44	14.4	0.9	4.2	0,3
Fish silage	5	10	35	7.3	6.4	0.8	10.0
Natural vinasse	17	95	20	1.2	0.4	8.0	2.0
Filter cake	21	65	32	1.5	1.7	0.3	4.6
Castor bean cake	9	9	49	5.2	1.8	1.6	2.0
Mucuna sp.	20	87	46	2.3	1.1	3.1	1.5
Crotalaria juncea	25	86	50	2.0	0.6	2.9	1.4
Corn	46	88	50	1.1	0.4	3.3	0.4

	Mg	S	B	Cu	Fe	Mn	Zn
	%		mg/kg				
Cow manure	0.3	0.3	15	16	2100	276	87
Cured cow manure	0.9	0.3	24	38	3512	335	329
Poultry litter	0.6	0.4	36	93	1300	302	228
Hen manure	1.1	0.4	27	230	3200	547	494
Pig manure	1.3	0.6	16	937	3700	484	673
Horse manure	0.5	0.2	10	22	2732	226	85
Dry coffee parchment	0.1	0.1	33	18	150	30	70
Bone meal	0.4	-	0.4	2	11	2	18
Hoof and horn meal	0.1	2.4	0.9	12	731	23	115
Fish silage	0.2	-	-	45	552	400	51
Natural vinasse	0.8	1.0	-	100	144	13	60
Filter cake	0.5	0.6	11	119	22189	576	143
Castor bean cake	0.9	0.2	30	80	1423	55	141
Mucuna sp.	0.3	0.3	30	23	370	103	66
Crotalaria juncea	0.3	0.2	20	7	281	60	14
Corn	0.2	0.2	16	10	120	110	25

Source: Trani & Trani (2011, Agüero et al., 2014)

Observation:

P_2O_5 / 2,29 = P; MgO / 1,66 = Mg;
K_2O / 1,20 = K; SO_4^{2-} / 3 = S;
CaO / 1,4 = Ca; O.M.% / 1,8 = C%

Table 13. C/N ratio, moisture and nutritional composition of compound organic fertilizer Class A – Forte C.

Type of compost	C/N	Moisture	N	P_2O_5	K_2O	Ca	Mg	S
	%	%	%	%	%	%	%	%
Compost Class A – Forte C	10	30	2.5	3.5	2	6	1.5	2

Source: Adapted from http://www.valoriza.net/index.php?page=2&id_institucional=8

Example:

Considering an expected productivity of 35 bags/ha of green coffee and a foliar N content of less than 26 g/kg (or in the absence of a foliar analysis), 240 kg/ha of N should be applied.
In order to offset N losses due to volatilization or lixiviation, as well as temporary immobilization due to the soil's microbial biomass, 30% more N can be applied, in other words, 312 kg/ha of N.
It is important to divide this amount into two or three applications during the rainy season to increase the efficiency of organic fertilization. For three applications, the first fertilization should be at the start of the rainy season, the second after 60 days and the third more 60 days after that.

Part 1	Part 2	Part 3
Organic compost	Castor oil cake	Cured cow manure
(2,5% de N; 30% de humedad) (2.5% N; 30% moisture) 100 kg/ha --- 2.5 kg/ha N X kg/ha --- 104 kg/ha N X = 4,160 kg/ha + 30% moisture = **5.4 t/ha**	(5.2% N; 9% moisture) 100 kg/ha --- 5.2 kg/ha N X kg/ha --- 104 kg/ha N X = 2,000 kg/ha + 9% moisture = **2.2 t/ha**	(2.3% N; 34% moisture) 100 kg/ha --- 2.3 kg/ha N X kg/ha --- 104 kg/ha N X = 4,500 kg/ha + 34% moisture = **6 t/ha**

N can be partly supplied through green manure intercropping. In that case, the N content of its biomass can be subtracted from the last part of the organic fertilization.

Observation:

The manure storage and handling facilities, including composting areas, should be planned, implemented and operated in such a way as to prevent contamination of ground water and surface water.

The next recommendation is to calculate the fertilization to supply **potassium (K)**, a nutrient the coffee tree needs a fair amount of in order to increase productivity and enhance the quality of its cherries. In organic coffee farming, the main sources of this nutrient are dry coffee parchment and low-solubility mineral fertilizers such as phonolite, potasium magnesium sulfate (K-Mag®) and potassium sulfate[23].

Example (continued):

Taking into account the same productivity of green coffee (35 bags/ha) and a K content in the soil ranging from 0.8 to 1.5 $mmol_c/dm^3$, 160 kg/ha of K_2O should be applied.
In order to offset K leaching losses, 30% more than that can be applied, in other words, 208 kg/ha of K_2O.
Then the amounts of K in part 1 and part 2 of the organic fertilization must be deducted: 208 kg/ha of K_2O - (83 + 32) kg/ha of K_2O = 93 kg/ha of K_2O.

Part 1	Part 2	Part 3
Organic compost	**Castor oil cake**	**Cured cow manure**
(2% K_2O; 30% moisture) 100 kg/ha --- 2 kg/ha K_2O 4 160 kg/ha --- X kg/ha K_2O X = 83 kg/ha K_2O	(1.6% K_2O; 9% moisture) 100 kg/ha --- 1.6 kg/ha K_2O 2 000 kg/ha --- X kg/ha K_2O X = 32 kg/ha K_2O	Part not considered in the calculation because it occurs more than 120 days after flowering.

[23]Potasium magnesium sulfate are always permitted, provided they are obtained by physical procedures and not enriched by a chemical process or chemically treated to increase their solubility.

This quantity of K can be applied in one or two parts before the coffee cherries' rapid growth phase, when K demand increases. In the case of two-part application, the first should be at the start of the rainy season and the second 30 days later. The recommended amount can be split 50–50, or else one third and two thirds, according to the example given below.

Part 1	Part 2
Phonolite	**Dry coffee parchment**
(1% K_2O) 100 kg/ha --- 1 kg/ha K_2O X kg/ha --- 30 kg/ha K_2O X = **3 t/ha**	(3.6% K_2O; 11% moisture) 100 kg/ha --- 3.6 kg/ha K_2O X kg/ha --- 63 kg/ha K_2O X = 1.75 t/ha + 11% moisture = **2 t/ha**

After calculating fertilization with N and K, it is recommended that the fertilization requirement of **phosphorus (P)** and other nutrients be calculated in accordance with the soil analysis. After that, it is a good idea to obtain the nutrient balance of the corrective measures and fertilizers recommended in order to find out if there are any nutritional imbalances.
Normally the amount of **micronutrients** found in organic fertilizers is insufficient to meet the nutritional requirement of the coffee tree. It may be necessary to use mineral fertilizers containing micronutrients (through the soil or the leaves). It is also normal to see some induced deficiencies of micronutrients. This will be noticeable if the content of a particular element in the soil is medium or high, even though its content in the respective foliar analysis might be below the critical range. In these cases, it is recommended that these micronutrients be applied by foliar spraying.
In addition, different fertilizers and bio-fertilizers can be applied in a solution through the soil or by foliar spraying in order to supply nutrients and/or to foster an improvement in the soil's biological properties (e.g. inoculation of beneficial microorganisms).

Example (continued):

Taking into account the expected productivity of green coffee in the respective plot (35 bags/ha) and soil P content ranging from 6 to 12 mg/dm³, 50 kg/ha of P_2O_5 should be applied. In the case of S, considering a soil content below 10 mg/dm³, 1/8 of the recommended amount of N should be applied, i.e. 39 kg/ha of S.
For a soil boron (B) content below 0.20 mg/dm³, 2 kg/ha of B are applied. In the case of a manganese (Mn) content of less than 1.5 mg/dm³, 2 kg/ha of Mn are applied. And for a zinc (Zn) content below 0.5 mg/dm³, 2 kg/ha of Zn are applied.

Table 14. Example of nutrient balance provided by fertilization.

Nutrients	N	P_2O_5	K_2O	CaO	MgO	S	B	Cu	Mn	Zn
Requirement (kg/ha)	312	50	208			39	2		2	2
Inputs (kg/ha)										
Organic compost (5.4 t/ha)	104	146	83	277	81	81				
Castor oil cake (2.2 t/ha)	104	36	32	40	18	4				
Cured cow manure (6 t/ha)	104	184	-	135	40	13				
Phonolite (3 t/ha)	-	-	30	-	-	-				
Dry coffee parchment (2 t/ha)	-	4	63	5	1	1				
Ulexite (20 kg/ha)							2			
Manganese sulfate (6 kg/ha)									2	
Zinc sulfate (5 kg/ha)										2
Total (kg/ha)	312	370	208	457	140	99	2		2	2

Table 15. Example of fertilization program (please adapt to regional conditions).

Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
	Organic compost		Castor oil cake		Cured cow manure						
Phonolite											
	Dry coffee parchment Ulexite		Manganese sulfate Zinc sulfate								

Observation:
Manganese sulfate (6 kg/ha) and zinc sulfate (5 kg/ha) can be applied in one part straight into the soil or in two parts in the case of foliar spraying.

Important:

These examples are merely suggestions to give an idea of the different fertilization possibilities to meet the coffee trees' nutritional needs.
In order to make an informed decision, the producer needs to weigh up benefits and the costs of each type of fertilizer, taking account of the factors involved, such as price, freight cost, topography of the farm, availability of labor, etc. It is also important to seek advice from a coffee agronomist.

Phenology of the coffee tree and accumulation of nutrients

Considering the dynamics of nutrient accumulation in the coffee cherries, care must be taken to ensure that the mineralization of organic fertilizers, as well as the solubilization of mineral fertilizers, occurs mainly at the stages of greatest nutritional requirement (stages 2 and 3).

- Stage 1:
First 7 weeks after flowering (0 to 50 days). This is a stage of slow growth, in which the cherries are the size of a matchstick.

- Stage 2:
Weeks 8 to 17 after flowering (50 to 120 days). The cherries grow quickly and reach their final size, and the seeds have a gelatinous consistency.

- Stage 3:
Weeks 18 to 25 after flowering (120 to 180 days). The seed completes its development, acquires a solid consistency and gains mass.

- Stage 4:
Weeks 26 to 32 after flowering (180 to 224 days). The coffee cherry is physiologically developed and starts to ripen.

- Stage 5:
After week 32 (more than 224 days), the coffee cherries over-ripen and turn a dark violet color and finally dry out. At this stage the coffee cherry loses mass.

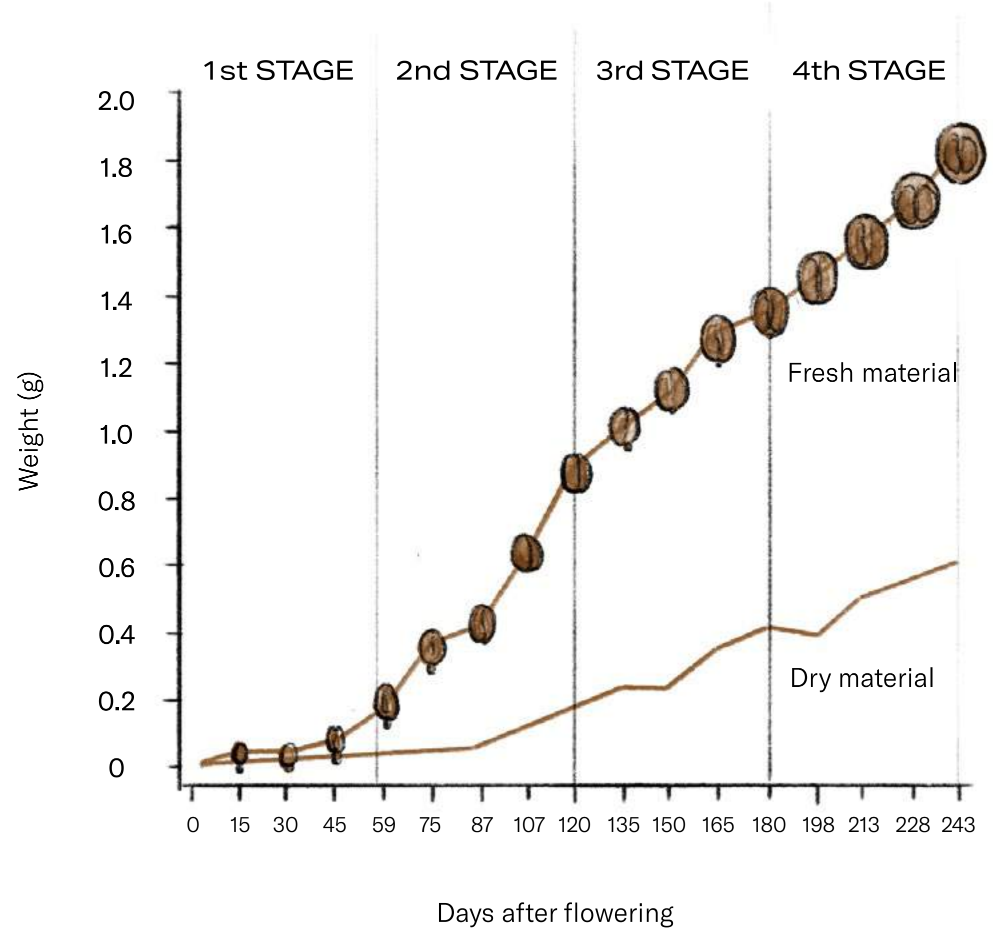

Figure 16. Stages of development of the coffee cherries. Source: Arcila et al. (2007)

3. Nutritional management

References:

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Inter-row management

4.

