SUSTAINABLE PRODUCTION

GUIDE

COLEAD

GREEN BEAN (*PHASEOLUS VULGARIS*)

Funded by the European Union

COLEAD

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DIAGRAM OF THE PRODUCTION PROCESS

STAGES	INPUTS OF THE GUIDE	
AWARENESS OF THE CHARACTERISTICS OF THE PLANT AND ITS DEVELOPMENT CYCLE	Description of the plant	
	Bean classification	
	Crop cycle	
AWARENESS OF THE CROP NEEDS	Climate	Temperature, humidity, wind, light, rain
	Water	Quantity and quality
	Soil	Texture, structure, depth, pH, salinity, toxic elements, moisture, organic matter
	Nutrition	Mineral manure
PRIOR CHOICES	Plot selection	Soil type, topography, location, preceding crop
	Plant material	
	Growing period	
	Planting method	
	Irrigation	Source, pumping, water storage and irrigation
	Intercropping and other associations	
	Rotations	
PREPARING THE PLOT	Landscaping	
	Weed management	
	Amendments	
	Tilling	
	Specific structures	
PLANTING THE CROP	Period	
	Method	
	Seed requirements	
MAINTAINING THE CROP	Water management	Irrigation and drainage
	Tilling	
	Weed management	
	Plant cover	
	Fertilisation	
	Pollination	
	Post-harvest waste management	

MANAGING PESTS	Conditions conducive to infestation
	Identification and monitoring
	Use and promotion of natural enemies
	Adapted agricultural practices
	Rational use of PPPs
		For each pest
		• Scientific name
		• Life cycle
		• Description/identification
		  • Other host plants
		  • Description of the pest organism
		  • Affected crop stages
		  • Symptoms and damage
		  • Impact on yield and quality
		• Quarantine organism
		• Conditions conducive to infestation
		• Monitoring
		• Control through good agricultural practices
		• Organic control
		• Control using Plant Protection Products
		• Other control methods

HARVESTING	Commercial quality; harvesting period and method; workforce	
MANAGING THE POST-HARVEST BEFORE PROCESSING	Field operations and transport	

1

INTRODUCTION TO THE CROP

1.1. DESCRIPTION OF THE PLANT

The green bean (or mangetout bean) is an annual dicotyledonous plant, *Phaseolus vulgaris*, native to South America and belonging to the botanical family *O. phaseoli* (legume or papilionaceae). The consumed part is the fruit (pod) at a non-ripe stage.

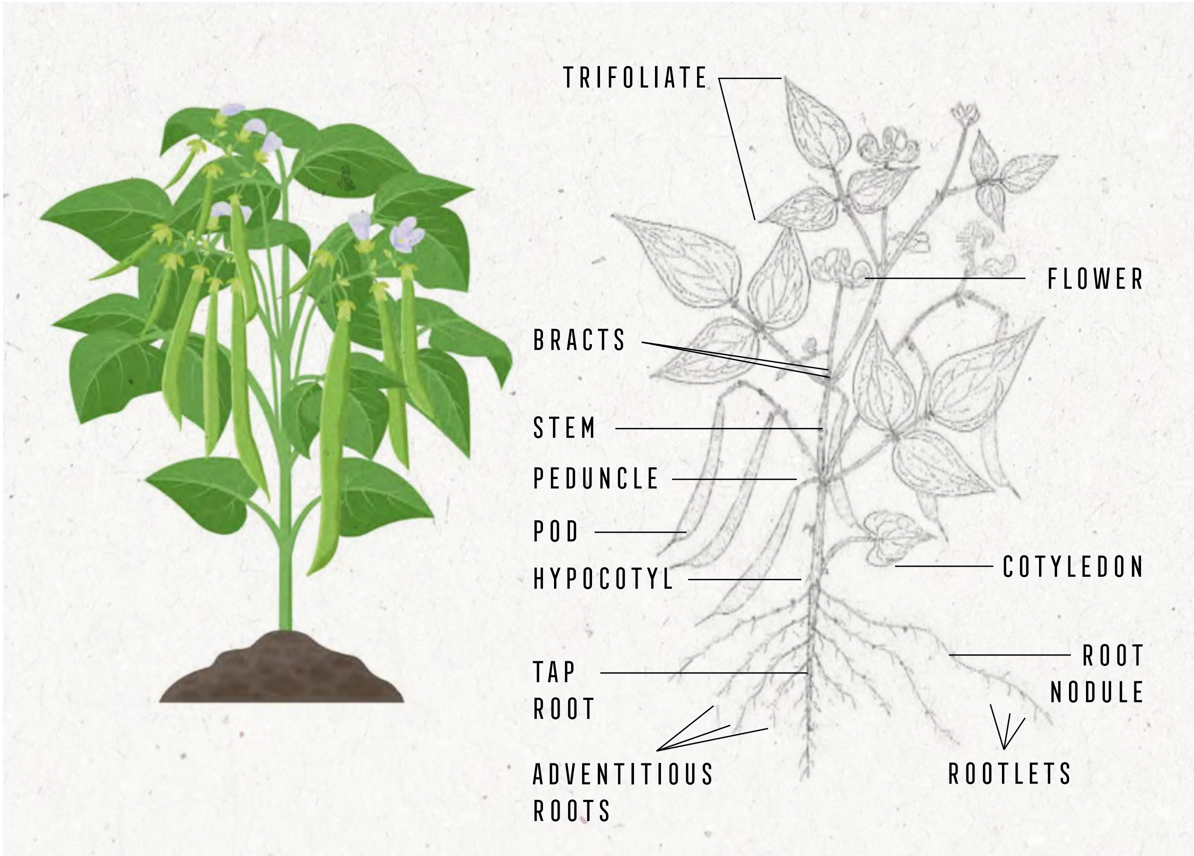


Figure 1 — Diagram of a dwarf green bean plant
http://34.250.91.188:8080/xmlui/handle/123456789/665

ROOT SYSTEM

The main root, a pivot root reaching 40 to 80 cm at maturity, is well developed, with numerous lateral and adventitious roots ranging from 20 to 40 cm. The root system stops growing when the plants reach the flowering and pod formation stage. Nodules (not to be confused with root-knot nematodes) containing nitrogen-fixing *Rhizobium* bacteria develop on the roots in the first weeks of growth.

FOLIAGE

The leaves are alternate and trifoliate, after the first which is simple; the stipules are triangular and small; the leaflets are oval, the basal leaves are asymmetric, the apical leaves are symmetric, whole, slightly pubescent, and three-ribbed from the base.

INFLORESCENCE

It consists of axillary or terminal racemes.

The bisexual flowers are papilionaceous with a pedicel up to 1 cm long, fine, with oval bracteoles; the calyx is campanulate with a tube about 3 mm long, triangular lobes, 2-3 mm long; the corolla is white to pale purple or red-violet. The flowers of the lower part develop first, followed by those of the middle part and those of the upper part.

FRUIT

The fruit is a linear green pod 12 to 16 cm long, with a diameter of 4 to 8 mm depending on the varieties, straight or more often curved with a prominent beak, fleshy, with seeds in the immature state.

1.2. CLASSIFICATION OF THE BEANS

The classification of bean types is based on the following elements.

THE GROWING METHOD

Based on botanical characteristics, beans are classified into groups according to shape, growth parameters, number of nodes after flowering, height and shape of the plant:

- determinate short plant;
- indeterminate short plant;
- indeterminate decumbent plant;
- indeterminate climbing plant.

The dwarf bean has a determinate growth, with short internodes. It reaches 40 to 60 cm in height. It is more or less erect and bushy, slightly pubescent.

THE STRUCTURE OF THE POD

It depends on the presence or not of 2 fibrous elements of the pod, the filament and the string. The filament consists of a cord of longitudinal fibres forming in the area of the conducting bundles on the underside and on the back. The string consists of 3 to 4 oblique sclerosing blades lining the inner face of each pod valve. The filament and string appear and develop at a more or less advanced stage of pod development, depending on the varietal type.

These 2 elements of the pod structure are involved in the dehiscence mechanism of fully mature pods.

THE COLOUR OF THE POD

The colour of the pod is either green (of different shades) or yellow (wax beans). There are also varieties with purple, variegated or marbled red pods.

THE SHAPE OF THE POD

It can be flat (runner beans), with a cylindrical or oval section.

THE COLOUR OF THE SEEDS

White, black, brown, variegated, etc.

This makes it possible to identify different types of beans.

— French bean: pods with filament and string, can be eaten fresh but only at a young, immature stage.

— Mangetout (or bobby) bean: pods without filament and with a reduced string that can be consumed at a more advanced stage corresponding to the beginning of seed development.

— Shelling bean: pods with filament and string that can only be consumed as seed. Pods of different colours with dry mature seeds.

Table 1 — Bean classification

CHARACTERISTICS	VARIETAL TYPE	POD
FILAMENT AND STRING	Classic French filet bean	green, sometimes purple variegated
	Shelling bean	flat
NO FILAMENT AND REDUCED STRING	French mangetout bean (or false French filet or French filet without filament) Flat butter bean	classic French filet type but lighter in colour

1.3. CROP CYCLE

The length of time between sowing and flowering or harvesting varies greatly depending on the variety, season or production area.

Thanks to the different altitudes and seasons of the production areas in Kenya, green beans are produced all year round. On the other hand, in West Africa (Senegal, Burkina), and particularly in Senegal, its production takes place during the cold counter-season (mid-November to early March in Senegal / December to February in Burkina). The mild climate that prevails at this time in Senegal is marked by sea trade winds from St. Helena, with temperatures around 25-30°C and good relative air humidity.

Young pods from flowering can be harvested 15-20 days after setting.

Harvesting takes place 48 to 55 days after planting in Senegal, while, in Kenya, because of the possibility of producing at different altitudes, harvesting takes place from:

- planting + 60 days at 1,500 m for fine green beans;
- planting + 40 days at 1,500 m for extra fine green beans;
- planting + 80 days at 2,000 m.

The length of the harvesting period depends on the production area, the variety and the type of bean (fine or extra fine). The harvesting period can last from 10-15 days to 20-30 days for bush and climbing cultivars, respectively. Harvesting immature pods induces prolonged flowering.

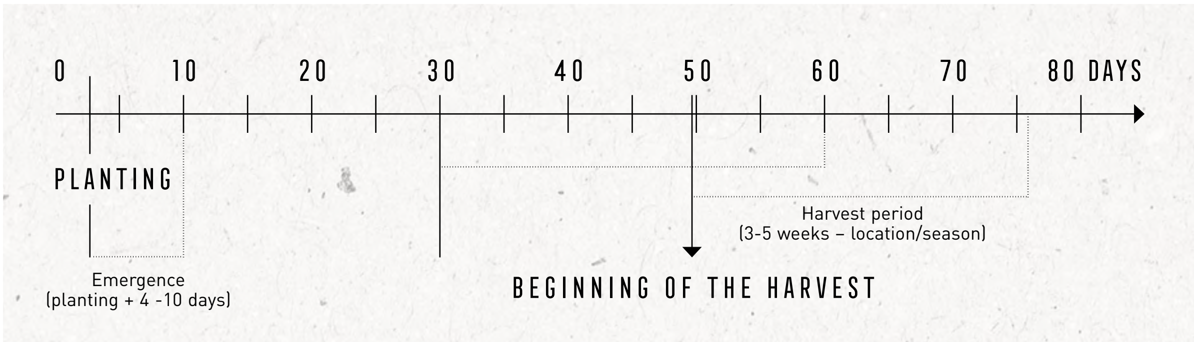


Figure 2 — COLEAD, 2012. Green bean crop protocol. Crop cycle of the dwarf green bean

For an international harmonisation of the characterisation of phenological stages defining the evolutionary phases of the bean cycle, we refer to the BBCH scale.

Figure 3 — Syngenta (2015). Illustration of the BBCH scale for beans.
https://www.syngenta.fr/agriculture-durable/reglementation/dossier-bbch/article/echelle-bbch-haricot

The BBCH makes it possible to define a scale of universal markers corresponding to the phenological development stages of the plant. It makes it possible to plan the crop treatment or management stages in line with a scale of internationally recognised benchmarks. This two-digit scale is based on certain basic principles. The main stages described on a scale from 0 to 9 are supplemented by secondary stages from 0 to 9 within a main stage (See Appendix 1).

2

CROP NEEDS

Green beans have several needs to secure their proper development and optimal production. These include needs related to climate, water, soil and nutrition.

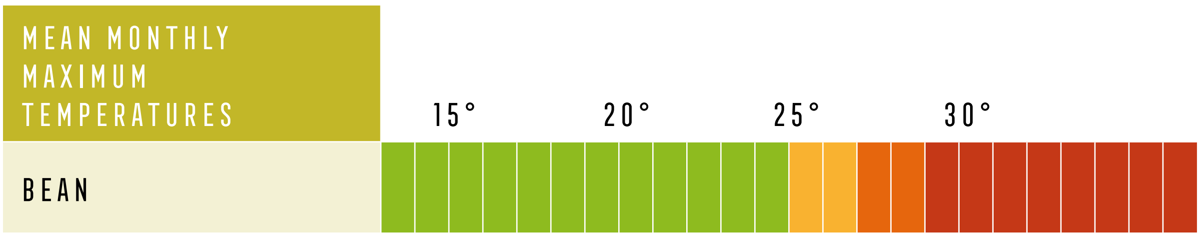
2.1. CLIMATE

The climatic factors favourable to the cultivation of green beans must match the needs to ensure an optimal production cycle. The climatic elements that influence bean production are: temperature, light, wind, rain, air humidity and soil moisture.

2.1.1. AIR TEMPERATURE

Air temperature plays a very important role in the different phases of crop development. It can either be conducive to optimal growth, or otherwise hamper or stop crop development. This explains why it is not advisable to grow green beans in areas exceeding maximum monthly average temperatures of 30°C during the main phases of the production cycle. Green beans cannot withstand temperatures below 10°C, and certainly not frost.

Table 2 — Ease of growing green beans as a function of temperature



Easy to grow

Less easy to grow

Delicate or difficult to grow (requiring the use of particular varieties and/or growing techniques)

Very difficult or impossible to grow (requiring the use of particular varieties and/or growing techniques)

The optimal temperatures for each stage of the crop cycle are as follows.

TEMPERATURE DURING GERMINATION

— optimum between 20°C and 25°C;
— between 25°C and 35°C, it is hampered;
— above 35°C, it stops.

TEMPERATURE DURING VEGETATIVE DEVELOPMENT

— optimum between 15°C and 25°C;
— above 25°C, it is hampered.

TEMPERATURE DURING FLOWERING

- optimum between 15°C and 25°C;
- above 30°C, the bean is subject to flower dropping and abortions.

TEMPERATURE DURING FRUITING

- optimum between 15°C and 30°C;
- above 30°C:
    - on the French bean, early formation of filament and string
    - on the mangetout bean, fall of young pods, early appearance of the seed, loss of quality, disruption of harvest planning.

2.1.2. RELATIVE HUMIDITY

The relative humidity of the air, and that of the soil, can affect the production conditions, resulting in physiological stresses and the development of certain diseases.

- If too high (>90% up to 100% or dew), the conditions are favourable to the transmission and development of certain diseases in relation to a temperature range:
    - rust (16°C to 25°C and 10 to 18 h of humectation);
    - fat (16°C to 24°C/25°C): *Pseudomonas* under conditions of saturated humidity (do not cross wet fields to avoid its spread).
- Air humidity has an influence on the effectiveness of the treatment of certain diseases (micronised sulphur against mites, the higher it is, the more effective the product).

2.1.3. WIND

Beans are an extremely wind-sensitive crop.

Mechanical damage caused by friction of vegetative organs on pods results in a drop in quality, is a gateway to disease, or causes damaged foliage that affects photosynthesis.

If the wind is hot and if it carries salt spray, there is a resulting drop in yield.

Wind also negatively impacts the commercial quality of production. Growing pods are very sensitive to wind. Under its effect, they become curved and hooked and are sorted into another category, as they no longer meet the commercial qualities defined by importers and distributors. Hence a loss of marketable products and income.

However, a good aeration of the field with the right sowing density and the installation of windbreaks, moderate and controlled ventilation are necessary for the proper development of the green bean. They help to avoid humidity conditions favourable to certain diseases, and mechanical damage affecting flowering and the commercial quality of the pods.

2.1.4. LIGHT

As a general rule, vegetable crops, including green beans, are crops that prefer direct sunlight.

Insufficient illuminance, linked to excessive shade or inadequate sowing density, is a condition that favours sub-optimal development of the crop.

The bean has significant needs in terms of light, to ensure better photosynthesis, to avoid the etiolation of plants and the proliferation of certain pests, such as the leaf miner fly, which abounds in shaded areas. Hence the need to avoid sowing under the foliage of trees.

Day length has no significant impact on the cultivation of green beans.

2.1.5. RAIN

In East Africa, in Kenya, rain and temperatures at different altitudes allow bean production throughout the year. Moderate and well-spread rains offer favourable conditions for growing green beans.

Generally, in sub-Saharan Africa, green beans are produced during the non-rainy season, particularly during the cold counter-season, when temperatures are favourable. The production season is characterised by the absence of rain, but the use of irrigation to meet the water needs of crops is necessary.

Heavy rains (irrigation by sprinkling, which can be likened to rain) promote the spread of several fungal and bacterial diseases.

2.2. WATER

This is a very important limiting factor for the production of green beans, especially in West Africa, in the Sudano-Sahelian zone. This makes it necessary to irrigate green beans grown during the off-season. In East Africa (Kenya) the crop adapts thanks to the spread of the rainy season and to the different climatic conditions at different altitudes and in different areas of the country.

The amount of water and the frequency of irrigation are variable depending on the type of soil (sandy, clayey, loamy, etc.), the stage of bean development and the climatic conditions of the production area.

Frequently, the tendency of fruit and vegetable growers is to overwater the beans, resulting in a waste of water and a significant development of several diseases.

2.2.1. QUANTITATIVE NEEDS

Green bean production requires significant amounts of water.

The water requirements of green beans stand at between 3,000 and 8,000 m^3 per real ha of crop, depending on the type of soil (clayey, clayey-loamy, sandy). The irrigation system has strong influence on water consumption. From the point of view of natural resource management, the most efficient irrigation systems (i.e. drip) allow for lower water consumption, offer an opportunity to extend the planted areas and lighten the crop management load.

If the crop is irrigated, water should be supplied at a regular interval.

From the emergence stage, it is essential that the plant is never subjected to water stress. The emergence and flowering/pod formation stages are particularly sensitive.

2.2.2. WATER QUALITY

The irrigation water must be of good quality.

SALINITY

Fruit and vegetable crops react differently to the presence of salts in irrigation water or in the soil.

Green bean crops are very sensitive to salt, especially in the germination and emergence phase. Salinity disrupts the plant's capacity to absorb nutrients and water. On the other hand, salinity promotes diseases such as *Rhizoctonia solani* and *Fusarium* and causes yield losses.

Water salinity poses serious problems in several production regions, particularly those close to the sea coast.

It is possible to detect a problem with water or soil salinity when, despite applying the necessary watering doses and compliance with other growing techniques, the plants struggle to grow, are stunted, wilt, show leaf burns, produce little and, ultimately, give only small pods.

In case of doubt about the quality of irrigation water with regard to the presence of salts, the water must be analysed (i.e. electrical conductivity measurement). This is done by taking a representative sample of irrigation water in a very clean container (bottle) that has been thoroughly washed with fresh water and dried before use.

If the salinity of the water is due to the presence of sodium salts, there is a risk of soil permeability problems, especially in heavier soils. Applying an input of phosphogypsum (15 to 20 tonnes/ha) or calcium thiosulfate may improve the situation because they encourage leaching and the replacement of undesirable salts (i.e. excessive Na).

If a slight salinity problem is detected in the irrigation water, the following practices are recommended:

— Ensure copious pre-irrigation of the soil before planting;
— Water more often in small doses and increase the total irrigation dose without suffocating the roots;
— Prevent water evaporation through hoeing, mulching, windbreaks, etc.;
— Improve soil water retention by adding organic matter;
— Choose a more suitable irrigation system such as spraying or drip irrigation (ensuring regular irrigation) instead of furrow irrigation;
— Ensure effective leaching of the plot (rain, watering with fresh water);
— As far as possible, mix slightly salted water with fresh water (storage of rainwater from wintering);

OTHER QUALITY CRITERIA

Water should have a moderate Ca, Fe, Cl content (beans are very sensitive to the presence of chlorine). Running water through a storage or transit basin will make it possible to obtain water at ambient temperature that is dechlorinated when using treated water in urban areas (*e.g.* the case in some parts of the Niayes region in Senegal).

From a crop protection point of view, the most reliable water is groundwater, provided that there is no pollution by infiltration or runoff. Surface water can be contaminated with bacterial or fungal germs that can cause plant disease and crop contamination.

2.3. SOIL

Certain soil (edaphic) conditions must be met to obtain a good yield.

2.3.1. TEXTURE

Soil texture depends on the size distribution of minerals in the soil, regardless of the nature and composition of these minerals. It interacts on the retention or permeability of fluids in a soil. Soil texture has a strong impact on the retention, distribution and circulation of water, air and nutrients. It therefore has consequences for water management and fertilisation.

The green bean adapts to a wide variety of soil textures. It can yield good economic results but prefers fertile soils with a good percentage of clay and organic matter. It also thrives in sandy-clayey and loamy-sandy soils.

The main effects of soil texture on green bean production conditions are given below.

CLAYEY TEXTURE

- Due to its low permeability, this type of so-called heavy soil leads to an excess of moisture, triggering the development of diseases and reducing the resistance of plants.
- On the other hand, it hampers the development of nematodes or other parasites by limiting their movement.
- *Fusarium* are also disadvantaged in these soils because of the abundance of antagonists.
- It facilitates the fixing of mineral nutrients in the soil with less loss through leaching or percolation.

LOAMY TEXTURE

- A dominantly loamy, sealed and suffocating soil is very unfavourable for germination (lack of oxygen) and emergence. Moreover, although rich in nutrients, the availability of the latter can be compromised by different types of blockages, as the compaction prevents the circulation of fluids.

SANDY TEXTURE

- It is very favourable to the proliferation of nematodes and *Fusarium*; and also to the loss of nutrients, through rainwater, irrigation via percolation and leaching.

CLAYEY-SANDY TEXTURE

- It is often characterised by risks of contamination by *Rhizoctonia*.

2.3.2. STRUCTURE

The bean calls for a soil with a homogeneous, stable and unblown (soil without troughs) structure which must allow rapid seepage; excess water leads to the risks of root and neck rot, as well as asphyxiation during germination.

The presence of salts in the soil can lead to the destruction of the soil structure, even when aerated and sufficiently drained.

2.3.3. DEPTH

The depth of the soil must be sufficient (40 to 50 cm) to allow good rooting and storage of soil fluids (water and air), and the mobilisation of the stock of mineral elements that are available and necessary for the plant's development.

2.3.4. PH

Beans are sensitive to soil acidity. The acidity of a soil, which has an action on the plant and the assimilation of nutrients, is expressed by the pH.

The optimum pH (H_2O) is between 6.0 and 7.5.

— If pH < 6.0: bean cultivation is not recommended because it induces a sharp drop in yield. It is possible to improve acidic soils by applying a limestone amendment, or by adding lime (magnesian lime, agricultural lime, dolomite). This is referred to as liming.
— If pH > 7.5: there is a slow downturn in yield as alkalinity increases. It is suggested that acidifying fertilisers are used and that composted organic matter are incorporated to buffer the pH.

2.3.5. SALINITY

The green bean is sensitive to salinity in the soil. It is already sensitive from a conductivity of 1 ms/cm, from which point it suffers a drop in yield.

Salty soils and saline waters must be avoided at all cost. This can be done by splitting up applications of fertiliser on soils with low cationic exchange capacity (CEC) to avoid excess salts.

If there is only a slight soil salinity problem, it can be remedied by following the following:

— do not use fertilisers that contribute to soil salinity (*e.g.* potassium chloride, ammonia nitrate);
— avoid excessive doses of fertiliser, as well as an excessively-localised addition of inputs on the planting strips and around the feet of the plants;
— ensure effective leaching of salts from the soil with fresh water (rains, copious irrigation leaching with unsalted water);
— use organic matter that is properly decomposed and not too fresh.

2.3.6. TOXIC ELEMENTS

An excess of boron or aluminium in the soil is harmful to bean cultivation.

2.3.7. SOIL HUMIDITY

If too strong, it becomes a factor conducive to some soil borne diseases, root and neck rot. The production plot must not be subject to flooding or submersion, hence special attention should be paid to very clayey or loamy-clayey soils.

2.3.8. ORGANIC MATTER

In addition to the various nutrients (major and minor elements) it supplies, organic matter plays a very important role in improving soil structure and its ability to retain irrigation water and mineral fertilisers.

An ideal organic matter content is around 3-6% in mineral soil, although there is no absolute rule. A sandy soil will have a lower rate, between 3-4%, while a clayey soil can maintain a higher percentage of around 5 to 6%. Organic matter must “turn”, that is to say, be created and then decompose to play its role. (Fédération québécoise des producteurs de fruits et légumes de transformation, 2018).

2.4. NUTRITION

During its production cycle, bean nutrition is ensured by the fertility of the soil and the fertilisation carried out in order to restore the lost elements with major (kg/ha) and micro crop elements.

Table 3 — Average green bean losses

NUTRIENTS	NITROGEN (N)	PHOSPHORUS (P_2O_5)	POTASSIUM (K_2O)	CALCIUM (CaO)	MAGNESIUM (MgO)
QUANTITY IN KG/HA	50-100	50 to 100	100-200	130	10-30

Source: La culture du haricot nain au Sénégal. RADHORT. (2012).

The following points must be taken into consideration.

- Because the crop has a short-cycle, green beans need nutrient inputs in an easily assimilable form.
- The green bean can develop nitrogen fixing nodules (not to be confused with root knots due to nematodes) which is a useful input, but does not replace nitrogen mineral fertilisation.
- Mineral nutrients need to be added by calculating the nutrient losses of the bean crop and analysing the soil reserves. These provide us with information about the crop's needs in line with the targeted yields.
- The excess or deficiency of certain nutrients influences the development of the bean and affects several crop enemies.

The green bean needs **major elements** (large quantities) such as carbon (C), oxygen (O), hydrogen (H), nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), sulphur (S), and **minor elements** (small amounts) **or trace elements** such as boron (B), copper (Cu), iron (Fe), manganese (Mn), chlorine (Cl), Zinc (Zn), etc.

The plant uses carbon, oxygen and hydrogen from the air and water, but the other elements must be in solution in the soil in order for it to use them. The presence and availability of these elements in the soil determine its natural richness. Unfortunately, most soils are very poor in many of these elements. It is therefore necessary to apply them in sufficient quantities to allow robust growth and therefore good crop production.

Nutrients or soil manure are applied using organic matter and mineral fertilisers. It is clear that the efficiency of mineral fertilisation is linked to the presence of organic matter which, thanks to the microorganisms it contains, makes it possible to promote mineralisation and optimise the fixing of mineral nutrients. For crop fertilisation, see points 4.3 and 6.5.

2.4.1. MINERAL AND TRACE ELEMENT REQUIREMENTS

NITROGEN (N)

It is an essential element for robust growth of the plants' stems and leaves and gives them a dark green colour. When this element is lacking, the plants are undeveloped with reduced foliage that takes on a pale or yellow green colour.

However, excess nitrogen must be avoided because:

— this curbs the efficiency of the symbiotic association between the plant and nitrogen-fixing bacteria;
— this not only causes accumulations of nitrates (toxic to humans at too high concentrations) in the vegetables, but also causes flower dropping, delayed maturity and conservation problems;
— this makes the plant more turgescent, more attractive to insects and mites, and more susceptible to the majority of leaf diseases.

PHOSPHORUS (P)

It enhances plant development, especially their roots, and acts on the maturity and precocity of crops. Phosphorus deficiency causes late development, pale green, purplish or tanned leaves, slow maturation and poor pod development. Phosphorus improves the taste of fruit vegetables as well as their firmness; in this sense, it improves the post-harvest rigidity of the pods.

Phosphorus, although needed in smaller quantities, is crucial for plant growth. Signs of deficiencies are dark green staining of the lamina, upright deportment and browning of the aged leaves followed by their fall.

POTASSIUM (K)

It conditions the quality of the pod, promotes the transport of reserve materials in the plant, as well as the development of the roots. It boosts disease resistance and drought tolerance. It is conducive to balance and health.

The deficiency of this element is first observed on old leaves that develop brown or grey spots near their edge. Sometimes, burns are also observed on the edge of the leaves.

Figure 4 — Symptoms of potassium deficiency
https://catalog.extension.oregonstate.edu/sites/catalog/files/project/html/images/screenshot2018-09-26at33246pm.png

However, when applied as potassium chloride (KCl), it has negative effects on chlorine-sensitive plants such as beans. Potassium in the form of sulphate or nitrate is more suitable for beans, however these formulations can weigh heavily on the budget.

If the soil analysis reveals a very high potassium value, it is necessary to moderate the inputs, or even eliminate them to avoid exaggerated vegetation of the bean. It is worth noting that 20% of the mineral fertiliser is found in the pods.

It should therefore not be used in excess, otherwise too vigorous foliage development will lead to risks of diseases and reduced pod production.

CALCIUM (CaO)

It is very important for the majority of fruit and fruit vegetables because it is a constituent element of the membrane walls of tissues and the survival of the product after harvest is very often linked to its content.

MAGNESIUM (MgO)

MgO deficiencies can appear in acidic, leached and sandy soils.

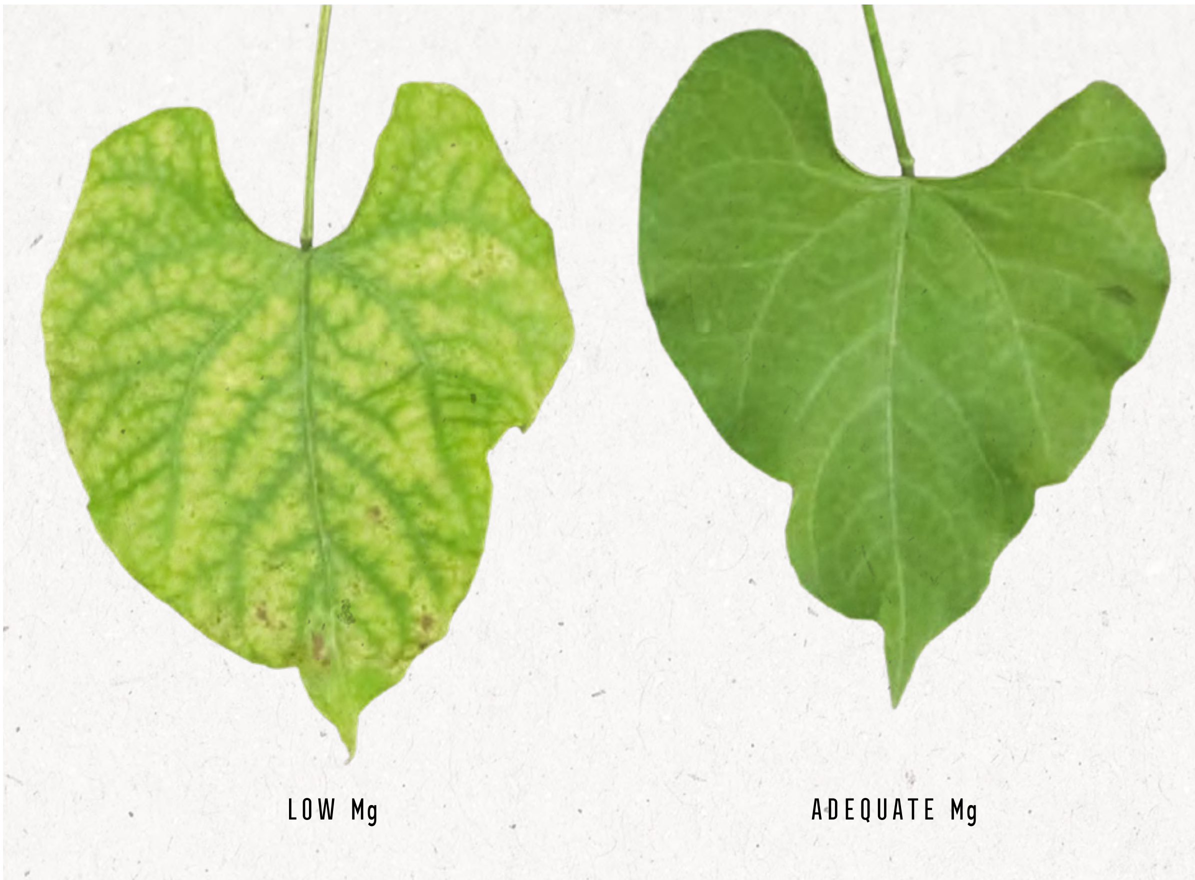


Figure 5 — Symptoms of magnesium deficiency
https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcR1_W5Fbuek0sCklhXRFM8tZ8Ct3GS-nse_JOhH6dMaiBCbpoeJB4wZk_vWgC4VzdqSUiY&usqp=CAU

A low Mg level can be identified by deformation of the leaves, a bronze-red colouration, discolouration of the veins.