The inter-row is the area of ground between two rows of coffee trees, which is readily taken over by weeds, especially in young or pruned crops and/or those that are planted and pruned in lines in the open ground. Managing the vegetation between coffee plant rows has innumerable benefits such as protecting the soil against erosion and producing organic matter in the planted area itself which encourages the biological activity of the soil and nutrient cycling.

The producer must always maintain soil cover, with either plants or dead cover, to prevent excessive heating, drying and the impact of rain, thereby contributing towards the health of the soil and the sustainability of the production.

Uncovered soil:

• Reaches very high temperatures (above 50°C) which inhibit root activity and microorganisms;

• Loses a lot of water through evaporation, as it is no longer used to produce biomass by plants;

• Forms crusts on the surface of the soil and compacted layers which decrease the infiltration of rainwater and prevent the roots penetrating into deeper layers, making plants more vulnerable to periods of drought.

Source: CafePoint

Plants are only able to absorb water up to 32°C in the root system. In the tropics, in uncovered soils, the temperature at the soil surface can easily reach 59°C and even rise as high as 74°C.

In a covered, healthy soil, the coffee tree:

• Has greater productive potential;
• Is more resistant to pests, disease and physiological disorders;
• Is more likely to be able to withstand unfavorable climate events such as drought.

Source: Caio Diniz

Important:

When implementing intercropping or planting cover crops in the inter-rows, if it is demonstrated that seeds or seedlings sourced from organic systems are unavailable, then materials from a conventional origin can be used, provided they have not been treated with prohibited substances.

4.1. Weed management

The weeds found between the rows of coffee trees can be great allies to the producer, provided they are well managed, especially during the period of critical competition with the coffee plants. The weeds that grow in coffee plantations are well adapted to the climate conditions and the soil in the plantation area, so they are very efficient in their use of natural resources.

Figure 1. Weeds in between the coffee rows.

Source: Durval Rocha Fernandes

The critical period of weed competition is in the rainy months, when the weeds compete more fiercely for nutrients. However, during the dry months, there is greater competition for water.

Nature makes use of native plants, invaders or weeds to correct the pH, mineral deficiencies or excesses, compactions, surface crusting or stagnant water. These are specific indicators of a situation that needs to be corrected.

Source: Primavesi (2016)

With adequate weed management, a layer of dead cover (mulch) forms over the coffee rows, providing a number of benefits:

- Protecting the soil against erosion, excessive heating, drying, impact of rain, surface crusting and compaction;

- Maintaining moisture and enabling greater infiltration of water in the soil, mainly through the formation of aggregates and pores, as well as small channels left by decomposing roots.

Weeds absorb nutrients from the soil and, when managed (e.g. cut), return those nutrients to the soil's surface through decomposition. Plants with an abundant root system can absorb nutrients from the deeper layers of the soil, making them available to the coffee tree after they are cycled. In addition, the root system of the weeds releases organic acids responsible for making the nutrients available and (depending on the species) help to loosen the compacted soil. The management of spontaneous vegetation also contributes to the diversification of organisms in the soil, fostering biological control of pests and diseases.

Table 1 shows the species of weeds commonly found in coffee plantations with their corresponding scientific names, and what they indicate.

Table 1. Species of common weeds in coffee plantations and what they indicate.

Scientific name	What they indicate
Galinsoga parviflora	Excess nitrogen causes a nitrogen/copper imbalance (deficiency). It hosts nematodes of the genus *Meloydogine* and *Heterodera*. Sandy, pH neutral soils, without aluminum, but poor in calcium.
Acanthospermum hispidum	Calcium deficiency.
Euphorbia heterophylla	Molybdenum deficiency.
Solanum palinacanthum	Sandy soils, with sufficient moisture, but deficient in copper.
Portulaca oleracea	Presence of organic matter and boron in sandy soils.
Amaranthus hybbridus var. paniculata, *Amaranthus deflexus*	Presence of organic matter and boron. Acute boron deficiency causes the inside of the stems and part of the flowers to rot.
Ageratum conyzoides	Appears in the cold period of the year in fields where, in the summer, the Bidens pilosa appears. Indicates the presence of organic matter.
Sida rhombifolia	Compact surface layer with a hard slab between 8 and 25 cm deep. Has a very strong pivotal (axial) root with which it breaks the compactions.
Cynodon dactylon	Soil that has been very trodden down, by people, animals or machinery. Grows in pH of 4 to 8. Indicates soils with a hard surface layer.
Cenchrus echinatus	Highly compacted soil, from top to bottom.
Eleusine indica	Compacted, but fertile soil.
Cyperus rotundus	Moist soils, exposed to sun.
Digitaria insularis	Impermeable layer between 60 and 80 cm in depth.
Brachiaria plantaginea	Recently prepared fields, zinc deficiency.
Taraxacum officinale	Clay, well aggregated, deep and fertile soils, rich in nitrogen and boron.

Source: Primavesi (2016)

When and how to manage weeds

Weeds should be managed in the period of highest competition with the coffee plant which coincides with the period of maximum nutrient accumulation (the rainy season). This period includes cherry growth and filling stages.

Strip-only management (in the rows) is the most important, because weeds that grow in that part of the soil develop very close to the coffee tree, competing directly for light, water and nutrients, in addition to hampering the application of fertilizers. This management consists of keeping the coffee tree rows weed-free. The width of the weed-free strips should be 0.5 m at each side of the row.

During the rainy season, in mechanized crops, it is recommended that row management be carried out using hoes or brush cutters and that the weeds between the rows be periodically cut by mechanical means.

Alternating management

With periodic cuts between rows, weed selection is possible, minimizing growth. An interesting option is to manage the inter-rows by alternating (every other row), leaving one lane with taller vegetation to encourage greater nutrient cycling due to the increased biomass accumulation, and to provide cover and food for the natural enemies of coffee tree pests.

Source: Caio Diniz

Management with animals

Sheep that feed on weeds can be used. The recommendation is 5 to 10 animals per hectare of coffee plantation. However, grazing should be avoided in the following conditions:

- While the cherries are ripening, as the animals might eat them;
- During the 120-day period preceding the harvest, as US Regulations do not allow fresh manure to be applied to crops during that period[24];
- In crops where heavy pruning was carried out, as the sheep may damage the sprouts.

Note:

Sheep do not control weeds completely; it is necessary to complement management with manual and/or mechanical weeding for adequate control.

[24]Reference: §205.203 (c).

Mechanical management

- **Rotary cutters**

  - The aerial part of the weeds is cut, they grow again and continue to absorb water and nutrients, requiring the use of a rotary cutter every 20 to 30 days during the rainy season;

  - Using tractors and tools around the plantation, particularly when the soil is moist, promotes compaction in the traffic lane where the large part of the coffee tree roots are.

Figure 2. Use of rotary cutters on organic coffee plantations.

Source: Caio Diniz

- **Brush cutters**

  - Less efficient than rotary cutters and should also be used every 20 to 30 days during the rainy season;

  - No negative effect on soil compaction.

Figure 3. Use of brush cutters in organic coffee plantations.

Source: Caio Diniz

• **Harrow**

- Its frequent use can form compacted layers between the coffee rows (plow pan) negatively affecting the soil's physical properties;

- Enables weeds to spread, so the equipment must be cleaned before use;

- Must be carried out before the weeds grow to a height of 0.5 m.

• **Mulcher**

- Not as efficient as a rotary cutter, but useful after pruning as it grinds the plant residues.

• **Rotary cultivator**

- Disrupts the weeds;

- Reduces soil porosity in the layer that is 15 to 30 cm deep.

Manual management

Hoes are very efficient and, when used sporadically, do not have a detrimental effect on soil health. Nonetheless, their disadvantages are:

• Low operational efficiency;

• Labor intensive;

• Expensive.

Figure 4. Use of hoes in organic coffee plantation rows.

Source: Caio Diniz

Integrated management

This is the best form of management as it combines and alternates different methods, minimizing the impact caused by the frequent use of one sole weed management method. Some examples:

• Use of hoes in coffee rows and dead (coffee dry parchment and rice husk) in inter-rows.

• Use of hoes in coffee rows and growing cover crops in inter-rows.

• Use of hoes in coffee rows and rotary cutter in inter-rows.

• Use of hoes in coffee rows and rotary cultivator in inter-rows.

Allelopathy

Allelopathy is a phenomenon that is defined as the direct, stimulant or inhibitory effects of a chemical compound released by one plant in specific conditions which affects the growth or the development of another plant. Allelochemicals can be release by volatilization, leaching and decomposition of plant residues in the soil or by root exudations.

The use of allelopathic substances can be an additional tool for weed, pest and disease controls. There are weeds with allelopathic potential such as specific green manures that reduce the presence of weeds when they are mixed in the soil. This is the case with the waste of Comelinaceae in coffee plantations under shade in Veracruz, Mexico. The farmers promote the development of Commelina to control the presence of undesirable plants in the agroecosystem.

4.2. Crop association

Crop association is the cultivation of annual species such as beans, maize, peanuts, pumpkins, etc. depending on the area's properties and market demand. In the case of irrigated crops, vegetables such as peppers can be associated. Intercrops can:

- Supplement the producer's income;
- Improve utilization of available labor;
- Reduce the cost of coffee production and increase earnings from the crops;
- Increase biodiversity in the coffee plantation;
- A possible disadvantage is that it may hamper the mechanization of farming practices.

It is important to bear in mind the characteristics (cycle and height) and requirements (light, water and nutrients) of intercropping.

For association to be successful, the following is recommended:

- Keep a distance of 1.0 m between coffee rows;
- Implement intercropping during the rainy season or with irrigation;
- Carry out organic management of the intercrop as recommended (e.g. fertilization, weeding, etc.) during rainy season or with irrigation
- Give preference to short-cycle, short plants in the case of coffee plantations in production;
- In the case of plantations where trees have been planted, avoid crops that require a lot of light, such as grasses (Poaceae) like maize.

The remains of the intercrop, such as bean straw, can be returned to the plantation and applied to the surface.

An association widely used in Brazil is coffee with *Brachiaria* sp., a perennial forage plant, easily formed and established, which tolerates mechanization, resists competition with weeds and is relatively easy to eradicate if necessary. Intercropping with *Brachiaria* sp. reduces the number of operations necessary for weed management and protects the soil from erosion, in addition to increasing the capacity to store water in the soil and to reduce the temperature and water loss from the soil through evaporation. Other benefits of *Brachiaria* sp. in association with coffee:

- Improves aggregation, the content of organic matter and the soil's biological activity;
- Acts in the nutrient cycling.

The association of *Brachiaria brizantha* or *Brachiaria ruziziensis* with coffee trees is recommended.

Figure 5. Association of organic coffee with *Brachiaria* sp. Source: Caio Diniz

4.3. Green manuring

The use of cover crops for green manuring is a thousand-year-old farming practice. Due to the difficulty of managing weeds in organic coffee growing, it is advisable to replace vegetation that grows spontaneously between the coffee rows with cover crops. Its main purposes include:

- Covering the soil, protecting it from excessive sun and rain;
- Increasing the levels of organic matter in the soil;
- Fixing nitrogen in its biomass via bacteria, transferring it slowly to the soil through decomposition.

By emulating nature, cover crops play the role of dead leaves in tropical woods and their management corresponds to the degradation of dead leaves, one of the main nutrient cycling mechanisms in natural environments.