Figure 6 — Symptoms of bronze colouration
https://www.haifa-group.com/online-expert/deficiency-pro/mg-magnesium

TRACE ELEMENTS

Virtually all trace elements necessary for plant growth are added via manure in sufficient quantities. However, in particular cases, deficiencies induced by a chemical or microbiological blockage may appear.

CROP NEEDS CHECKLIST

TO REMEMBER FOR CULTIVATION REQUIREMENTS

CLIMATE

— **Air temperature**

- The monthly maximum averages must not exceed 30°C.
- During germination, the optimum temperatures are 20 to 25°C.
- 15 to 25°C are the optimal temperatures during the vegetative phase until flowering
- Above 30°C, the quality of the pods diminishes

— **Humidity**

- A relative humidity of >90% is not favourable to green bean cultivation

— **Wind**

- The bean is a crop that is extremely sensitive to wind and particularly to hot and dry winds

— **Light**

- It is a crop that needs a great deal of light

— **Rain**

- Heavy rains are not favourable to green bean cultivation

WATER

— **Quantitative needs**

- The crop requires large amounts of water (3,000 to 8,000 m^3 per hectare depending on soil type and climate)

— **Water quality**

- The green bean is a very salt-sensitive crop, especially during the germination and emergence phase
- Water should not have an excessive Ca, Fe, Cl content (the bean is very sensitive to the presence of chlorine)

CROP NEEDS CHECKLIST

SOIL

— **Texture**
  - The green bean adapts to very diverse soil textures. It is better suited to sandy-clayey and loamy-sandy soils

— **Structure**
  - The bean requires a soil with a homogeneous structure, stable and unblown (soil without troughs) which must allow rapid seepage

— **Depth**
  - At least 40 to 50 cm

— **pH**
  - The optimum pH (H_2O) is between 6.0 and 7.5

— **Salinity**
  - The bean is sensitive to soil salinity

— **Toxic elements**
  - Excess boron or aluminium in the soil is harmful

— **Soil moisture**
  - The production plot must not be subject to flooding or prolonged submersion

— **Organic matter**
  - An ideal organic matter content is around 3-6%

CROP NEEDS CHECKLIST

NUTRITION

— Because the crop has a short-cycle, green beans need nutrient inputs in an easily assimilable form.

— The green bean can develop nitrogen fixing nodules, which is an useful input but does not replace nitrogen mineral fertilisation.

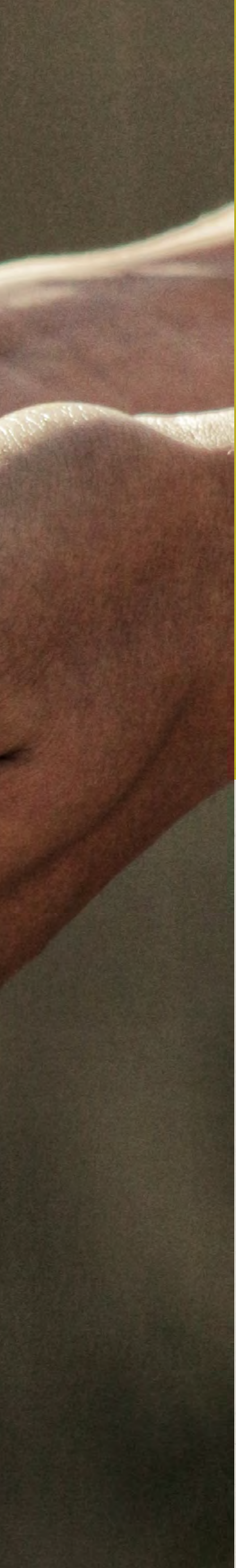
— Mineral nutrients need to be added by calculating the nutrient losses of the bean crop and analysing the soil.

— The excess or deficiency of certain nutrients influences the development of the bean and several crop enemies.

— Mineral elements

- Nitrogen: essential for vegetative development, but avoid excesses
- Phosphorus: important for plant growth and pod quality
- Potassium: gives vigour to the foliage, roots and conditions the quality of the pods
- A good availability of calcium, magnesium and trace elements is also essential

— These nutrients or soil manure are applied using organic matter and mineral fertilisers.



3

PRE-PLANTING CHOICES

3.1. PLOT SELECTION

The choice of a growing plot is an important stage in successful bean cultivation.

The main criteria to be taken into account when making this choice are: the soil, the location and topography of the site and the preceding crop.

The area of the plot will depend on the amount of water available, the available workforce and the intended investment for the purchase of the means of production.

3.1.1. SOIL TYPE

The plot must have a high degree of homogeneity regarding the nature of the soil and the soil profile in order to obtain an identical stage of maturity at the time of harvest.

Although it is possible to grow green beans on several types of soil, as far as possible, the soil must be chosen in line with the crop needs.

3.1.2. TOPOGRAPHY

To avoid erosion by the runoff of rain and watering, the relief of the ground must be as flat as possible or even well levelled.

3.1.3. LOCATION

The cultivated plots must be well exposed to the sun and protected from strong winds, especially the harmattan, a hot, dry and strong wind.

In West Africa, in the Sudano-Sahelian zone, the location of the plot must be close to a source of water for irrigation purposes, due to the long dry season of the bean production period.

In East Africa (*e.g.* Kenya), the country's seasons allow year-long production taking advantage of the climate (freshness and rainfall), which varies according to region and altitude.

3.1.4. PRECEDING CROP

Crop rotation plays an important role in the health of the bean crop, which is prone to *Fusarium*, root-knot nematodes, and other soil-borne pests and diseases. The bean crop must be planted after crops which are likely to harbour pests and diseases affecting beans (see point 3.7. on rotations). In particular, it is important to avoid the cultivation of other legumes.

3.2. PLANT MATERIAL

As a general rule, the commercial varieties exploited, whether in Kenya or West Africa, are decided or supplied by the partners (i.e. exporters, importers).

Depending on the expectations of consumers, these partners require beans with precise characteristics. According to their destination markets and the production period, exporters plan production with varieties tested and recommended by agricultural advisors.

West African countries (*e.g.* Senegal, Burkina Faso) have positioned themselves on the fine and mangetout varieties given their better adaptation to climatic conditions and availability of a qualified workforce. On the other hand, Kenya is positioned on the extra fine, fine and French filet bean with a management system, close harvest and very short evacuation times.

Some varieties (extra fine and very fine) require harvesting every twenty-four hours, hence the need for a large, available and well-trained workforce.

These varieties are very sensitive to climatic conditions (high temperatures), to handling (sorting of the pods is practically done at field level) and the crops are evacuated as soon as possible to the processing stations.

Table 4 — Main varieties of green beans for export in Kenya and Senegal (this list is not exhaustive and is subject to change as exporters may use other new varieties)

TYPE/ VARIETY	MATURITY NB OF DAYS APPROX	RESISTANCE / TOLERANCE	PERCENTAGES OF THE SIZES			LONG CM
			6-8 MM	8-9 MM	9-10.5 MM	
MANGETOUT						
Paulista		*Anthracnose* Bean common mosaic virus *Pseudomonas* *Xathomonas* Thrips (tolerance)	30	60	10	13-14
Xera		*Anthracnose* Bean common mosaic virus	40	60		13-14
Olivia		Bean common mosaic virus	20	60	20	13-14
RS1391		Bean common mosaic virus Bean rust	10	50	40	13-14
RS1389		Bean common mosaic virus Bean rust	20	60	20	13-14

FINE BEAN						
Amy	60	*Anthracnose* Bean common mosaic virus Prone to rust	70	30		10-12
Tanya	60	*Anthracnose* Bean common mosaic virus *Pseudomonas* (tolerance)	60	40		11-12
Samantha	60	*Anthracnose* Bean common mosaic virus	60-70	30-40		12-13
Teresa	60	*Anthracnose* Bean common mosaic virus Bean rust	60	40		
RS1518	59	*Anthracnose* Bean common mosaic virus	70	30		10.5-12.5
EXTRA FINE			**5-6.5 MM**	**6.5-8MM**		
Julia		*Anthracnose* Bean common mosaic virus	85	15		10-11
Lausanne		*Anthracnose* Bean common mosaic virus	70	30		11-12
ROMANO TYPE					**WIDTH**	
Emelia		*Anthracnose* Bean common mosaic virus *Pseudomonas*			18-22 mm	Flat pods 12-16 mm

Source: COLEAD, 2012. Green bean crop protocol

3.3. GROWING PERIOD

In West Africa, the green bean is grown from October to March-April, given the cool season that prevails at this time.

In East Africa, production can take place all year round in view of the opportunities offered by the climate.

Table 5 — Examples of green bean growing periods in 3 countries

MONTH N°	1	2	3	4	5	6	7	8	9	10	11	12
SENEGAL												
BURKINA												
KENYA												

(1 to 12, being the months of January to December)

3.4. SOWING METHODS

Various sowing methods are used depending on the country, although manual sowing is practically no longer adopted. There is a strong trend towards the mechanisation of sowing using seeders towed by animals and machines (ploughs and tractors); the motorisation of the equipment increases the possibilities and the scale of production.

In ACP countries, the green bean is generally sown on ploughed and harrowed soil. Direct sowing without ploughing under vegetation cover is almost never practised for export crops. However, this technique has several advantages:

- Much more energy-efficient.
- Promotes the restoration of the biological, physical and even chemical qualities of the soil, since it is not disturbed.
- Earthworms, fungi and bacteria colonise the soil, creating networks and channels that improve soil structure in the medium term.
- It creates a healthy soil: aerated structure, efficient water infiltration, good organic matter content.

However, the implementation of direct sowing under vegetation cover requires a lot of patience, since a few years of adjustments (from 3 to 5 years) are necessary. It takes some time before microbial activity achieves its full potential and for the soil to loosen a little.

The sowing under vegetation cover system significantly reduces cultivation operations. This translates into a major reduction in the number of machines and the weight of the equipment used. Significant savings can therefore be achieved.

Figure 7 — Bean under permanent kikuyu cover (*Pennisetum clandestinum*).
Husson O, Séguy L, Charpentier H, Rakotondramanana, Michellon R, Raharison T *et al.* (2013).
Practical manual for direct sowing under permanent vegetation cover

3.5. IRRIGATION

The sown surface area depends on the water source, the pumping method and the distribution method. In some areas, as periods of low humidity (rainfall) are the most favourable for growing green beans, it is often necessary to use irrigation to obtain good yields and quality pods. If the beans are grown during a rainy season, irrigation will provide the necessary water supplements during periods when there is a rainfall deficit.

3.5.1. THE WATER SOURCE

Irrigation water can come from surface water (lakes, rivers, backwaters, etc.) or groundwater (surface or deep aquifers).

In some countries, irrigation water comes from retention basins (Burkina, Senegal). In Senegal, for example, some of the producers receive water supply through a connection to the national water distribution network. Often, a "grower" rate is applied to this water with quotas for its use for fruit and vegetable crops. Increasingly, these connections are being disconnected in the face of the high water demand among urban populations.

When choosing the water source, it will also be necessary to check that the water does not contain mineral elements toxic to beans, germs pathogenic to humans and that it is not polluted by elements or chemicals toxic to humans (heavy metals (Pb, etc.), pesticides, etc.). Pollution can reach the water source by infiltration or runoff and is common in large African cities under-equipped with wastewater treatment systems.

3.5.2. WATER PUMPING

Several systems can be used to pump irrigation water.

MANUAL PUMPING

Manual pumping is the most frequently used technique, using watering cans or with bucket, rope and possibly pulley. This pumping system is work-intensive for growers and gives relatively small quantities of water, thus only making it possible to cultivate limited areas.

Sometimes, using animals for pumping (donkey, horse, ox) increases the quantities of water drawn.

Hence, the water needed to supply fruit and vegetable cropping basins is drawn less and less from "caesans" (water recovery basins in the lowlands that excavate groundwater (3 to 7 metres deep).

Today, almost throughout the Niayes region (in Senegal, dune depression areas), water is obtained from filtering points (10 to 15 m deep) by manual sinking of pumping pipes 160 to 200 mm in diameter) in sedimentation sands.

However, with the evolution of working conditions, GAP requirements and the standards imposed by importers, there is a visible trend in bean-growing peri-urban areas to use irrigation mechanisation and motorisation to lighten the workload and sow larger areas.

MECHANICAL PUMPING

This is done using pumps. There are many different types of pumps and certain characteristics, such as the desired flow rate expressed in m^3/hour and the desired elevation height, etc., will be decisive when choosing a pump.

The pumps can be driven by manual or animal traction (low flow rates), but most often they will be driven by electric or internal combustion engines (petrol, diesel). Wind and solar energy can also be used for pumping.

Mechanical pumping requires sometimes very large basic investments and thorough maintenance of the equipment. The risks of breakdown can lead to the failure of the fruit and vegetable crop. When resorting to mechanical pumping, due consideration should be given to the fact that, for most of these pumping systems, recurrent costs (fuel, spare parts, damping) and rigorous maintenance need to be factored in.

Pedal pump

The pedal pump developed by the NGO ATI (Appropriate Technology International) is used by fruit and vegetable growers in Senegal and other countries. It allows water to be drawn from depths of up to 7/5 m for a drawing height of 6 m, 50 m discharge through a pipe with a diameter of 50 mm. Depending on the drawing height, this pump can provide a flow rate of 5,000 to 7,000 litres of water per hour.

In fruit and vegetable production, wind or solar energy sometimes poses the risk of not being available when plants are most in need of irrigation (hot days without wind, overcast weather, dust).

Solar energy

Solar energy has a number of advantages to cover energy and service needs; daily sunshine allows continuous pumping for an average of six hours.

The solar potential of the Sudano-Sahelian African countries is of very good quality and represents a resource that is universally available. In addition, there is a "natural" seasonal correlation between irrigation needs and the intensity of solar radiation on the ground.

Compared to a solution based solely on one or more thermal motor pumps, the use of a solar pump using the sun to ensure the total water needs of the day offers a number of advantages.

- Fuel economy and reduced greenhouse gas emissions.
- Better use of water resources than in the case of several small pump units.
- Gradual familiarisation of the public authorities, local decision-makers and potential users with the technology and the applications and management of photovoltaic pumps, in a configuration (solar pumping, collective management) already widely tried and tested in West Africa.

To keep down the cost of photovoltaic pumping per unit of cultivated area, irrigation methods that are economical in water and distribution energy should be chosen. Hybrid, localised irrigation systems are also available: collective solar pumping and recovery by individual thermal motor pump units.

3.5.3. WATER STORAGE

In the case of watering can irrigation, the distances between the water point (ceanes or retention basins) and some crop plots can be too large, making it necessary to store the water intended for irrigation. This can be done in basins, possibly connected to each other and to a central basin next to the well, spread across the plot to reduce the number of trips necessary to fetch water.

Larger quantities of water are stored in water towers or large geomembrane reservoirs.

3.5.4. IRRIGATION

A number of different watering methods are used for green bean cultivation, depending on water availability and soil type.

WATERING CAN IRRIGATION

This is labour-intensive and therefore also limits the areas that can be cultivated, which is why it has been more or less abandoned.

WATERING HOSE IRRIGATION

Pressurised by motor pump or submerged pump and less restrictive, it makes it possible to water larger areas. The jet should not be too strong, as this may destroy the structure of the surface layer of the soil, pummel the plants and create conditions of asphyxiation.

GRAVITY-FED OR FURROW IRRIGATION

This is the irrigation method that requires the most water reserves. Larger amounts of water are required for a given area and evaporation takes place at the surface of the water. Although this method has the advantage of requiring only a small initial capital investment, it limits the potential yields per plot area because of the need for furrows and canals (which are not cultivated), alongside the paths.

Figure 8 — Furrow irrigation
https://tse3.mm.bing.net/th?id=OIP.h0Fu5G_uehtxIfCRqZknTwHaEK&pid=Api&P=0&w=300&h=300

This is done by distributing water in channels via syphons or by opening or closing channels or furrows with a shovel. The efficiency of this type of irrigation is around 40-50%.

Bean quality is diminished by mud splashing on the harvested pods. These splashes, which come from overirrigated furrows or which cover the beans hanging in the furrows, can be a problem for crops irrigated using the gravity-fed method (especially during the rainy season).

Plot landscaping (channelling, levelling) is important and is practised on heavier soils. It makes it possible not to wet the foliage and is practised especially with greater spacing between the planting lines.

In Senegal, where bean cultivation has been heavily modernised to optimise the cost of water and increase the area sown, furrow irrigation has been virtually replaced by the two systems described below.

SPRINKLER IRRIGATION

This irrigation requires fairly large underlying investments (pumps, pipes, ramps, sprinklers, etc.) but makes it possible to irrigate larger areas. Sprinkler irrigation is more efficient than furrow irrigation, with an efficiency of between 50-70%. However, it will be necessary to consult irrigation specialists if the decision is made to adopt this irrigation system.

Figure 9 — Sprinkler irrigation
https://tse2.mm.bing.net/th?id=OIP.r6ir4LBRTUSdEtsIA08g7QHaC0&pid=Api&P=0

LOCALISED

Localised irrigation or micro-irrigation, increasingly adopted for growing green beans, is a technique that consists of bringing water to the foot of plants by means of pipes and water dispensers. This clearly means that only a proportion of the soil receives watering water. In principle, this is the area colonised by the roots. Its efficiency, generally around 80-90%, is now recognised by all growers (cost savings and optimisation of irrigation), which is also valid in terms of workforce (larger exploitable surface per unit of work / man), fertilisation efficiency (fertigation) and the effectiveness of certain phytosanitary treatments (chemigation).

Figure 10 — French bean residue trial, Naivasha, Kenya. Plot layout with maize border rows and drip irrigation lines Report COLEAD – PIP French bean residue trial Kenya by Susanne Michalik. International Centre of Insect Physiology and Ecology (ICIPE) February 2005

This method is suitable for row crops. The benefits of micro-irrigation have been highlighted for decades. Despite requiring significant investments at the outset, the localised irrigation system has many arguments in its favour.

— It is strongly recommended in areas facing chronic water scarcity. Indeed, this system generates an efficiency of around 90% compared to sprinkling and gravity-fed irrigation.

— It is particularly useful when irrigation water is of poor quality, (salt-laden) since the constantly moist soil has a low hydric potential, making quality water available to plants.

— The water supply to the crops is regular because the system waters in low doses and at high frequencies. Moreover, the plants make more efficient use of the water, as losses in the supply channels are minimal. Water losses by evaporation are also very low.

— It is relatively easy for the irrigator to manage the water towers in terms of the speed of execution of the inputs. The workforce is optimised and used for other tasks.

- The mineral feeding of crops can be controlled because the system easily adapts to so-called "fertigation", by which mineral fertilisers are injected directly into the irrigation water.
- Watering is completely independent of other growing techniques, such as crop maintenance and management or harvesting for example.
- The risks of certain diseases are greatly reduced because the foliage is not wet, hence the decrease in the impact of cryptogamic problems.
- The plot suffers fewer grass weed problems, since only part of the soil is wet.
- The energy expenditure for water distribution is low, since it operates at low pressure.

However, it is important to point out that localised irrigation is a technology rather than a simple technique. All of the above qualities may prove to be inaccurate in the case of:

- poor design of the irrigation network,
- poor irrigation management,
- faulty hardware maintenance.

With this irrigation system, there is no loss of evaporation, because the water is contained in a pipe. Dripper lines must be arranged in a straight line, with the holes facing upwards, so as not to become clogged. Care must be taken to ensure that dirty water does not clog the drip-head holes. In some cases, filters may be required to prevent the clogging of dripper lines. Dripper lines and filters must be carefully maintained in order to avoid physical, chemical, microbiological clogging, and benefit from the potential of this system. Drippers can be maintained with acid, acidifying fertilisers.

Avoiding unnecessary wetting of uncultivated soil parts (paths, spacing between plants in the early growing stage) will reduce the spread of pests such as root-knot nematodes and weed growth.

Simple drip irrigation systems are available for small farmers (family drip systems). These are kits designed for small areas and taking into account the meagre financial resources of small producers.

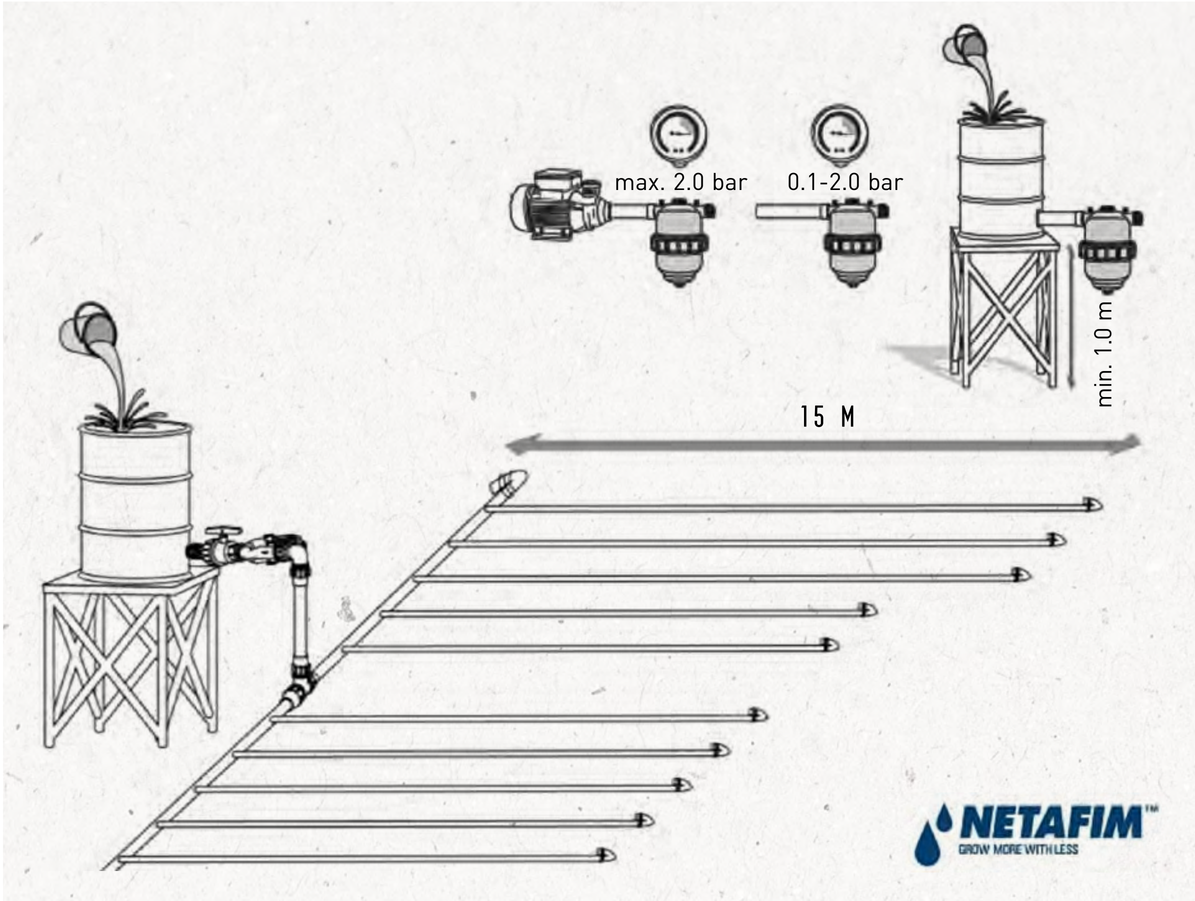


Figure 11 — Drip irrigation system for small producers
Netafim family drip system/ engineeringforchange.org

The method of irrigation used will have a significant influence on the development of crop production problems (see tables below) and should be taken into account when choosing irrigation systems.

Table 6 — Impacts of irrigation method on bean cultivation

METHOD	ADVANTAGES	DISADVANTAGES	COMMENTS
GRAVITY-FED	The foliage remains dry, which reduces the risk of rust, foliar *Rhizoctonia* and fat	The foliage remains dry, which increases the risk of thrips and mites Encourages the movement of nematodes Any excess water promotes the development of neck and root rot	Difficult to control inputs, leading to possible excesses Quantities used: from 6,000 to 8,000 m³/ha
SPRINKLING	Limits the development of thrips and mites. The dust is washed off the foliage and pods	Increases the risks of fat spread, rust, foliar *Rhizoctonia*, *Pythium*, *anthracnose*	Use sprinklers with a low precipitation rate of 5 to 6 mm/h. Quantities used: from 4,000 to 6,500 m³/ha
DRIP	The foliage remains dry, which lowers the risk of rust, foliar *Rhizoctonia* Hampers the movement of nematodes	Increases the risk of thrips and mites	Limits weeding Allows fertilisation and treatment via irrigation Quantities used: from 3,000 to 3,500 m³/ha

Source: La culture du haricot nain au Sénégal. RADHORT. (2012).

Table 7 — Influence of irrigation methods on some crop enemies

IRRIGATION METHOD	WHITEFLIES	APHIDS	THRIPS	SMALL CATERPILLARS	MITES	*RHIZOCTONIA SOLANI*	*PYTHIUM*, *SCLEROTIUM*	BACTERIAL FAT	ALTERNARIOSIS, RUST, *ANTHRACNOSE*	*FUSARIUM*	*MELOIDOGYNE* NEMATODES
SPRINKLER	↘	↘	↘	↘	↘		↗	↗	↗		↗
FURROW	↗	↗	↗	↗	↗	↗	↘	↘	↘	↗	↗
DRIP	↗	↗	↗	↗	↗	↘	↘	↘	↘		
WATERING CAN FROM ABOVE			↘	↘				↗	↗		
WATERING CAN FROM THE NECK	↗	↗	↗	↗	↗			↘	↘		

↗ Encourages the dispersion and/or development of the enemy
↘ Discourages the dispersion and/or development of the enemy
An empty box indicates that there is no known effect or no information

3.6. INTERCROPPING AND OTHER ASSOCIATIONS

Although not very common in green bean growing, intercropping makes it possible to improve conditions of cultivation, protection and defence of crops in relation to climatic and biological factors. However, it is important to make the right choice of crop in terms of their synergy and complementarity.

Beans are very often used in mixed crops, intercropping, strip cropping and relay cropping. Common companion crops are: corn, banana, sweet potato, cassava, peanut, peas, taro, potato, yam, coffee.

Figure 12 — Green bean crop alternating with rows of corn serving as windbreaks. G. Delhove

For more information, please consult COLEAD's "Guide to the Management of Biodiversity on Farms".

3.7. CROP ROTATION

Ideally, the same soil should not be used to grow beans more than one time in three. Between two bean crops, one or, preferably, two "recommended preceding crops" should be grown to actively manage the health of the soil and optimise the bean harvest. Yields will decrease if no rotation is performed. A low level of rotation will also lead to an increase in the number of pests and diseases in the soil, which may be difficult to get rid of with chemical treatments. Crop rotation is the most cost-effective way to protect the health of the soil and maintain yields.

Table 8 — Positioning of the green bean in rotation with other crops

NOT RECOMMENDED PRECEDING CROPS	UNFAVORABLE PRECEDING CROPS	RECOMMENDED PRECEDING CROIPS
BEAN, PEA	Peanut	Cereals (corn, *sorghum*, millet)
POTATO	Chilli, celery, lettuce	Cabbage, turnip, pak choi
JAXATU, AUBERGINE	Carrot	Bissap
MELON, CUCUMBER	Onion, garlic, shallot	Beetroot
COURGETTE, WATERMELON		Cassava
LETTUCE		Sweet potato
OKRA		Strawberry

Source: La culture du haricot nain au Sénégal. RADHORT. (2012).

Incorporating debris from cruciferaceae cultivation or preceding crops as a green fertiliser allows for useful partial soil sterilisation, as the debris decomposes and diffuses gases similar to the active ingredients used in certain soil chemical fumigants.

Beware of herbicides that can interfere with the emergence and growth of beans in case the periods and conditions before a successive crop are not respected. Caution should be exercised if herbicides have been used on preceding crops, as crop debris may sometimes contain herbicide residues that counteract the subsequent emergence and development of the plant (*e.g.* atrazine in corn).

To deal with an infestation of root-knot nematodes, it is possible to reduce the number by a short rotation with the Mexican tarragon (*Tagetes lucida*) or other *tagetes* such as *Tagetes minuta*.

The herb *Cyperus* needs direct sunlight to grow. Management measures that make use of dense vegetation cover, such as corn, cereals or intercropping and green fertilisers reduce optimal growing conditions, which hampers its development.

PRE-PLANTING CHOICES CHECKLIST

TO REMEMBER FOR PRE-PLANTING CHOICES

PLOT SELECTION

— The soil must be homogeneous in terms of the nature of the soil and topography
— The soil must meet the crop needs
— The ground should be as flat as possible
— The plot must be well exposed to the sun but not to strong prevailing winds
— The preceding crops on the plot must be taken into account.

PLANT MATTER

— The variety is generally imposed by the exporter and/or importer in the country of destination
— The extra fine and fine varieties require a large, available and well-trained workforce
— Take into account the resistance and tolerance of different varieties to pests

GROWING PERIOD

— It depends on the climatic conditions of the area and market opportunities

SOWING METHOD

— It can be manual or mechanised, depending on the capabilities of the grower and the size of the farm
— It is possible to sow under vegetation cover without prior ploughing but, for the green bean, there is almost no data about the vegetation cover systems to adopt according to climate and soil type

PRE-PLANTING CHOICES CHECKLIST

IRRIGATION

— **The water source**

- Groundwater is preferable to surface water

— **Pumping**

- It can be manual or mechanical but at present solar energy pumping is the best option, provided the means is available to invest

— **Water storage**

- Several options are available depending on the water source, type of pumping and type of irrigation

— **Irrigation**

- Localised irrigation is the best option for green beans but it requires a certain technicality and a relatively large investment
- The chosen irrigation method will have significant influence on the development of the different pests. When making the choice, due consideration should be given to

INTERCROPPING

— Take care when choosing the crops, their synergy and complementarity

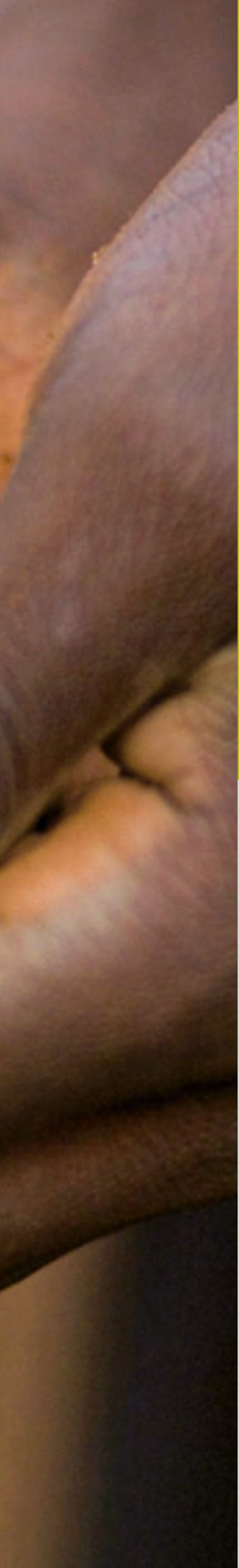
GROWING SEASON

— It depends on climatic condition in the region and on market opportunities

CROP ROTATION

— Good preceding crops are: cereals, *brassicaceae*, bissap (Guinea sorrel), cassava, sweet potato

— Green fertilisers or plants such as *Tagetes* are also useful preceding crops for the control of nematodes or weeds such as *Cyperus*



4

PLOT PREPARATION

If the crop development conditions are respected, production can begin after having landscaped the plot (to correct any defects).

4.1. LANDSCAPING

LEVELLING

Before levelling, the plot will have to be cleaned. The plot is cleared of the vegetation that covers it and, if required, the bases of the trunks and the roots of the trees to be cut are removed (grubbing). Stones and pebbles must be removed.

Good levelling of the soil (the plot will have to be perfectly flattened and not too stony, which will help with the precision of the sowing and later facilitate the harvest) will prevent the accumulation of water, which can cause asphyxiation of the seedlings or the development of diseases.