Source: Ambrosano et al. 2014

There are several options for using cover crops (green manures) in between coffee rows:

- Leguminous plants proven to be efficient in biological nitrogen fixation, such as *Mucuna deeringiana*, *Crotalaria breviflora*, *Crotalaria spectabilis* and *Cajanus cajan*;
- Plants with high biomass production that assist the nutrient cycling of the soil and the suppression of weeds, such as *Fagopyrum esculentum* and *Pennisetum glaucum*;
- Plants that reduce the nematode population which is harmful to coffee trees, such as *Crotalaria spectabilis;*
- Plants whose roots break compacted soil layers, such as *Cajanus cajan.*

Figure 6. Use of *Mucuna deeringiana* between coffee rows.

Source: CafePoint

Figure 7. *Crotalaria spectabilis* as a cover crop between the coffee rows.

Source: Caio Diniz

It is also possible to use an association (cocktail or mix) consisting of three or four species of cover crop in the same area. The right combination will use resources such as light, water and nutrients more efficiently. For example the association of *Pennisetum glaucum*, *Crotalaria* sp. and *Cajanus cajan.*

Implementation of green manures

- ***Before planting coffee trees***

  - Choose spring/summer species and plant them at the beginning of the rainy season.

  - In areas previously cultivated with coffee, preference should be given to species that reduce the nematode population, such as *Crotalaria spectabilis*.

  - Coffee trees should be planted during the rainy season, 30 to 60 days after planting cover crops.

- ***Crops in production***

  - Use short-cycle species and long-cycle species simultaneously in the spring/summer and plant them when it first starts to rain, in alternate rows, swapping positions the following year.

  - The period during which nutrients are most required by coffee trees occurs when the cherries are growing, and it coincides with the greatest vegetative growth of the cover crops. With the right fertilization regime it is possible to reduce competition between the cover crops and coffee plants and obtain the following benefits:

    1. Additional nutrients to meet part of the nutritional requirement of coffee from growing short-cycle plants, such as *Mucuna deeringiana*, *Crotalaria breviflora*, *Fagopyrum esculentum*;

    2. Soil cover for as long as possible from the growth of longer-cycle plants, such as *Crotalaria spectabilis*, *Cajanus cajan* and *Pennisetum glaucum*.

  - However, it is important to diversify the species each year.

The use of green manure in between coffee rows to supply nitrogen (N) makes great financial sense as it is far less expensive than applying an equal amount of organic fertilizer or even chemical (conventional) fertilizers. Considering 100 kg/ha of N from green manure (e.g. *Crotalaria spectabilis*), we have the following costs of inputs:

Green manuring	Organic fertilization (example 1)	Organic fertilization (example 2)	Chemical fertilization (conventional)
15 kg/ha of seeds of *Crotalaria spectabilis*	5.4 t/ha of organic compost	2.2 t/ha of castor oil cake	250 kg/ha of urea
USD 36/ha	USD 430/ha	USD 590/ha	USD 80/ha

Management of green manures

Cutting must be done during full flowering, using hoes, rotary cutters, mulchers or roller-crimpers, and the biomass produced must stay on the soil's surface until it decomposes. It must then be deposited onto the coffee rows so the coffee trees can use the nutrients to greater advantage.

The management of green manures takes place in the main blooming. In that phase, the aerial part of the plants has the highest levels of nitrogen (N) and moisture, fostering its rapid decomposition by the soil organisms and the mineralization of nutrients.

Figure 8. Green manuring with *Canavalia ensiformis* in organic coffee plantations.

Source: Enes Pereira Barbosa

4. Inter-row management

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Plant health management

5.

In coffee agroecosystems, plant health is closely related to soil fertility and environmental balance, given that plants are influenced by different edaphic and climatic factors and form part of a complex network of ecological interactions. This means that in order for a coffee tree to develop healthily, it must be cultivated in soil that is fertile from a chemical, physical and biological perspective. It's environment should have a favorable microclimate and a high degree of biodiversity, making it less susceptible to pests and diseases.

Balanced nutrition plays an extremely important role in plant health. It is also worth emphasizing the importance of biodiversity in the cultivation environment for the natural biological control of pests and pathogens.

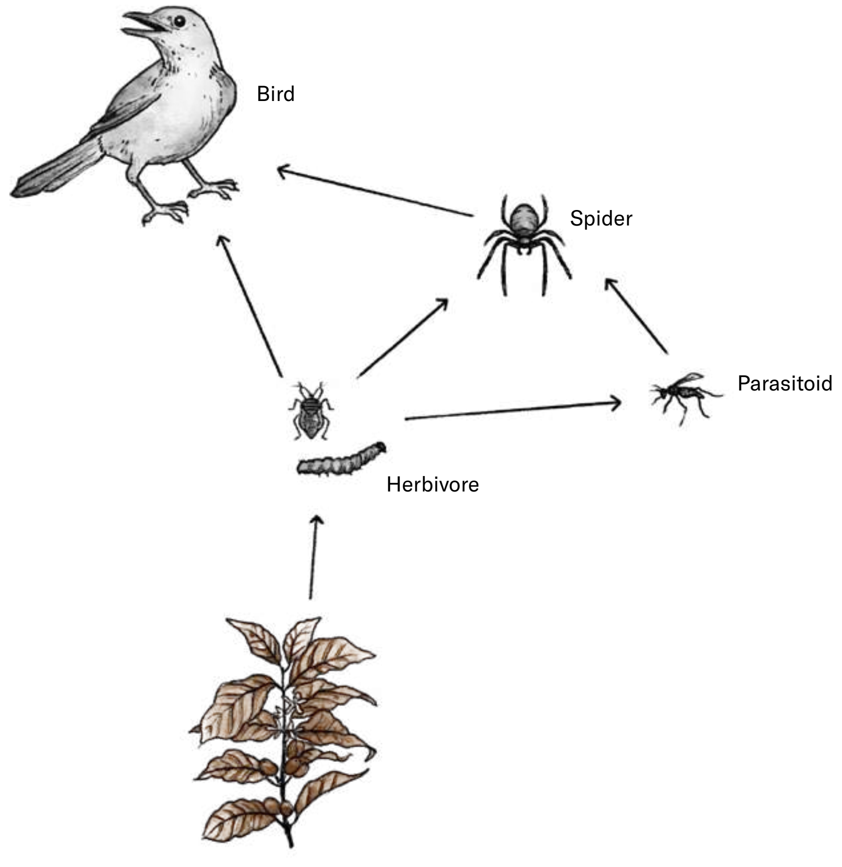

Figure 1. Example of a trophic structure in a coffee plantation. The arrows indicate energy transfers, in other words, who feeds who.

Source: Perfecto et al. (2014)

5.1. Pest and disease management

In coffee plantations, there are different types of organisms (insects, mites, fungi, bacteria, etc.) that live in the soil or in the aerial part of plants. Most of these organisms are beneficial for coffee growing and only some can become pests or cause diseases, leading to economic losses.

Pest and disease management seeks to minimize economic loss with the integrated use of different methods of control, avoiding damage to human health and the environment.

Organic plant production systems must prioritize:

- The use of improved material to propagate plant species adapted to local edaphic and climatic conditions and tolerant to pests and diseases;

- Adoption of pest and disease management which:

a) respects the natural development of plants;
b) respects environmental sustainability;
c) respects human and animal health, even at its early storage stage; and
d) gives preference to cultural, physical and biological methods.

The regulations of each consumer market (e.g. Brazil, the European Union, the United States and Japan) have their own requisites for pest and disease management in organic plant production systems. This is the reason why organic farmers can only use the authorized substances and practices by the respective regulations.

Pest and disease management components:

1. Diagnosis: the pest or disease is identified, as well as the favorable conditions for its occurrence, through an assessment of the agroecosystem.

2. Decision-making for control: a decision is taken on whether or not to use control methods, based on monitoring the level of control established for each pest or disease.

3. Selection of control methods: control methods are selected based on technical parameters (efficacy), economic parameters (better cost-benefit ratio), toxicological parameters (preservation of human health and the environment) and sociological parameters (adaptation to the reality of the producer or rural worker).

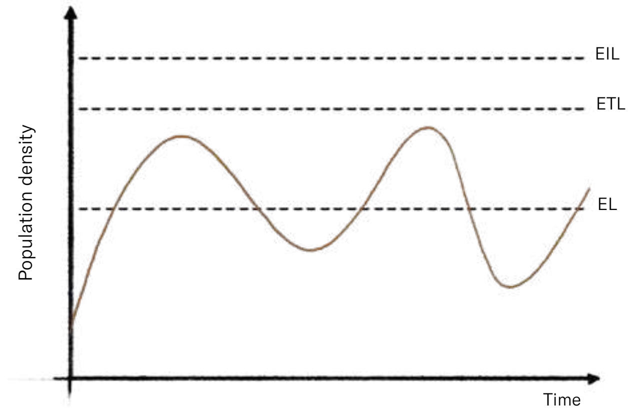

Figure 2. Variation in the population density of insects and other organisms in relation to a particular equilibrium level (EL). In agroecosystems, control methods are used when the population reaches the economic threshold level (ETL) in order to prevent the economic injury level (EIL) being reached.

The **control methods** can be divided into groups:

1. Used to prevent pests and diseases from causing economic injury:

• **Cultural control:** use of cultivation methods that contribute to greater coffee tree resistance and an environment that is less favorable to pests and diseases and, at the same time, more favorable to natural enemies **(e.g. choice of cultivation area, planting of resistant varieties, balanced nutrition, use of homeopathic preparations, weed management or planting cover crops in between coffee rows, establishing windbreaks, hedges or natural vegetation belts, tree planting on the coffee plantation, irrigation, pruning and harvesting).**

• **Ethological control:** use of pheromones, hormones and compounds to attract or repel insects, which interfere with the insects' behavior, thus reducing damage to the plantation **(e.g. use of traps which attract insects).**

• **Natural biological control:** use of cultivation methods that favor populations of natural enemies **(e.g. diversification of vegetation, use of the allelopathic potential of existing plants or plants that will be introduced into the agrosystem, and use of selective insecticides to favor natural enemies).**

2. Used when pests and diseases reach the economic threshold level:

• **Applied biological control:** application of natural enemies on the plantation **(e.g. Fungus *Beauveria bassiana* to control the coffee berry borer).**

• **Alternative chemical control:** application of plant extract or mineral mixtures, which have pesticidal or repellent properties, approved for use in organic agriculture **(e.g. Natural insecticide based on neem oil to control the coffee leaf miner).**

Figure 3. Spraying of plant health products approved for use in organic agriculture. Source: Caio Diniz

5.2. Coffee tree pests and diseases

The coffee tree is normally attacked by pests and pathogens which, if not adequately managed, can restrict production and cause serious losses. The degree of importance of these plant health problems varies according to the production system and the climate of the region.

The pests that require the most attention from the organic coffee producer are the **coffee leaf miner** and the **coffee berry borer**, but also mites and, to a lesser extent, cicadas and cochineal scale.

The most frequently occurring diseases in organic coffee growing are **coffee leaf rust** and Cercospora **leaf spot**, which is why these diseases warrant special care. Coffee branch dieback is often the result of many complex factors and organic coffee trees are no exception.

Nematodes cause serious damage in many coffee-growing regions. However, they can normally be controlled in organic coffee farming with practices that increase the biological activity of the soil (e.g. use of cover crops and organic fertilizers).

Figure 4. Organic coffee plantation with high incidence of leaf miner.

Source: Caio Diniz

5.2.1 Coffee leaf miner

a. Description:

The coffee leaf miner (*Leucoptera coffeella*) is a small moth whose larvae form mines within the coffee leaves, causing lesions and foliar area loss.

Figure 5. Miner larvae attacking the leaves of coffee trees.

Source: Paulo Rebelles Reis

Figure 6. Leaf miner pupa.

Source: Paulo Rebelles Reis

Figure 7. Leaf miner moth.

Source: Fundação Procafé

b. Causes:

Dry, hot seasons and sites, plants with water deficits, new, pruned or highly ventilated plantations, imbalanced fertilization (e.g. excess nitrogen), excessive use of copper-based fungicides, very sunny areas, very high peaks, dusty areas, absence of native vegetation and woods (conducive to the natural enemies of leaf miners) and use of insecticides that kill natural enemies.

c. Decision-making for control:

I. Monitoring: In the time of year when conditions are favorable, leaves should be sampled every two weeks. Take samples from uniform plots (same slope, coffee variety, etc.). Walk in a zigzag inside the plantation, taking the 3rd or 4th pair of leaves from 25 plants at random, from the middle third and from both sides of the plants[25]. Take 100 leaves per plot and take note of the number of leaves attacked.

II. Economic threshold level: 10 or 25% of leaves mined (with live larvae).

In regions that are highly susceptible to pests, alternative chemical control through spraying must begin with around 10% of mined leaves (with live larvae). For less problematic areas, the starting level can be up to 25%.