PLOT FENCING AND SECURING

The plots will be fenced to prevent livestock from grazing. It is not advisable for livestock to enter the plots to graze on crop residues (addition of weed seeds, dissemination of nematodes). Fresh manure left by animals grazing on a plot is a source of *E. coli* bacteria that can spread to the beans planted there immediately afterwards. To avoid contamination, a minimum of six months must elapse between applying fresh manure and planting beans. It is also possible to remove crop debris and feed animals away from the crop site. The manure can then be composted with other crop debris before being applied to the sowing site.

This fence can sometimes serve as a windbreak and can be made of thorny plants (*e.g. Acacia mellifera*), "crintings" (braided bamboo panels used in Senegal), millet or *sorghum* stems, barbed wire, etc. Make sure that the entrance can be shut closed.

WINDBREAKS

The site must not be exposed to strong winds, especially not the harmattan (hot and dry wind) which is very harmful to beans; it is necessary to put in place inert artificial windbreaks or, even better, hedgerows serving as windbreaks, to protect and secure the farm, hedgerow creation systems that are adapted to the crop and the production area. It is worth considering the possibility of using artificial windbreaks (such as crintings, millet, *sorghum*, corn stalks, etc.) and also seasonal windbreaks with cereals sown almost at the same time as the bean.

Some species are not only suitable as windbreaks but also offer protection against various wandering animals and have fertilising properties.

Table 9 — Plants used to create windbreak and protection hedges

SPECIES (LATIN NAME)	COMMON NAME	CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
ACACIA MELLIFERA		Thorny shrub up to 9 m. Prefers clayey soils.	Used in fences. Gives fuel and coal.	
ACACIA NILOTICA	Red gum tree or Gonakier	Thorny tree up to 20 m.	Very resistant to dry conditions ((250 to 1,000 mm). Fuel and charcoal wood. Poles and stakes. Young pods used as a vegetable. Fodder.	
ACACIA SENEGAL	White gum tree	Thorny shrub or tree from 2 to 6 m. Prefers sandy soils.	Very resistant to dry conditions (100 to 800 mm). Gum arabic. Melliferous plant.	
VACHELLIA (*ACACIA*) TORTILIS	Umbrella thorn acacia	Thorny tree native to the arid lands of Africa that can reach heights of up to 21 m. Needs a light and well drained soil.	Is able to withstand temperatures ranging from 0°C to 50°C and precipitation ranging from 100 to 1,000 mm/year It is one of the essences used to create the great green wall African	
ANACARDIUM OCCIDENTALE	Cashew tree	Bushy	Vigorous and very resistant	
AZADIRACHTA INDICA	Neem	Tree 5 to 20 m high.	• Persistent foliage • Well suited to arid areas • Not fed on by livestock • Fast growing • Heat resistant • Leaves and seeds can be used as insecticide • Poles	
BAUHINIA RUFESCENS		Shrub or small tree up to 8 m high	Very frugal. Very good fodder. Firewood and fencing material. Recommended species for the creation of defensive, forage or ornamental hedges	

SPECIES (LATIN NAME)	COMMON NAME	CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
CAJANUS CAJAN	Pigeon pea	Shrub		
CASSIA SIAMEA	Sindian	Tree 5 to 20 m high.	Coppices vigorously and resists termites. Firewood. Poles.	
CASUARINA EQUISETIFOLIA	Filao	Tree 25 to 30 m high.	• Well suited to heat and arid conditions • Fast growing • Salt tolerant • Enriches the soil with nitrogen	Needs irrigation
CONOCARPUS LAURIFOLIUS			• Fast growing • Very salt tolerant	Needs irrigation
EUCALYPTUS CAMALDULENSIS	Eucalyptus	Tree up to 20 m.	• Fast growing • The leaves can be used for the preparation of an acaricide-insecticide • Coppices easily • Poles • Melliferous species	• May suffer in windy conditions • Highly developed root system competitive for crops and therefore to be used only around the edge of the farm
LEUCAENA GLAUCA (LEUCAENA LEUCOCEPHALA)	Lead tree	Shrub up to 4 to 5 m.	Grows very quickly with good permeability, as a legume, it enriches the soil and provides feed to livestock, along with perches and stakes for the farm	At maturity, its dehiscent pods disperse thousands of seeds that risk invading the whole plot
PENNISETUM PURPUREUM	Maralfalfa / Grass / Elephant grass	A *Pennisetum* of the family Poaceae	Grows very quickly with abundant leaves, very nutritious for livestock, very resistant to water stress, propagation through cuttings	Very popular with herbivores
SENEGALIA LAETA		Thorny shrub or small tree. Prefers sandy-clayey soils.	Branches used for fences. Very resistant in dry conditions (250 to 750 mm)	

Some distance must be left between these windbreaks and crops to avoid competition for water and fertilisers, to prevent them from shading crops and the live windbreaks from serving as a shelter for birds, insects and other pests (nematodes, diseases).

When choosing, installing and maintaining windbreaks, it will be necessary to take into account the specific indications for each species.

It is also important to point out that:

- A good windbreak must be permeable and will protect the terrain over 10 to 15 times its height. If this is not enough, small windbreaks (corn, forage grasses) can be added inside the plot.
- Crops must be kept 10 to 20 m away from windbreaks (depending on the size of the trees) and trenches must be dug to cut their roots because they can harbour crop enemies and/or enter into water competition with the crop.
- Windbreaks increase the ambient humidity and promote leaf diseases where their permeability is less than 50%. They can also provide a refuge for certain animal pests (birds,..) but also a shelter for predators.
- It should also be noted that the leaf miner thrives in a windless atmosphere. *Bemisia tabaci* also flourish in a humid and sheltered biotope.

4.2. WEED MANAGEMENT

Crops do not need to be weed-free throughout the crop cycle. On the other hand, they must be protected from competition during the juvenile period when they are most sensitive. After this period, weeds can develop without harming the crop. The weed-sensitive period varies from one crop to another and depends mainly on its growth rate. For the green bean, weed management is essential until flowering, before the canopy provides adequate soil cover.

During the plot preparation phase, the stale seedbed or "false seeding" technique can be used. This preparation of the soil makes it possible to limit the early emergence of weeds in the crop. It entails preparing the seedbed 2 to 4 weeks before sowing or planting. The weeds are left to germinate under the effect of rain or irrigation, repeatedly, at intervals of 7 to 10 days, before the weeds are destroyed with the harrow (3 to 5 cm deep). Note that each mechanical intervention stimulates the germination of new seeds, provided that the soil is sufficiently moist. In order not to damage the ground, towed machines are preferable to PTO driven machines.

Cyperus rotundus, due to its very rapid development and its high tolerance, is the most harmful weed for fruit and vegetable crops, particularly so in wet soil with good drainage. Mechanical control methods can reduce the degree of infestation of *Cyperus rotundus*. Right at the beginning of the dry season, extracting tubers via very deep ploughing allows them to dry out and shrivel up in the sun; harrowing makes it possible to extract the tuber chains across the plot. This operation must be repeated several times to eliminate the entire population of *Cyperus rotundus*.

The rotary cultivator and the rotary harrow increase the weed's capacity to multiply by separating the bulbs; they must therefore be avoided at all costs.

4.3. AMENDMENTS AND BOTTOM DRESSING

Organic matter (very well decomposed) and deep fertilisers should be incorporated as bottom dressing and amendments when preparing the soil.

This is part of the application of good agricultural practices for **an integrated soil fertility management** (ISFM) which is based on 4 main components including:

— The use of improved germplasms

— The use of mineral fertilisers

— Organic matter management

— Adaptations to local conditions

This management is based on:

- Consideration for agro-ecological and socio-economic conditions
- Endogenous knowledge and experience of producers (good agricultural practices)
- The proposal and/or participatory development of a set of technologies for organisational and socio-economic measures by integrating gender.

It must also contribute to:

A reduction in nutrient losses, often resulting from:

- Soil preparation (clearing and ploughing)
- Erosion
- Runoff
- Volatilisation (N and S)
- Removal of harvest residues

FOR MORE INFORMATION ON ISFM AND SUSTAINABLE SOIL MANAGEMENT, SEE

— https://www.cariassociation.org/Publications/Manuel-de-gestion-integree-de-la-fertilite-des-sols

— https://ifdc.org/wp-content/uploads/2019/07/FICHE-TECHNIQUE-1-GESTION-INTEGREE-DE-LA-FERTILITE-DES-SOLS-ET-PRINCIPES-DE-BASE-INTEGRATED-MANAGEMENT-OF-SOIL-FERTILITY-AND-BASIC-PRINCIPLES.pdf

— https://cgspace.cgiar.org/handle/10568/76787

— https://www.africmemoire.com/part.3-chapitre-i-principe-de-la-gestion-integre-de-la-fertilite-des-sols-gifs-730.html

— https://eservices.coleacp.org/en/e-bibliotheque/sustainable-soil-management

— https://eservices.coleacp.org/fr/e-bibliotheque/gestion-durable-sols-0

ORGANIC MATTER

Organic matter is essential for a good soil structure. Ideally, the goal is to have a 5% organic matter content in the soil.

The management of organic matter is particularly important in integrated production to maintain humus levels, meet plant needs and limit soil erosion.

Organic matter inputs affect not only soil nitrogen availability, but also the evolution of the microorganisms it harbours, as well as the biodegradation of plant protection products. Micro-organisms (harmful pathogens and beneficial antagonists) make up a significant fraction of soil organic matter. The interrelationships between soil microorganisms, crop and organic matter can be modified by cultivation practices.

Soil improvement, as well as the application of bottom dressing and maintenance manure with organic matter and chemical fertilisers, should be based on the interpretation of a soil analysis and other data such as crop type, crop development stage, etc.

Different organic matter can be used for fruit and vegetable crops. Those most frequently used are manure and compost but attention is needed, as the bean suffers from strong inputs of non-decomposed organic matter.

It is therefore important that the organic matter is well decomposed and is buried in the ground by digging or by deep harrowing after ploughing or by combing or during weeding and hoeing for cover manure. Organic manure inputs should be limited just before sowing because this comes with an increased sensitivity to diseases (rots) and pests (nematodes, bean seed fly). On the other hand, fresh manure should not be applied to bean fields before sowing due to the risk of contamination by *E. coli* bacteria. The fine bean crop cycle is very short between planting and harvesting. It is therefore generally more prudent to apply the input at the end of the preceding crop. In case of doubt, care should be taken to cover the manure with a polyethylene film to ensure that the temperature of the pile reaches at least 55°C for three days before application in the field (solarization).

In the event of a shortage of well-decomposed organic matter, it is advisable to apply it locally. In a soil heavily infested with nematodes, instead of field spreading, it is more useful to spread this well-decomposed organic matter along the planting lines. This will protect the plant from nematodes at the beginning of the crop.

Unlike peas, beans react well to organic manure: 20 to 30 t/ha of well-decomposed manure when laying the crop can be beneficial if soil organic matter is too low. Otherwise, apply a dose of 10 to 20 t/ha of manure if possible.

MINERAL AMENDMENT

Perform liming if soil acidity is a problem and apply phosphogypsum or calcium thiosulfate in the event of salinity problems. For more information on liming see the COLEAD manual on soil management.

MINERAL BOTTOM DRESSING

As a general rule, in addition to the input of organic matter, it creates a reserve of elements and a foundation for soil fertility. It consists mainly of half or ¾ of the estimated phosphorus requirements and one third of that of potassium.

4.4. TILLAGE

If the ground has a slight slope, when tilling, opt for the direction perpendicular to the direction of the slope.

Green bean crop needs.

- Calls for a soil ploughed to a depth of 30 to 50 cm that is refined with a homogeneous structure. The seedbed should be finely structured and aerated through harrowing. The preparation of the soil must allow the root system to colonise the soil quickly over the first 25 – 30 centimetres, which will ensure that the plant (very delicate tracing roots) is effectively fed with water and minerals. Care should be taken to maintain a lightly packed, crumbly structure and soil that is properly tilled and well seeped.
- Loamy soils that tend to be sealed should be pre-irrigated abundantly (reach field capacity), prepared just before sowing. They should only be irrigated and tilled after emergence.
- Depending on the type of soil (very clayey or loamy) and the irrigation system (furrow), the producer may have to landscape the soil in ridges.
- If there is a risk of excess water (rainy season), grow the crop on ridges or boards raised higher than the paths in order to ensure better drainage.
- Avoid wasting water, possibly by creating ridged fields around the boards, or basins around the feet of the plants.

No-till sowing under vegetation cover has been shown to preserve soil structure, limit the spread of weeds and pests, and to protect the soil from various types of erosion. However, green beans are almost never grown under vegetation cover in ACP countries, probably because of a lack of research on the subject. The cultivation of (shelling) beans under vegetation cover has been studied in tropical zones, more particularly in Madagascar. Recommendations exist for cropping systems depending on climatic conditions and soil type. For example: sowing under a cover of kikuyu (*Pennisetum clandestinum*), a perennial grass adapted to altitude zones (between 900 m and 1,600 m in Madagascar). The cover plant can be easily controlled using herbicide, and possible by mowing and grazing. Kikuyu is very demanding in terms of soil fertility. It is not recommended on poor soils.

4.5. SPECIFIC STRUCTURES

TUTORING

The climbing bean must be tutored. Tutors at least 2.5 m high are installed after sowing. The trailing vines should be guided on the tutor at the beginning of growth. A net can also be installed between the tutors to allow the trailing vines to run.

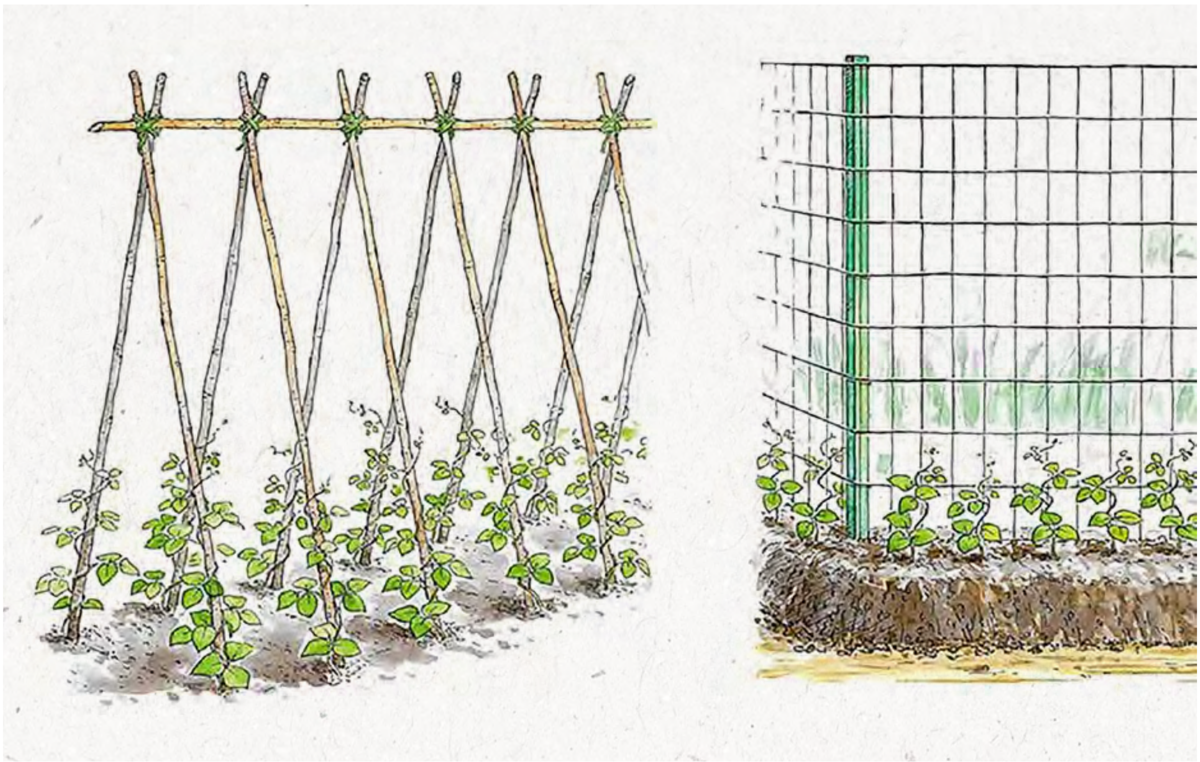


Figure 13 — Two climbing bean tutoring methods
Source https://monjardinmamaison.maison-travaux.fr/wp-content/uploads/sites/8/2016/05/une-10-750x410.jpg

PLOT PREPARATION CHECKLIST

TO REMEMBER FOR PLOT PREPARATION

GROUND PREPARATION

- The ground should be well levelled without any troughs where water could accumulate
- Stones and pebbles must be removed
- The plot must be fenced to keep out wandering livestock
- Windbreaks must be installed around and in the plot given the sensitivity of the green bean but the air must be able to circulate to avoid excess humidity

WEED MANAGEMENT

- The presence of weeds should be avoided as soon as the bean emerges by applying the "false sowing" technique, for example, 2 to 4 weeks before sowing the crop
- If the plot is infested with *Cyperus*, its population must be reduced as much as possible through deep and repeated harrowing in the dry season

AMENDMENTS

- Organic matter inputs, a very important part of **Integrated Soil Fertility Management**, must be applied in a well decomposed state. The ideal content of organic matter in the soil is 5%. In the event of organic matter shortage, it should be applied as close as possible to the planting lines.
- A mineral amendment must be applied if salinity and acidity need to be corrected
- A mineral bottom dressing input is necessary to supplement the mineral elements obtained from the organic matter

PLOT PREPARATION CHECKLIST

TILLAGE

— **Preparation with ploughing**

- When ploughing, select the direction perpendicular to the direction of the slope of the ground
- Plough 30 to 50 cm deep followed by harrowing

— It is possible to sow **under vegetation cover without prior ploughing** but almost no information is available for green beans on the sowing under vegetation cover systems to adopt according to climates and soil type

SPECIFIC STRUCTURES

— Growing green string beans requires the installation of plant supports (staking and/or trellis)

5

PLANTING

5.1. SOWING PERIOD

In Kenya, beans can be sown throughout the year.