[25]See Figure 6 of module 3. Nutritional management.

Cultural control

· Creating **windbreaks, hedges, belts of natural vegetation** or **tree planting on the coffee plantation**, in a well planned manner, with the right plants will help to reduce the leaf miner which prefers well ventilated and drier places. Moreover, diversified vegetation like this serves as a refuge for the pest's natural enemies, contributing to natural biological control.

Natural biological control

· The diversification of vegetation in the crop area or close to the plantation favors the presence of **natural enemies** that control the leaf miner population. These include:

- · Predators: wasps, ants and green lacewings;
- · Parasitoids: tiny parasitic wasps;
- ·Entomopathogens: bacteria and fungi.

· Avoid **excessive use of copper-based fungicides** (mainly in regions that are more susceptible to leaf miners).

Applied biological control

· It is not necessary to introduce natural enemies to control the leaf miner in coffee plantations where conditions for natural biological control to occur exist.

Ethological control

· The leaf miner's **sex pheromone** can be used for monitoring pests and capturing adult males in traps using pheromones and glue, thus reducing the possibility of pairing and, consequently, the pest population.

Figure 8. Predatory wasps. Source: Caio Diniz

Alternative chemical control

· **Neem extract**, a native tree from southeast Asia. It is a natural insecticide proven to be effective in controlling the leaf miner through foliar spraying onto the coffee trees. Currently there are commercial azadirachtin-based products (the main active substance in neem extract) registered to control the leaf miner in coffee crops.

· Foliar spraying with **lime sulfur**, a mixture made from sulfur and lime, or **visosa mixture**, made of copper sulphate, lime and micronutrients, reduces oviposition site selection by the leaf miner.

5.2.2 Coffee berry borer

a. Description:

The coffee berry borer (*Hypothenemus hampei*) is a small beetle that attacks coffee cherries by perforating the cherries to lay its eggs. Most losses are caused by the larvae that feed on the seeds, causing weight loss and lower green coffee quality.

Figure 9. Coffee berry borer in coffee cherries.

Source: EPAMIG

Figure 10. Bored beans attacked by the coffee berry borer.

Source: EPAMIG

b. Causes:

Very humid locations and seasons, abandoned plantations, poor harvesting, crops with high density planting, slopes with less exposure to sun, non-uniform flowering, late harvests and drought that coincides with the spread of coffee berry borer.

c. Decision-making for control

I. Monitoring: On each plot, 1% of the plants are taken from different points, with 30 cherries/plant collected randomly, 15 from each side, taken from the middle third of the plants, during the first flowering. From the full sample of cherries collected on the plot, the number of healthy cherries and infested cherries must be counted in order to determine the percentage of infested cherries (with alive coffee berry borers).

II. Economic threshold level: 3% to 5% of infested cherries among the green fruit from the first flowering.

The point at which to begin with alternative chemical control will be determined by sampling and calculating the percentage of infested beans. Control should begin when 3% to 5% of the berries from the first flowering are attacked.

Alternative chemical control

- **Neem extract**, a native tree from southeast Asia. This is a natural insecticide with the potential to be used to control the coffee borer beetle by spraying the cherries. Currently there are commercial azadirachtin-based products (the main active substance in neem extract) registered for the control of the coffee berry borer.

Cultural control

- Cultural control is known to be the most effective means of controlling coffee berry borers. Any coffee beans remaining on the plantation after the harvest will harbor the coffee berry borer insects that will infest the next cycle. Hence **the importance of careful harvesting** and collecting any beans that remain on the plants or fall to the ground.

- Producers who prefer not to collect the coffee from the ground, should encourage **rapid decomposition of the beans** by soil organisms (e.g. inoculation of effective microorganisms).

Natural biological control

- The diversification of vegetation in the crop area or close to the coffee plantation encourages the presence of **natural enemies** that control the coffee berry borer. These include:
  - Parasitoids: tiny parasitic wasps;
  - Predators: ants and thrips;
  - Entomopathogen: *Beauveria bassiana* fungus.

- **Avoid excessive use of fungicides.**

Ethological control

- Allelochemicals (kairomones) are efficient both for sampling and controlling coffee borer beetles. Each 2 liter **PET plastic bottle trap**, painted red, with kairomone, can capture more than 30,000 adult coffee borer beetles every two weeks. Ethanol and methanol in a 1:3 ratio and 1% of benzoic acid, are used in such a trap. Using 30 traps/ha has been known to reduce attacks by coffee berry borers on plantations by 60%.

Figure 11. PET plastic bottle trap to control the coffee berry borer.

Source: EMATER-MG

Applied biological control

- Currently some fungus-based ***Beauveria bassiana*** biological insecticides registered for the control of the coffee berry borer are available on the market. They should be applied if the level of infestation reaches 2% during the period when the coffee borer beetle is spreading. Apply twice at 20 to 30-day intervals.

- In order to promote the natural biological control of coffee borer beetles with *Beauveria bassiana*, producers should collect cherries with fungus-infected adult coffee borer beetles (presence of white mycelium at the entrance to the gallery) and transfer them to areas where no infected beetles have been observed. The cherries must be put into thin mesh bags tied to the branches of the coffee trees, in a shady, well ventilated place. A solution can also be prepared with infected coffee borer beetles and water, mixed in a blender for one minute, and applied directly to the coffee tree branches.

Figure 12. Coffee berry borer colonized by the *Beaveuria bassiana* fungus.

Source: José Nilton Medeiros Costa

5.2.3 Coffee leaf rust

a. Description:

Coffee leaf rust is a disease caused by the fungus *Hemileia vastatrix*. Rampant coffee leaf rust can be devastating for coffee farmers. The first signs of it are small yellow-orange powdery blotches that appear on the undersides of the coffee tree leaves. The disease causes intense defoliation of the coffee tree and, consequently, loss of productivity.

Figure 13. Incidence of coffee leaf rust on coffee tree leaves.

Source: Caio Diniz

Figure 14. Defoliation caused by coffee leaf rust on organic coffee plantations and susceptible variety.

Source: José Braz Matiello

b. Causes:

Temperatures of 22°C to 26°C, or if leaves remain wet for more than 8 hours, high relative humidity, high planting density or excess nitrogen in the leaves. The disease is also more prevalent in regions with low altitude or in low-lying sections of plantations.

c. Decision-making for control:

I. Monitoring: Take samples from uniform plots (same slope, coffee variety, etc.). Walk through the plantation in a zigzag, taking the 3rd or 4th pair of leaves from 25 plants at random, from the middle third and both sides of the plants[26].

II. Economic threshold level: Application of fungicide at the start of control with 5% incidence of coffee leaf rust.

[26]See Figure 6 of module 3. Nutritional management.

Cultural control

- The use of **resistant varieties** is the most efficient method of control.
- Always carry out **balanced fertilization**, avoiding too much nitrogen.
- **Choose the shoots**, avoiding too much stem and, consequently, self-shading.

Applied biological control

- Investigation is ongoing into the use of fungi and bacteria as potential agents for the biological control of coffee rust. However, to date no commercial products have been registered for this purpose.

Alternative chemical control

- In the case of conditions conducive to coffee rust, foliar application of **copper-based fungicides** is recommended:
    - Copper hydroxide;
    - Copper oxychloride.
- **Bordeaux mixture**, made of copper sulphate and lime) or **visosa mixture** (made of copper sulphate, lime and micronutrients) can be used in foliar sprays at 45 to 60-day intervals throughout the rainy season.

5.2.4 Brown eye spot

a. Description:

Brown eye spot is a disease caused by the *Cercospora coffeicola* fungus which attacks the coffee tree leaves and cherries. Circular, brown spots with a light grey center form on the leaves, usually surrounded by a yellow ring that looks like an eye. The fruits have depressed brown or purple lesions that start to appear when they are still young, escalating during grain filling and remaining until cherries mature. The disease causes damage in nurseries, such as leaf fall and development issues in seedlings. In the field (mainly in young or stressed plantations) it causes leaf fall, branches dieback, early maturing, premature fruit fall, malformed beans and loss of beverage quality.

Figure 15. Incidence of brown eye spot in coffee tree leaves.

Source: Camila Cristina Lage de Andrade

Figure 16. Incidence of brown eye leaf spot in coffee cherries.

Source: Fundação Bahia

b. Causes:

Temperatures of 16°C to 20°C, high relative humidity, generalized nutritional deficiency, hydric stress, sandy soils, cold winds and exposure to intense sunlight.

c. Decision-making for control:

To date, no research has been conducted to indicate the control levels for brown eye spot.

Cultural control	Alternative chemical control
· Always carry out **balanced fertilization**, avoiding too much potassium. · Promote the development of the coffee tree's **root system** through **healthy soil**, free of compactions. · Prevent weeds from growing very close to the coffee trees, especially in drier weather when the beans start to ripen. · **Tree planting on the coffee plantation**, using suitable plants and doing so in a well-planned manner, is an efficient way of controlling the disease, as its incidence increases in crops in full sun. · In nurseries: · Avoid high humidity, low temperatures, cold winds and excess sun exposure; · Grow the seedlings in good quality substrates.	· In the case of conditions conducive to brown eye spot, foliar application of **copper-based fungicides** is recommended: · Copper hydroxide; · Copper oxychloride. · **Bordeaux mixture**, (made of copper sulphate and lime) or **visosa mixture** (made of copper sulphate, lime and micronutrients) can be used in foliar sprays at 45 to 60-day intervals throughout the rainy season.

5.2.5 American leaf spot

a. Description:

American leaf spot (*Mycena citricolor*) is a fungus that attacks coffee leaves and coffee cherries. It causes round, dark brown spots on both sides of the leaves and round brownish yellow spots on the fruits. Defoliation of the plant occurs with severe infestation.

Figure 17. American leaf spot.

Source: Anacafé

b. Causes:

The fungus is present in low-tech coffee plantations, with excessive shade, high relative humidity and cool temperatures ranging from 19°C to 23°C.

c. Decision-making for control:

To date there is no official methodology indicating the level of control for American leaf spot.

Cultural control

· **Reduce the percentage of shade.** Use easily managed shade trees that allow the plantation to benefit from sufficient light and good ventilation.

· **Pruning**.

· **Weed** control.

· **Fertilize** at the right times and in the right amounts.

Biological control

· The *Trichoderma* spp. fungus inhibits the development of the bud. The *Trichoderma* spp. on its own is not sufficient to control the disease.

Alternative chemical control

· Applications of **copper-based fungicide** or calcium hydroxide.

· Foliar spraying with **lime sulfur** or **bordeaux mixture**.

5. Plant health management

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Adaptation of climatic conditions

6.

Figure 1. Windbreak in an organic coffee plantation.

Source: Caio Diniz

The Arabica coffee tree is native to the understory of the tropical forests of Ethiopia and southern Sudan. Arabica is well-suited to altitudes between 1,600 and 2,000 m, a mild, humid climate, a dry season lasting between two and four months, and mean temperatures ranging from 17°C to 19°C in the coldest months and 22°C to 26°C in the warmest. These forests have four layers: the two upper layers are 10–40 m tall. Coffee tree grows in the lower two layers, rarely reaching 5 m. Therefore, the coffee tree is highly tolerant to shade and is affected by excessive sunlight and high temperatures.

At temperatures above 28°C, there is a reduction in photosynthetic activity and above 34°C the flowers may not develop. In addition to high temperatures, constant winds, low relative humidity and lack of available water in the soil also reduce the coffee tree's production potential.

This is why it is important to adopt practices that help to adjust the plantations' microclimate, providing favorable climate conditions that foster coffee tree productivity and high-quality beans. It is also particularly important to establish windbreaks and shade trees on plantations.

6.1. Establishing windbreaks

In combination with high temperatures, the presence of constant winds, associated with low relative humidity, is detrimental to the production of the coffee tree; soil moisture is reduced due to the increased evapotranspiration of the system. Persistent winds also cause the plants' stomata (where the exchange of gases occurs) to close which results in a reduction of coffee trees' photosynthetic rates.

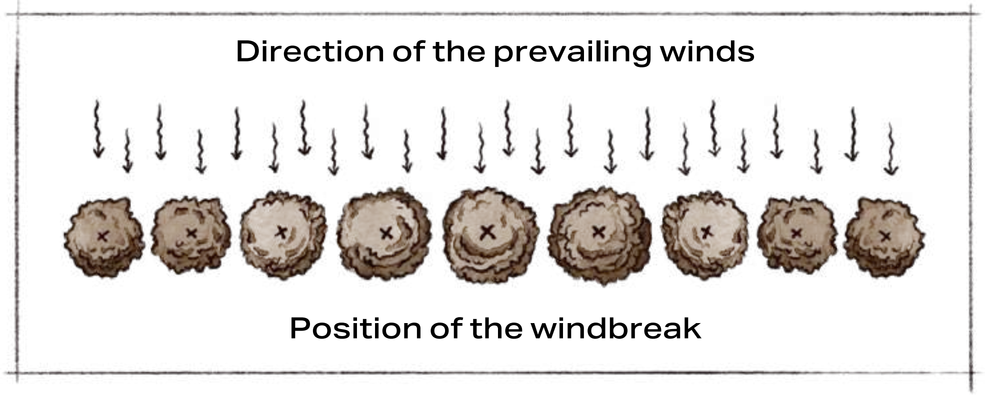
Evapotranspiration is the loss of water from the soil through evaporation and from plants through transpiration.

That is why the installation of barriers against constant winds (both strong or moderate) has a favorable effect on coffee production. The ideal positioning of these barriers is where they are best able to reduce the intensity of dry or cold winds and provide shade in the summer. Another advantage of establishing windbreaks is that they serve as a refuge for birds and beneficial insects (e.g. natural enemies and pollinators).

a. Tree planting on coffee plantations

1. Position: The species chosen should be established in a line perpendicular to the direction of the prevailing winds (Figure 2).

Figure 2. Position of the windbreak.



2. Characteristics: The species must grow upright, be fast growing and have a deep root system. It must be an evergreen (in other words, it does not shed its leaves). It must withstand wind well and have good pest and disease resistance. It is also an advantage if the species has a commercial use – if it bears fruit or provides wood, for instance. Some of the most frequently used species are *Grevillea robusta* and avocado.

Trees must be spaced 4, 5 or 6 meters apart, in lines, with the plants coinciding with (or crossing) the coffee rows. Tall plantain or banana trees can also be planted every 2 or 3 meters, evenly spaced between 6, 7, 8, 9 or 10 coffee rows.

3. Height and distance: On flat ground, a line of windbreaks can protect an area corresponding to a distance of 10 to 15 times their height. This means that if a tree is 10 m high, the effect of the windbreak will be felt up to 100 to 150 m away. If the coffee plantation is surrounded by a line of trees, the distance protected will increase as much as 20 times the height of the line[27].

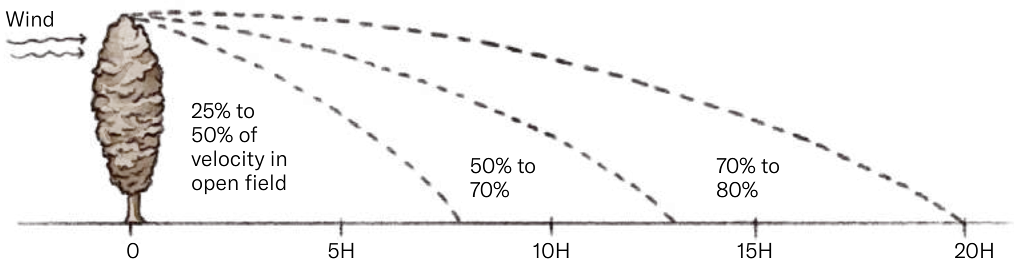


Figure 3. Wind velocity reduction zones, vertical scale exaggerated.

Source: Adapted from Read (1964)

[27]It is recommended that the lanes be used to establish windbreaks, preventing loss of too much productive area. On sloping ground, the windbreak's protection distance varies with the slope, in other words, the steeper the slope, the smaller the area protected. If the slope tends to be frequently battered by strong winds, then the best practice is to plant trees on the coffee plantation.

4. Density: Trees with more upright crowns (rounded or triangular), small, thin leaves and trunks without branches up to 2 or 3 m high (pruned lower branches) are most suitable for forming efficient barriers. Spacing along the tree line must ensure approximately 50% crown porosity, depending on the species available and adapted to the region.

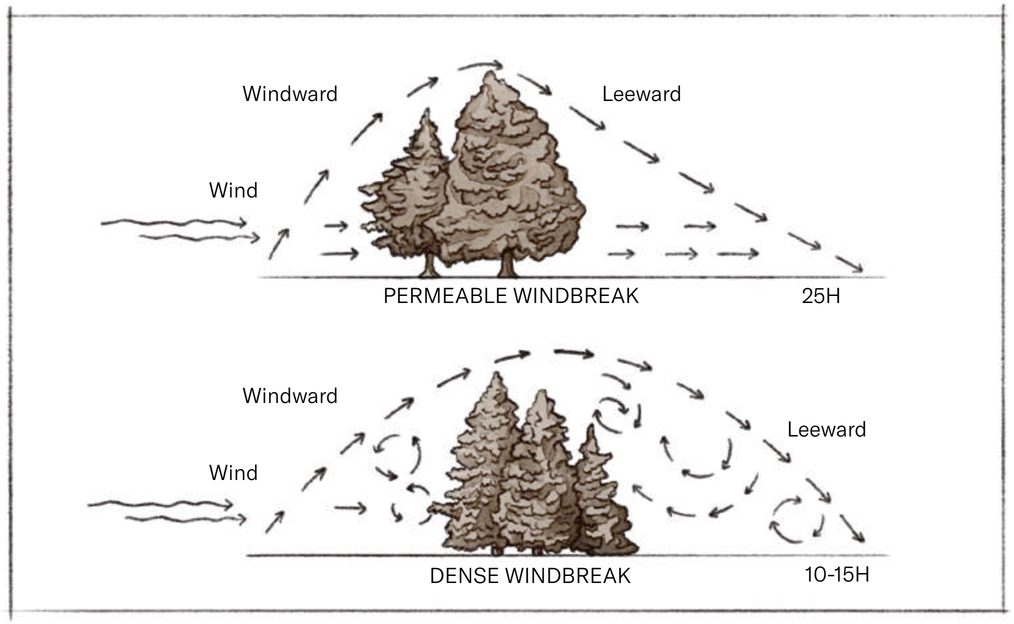


Figure 4. Difference between the aerodynamic action of a permeable barrier and a dense one.

Source: Adapted from Rosenberg, Blad & Verma (1983).

Figure 5. Rows of plantain or banana trees between six rows of coffee trees in Andradas - MG, Brazil.

Source: Fundação Procafé

b. Temporary windbreaks

While permanent windbreaks are forming, it is important to set up temporary ones, especially in the first three years of the coffee plantation.

Temporary windbreaks can be formed using annual species, planting them each year between every three or four inter-rows of coffee, normally using corn, sunflower and *Crotalaria juncea*.

Perennials can also be used, if they are planted only once, in order to reduce wind velocity while the permanent windbreaks are growing. Lines with sugarcane, castor oil and *Cajanus cajan* can be used, planted every 3, 4, 5 or 6 coffee inter-rows.

Figure 6. Temporary windbreaks with *Crotalaria juncea* every four inter-rows in Alfenas - MG, Brazil.

Source: José Braz Matiello

6.2. Tree planting on coffee plantations

The shaded coffee tree develops morphological and physiological adaptation mechanisms that enable it to survive in shaded condition. However, this may be at the expense of cherry production because of the lack of adequate sunlight, especially in the floral induction phase, has negative (low) effects on coffee production.

LIGHT	SHADE
Decisive factor for fruit production	Important factor for the health and longevity of the coffee tree
→ Meeting the commercial objective of the crop	→ Reducing the demand for fertilizers and plant health products, as well as the cost of production

Tree planting is intended to provide moderate shading in order to reduce high temperatures and depletion of the coffee tree as a result of excessive production under soil degradation conditions, using fewer resources.

Source: Caramori et al. (2004)

Tree planting can help the coffee tree to develop in areas with a water deficit and high temperatures or frosts, as long as the species of tree are carefully selected. Tree planting is carried out with trees which, due to their growth patterns and longevity, grow well alongside coffee trees, providing coffee trees with shade throughout the plantation's cycle.

The basic function of tree planting is to create a more favorable microclimate for coffee production by:
- **Attenuating high temperatures in spring and summer;**
- **Reducing heat loss in winter and damage due to low temperatures (e.g. frost);**
- **Protecting the coffee plantation from the direct action of the wind by reducing its velocity;**
- **Reducing water loss from the soil through evaporation;**
- **Decreasing the temperature at the soil surface;**
- **Reducing transpiration of the coffee tree;**
- **Decreasing the biennial production cycle;**
- **Increasing the productive longevity of the coffee plantation;**
- **Reducing the incidence of pests and diseases (e.g. leaf miner and Cercospora leaf spot);**
- **Increasing biodiversity (fauna and flora);**
- **Conserving natural resources (water and soil);**

Additional benefits that can be obtained with tree planting:
- **Production of larger and sweeter coffee cherries;**
- **Extension of the ripening period, improving bean quality;**
- **Promotion of more uniform ripening;**
- **Weed reduction;**
- **Increased content of organic matter and soil nutrients;**
- **Nutrient cycling through leaves and branches that have fallen from the trees onto the ground;**
- **Reduction of soil erosion;**
- **Reduction of nutrient leaching;**
- **Atmospheric nitrogen fixation, when leguminous species are used;**
- **Higher earnings from fruit and wood, among other products;**
- **Reduced use of inputs (fertilizers and phytosanitary products);**
- **Lower production cost;**
- **Mitigation of the effects of climate change, sequestering carbon and reducing external dependence on nitrogen.**

Possible disadvantages of tree planting on coffee plantations:
- **When trees are poorly established or unmanaged, they can compete with the coffee trees for sunlight, water and nutrients, causing production to drop and hampering the mechanization of farming activities and coffee harvesting;**
- **Trees with closed, unmanaged crowns, intercept wave lengths that would otherwise be used in coffee tree photosynthesis, reducing fruit production;**
- **Trees with a high water requirement, with surface roots and in regions with drought issues, can compete with coffee trees for water;**
- **Shaded coffee trees yield cherries that produce a less acidic beverage;**
- **Increased incidence of coffee leaf rust and coffee berry borers, due to the higher relative humidity of the air.**

Below are some key points for successful tree planting.

1. Define the main climate factor to attenuate

Determines the type of tree that will be used, as indicated here:

High temperatures in spring and summer	Water deficit in winter	Frost
Trees whose crowns keep their leaves in spring and summer	Trees that shed their leaves in winter (deciduous)	Trees that do not shed their leaves in winter (evergreen)
	Trees that do not compete for water	Fast-growing trees

2. Identify the priority product for generating income for the producer

- Coffee as the exclusive focus of the tree-planted coffee plantation:
  - › Leguminous species can be chosen, as nitrogen (N) fixation helps to reduce the crop's production cost;
- Tree planting to diversify sources of income:
  - › Species whose products have a market value in the region can be selected, such as fruit, wood, etc.

If the main objective of tree planting is to increase biodiversity, several species of tree should be planted, which renders its management more complex.

3. Define tree species and planting location

Taking into account points 1 and 2, tree species must be defined according to the following classification[28]:

- **Deciduous trees** are trees that shed all their leaves during the dry, cold period of the year (Table 1);

- **Semi-deciduous trees** are trees that partially shed their leaves during the dry, cold period (Table 2);

- **Evergreen trees** are trees that do not shed their leaves during the dry, cold period (Table 3).

In tropical and subtropical coffee farming it is recommended that the plantations receive shade from deciduous trees while allowing them to receive sunlight at the end of autumn and during the winter. As a result, the coffee tree flower buds will experience abundant flowering. During the period of warm days, the crowns of deciduous trees are laden with leaves, which guarantees beneficial shade.

Intense shading with semi-deciduous or evergreen trees can reduce floral induction and coffee productivity, so it is preferable to plant them around the coffee plantations. However, if these trees have a scant or fairly high crown and good regeneration capacity, they can be used within the plantations, provided they are pruned at the end of autumn or beginning of winter. On the other hand, in regions at risk of frost, the use of perennial trees that are well managed and adequately spaced, affords good protection against mild frosts.

[28]Some trees are deciduous, but recover their leaves quickly, which is why it is important to notice how long the tree remains leafless. It is necessary at least 60 to 90 days of intense sunlight, during the period of short, dry and cold days, to stimulate coffee tree flowering.

Desirable characteristics of a species for tree planting in coffee plantations:

- **Rapid growth, good development and longevity compatible with the coffee tree (trees that adapt well to temperature variations and humidity at the site);**
- **Open, non-cylindrical crown;**
- **Crown that allows adequate infiltration and distribution of sunlight;**
- **Deep roots so there will be no competition with the coffee trees;**
- **Wind resistance;**
- **Leaves are shed at the end of autumn and in winter, allowing light in and favoring nutrient cycling;**
- **Leaves that provide adequate shade for coffee plantations in spring and summer;**
- **Abundant ramification;**
- **Easy to manage, with good capacity to regenerate;**
- **A large amount of dry leaves produced;**
- **Atmospheric nitrogen fixation.**

Table 1. Deciduous trees suitable for tree planting on coffee plantations.