On the other hand, in West Africa, the green bean is sown in the cold counter-season from October to February, the season when climatic conditions are favourable (temperature and humidity).

Moreover, a bean planted on a warmer soil germinates faster, emergence is more homogeneous and the advance gained is visible up until the harvest through a better grouped maturity. The planning of sowing dates takes into account a significant amount of other data such as shipping capacity or length of crop cycle (8 to 10 weeks for green beans) and the favourable marketing period compared to competing origins.

5.2. SOWING METHOD

Depending on the country and the size of the farms, beans can be sowed manually, with an animal traction or mechanical or pneumatic seeder to increase the speed and performance of the operation.

The sowing method will depend on the following:

- the abundance of foliage of the variety used; the mechanisation of maintenance operations (use of horses or tractors); the type of irrigation (gravity-fed, sprinkling or drip);
- seed volume should be reduced during the rainy or wet season to increase air circulation and ensure that leaves dry faster. This will reduce the risk of rust affecting crops during rainy seasons. In Senegal, seed volume should be lower at the beginning of the season and increase thereafter.

FARM USING GRAVITY-FED IRRIGATION

The planting lines are positioned on the side of the furrow, at the height of the waterline expected when the furrow is flooded. Seeds are spaced 4 to 8 cm apart in the furrow, depending on variety, season and soil type.

The planting lines are usually about 30 cm apart (furrow width). The ridges of the furrows are usually spaced about 70 cm apart.

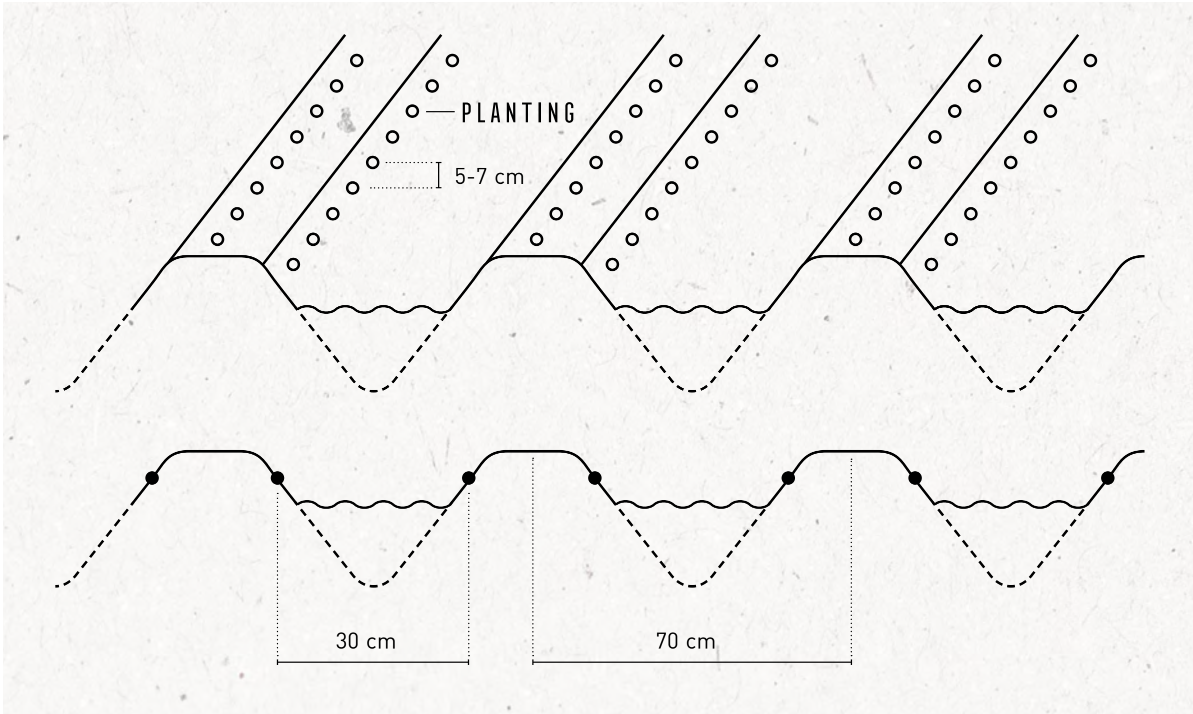


Figure 14 — Diagram of sowing method in the case of gravity-fed irrigation

FARM USING SPRINKLING IRRIGATION

Fixed and semi-mobile irrigation is adopted in Senegal in the Niayes region, the distance between planting lines is around 50-70 cm depending on the type of soil with the seeds planted 5-7 cm apart on the line, and 1 m passing strips left every 10 m for maintenance and harvesting.

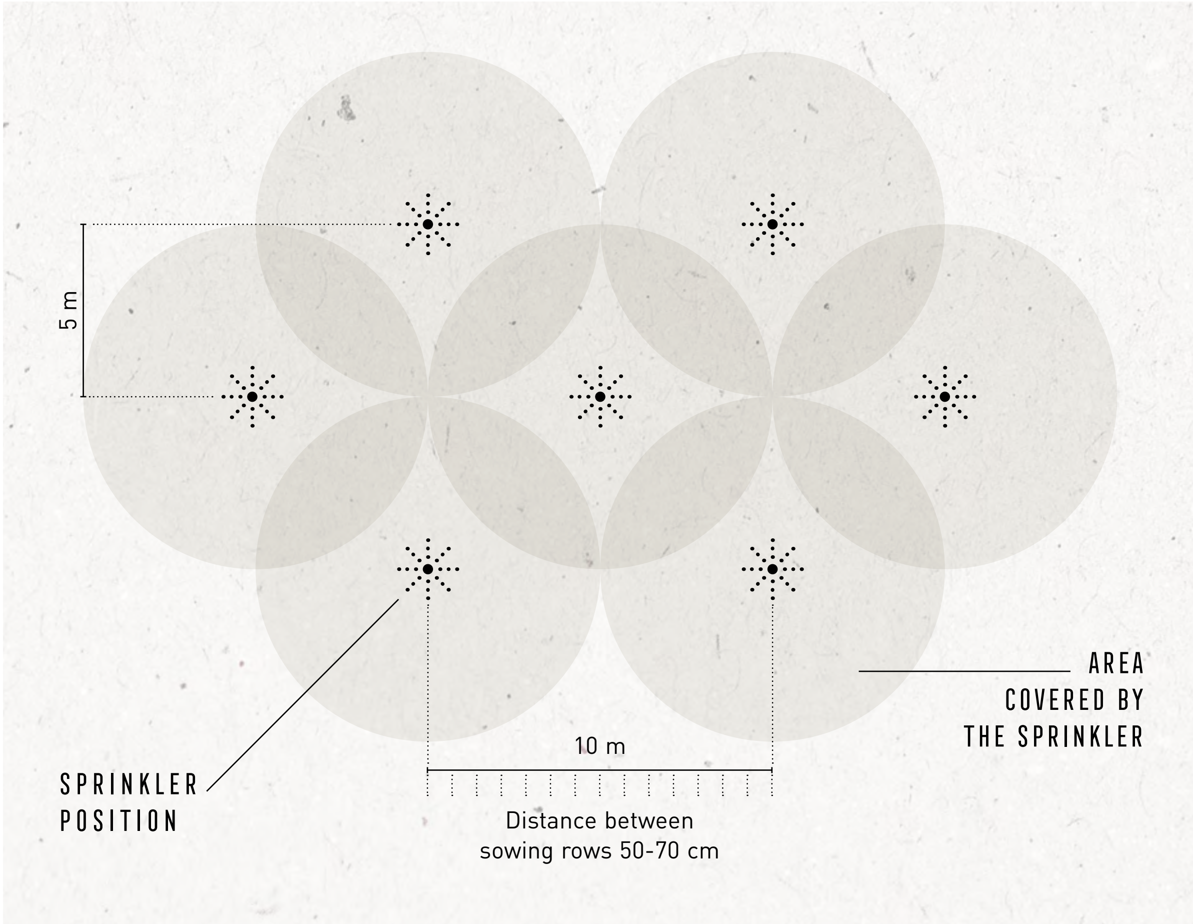


Figure 15 — Diagram of sowing method in the case of sprinkler irrigation

FARM USING DRIP IRRIGATION

Beans are planted with localised irrigation in the open field with dripper lines spaced 80 cm apart and seeds planted on the line every 4-5 cm.

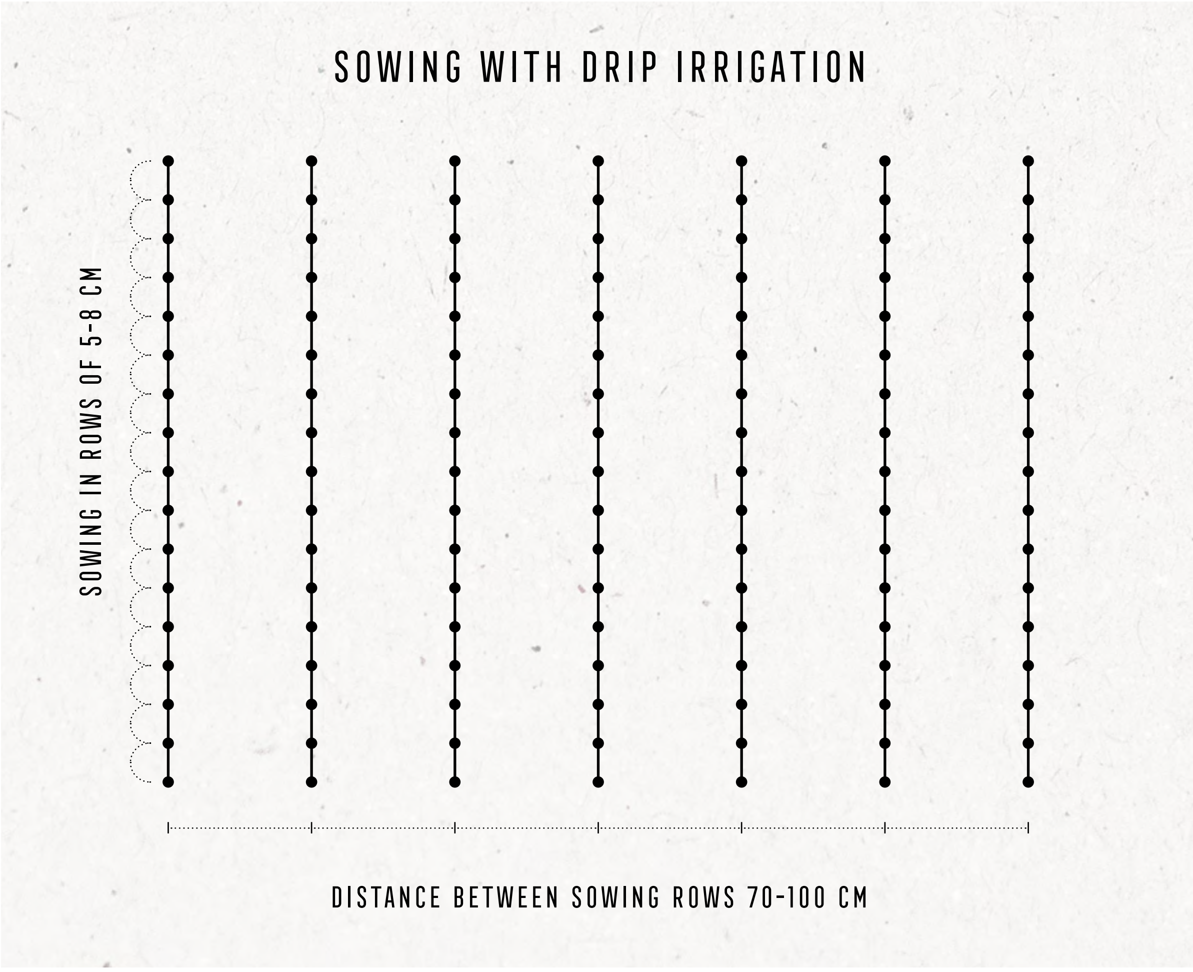


Figure 16 — Diagram of sowing method in the case of drip irrigation

However, drip irrigation is also adopted when planting seeds on a raised bed according to various methods – either two, three or four seed rows per bed. The more rows per bed, the wider the beds.

Two-row beds are one metre wide (from the centre of the bed to the centre of the neighbouring bed); three-row beds are 1.5 to 1.8 metres wide; and a four-row bed is 2 to 2.2 metres wide.

The aim is to have a minimum distance of about 40 cm between the lines and the seeds in a zigzag pattern between the lines, in order to increase the air circulation in dense plantations.

It is advisable to avoid sowing large volumes of seeds during the rainy season or when using varieties that are prone to rust. Plant a seed every 7 to 8 cm along the lines and increase spacing in rainy periods.

SOWING DEPTH

Sowing must be done on a regular basis in order to obtain a homogeneous emergence and therefore a homogeneous maturity.

Since the bean has epigee germination (the cotyledons come out of the soil), to avoid difficulties with the emergence of the seedling, it is necessary:

- in sandy soil, to plant seeds between 3 and 5 cm deep,
- in heavy soil, to plant seeds 2 cm deep (no irrigation before emergence).

Everything that promotes asphyxiation (heavy soils, excess water, compacted soils, too deep sowing, etc.) will compromise emergence. It will be irregular and prone to neck and root diseases.

In loamy or loamy-clayey soils, it is important to manage irrigation well by ensuring effective pre-irrigation before sowing and waiting for the emergence of the beans to avoid having to deal with emergence difficulties due to soil compaction because of the sealing of these types of soils.

5.3. SEED REQUIREMENTS

Seeding density varies depending on the irrigation method and soil type. Gravity-fed irrigation uses more crop area due to irrigation grooves and channels. These soils will need less seeds per ha. Drip irrigation makes it possible to cultivate more of the soil.

For dwarf beans, the goal is to grow 200,000 to 300,000 plants per hectare of land. More vigorous varieties, such as Teresa, require less seed per hectare because they are sown less densely.

The average seed requirement is 29-34 kg/ha depending on the seed size of the different varieties.

Seeds must be tested before planting to ensure that they are not physically damaged or dessicated (old seed stock). Exporters distributing seed recommended by or obtained from an importer must ensure that the germination percentage is greater than 95% before commencing seed distribution to growers. If seed viability is not optimal (95-100%), increase the number of seeds per hectare.

It is advisable to avoid self-production and storage of seeds at the farm, as this increases the risk of transmission of diseases, such as *Fusarium* and bean fat.

Do not plant seeds when you have doubts about their quality. If necessary, sort poor quality seed before starting to sow. If the seed has been treated with pesticides, make sure that those who plant the seed are equipped with protective gloves.

All imported seeds must be accompanied by a health certificate. If the exporter supplies the seed, its lot number may be recorded in the crop log book with a reference to the health certificate number.

Ideally, seeds should be planted immediately after treatment with insecticides or fungicides. Planting delays can reduce the effectiveness of seed treatment or even deteriorate seed quality.

In Kenya, seed treatments must be recorded in the Register of Pesticides applied to crops (RPA) (including treatments that have been applied by the seed producer in accordance with import requirements to Kenya – usually thiram treatment). If seeds are treated in Kenya (against bean flies, etc.), these treatments must also be registered in the RPA.

PLANTING CHECKLIST

TO REMEMBER FOR PLANTING

SOWING PERIOD

— Depending on the climate in the area

— Depending on the favourable marketing period

SOWING METHOD

— **Planting line layout and density** depend on:

- the abundance of foliage of the variety used;
- mechanisation of maintenance operations;
- the type of irrigation

— Density should be lower in the rainy season

— The sowing depth must be adapted to the soil type

SEED REQUIREMENT

— The average seed requirement is 29-34 kg/ha

— All imported seeds must be accompanied by a health certificate

— Seeds should be tested for germination before sowing

6

CROP MAINTENANCE

6.1. WATER

The most limiting factor in vegetable production is usually water. The presence of a dry season and a rainy season, during which rains are often irregular and insufficient, makes it necessary to irrigate fruit and vegetable crops. If the needs are not covered by the initial useful reserve and by precipitation, irrigation is used.

6.1.1. IRRIGATION

The quantities of water, i.e. the watering rate, can be expressed in litres (l) of water per square metre (m^2), cubic metres (m^3) per hectare (ha) or millimetres (mm), i.e. the height of a layer of water on the irrigated land.

The equivalence between these irrigation units is as follows: 1 l/m^2 = 1 mm = 10 m^3/ha (1 m^3 = 1,000 l water and 1 ha = 10,000 m^2).

In general, the requirements that depend on potential evapotranspiration (PET) and Kc (crop coefficient) of the crop are 60 to 100 m^3/ha or 6 to 10 mm of water per day for one hectare of beans. A field must have at least 8 l/m^2 or 80 m^3/ha or 8 mm of water per day.

The dose of water applied during each irrigation session will vary according to the stage of development of the crop, the type of soil (sandy, clayey, loamy, etc.) and the climatic conditions of the production area.

The frequency of irrigation will also depend on the stage of the crop, soil type and climate. Of course, this input volume varies according to the type of irrigation.

Very often, the tendency of fruit and vegetable growers is to water too much, with consequently a waste of water and significant developments of several fungal or bacterial diseases.

QUANTIFICATION OF INPUTS

Consumption relative to PET varies according to the stage of growth. Do not exceed 12 mm per daily input (fractionation); stop irrigation a few days before harvesting the beans.

To quantify water inputs, the following crop coefficients may be used, which will be applied to the PET:

- from emergence to the first leaves: 0.3 to 0.6,
- from the first leaves to the beginning of flowering: 0.6 to 0.7,
- from flowering to the first pods: 0.7 to 0.9,
- during the production of pods: 0.9 to 1 or 1.2.

Example: for a PET of 6 mm/d, the following daily doses will be obtained, depending on the stages of the crop:

— 6 mm x 0.3 to 0.6 = 1.8 to 3.6 mm,
— 6 mm x 0.6 to 0.7 = 3.6 to 4.2 mm,
— 6 mm x 0.7 to 0.8 = 4.2 to 4.8 mm,
— 6 mm x 0.9 to 1 = 5.4 to 6 mm.

Irrigations must be carried out on the basis of the soil in line with the capacity of the field. The PET of course varies according to the climatic conditions:

— overcast and cold day, PET < 6 mm,
— sunny day with the harmattan blowing, PET > 6 mm.

INPUT FREQUENCY

On sandy soils, irrigations will be more frequent than on heavier soils.

— Before sowing: Irrigation is necessary if the useful reserve of the soil is insufficient.
— During sowing: Irrigation during sowing is generally not recommended (as it results in the establishment of a superficial root system only). Loamy soils that tend to be sealed should be pre-irrigated abundantly (reach field capacity) and prepared just before sowing.
— After sowing: In order to avoid neck diseases, irrigation should be rational, not excessive until emergence, in sandy soil.
— Early in vegetative development: Do not water too often to allow the root system to colonise the soil.
— During flowering: Drought during pre-flowering is the most damaging to the final yield. From the "beginning of flowering" stage, irrigations should be carried out regularly according to needs and continued until the growing stage of the pods. When sufficiently supplied with water, the pods are of higher quality (less filament, reduced seed content).

TIMING OF IRRIGATION

In case of irrigation by sprinkling and furrow irrigation, water in the morning to reduce the risk of high relative humidity at the foliage and neck (risk of rust, *Rhizoctonia*, *Sclerotium*, *anthracnose*, fat and *Pythium*) for a long time, and avoid water shock in case of high heat. When sprinkling, do not irrigate after a foliar treatment.

During periods of high heat, it is best to sprinkle at the beginning of the day to avoid thermal shock, leaf burning, flower dripping and the creation of a disease-friendly microclimate.

Table 10 — Doses and frequency of irrigation by sprinkling in litres/m² per day according to the different phases of development of the dwarf bean crop on sandy soil (CDH, Senegal)

DOSES AND FREQUENCIES IN LITRES/M² *			
STAGE 1 SEEDLING EMERGENCE	STAGE 2 YOUNG PLANT	STAGE 3 ADULT PLANT	STAGE 4 AFTER MAX. GROWTH
4 l/m² per day	8 l/m² /2 days	12 l/m² /2 days	12 l/m² /2 to 3 days

According to W. Baudoin, G. Benvenuti, T. BA – "experimentation Section Reports, CDH" – 1973-1985.
* On dry, sandy soils, left fallow for some time, pre-wetting is essential. The dose can vary from 20 to 40 l/m²

6.1.2. DRAINAGE

On poorly permeable soils, it is advisable to cultivate on raised soil beds, creating grooves and channels of seepage with drainage in their vicinity. This drainage will avoid drowning the roots in arable strata that would otherwise be permanently flooded and it helps to avoid salt accumulations in the root development zone

6.2. TILLAGE

Hoeing or weeding-hoeing are essential to aerate the soil. They must be very superficial so as not to damage the shallow roots. Usually, they are carried out with hand tools or in large farms with tractors hitching an implement carrier with cultivators or claws.

At least 2 rounds of hoeing are required after emergence: sowing + 15 days and sowing + 25 days, with incorporation of correction manures in order to reach a level of coverage unfavourable to the development of weeds.

6.3. WEED MANAGEMENT

Weeding is useful for bean crops because it eliminates weed competition for sunshine and water, as well as nutrients. Plant protection and foliar treatments penetrate the canopy of bean plants better if the soil has been weeded. Some weeds also harbour pests, such as thrips, red spiders and nematodes, and must be eliminated. As a rule, in the case of bean crops, it is sufficient to control weeds until the end of the first half of the crop cycle (mid-crop). However, it will be necessary to prevent the weeds from going to seed.

If weeding is necessary, it should be combined with (weeding) hoeing, which must also be superficial to avoid damage to the roots.

Mechanical weeding methods are becoming more widespread. For example, the harrow is used for large-scale crops, while smaller areas are treated with the wheel hoe, which makes it possible to extract and cut creeping or pivot weeds. Complementary to the hoe, it is the only alternative to manual weeding. Mechanised weeding by a towed tool can only be carried out post-emergence if the sowing, or the transplantation of the vegetable, has been carried out in a straight line and at constant spacing.

It is also possible to carry out selective chemical weeding (*e.g.*: 15 days before sowing with haloxyfop-R-methyl ester); however, given the regulations on maximum residue limits and environmental management, this system is not widely used in West Africa. In pre-emergence treatment, the rational use of halosulfuron-methyl prevents the formation of rhizomes of the superficial tubers of *Cyperus*, allowing time for the covering crop to develop its canopy and subsequently become more competitive.

Examples of other herbicides that can be used on beans are given below.

- Bentazone: a post-emergence herbicide on small dicotyledons (up to 4 to 6 leaf stage) and in active growth phase. It is used at low doses from the stage 2 single leaf stage of the bean or from the 2^{nd} trifoliate leaf stage for higher doses.
- Ethofumesate: against annual dicotyledonous plants and annual grasses. Apply when the culture is at the 1-3 trifoliate leaf stage (BBCH 11-13). Its action on both root and leaf allows it to ensure excellent effectiveness even in drier conditions. The best results are obtained on young weeds (before tillage for grasses and cotyledon stage for dicotyledons).
- Imazamox: a post-emergence herbicide in combination with bentazone, helps to reduce the amount of bentazone applied while improving efficacy.
- Benfluralin against grasses.

6.4. VEGETATION COVER

Vegetation cover is recommended when appropriate organic matter and plant waste are available. It prevents the heating of the production plots and preserves moisture, as well as the development of weeds. It is very important during the harvest period on clayey plots that can be saturated with irrigation water or rain.

Cyperus is a weed that needs plenty of sunlight to grow. It is possible to use the properties of certain mulches to control it, such as a cover of *sorghum* (or oat) mulch. Prolonged shading of the soil surface, combined with allelopathic effects (emissions of substances that act as natural herbicides), makes it possible to partially control this weed. A cultivation system with *sorghum* production used as mulching for the following season can therefore be useful.

6.5. FERTILISATION

GENERAL REMARKS

Fertilisation must be rational in such a way that the total dose of each nutrient is perfectly adapted to the conditions encountered in each plot (soil analysis necessary). It is useful to keep a record of soil tests that have been carried out and which justify the application of fertilisers in order to comply with the provisions of the certifying bodies.

The crop needs must be established as precisely as possible in order to avoid any excesses.

The observance of good agricultural practices in order to ensure proper management of the crop environment helps to meet the challenge of efficient, healthy and sustainable production.

Soil, leaf and production analyses are elements that inform the decision on how to feed plants in order to achieve the best results in terms of productivity.

In this context, the practice of fertilisation will be done according to the **4R principles.** This concept emphasises the need to apply fertilisers from the right source, at the right dose, at the right time and in the right place. To this end, **several methods of applying fertilisers can be envisaged for green beans such as fertigation, foliar sprays, broadcasted or localised.** This is the only way to ensure that plants receive proper nutrition.

THE 4R PRINCIPLES

4R nutrient management principles are the same around the world, but the way they are used locally varies depending on the characteristics of the field and site, such as soil, crop system, management techniques and climate. The scientific principles underlying the 4R are:

— THE RIGHT SOURCE – Ensure a balanced supply of essential nutrients taking into account both naturally available sources and the characteristics of specific products, in forms available to plants.

— THE RIGHT DOSE – Assess and make decisions based on the supply of soil nutrients and plant demand.

— THE RIGHT TIME – Assess and make decisions based on the dynamics of crop uptake, soil supply, nutrient loss risks and logistics of field operations.

— THE RIGHT PLACE – Consider root-soil dynamics and nutrient movement, and manage spatial variability in the field to meet specific crop needs and limit potential field losses.

For more information on 4R, please consult:

https://nutrientstewardship.org/4rs/;

http://www.ipni.net/4r;

https://www.sprpn.org/issue-briefs;

https://4rsolution.org/fr/a-propos/

https://www.yara.us/crop-nutrition/podcasts/4r-nutrient-stewardship/

and https://edis.ifas.ufl.edu/publication/HS1264

Table 11 — Examples of 4R key scientific principles (good) and associated practices

	THE FOUR RS (4R)			
	SOURCE	DOSE	TIME	PLACE
EXAMPLES OF KEY SCIENTIFIC PRINCIPLES	• Ensure a balanced supply of nutrients • Responding to soil properties	• Evaluate the supply of nutrients from all sources • Assess the plant's needs	• Assess the dynamics of plant uptake and soil supply • Determine when losses are likely	• Identifying the distribution of the root system • Managing spatial variability
EXAMPLES OF PRACTICAL CHOICES	• Commercial fertilisers • Farmyard manure • Compost • Crop residues	• Soil analysis for nutrients • Economic calculation • Balance of plant withdrawals	• Before sowing • At sowing • At flowering • At fruiting	• On the fly • Banded/ injected • Application application variable

Source: 4R Plant Nutrition – International Plant Nutrition Institute

Since the crop is short-cycle, the bean must be treated with fertilisers providing the elements in easily assimilated form.

Beans develop nodules at the roots, which fix nitrogen. However, for maximum yield, this nitrogen does not replace mineral nitrogen inputs.

If *Rhizobium* inoculants are used, initial fertiliser applications should be reduced in nitrogen content, as excess nitrogen impedes *Rhizobium* development in bean roots. Healthy *Rhizobium* nodules are pink inside and appear to be attached to the outer surface of the root. They should not be confused with the root-knot nematodes, which are smaller, less rounded and appear to be integrated into the root structure. Roots with many *Rhizobium* nodules are less susceptible to root-knot nematodes.

Since beans are very sensitive to salinity, fertilisation should be fractionated during cultivation to reduce leaching or volatilisation losses. It must be applied without touching the foliage to avoid burns. Application should be followed by a superficial incorporation combing (at the time of hoeing).

It is recommended to:

— water following fertiliser application and to monitor soil moisture because the plant only absorbs nutrients dissolved in water;

— keep fertiliser bags dry.

Another solution is to apply soluble fertilisers on drip irrigation lines or spray foliar nutrients on the foliage. Do not apply these fertilisers during hot hours of the day to prevent the leaves from burning.

It is advisable to use simple and practical units of weight and measurement (benchmark) for fertilisers and organic matter. A 10 l bucket, for example, normally contains 10 kg of peanut powder and 7.7 kg of dry pig manure, 1 tea glass contains +/- 80 g of fertiliser (10.10.20, 14.7.7, 6.20.10) and 1 matchbox contains +/- 20 g of these fertilisers.

ORGANIC MANURE

Significant yield increases can be obtained from adding significant amounts of organic matter to the soil.

To boost the growth of green bean crops in Senegal, given their easy assimilation, peanut powder or chicken droppings are often used as an organic amendment as a starter once the seedlings emerge. Organic matter is spread manually by passing through the planting lines, or by a coupled or towed mechanical spreader.

MINERAL MANURE

Mineral manure is applied manually on small farms, but is usually distributed by a mechanical animal traction or motorised spreader. It should be noted that, with the current adoption of localised, drip irrigation, the aim is to distribute fertilisers during irrigation (fertigation) by optimising the quantities, the dose, the time and the location near the roots.

NITROGEN (N)

Nitrogen input is necessary, especially at the beginning of cultivation, but never in excess. A late input lengthens the cycle, decreases the yield and creates conditions conducive to the development of rust; excess nitrogen favours the lodging of plants and the dripping of flowers.

The dose ranges from: 50 to 100 kg/ha of N in ureic (urea), ammoniacal or nitric (nitrate) forms, depending on the stages of bean development (ureic at emergence, growth; ammoniacal and nitric at setting and maturation).

SODIUM NITRATE IS TO BE AVOIDED

However, it is important to maintain a certain balance: N/K20 which should be between 1/2 and 1/3 at the time of bottom dressing and sometimes top dressing.

PHOSPHORUS (P_2O_5)

Phosphorus promotes solid rooting (important in sandy soils); given its reduced mobility in the soil, it must be available in assimilable form from the emergence stage.

In mineral soils, the optimum pH for P_2O_5 availability is 6.5. Below 6.1 above 7.4, availability decreases, which leads to a greater input of bottom dressing and top dressing input may be necessary.

The recommended dose ranges from 70 to 100 kg/ha of P_2O_5 in the forms of ammonium phosphate, diammonium phosphate, triple superphosphate and phosphogypsum, at the time of bottom dressing, possibly supplemented with top dressing in the case of certain soils: see above the note concerning pH.

POTASSIUM (K_2O)

The recommended dose ranges from 100 to 200 kg/ha of K_2O in the forms: potassium sulphate and potassium nitrate at the time of bottom and top dressing. Potassium chloride should be avoided given the sensitivity of the bean to chlorine. Potassium remains very important, determining the quality of the pods that will be produced. Hence the need for a correct input from the setting of the flowers to the maturity of the pods.

CALCIUM (CaO)

Calcium is supplied by the soil, organic matter, superphosphate and phosphogypsum. Thomas slag, phosphal and natural phosphates are sources of CaO inputs and are to be used for medium-term, rather than immediate, action.

MAGNESIUM (MgO)

The recommended dose ranges from 10 to 30 kg/ha of MgO in the form of magnesium sulphate. The decomposed organic matter is also a source of input. The input periods are the bottom dressing or foliar spraying periods.