Scientific name	Common name
Caryocar brasiliense	Pequi
Cedrella fissilis	Cigar box cedar
Chorisia speciosa	Silk floss tree
Commiphora leptophloeos	Imburana
Cordia trichotoma	Peterebi
Enterolobium contortisiquuum	Pacara earpod tree
Handroanthus albus	Golden trumpet tree
Handroanthus impetiginosus	Pink trumpet tree
Hevea brasiliensis	Rubber tree
Jacaranda mimosifolia	Jacaranda
Melia azedarach	Chinaberry
Peltophorum dubium	Cambui
Platyciamus regnelli	Pau pereira
Quercus robur L	Common oak
Schizolobium parahyba	Brazilian firetree
Spathodea campanulata	African tulip tree
Toona ciliata	Red cedar

Table 2. Semi-deciduous trees suitable for tree planting on coffee plantations.

Scientific name	Common name
Anadenathera macrocarpa	Bilka
Cabralea canjerana	Canjerana
Ceasalpinia peltrophoroides	Sibipiruna tree
Erythrina spp.	Erythrina
Gliricidia sepium	Mother of cocoa
Inga spp. (principally *Inga edulis*, *Inga laurina* and *Inga vera*)	Inga
Machaaerium villosum	Jacaranda do cerrado
Maclura tinctoria	Dyer's mulberry
Morus nigra	Black mulberry
Tipuana tipu	Rosewood

Table 3. Evergreen species suitable for tree planting on coffee plantations, preferably surrounding the plantations.

Scientific name	Common name
Acacia mangium	Mangium
Azadirachta indica	Neem
Acrocomia acuelata	Coyol palm
Anacardium accidentale	Cashew tree
Artocarpus heterophyllus	Jackfruit
Bactris gasipaes	Peach palm
Copaifera langsdorffii	Diesel tree
Grevillea robusta	Silky oak
Hymenaea courbaril	West Indian locust
Macadamia integrifólia	Macadamia
Mimosa scabrella	Bracatinga
Musa spp.	Bananas and plantains
Orbignya phalerata	Babassu palm
Persea americana	Avocado
Syagrus oleracea	Queen palm
Trema micrantha	Ixpepe

Note: The common name of the trees tends to change according to origins. The translation in English of the scientific name might be different to what the reader is used to.

Example:

Pinus Caribaea, Pinus Tecunumani, Pinus Ocarpa pines are perennial trees used in many Peruvian coffee plantations to create shade. In addition to providing shade, they regenerate degraded soils and are fast growing (Watson, 2018).

Villagaray *et al.*, 2011 conducted a study on yield per hectare on various associations of shade trees with coffee growing. Combinations of *Pinus Tecunumani*–coffee, *Inga*–coffee and full-sun–coffee were studied. The highest yield was found with the association of *Pinus Tecunumani* and coffee, three years after planting. This combination experienced a yield of 1,886 kg/ha versus 1,610 kg/ha with the Inga-coffee combination and 700 kg/ha with full-sun coffee.

Pine trees are highly dependent on mycorrhiza. Mycorrhizal symbiosis with pine trees benefits coffee plants. Mycorrhizal fungi contribute to better absorption and assimilation of nutrients, favoring the protection and development of plants, stability and the formation of aggregates in the soil, pest control, and numerous other benefits (Osorio, 2003).

It has also been reported that within coffee agroecosystems, rainfall plays a very important role, as a result of raindrops passing through the tree canopy, enriching the solution that drips onto the soil. It has been reported that coffee plantations where guama, mahogany, ocote pine and eucalyptus are growing, attract the most rain, in the respective order listed. In terms of incorporation of nutrients when rainwater washes the fallen leaves, *Pinus oocarpa* contributes 26% of the kg/ha of the nutrients present in the soil through runoff as a result of rain, containing K (49%), Ca (8.7%), Mg (2.9%), nitrates (25.9%). The above varies depending on management of the coffee plantation's agroecosystem (Jaramillo-Robledo A, 2003).

4. Tree spacing and spatial positioning

Defining spacing is a complex task as it depends on the species of tree, the shape of the crown, the intensity of shade desired and how pruning is managed. Little research has been conducted on the subject and it is not possible to define the best spacing for different producing regions. However, some guidelines are available to enable the producer to determine the spacing and spatial arrangement best suited to them.

· **More trees** (and less space between them) are recommended when the coffee plantation needs more shade (50% to 70%) and less sunlight (30% to 50%), under the following conditions:

- High temperature in the environment and in the soil;
- Low relative humidity in the environment and the soil;
- More exposure to sunlight;
- Soils with low natural fertility;
- Lower height.

· **Fewer trees** (and more spacing) are recommended when the coffee plantation requires less shading (25% to 30%) and more light (70% to 75%), under the following conditions:

- Low temperature in the environment and in the soil;
- High relative humidity in the environment and the soil;
- Less exposure to sunlight;
- Soils with high natural fertility;
- Higher altitude.

> **Observation:**
> **If the days are often cloudy in the region in question, less shading (10% to 25%) and more sunlight (75% to 90%) is recommended, in combination with the above mentioned conditions.**

Therefore, spacing between trees depends on the species and level of shade desired, considering the region's climate (mainly the mean annual temperature). The higher the mean annual temperature, the more shade required and the closer the spacing should be. In the southern hemisphere, north-facing slopes require more shade, while south-facing ones require less. In plantations whose coffee trees are very close together in the rows, tree planting can be carried out with less intensity, due to self-shading by the coffee trees themselves.

Trees should be spatially arranged in squares or rectangles, but positioned in such a way that each plant in the line is not "in front" of a plant in the other line, which allows better shade distribution. The trees can be planted in the following places:

In different coffee rows for mechanized harvesting to be carried out on the entire plantation, with one line of trees planted for every 4, 6 or 8 coffee rows

In the same coffee rows in order for mechanized harvesting to be carried out on part of the plantation, with one line of trees planted for every 4, 6 or 8 coffee rows. In the lines where the trees are planted, harvesting should be manual or semi-mechanized (portable harvesting equipment).

Figure 7. Coffee plantations planted with *Platyciamus regnelli* trees at different times of the year in Machado - MG, Brazil: October to March (left) and May to August (right).

Source: Cassio Franco Moreira

Figure 8. Tree planting with *Toona ciliata* in new coffee plantation in Santo Antônio do Amparo - MG, Brazil.

Source: EPAMIG

Figure 9. Organic coffee plantation planted with *Grevillea robusta* trees in Andradas - MG, Brazil.

Source: Cassio Franco Moreira

Figure 10. Coffee plantation planted with different native tree species in Chapada Diamantina in Seabra - BA, Brazil.

Source: Fábio Martins Neto

Figure 11. Shaded organic coffee plantation with different tree species in Santo Antônio do Amparo - MG, Brazil.

Source: Caio Diniz

5. Tree management

Shade tree management (e.g. fertilization and pruning) must allow the trees to grow according to the desired characteristics required to achieve the degree of light distribution envisaged.

• **Fertilization:** The trees must be fertilized in the first two to three years with the recommended doses of nutrients. If this information is not available, use the same doses recommended for coffee trees.

• **Pruning:** The purpose of pruning is to maintain the uniform height of the trees. The best time to prune is at the end of autumn so the plantation is exposed to sunlight and productivity is increased. The more sunlight and ventilation there is in the coffee plantation, the greater the likelihood of avoiding conditions that encourage fungal diseases to develop.

◦ **Formation pruning:** should be done when the trees are young (under five years) in order to structure them so they form a single trunk, two to three meters high, above which the horizontal branches will grow.

◦ **Maintenance pruning:** should be done to allow sufficient sunlight to reach the coffee tree and be well distributed. This is achieved by pruning branches from the center of the crown of the tree, leaving the branches two to three meters above the coffee tree canopy.

◦ **Drastic pruning:** should be done on plots where the coffee plantation will be renewed. This pruning consists of cutting the main trunk of the tree to 4.5 m high to completely regenerate the tree while facilitating future management. This should be done after the coffee harvest.

When the phenological stages of the tree species coincide with those of the coffee tree, with a large number of leaves shed during the dry, cold periods of the year and faster growth in the hot, rainy season, the tree species and the coffee trees will likely compete with one another. Moreover, in the leaves that fall through natural senescence, many nutrients have already been redistributed to other plant organs, which results in low contents in the dry leaves.

Hence it is advisable to prune tree species which exhibit this behavior when the leaves are still green. This means that the nutrients present in the trees' leaves will be available when the coffee trees need them the most.

6. Adaptation of climatic conditions

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Processing

7.

Figure 1. Coffee processing unit. Source: Marcelo Viviani

To produce quality beans, the organic coffee producer should take great care when processing the fruits from the plantation as well as during the preparation, drying, storage and shipping stages.

A day's harvest will usually yield various qualities of coffee cherry. Coffee cherry is separated into lots, according to level of quality, during processing.

Organic certification does not guarantee the quality of the coffee. In other words, there is no sensory evaluation when certifying coffee as organic. Nevertheless, market experience shows that consumers interested in buying organic coffee also wish to consume a flavorful product produced through a process that preserves its sensory properties.

7.1. Processing, storage and transport

During the coffee processing, storage and transportation stages, measures must be taken to prevent the product from mixing with non-organic products or being contaminated by substances that are not permitted under organic production rules. Below are some of the practices recommended at each stage to ensure high quality organic coffee.

a. Preparation

Dry processing: After the harvest, the coffee is transported to the processing unit after the fruit has been washed and sorted and graded, based on density, size and ripeness. Two lots of coffee cherries are obtained: ripe/unripe cherries and floaters. After this step, the coffee lots are dried separately in drying grounds (patios) and/or mechanical dryers. This is the type of process in which the coffee cherries are dried whole, yielding what is known as natural coffee. Depending on the properties, it is quite usual to send the coffee straight to the drying patio, without washing it.

Wet processing: This primary processing method depulps (and demucilages) the ripe fruit after washing and sorting. Parchment coffees (honey or washed coffee) are obtained through this process. This type of primary processing allows for new possibilities in terms of quality and optimization in the use of patios and dryers, as it reduces the volume and time needed to complete drying. Wet processing requires proper treatment and disposal of waste products, as a certified production unit is not allowed to discharge wastewater directly into bodies of water.

In post-harvesting activities, the production unit must install systems that allow water and waste products to be used and recycled, thereby avoiding waste and chemical or biological environmental contamination.

Source: Normative Instruction (NI) No. 46/2011, amended by NI No. 17/2014, Art. 99

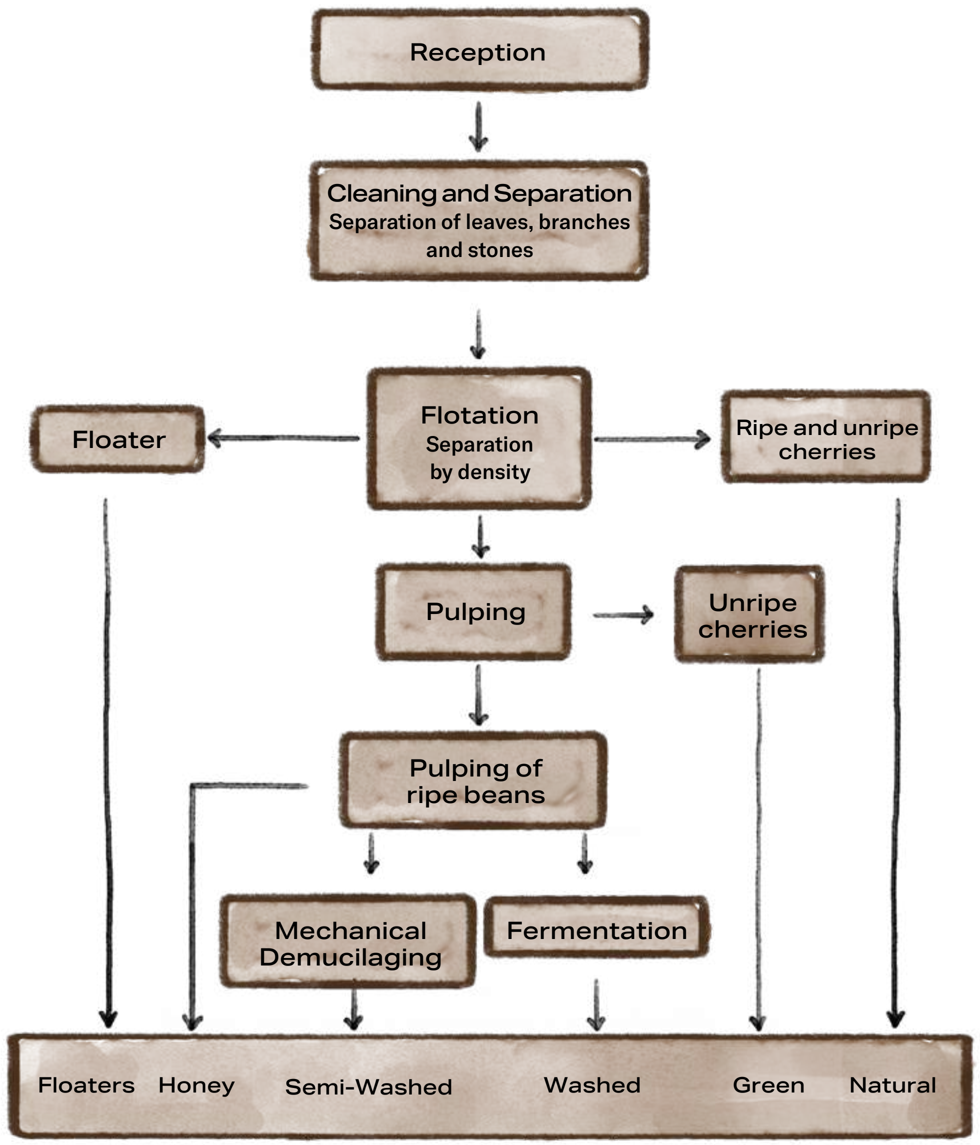

Figure 2. Coffee processing flow chart. Source: Marcelo Viviani

b. Drying

Once the coffee has been dry processed or wet processed, it must be dried (preferably in the sun) until the moisture content drops to 11%. Coffee is often pre-dried on patios, and the process completed in mechanical dryers.

Control records must be kept on the data obtained during drying: batch number, date/time drying started, volume/weight of batch before drying, volume/weight of batch after drying, etc.

The patio used for drying should preferably be cemented, for easier operation and cleaning. Drying can also be done in a solar tunnel dryer or using other methods. In addition, a mechanical dryer can be used to complete the drying that began on the patio.

Figure 3. Coffee drying patios.

Source: Marcelo Viviani

c. Processing

After drying and temporary storage, the coffee is sent to processing units with machinery that is owned or hired (mobile equipment).
Processing or hulling consists of removing the cherry husks and the parchment husks from the coffee, yielding the finished product called green coffee or hulled coffee, which is then packed and stored.

Figure 4. Coffee processing using mobile equipment. Source: Marcelo Viviani

d. Storage

At the end of the drying stage, coffee is stored at the production unit in warehouses. Natural coffees are stored with their hull intact for a minimum of 30 days and wet-processed or semi-processed coffees are stored with their parchment intact for a minimum of 10 days. After that the coffee is hulled and moved to a certified warehouse, as soon as possible.

In the warehouse, the coffee can be reprocessed, as described in Figure 5.

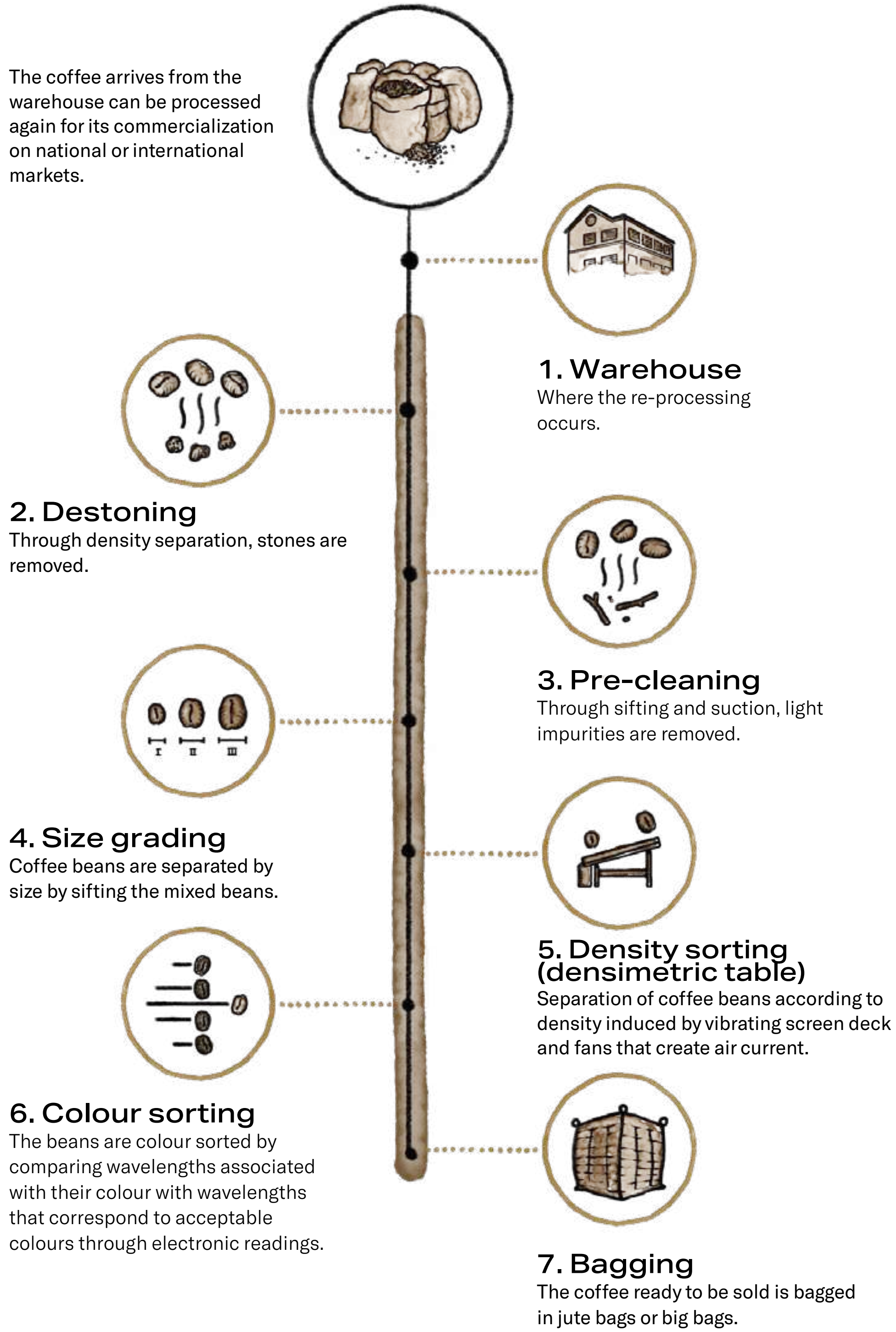

Figure 5. Coffee re-processing flow chart. Source: Marcelo Viviani

A certified warehouse must have:

- **Traceability of stored and processed lots;**
- **Compliance with environmental and labor legislation;**
- **Qualified workers involved in its operations;**
- **Physical identification of batches to prevent mixing.**

e. Transportation

During transportation (either from the plantation to the processing unit or from the unit to the warehouse), organic coffee must be properly packed and identified to ensure that it is kept separate from non-organic products.

On arrival, the warehouse must check the labeling of the coffee and the certificates and invoices accompanying the product. Bulk coffee shipments must be transported separately.

7.2. Traceability and labeling

During processing, important data on the coffee lots is generated and must be recorded to guarantee traceability. The data recorded must be filed and given to the certifier as supporting evidence demonstrating the product's organic quality.

The production unit must keep up-to-date records that describe how the quality of the organic products was maintained during processing and which guarantee the traceability of the ingredients, raw materials, packaging and finished product.

Source: Joint Normative Instruction (NI) MAPA/MS No. 18/2009, Art. 3, Sole paragraph.

A traceability system is a set of procedures and registers which records all coffee production information. This information covers everything from the production inputs used as well as harvesting, processing, and storage leading up to commercialization.

Traceability is an identification system that enables the origin and history of the product to be traced back to each stage of the production process, from production to consumption.

Source: Pereira (2013)

Figure 6. Coffee stored in labeled bags.

The labels on organic products must contain specific information in accordance with the rules of each consumer market. The bags used to store and ship the organic coffee must be properly labeled. The minimum information required by the Brazilian, EU, US and Japanese rules is as follows:

NAME OR COMPANY NAME

OFICIAL REGISTRATION NUMBER

ADDRESS

ORGANIC COFFEE

CERTIFIED ORGANIC BY (NAME OF CERTIFIER)

COUNTRY CODE-BIO-(CODE NUMBER OF CERTIFIER)

BATCH NUMBER

In the case of products for export only, where compliance with the importing country's requirements involves the use of products or processes prohibited under Brazilian regulations, for example, the labels must contain the following notice: "PRODUCT FOR EXPORT ONLY".

Source: Normative Instruction No. 19/2009, Art. 121

Observations:

Use of EU and US seals is optional for products not intended for the end consumer, as is the case of green coffee beans. The Japanese seal must contain the name of the certifier and the certification number.

7.3. Separation and hygiene procedures

Parallel processing of organic and conventional coffee in the same facilities is allowed under organic production rules, provided there is adequate separation (either physical or temporal) at all stages of the production process.

Ensuring that organic and conventional coffees are not mixed together is a task that calls for the commitment and responsibility of everyone involved in the supply chain.

This means that the equipment and facilities used during processing, such as the washing station, drying grounds, mechanical dryers and warehouses, can be used exclusively for organic coffee (physical separation) or can be used for organic coffee at different times to its use for processing conventional coffee (temporal separation). Organic coffee must be stored in separate areas and identified. This can be done in the same facilities but always in exclusive lots.

Organic products must be processed separately to non-organic ones, in areas that are physically separated or, if in the same area, at different times.

During storage and transport, organic products must be properly packed and identified, guaranteeing their separation from non-organic products.

Source: Normative Instruction (NI) MAPA/MS No. 18/2009, Art. 5 and Art. 18

The equipment and facilities used in the processing of organic coffee must be free from residues of non-organic products. This means that physical methods (e.g. sweeping, compressed air) and/or permitted sanitization products for use in processing of organic products must be used. In the case of equipment that cannot be fully sanitized, an initial amount of organic coffee sufficient to avoid any risk of contamination (for example, one 60 kg bag of green coffee) can be discarded and sold as conventional coffee.

During the processing, storage and shipping of organic products, only legally authorized sanitization products can be used to clean the equipment and facilities.

Figure 7. Sanitization of electronic sorters using compressed air.

Source: Caio Diniz

7.4. Pest control

It is well-known that coffee can be infested by pests, mainly insects, while in storage. This is especially so when coffee is stored with its husk for a long period of time. Rodents are also common pests in coffee warehouses and must therefore be controlled.

Table 1. Main insects infesting stored coffee.

Common name	Scientific name	How to identify pests
Moths	*Corcyra cephalonica*	Presence of small caterpillars, excrement and silk webbing spun by moths among coffee cherries, in addition to the presence of small moths that fly at night.
Beetles	*Lasioderma serricorne* and *Tribolium castaneum*	Usually reddish brown.
Coffee bean weevil	*Araecerus fasciculatus*	The adults have a globular body, their color ranges from brown to dark grey, and their body is covered with shiny hair.
Coffee berry borer	*Hypothenemus hampei*	Small beetle that attacks coffee cherries in the field and can continue to infest stored coffee, especially if the drying is finalized with over 12% humidity.

Source: Souza & Reis (2004)

In physical areas[29] for processing, storing and transporting organic products, in addition to complying with the specific legislation, the following pest control measures must be adopted, preferably in this order:

I – eliminate pest harborage and access by pests to facilities, using suitable equipment and facilities;

II – mechanical, physical and biological methods, with the following description:
a) sound;
b) ultrasound;
c) light;
d) plant-based repellents;
e) traps (pheromone, mechanical, color); and
f) mouse traps;

III – use of substances permitted under organic agriculture regulations[30].

Synthetic chemicals are banned from use in areas used for processing, storing and shipping organic products.

Source: Normative Instruction (NI) MAPA/MS No. 18/2009, Art.20 and Art. 21

[29]These requisites only apply to the internal areas of facilities used to process, store and ship organic products.
[30]For example, the use of natural neem oil insecticide (azadirachtin) is allowed.

Figure 8. Mouse trap with glue board plate on internal area of warehouse. Source: Caio Diniz

7. Processing

References:

BRASIL. Lei nº 10.831, December 23, 2003. Dispõe sobre a agricultura orgânica e dá outras providências [Law No. 10,832, dated December 23, 2003, on organic agriculture and other provisions] **Diário Oficial da União**, Brasilia, 24 Dec. 2003. Section 1, p. 8.

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Certification

8.

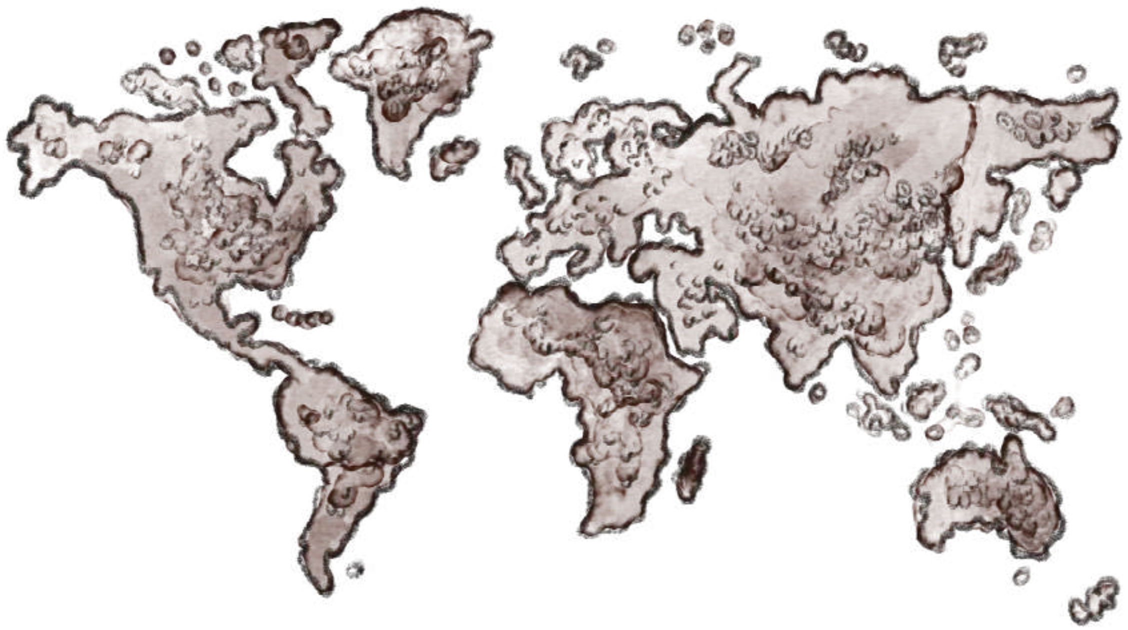
To market coffee as organic, producers are required to obtain product certification in the destination market. It is interesting that coffee is certified under the organic production rules of certain countries or commercial blocks in addition to its country of origin, which expands sales options on the international market.

Organic certification is the means by which an officially recognized certification body evaluates compliance with organic regulations and guarantees in writing that the production or a clearly identified process was methodically assessed and meets the organic production rules in force

Source: Decree No. 6,323/2007, Art. 2

8.1. Organic regulations

Depending on the destination market, specific legislation regulating organic production must be met. The European Union was a pioneer in regulating the sector in 1991, followed by Japan in 2000 and the United States in 2002. Currently, organic production is regulated in over 80 countries, without counting the long-standing private regulations which tend to be more stringent (e.g. Demeter, Soil Association, Bio Suisse, Naturland, Krav).



Some of the principal organic coffee consumer markets and their respective rules are:

- European Union[31]: Commission Regulations (EC) No 834/2007 and No. 889/2008
  - https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/legislation_en
- United States: National Organic Program (NOP)
  - https://www.ams.usda.gov/rules-regulations/organic
- Japan: Japanese Agricultural Standard (JAS) for Organic Foods
  - http://www.maff.go.jp/e/policies/standard/jas/specific/organic.html
- Brazil: Law No. 1,831/2003, Decree No. 6,323/2007 and Normative Instructions (NI)
  - https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/organicos/legislacao-organicos

Equivalency arrangements

Some countries or commercial blocks have some bilateral equivalency arrangements for their regulations such as the United States, Canada, Japan and the European Union.

Such arrangements apply to organic products from those countries. In other words, they do not apply to organic coffee produced in Brazil, Mexico, Peru or Colombia. Only in the case of the equivalency agreement between the United States and Canada, is it possible to obtain certification in accordance with the US regulation and ask the certifier to validate the equivalency with the Canadian regulation.

[31]In non-EU countries, for the purpose of equivalence under the terms of No. 3, Art. 33 of Commission Regulation (EC) No. 834/2007, compliance with the rules of the appropriate recognized certifier is necessary.

8.2. General requirements[32]

Many of the requisites are common among the main organic regulations, as the regulating of organic agriculture in different countries was drawn from the basic standards of IFOAM and the CAC/GL 32 *Codex Alimentarius* guidelines, in addition to existing private regulations. Some of the common requisites[33] of the main organic production regulations are listed below.

a. Documentation and records

The organic production unit must keep documents and records on all the operations involved in production. In particular, detailed and up-to-date records of all inputs and management practices used in the organic production system must be kept, as well as records of processing, storage and commercialization activities. Invoices for materials purchased and organic products sold must also be kept. All documents and records must be kept for at least five years and, if requested, must be submitted to the certifier or competent authority.

Records of materials and management practices must contain, as a minimum, the following information: date, type, quantity, plot and justification.

Records on the purchase of materials or sale of products must contain: date, type, amount of material purchased, or product sold.

References:

- European Union: 889/2008, Art 66 and Art 72.
- United States: §205.103.
- Japan: Notification No. 1830, II. 3.
- Brazil: NI 46/2011 + NI 17/2014, Art. 7º and Art. 105; NI 19/2009, Art. 41.

[32]Specific requirements for plant production and processing are described in other modules of this manual.

[33]The specific requirements of each regulation will not be covered in this manual.

b. Organic management plan

Under organic regulations, producers must write a full description of the activities carried out in their production unit. The name of this document can vary, according to its origin, but it is usually called the Organic Management Plan (OMP) and it must include the information required by the appropriate regulation in order to be approved by the certifier.

References:

- European Union: 889/2008, Art 63 and Art 70.
- United States: §205.201.
- Japan: Notification No. 1830, II.
- Brazil: NI 46/2011 + NI 17/2014, Art. 8º and Art. 9º.

Generally speaking, certifiers provide an OMP template to be filled out by the producer.

c. Measures to prevent contamination

The producer must adopt measures to prevent organic products being contaminated by banned substances applied in neighboring areas which are not under organic management. Such measures include setting up perennial plant barriers (e.g. *Pennisetum purpureum*, plantain or banana, *Mimosa caesalpiniaefolia*, *Syzygium cumini*, etc.) bordering conventional cultivation areas. Where it is not possible to plant barriers (or while they are growing), a buffer zone must be maintained in the organic coffee area adjacent to its border, and the product harvested in this zone kept separate and sold as conventional.

References:

- European Union: 889/2008, Art 63.
- United States: §205.202.
- Japan: Notification No. 1605, Art 4.
- Brazil: NI 46/2011 + NI 17/2014, Art. 8.

Important:

To allow the plant barrier to fulfil its purpose, the producer must plant the right height of perennial species, with correct spacing and organic management, in keeping with the recommendations (e.g. fertilization, weeding, etc.) taking into account a contamination risk analysis of their plantations.

Figure 1. Plant barrier on border between organic coffee and conventional farming area.

Source: Caio Diniz

d. Conversion period

For a product to be considered organic, the requisites of the regulation(s) must be met in the respective area or plot during a conversion period. In other words, the conversion period is the minimum time between the last application of prohibited substances in a given area or plot and the first harvest of coffee as organic, during which time the producer complies with the regulation(s) but the product harvested there is not yet considered organic.

References:

- European Union: 889/2008, Art 36.
- United States: §205.202.
- Japan: Notification No. 1605, Art 4.
- Brasil: NI 46/2011 + NI 17/2014, Art. 10, Art. 11, Art. 12 and Art. 14.

In the case of perennial crops such as coffee, the conversion period lasts at least 36 months, depending on the relevant international regulations.

Important:

If the producer needs to apply any banned substance, the certifier must be informed in advance and, subject to authorization, the respective area or plot will have to comply with the conversion period. In the event of the intentional application of a banned substance without prior authorization from the certifier, the producer (or group of producers) will be subject to sanctions such as the loss of certification.

e. Parallel production[34]

Parallel production of organic and conventional coffee in the same production unit is only allowed if carried out in different, demarcated areas, for a maximum of five years, and if it is authorized by the certifier in accordance with certain criteria. The equipment and tools used in conventional production must be cleaned in order to be used in organic production, except for sprays which must be used exclusively for organic management. Moreover, banned inputs cannot be stored in the organic production unit.

References:

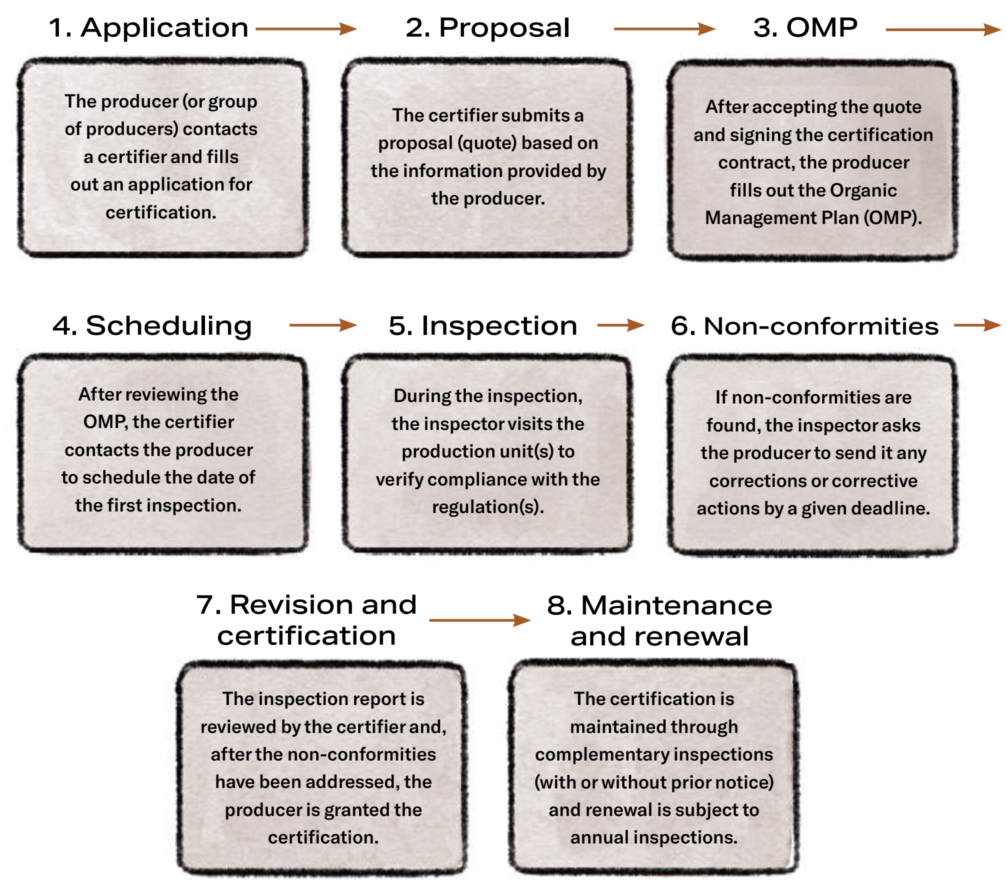
- European Union: 889/2008, Art 40.
- United States: Not applicable.
- Japan: Not applicable.
- Brasil: NI 46/2011 + NI 17/2014, Art. 16, Art. 17, Art. 18, Art. 19.

Producers must prepare a conversion plan which outlines how they will convert the coffee plantations of their production unit to organic management within a five-year period.

[34]The production will not be considered parallel if the organic production unit is managed by a producer (or team) other than the non-organic production unit, and these units are located in different, demarcated and legally separate areas.

8.3. Certification process

Certification of organic coffee is carried out by accredited certifiers in the scopes of plant production and/or processing, either individually or as a group. The process of conformity assessment is defined by the procedures of each certifier which, in turn, is based on ISO/IEC 17065 and the respective organic production regulations. The certification process usually follows the steps listed below. It takes around 90 days from application to granting a first certification:



8. Certification

References:

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