Please note that, at certain levels, the ratio of percentages between Ca, Mg and K can induce mobility blockages, and phytotoxity.

TRACE ELEMENTS

Inputs are possible via the drip irrigation system, by burial or by foliar spraying to correct possible deficiencies of:

- manganese: the use of Thomas slag can reduce this frequent deficiency in soils with a pH of > 7,
- zinc: this can be remedied by spraying on the leaves (from sowing + 25 days, 40 days and possibly 60 days) at low pressure, a 1% zinc sulphate solution neutralised by 0.5% lime,
- molybdenum: especially in leached, acidic, sandy soils,
- copper: if possible, use foliar fertiliser containing copper.

Table 12 — Possibilities of correction of the main deficiencies

DEFICIENCIES IN	CORRECTIVE FERTILISERS	BURIAL IN KG/HA	FOLIAR FERTILISER IN G/100 L
Mn (1)	Manganese Sulphate	-	200
Mo	Ammonium molybdate	-	2
B	Sodium borate (11% B)	10	300
Cu (1)	Copper sulphate	30	-
	Copper oxychloride	-	100
Fe	EDDHA (6% Fe)	15	-
	Iron nitrate	-	500
Zn (1)	Zinc sulphate	50	100
Mg (2)	Magnesium sulphate	-	1,500
	Magnesian fertiliser		
S (2)	Sulphate-based fertilisers	depending on the crop	-

(1) It should be noted that manganese, copper and zinc deficiencies can be combated with fungicides containing these elements.
(2) Although these are major elements, for convenience, we also address their deficiency here

Examples of fertilisation protocols are given below but, ideally, the fertilisation protocol should take into account soil analysis and the level of intensification of the crop.

EXAMPLES OF FERTILISATION PER HECTARE

These examples correspond to inputs, per hectare of actual crop. In case of localised applications on the boards, the quantities can be reduced by 25%.

Table 13 — Examples of fertilisation

FERTILISATION	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3
BOTTOM			
	10 to 20 t organic matter	10 to 20 t organic matter	10 to 20 t organic matter
	200 to 400 kg 10.10.20	200 kg potassium sulphate + 150 kg diammonium phosphate (DAP)	200 kg potassium sulphate + 150 kg diammonium phosphate (DAP)
TOP			
S +20 DAYS	150 to 300 kg 10.10.20	150 kg potassium nitrate + 50 kg diammonium phosphate	150 kg potassium sulphate + 150 kg diammonium phosphate
S +25 DAYS	Foliar spray	Foliar spray	Foliar spray
S +40 DAYS	150 to 300 kg 10.10.20	150 kg potassium nitrate	50 kg urea + 20 kg potassium sulphate
S +40/45 DAYS	Foliar spray	Foliar spray	Foliar spray
(S +60 DAYS)	(Foliar spray)	(Foliar spray)	(Foliar spray)
INPUTS IN NPK UNITS	50 to 100/50 to 100/100 to 200	76/92/232	77/138/235
N/K_2O BALANCE	1/2	1/3	1/3

OTHER SOURCES OF INFORMATION FOR BEAN FERTILISATION

https://www.haifa-group.com/complete-recommendation-fertilization-beans
https://www.horticulture.org.za/fertilizer-green-beans-bush-beans/

6.6. POLLINATION

Bean flowers are self-pollinating. It is not normally necessary to bring in bees or other pollinating insects.

6.7. POST-HARVEST MANAGEMENT OF THE PLOT

Bury the remains of plants with the roots. In the event of infestation, remove plants and roots to avoid contaminating other crops and to avoid leaving crop residues that can serve as a reservoir of soil enemies.

Do not allow livestock to graze on plots at the end of the crop to avoid contamination with *E. Coli* in the following crop.

CROP MAINTENANCE CHECKLIST

TO REMEMBER FOR CROP MAINTENANCE

WATER

- Irrigation
  - The dose of water applied at each irrigation will vary according to the stage of development of the crop, the type of soil (sandy, clayey, loamy, etc.) and the climatic conditions of the production area
  - In general, the needs, which depend on the PET (potential evapotranspiration) and the Kc of the crop, are 60 to 100 m^3/ha or 6 to 10 mm of water per day for one hectare of beans. Of course, this supply volume also varies according to the type of irrigation.
  - The frequency of irrigation will depend on the stage of the crop, soil type and climate. On sandy soils, irrigations will be more frequent than on heavier soils.
  - Drought during pre-flowering is the most damaging to the final yield
  - In periods of high heat, it is best to irrigate by sprinkling at the beginning of the day
- Drainage
  - On low permeability soils, the soil should be prepared in such a way as to ensure drainage that will avoid drowning roots in arable strata and avoid salt accumulation

TILLAGE

- It should be very superficial so as not to damage the roots that are at a shallow depth
- It must be performed at least twice after the emergence of plants

WEED MANAGEMENT

- For the dwarf bean, in principle, it is sufficient to control the weeds until the end of the first half of the crop cycle (mid-crop).
- However, it will be necessary to prevent the weeds from going to seed
- Weeding can be done by mechanical means: spiked chain harrow for large areas or wheel hoe for small areas
- Several herbicides can be used but local legislation and MRLs of the markets where production is to be exported must be taken into account

CROP MAINTENANCE CHECKLIST

VEGETATION COVER

- Vegetation cover is recommended when suitable cover plants or plant waste (for mulch) are available
- A cover of *sorghum* mulch makes it possible to control most weeds including *Cyperus*

FERTILISATION

- It must take into account **the principles of 4R (right source, right dose, right time, right place)** to ensure the best possible efficiency.
- Since the crop is short-cycle, the bean must be supplied with fertilisers providing the elements in easily assimilated form
- Beans develop nodules at the roots, which fix nitrogen. However, for maximum yield, this nitrogen does not replace mineral nitrogen inputs
- Yields can be increased considerably as a result of significant organic matter input into the soil. The input of organic matter is a basic principle of integrated soil fertility management and makes the use of mineral fertilisation more efficient
- **Mineral manure**
    - Nitrogen: Its input is necessary, especially at the beginning of cultivation, but never in excess. Late intake lengthens the cycle, decreases the yield and creates favourable conditions for the development of certain diseases
    - Phosphorus: Phosphorus promotes solid rooting (important in sandy soils), so it must be present in assimilable form as soon as it emerges.
    - Potassium: Potassium chloride should be avoided given the sensitivity of the bean to chlorine

POLLINATION

- It is not normally necessary to bring in bees or other pollinating insects

POST-HARVEST MANAGEMENT OF THE PLOT

- Bury the remains of plants with the roots
- In case of infestation, remove plants and roots and destroy them
- Do not allow livestock to graze on plots at the end of the crop

7

PEST AND DISEASE MANAGEMENT

In integrated production, pest control is based on integrated pest management (IPM). See the training manual "Integrated pest management" for more information on integrated production.

This part of the document first explores the main principles of an "integrated" management before useful elements are provided for each pest, to help understand and control them as effectively as possible.

Pest control is part of the general framework of "Good Agricultural Practices" (GAP) by respecting the general requirements as set out, for example, in the Global GAP reference.

The basis of Global GAP is Good Agricultural Practice, which is also the backbone of good agriculture. Replacing pesticides with biocontrol products will not improve crop protection if the grower does not also adopt GAP.

Indeed, without GAP, crop damage can increase if pesticides are reduced, as biocontrol products take longer to deliver their protection than conventional products. Even chemical controls will be less effective if GAP are not followed.

GAP can potentially reduce the need for chemical protection of crops because it involves ensuring good growing conditions through optimal fertilisation and irrigation programmes and effective aeration of crops in the root zone and vegetation cover. Not only will the plant be less stressed and therefore less susceptible to pests and diseases, but the environment in the soil and canopy will also be less favourable to the development of the pests.

The ultimate goal is to supply a healthy, high-quality product (i.e. meeting quality standards) that is also affordable. It is essential to associate all available cultivation techniques (variety selection, rotation, staggered planting, tillage, rational fertilisation, etc.) with the specific control methods recommended to achieve optimal growth and protection of the crop, with due consideration for the role and impact of agronomic and ecological factors.

The effect of the measure(s) chosen will have to be evaluated from all points of view, allowing the balance between the "costs" and the "benefits" of the measure(s) to be applied:

— efficiency and profitability for the grower,
— selectivity for culture and non-target organisms,
— compliance with MRLs (consumer safety),
— side effects for the operator, domestic and wild animals,
— effects on the environment (soil, water, plants, air),
— effects on growing techniques,
— and even, the resulting social consequences. (*e.g.* freeing up working time when using herbicides).

The grouping of the different cultivation practices in a synoptic table makes it possible to better illustrate that certain practices make it possible to contribute to the fight against several pests at the same time. On the other hand, it is useful to also indicate whether certain practices favourable to the control of one pest may, on the contrary, favour other pests. For example, sprinkling irrigation reduces attacks by aphids and spider mites but may promote diseases such as *anthracnose*, rust and *bacteriosis*. Below is an example of a synoptic table for 10 pests.

Table 14 — Synoptic table of control methods against 10 pests

CONTROL METHOD	BEAN FLY	APHIDS	WHITEFLY	THRIPS	SPIDER MITES	*MELOIDOGYNE*	*RHIZOCTONIA SOLANI*	*ANTHRACNOSE*	RUST	*BACTERIOSIS*
PRIOR CHOICES AND PLOT PREPARATION										
Infection-free seed							√	√		√
Resistant or tolerant varieties				√				√	√	√
Avoid planting near sensitive crops	√	√	√	√	√	√		√		
Avoid plots with too much shade cover							√	√	√	√
Avoid areas with persistent fog									√	
Rotate crops	√			√	√	√	√	√	√	√
Green fertiliser in preceding cultivation						√				
Light to semi-heavy soil (no compacted and asphyxiating soil)	√						√			
Intensive tillage (deep) before sowing	√			√						
Tillage to aerate the soil							√			
Soil solarization				√		√				
High level of well-decomposed organic matter						√	√			
Avoid potentially infected waters						√				
Avoid salt water							√			
Intercropping with corn	√			√					√	
Intercropping with sunflower				√					√	
Intercropping with chives/garlic		√								
Intercropping with *sorghum*		√								
Repellent plants on the perimeter of the plot			√							
Presence of flower strips	√	√	√	√	√					
Presence of hedges	√					√				

CONTROL METHOD	BEAN FLY	APHIDS	WHITEFLY	THRIPS	SPIDER MITES	*MELOIDOGYNE*	*RHIZOCTONIA SOLANI*	*ANTHRACNOSE*	RUST	*BACTERIOSIS*
PRIOR CHOICES AND PLOT PREPARATION										
Presence of windbreaks			√		√	√				
Regular cleaning of agricultural equipment						√				√
Flooding of the ground before cultivation in flood-prone ground						√				
Ensure soil drainage							√			
PLANTING										
Do not sow too deep	√						√			
Avoid high density		√	√				√	√	√	√
Installation of insect net after sowing			√							
MAINTENANCE										
Mound the plants	√					√				
Ensure good fertilisation	√								√	
Compensation by foliar fertilisation							√			
Ensure good irrigation	√						√			
Mulching	√									
Grubbing of severely affected plants	√						√	√	√	
Grubbing of plants at the end of production	√	√	√	√	√	√	√	√	√	√
Regular weeding of the plot and surroundings		√	√	√	√			√	√	√
Sprinkler irrigation		√			√			✕	✕	✕
Drip irrigation							√			√
Avoid excess nitrogen (balanced nitrogen fertilisation)		√	√		√					
Limit the movement of workers in the plots								√		
Tillage at the end of the crop							√			√

√ = practice favourable to the control of the pest.
✕ = practice that can favour the development of the pest.

7.1. INTEGRATED PEST MANAGEMENT

7.1.1. CONSIDERATION OF ENVIRONMENTAL CONDITIONS

Several elements related to the surroundings, that is to say to the environment in the broad sense, interfere in many different ways with the relations between cultivated plants and the pests, not least the climatic parameters (possibly including the microclimate that settles in a crop as a result of its management or sheltering) such as temperature, relative humidity, sunlight, photoperiod, difference between day and night temperatures, etc.

For example, cultivation under cover from rain can limit the incidence of diseases such as *bacteriosis* or alternariosis, but the absence of the mechanical effect of rain on the leaves favours the installation of certain stinging/sucking insects, such as aphids or spider mites that are no longer disturbed by the rain. Fungi such as *Pythium* are favoured by hot and humid weather. On the other hand, a fungus such as *Macrophomina* prefers warm, dry conditions.

Soil structure, texture, depth, pH, organic matter content, moisture and salinity can also play an important role in the development of crop pests, particularly those present in the soil. For example, soils with persistent high humidity are conducive to bean seed fly development, nematodes and fungal diseases such as *Fusarium* and *Rhizoctonia*.

7.1.2. PEST IDENTIFICATION AND MONITORING

It is important to clearly identify the different pests present in a field in order to implement the most appropriate control. A description of the pests potentially present is given under point 7.2. of this document.

There are several possible ways of assessing the extent to which auxiliaries are present on crops. Examples are available for some pests (whiteflies, aphids, thrips, etc.) in Appendix 7 of the COLEAD handbook on managing biodiversity on farms.

The following information relates to Kenya. The remaining principles are valid for other production areas but the instructions on observations must be adapted to the context of each production area.

INTRODUCTION

Integrated management is about exploiting the presence of crop auxiliaries. It therefore requires more detailed monitoring than simple chemical control, since the degree of biological control is directly influenced by the balance between the number of beneficial insects and that of pests. The crop is better off if there are only 5 pests for one useful insect than if there are 500. This explains the need for a crop sampling method to estimate the actual number of major pests and auxiliaries.

Weekly flowsheets must be completed for each field. Some data from these sheets are transcribed every week on a weekly summary sheet, which allows the grower to compare progress from one week to the next and provides objective guidance for choosing the measures that need to be taken to protect the crop and to assess the level of progress. Examples of weekly and summary sheets are provided in Appendix 2. One factor to consider is the average number of pests present per week. However, the average number of pest should not be based solely on the average, as it may increase from week to week, while the ratio of pests to beneficial insects shows positive signs of balance. If the ratio of pests to beneficial insects in the field was 150 last week, but only 60 this week, the grower will see that the balance is leaning in favour of beneficial insects. This means that the biological control is in progress and justifies not resorting to spraying, but allowing the biological control to continue.

The following information is intended to steer monitoring in IPM and should be reinforced by ad hoc training dispensed by experienced service providers.

They will assess the presence of the pests and some of their respective natural enemies listed below. For other pests refer to the information given under point 7.2.

Table 15 — Pests and natural enemies mentioned in the monitoring methodology

PEST	NATURAL ENEMIES
Leaf miner	*Diglyphus*
Whitefly	*Encarsia*
Thrips	/
Spider mites	*Phytoseiulus* and *Amblyseius*
Aphids	/
Grey worm	/
Caterpillars[1]	/
Diseases (rust, *Fusarium*, fat, etc.)	/
Root-knot nematodes[2]	/
Bean fly[3]	/

Caption:
1. For more details on the monitoring of the different caterpillar species, refer to the data in the texts by pest under point 7.2 of the document.
2. A more detailed monitoring methodology is developed under point 7.2 for root-knot nematodes.
3. For bean fly, a more detailed methodology is presented under point 7.2.

PREPARATION

Observers should be equipped with:

- a clip-on clipboard for easy note-taking,
- observation sheets,
- a piece of clean white paper over which to shake the flowers (to count the number of thrips),
- a magnifying glass with a magnifying factor of ten;
- a pencil,
- a calculator,
- a bag to collect the samples,
- enough markers for sensitive areas (visible red markers. Do not use yellow as this colour attracts pests).

A good quality automatic counter is a useful tool that speeds up the counting process and reduces errors and fatigue.

INSTRUCTIONS FOR OBSERVATIONS

The area to be observed should be as uniform as possible (slope and appearance of the field, variety of crop, etc.). Too many variations will result in an overestimation or underestimation of the number of pests or diseases. If necessary, divide the crop into sections if they are likely to have very different rates of pests and diseases.

The maximum area to consider as a unit is about one hectare – unless it is very uniform.

For one hectare, allow approximately two hours per block for observations by a trained and experienced observer (a "block" equals twenty lines of observation).

Pests are used to moving around the crop at various times of the day. The block should be inspected at least once a week, ideally twice, preferably at the same time of day, in order to accurately compare pest levels. If the observation is not made at a more or less identical time of the week on the same field, the observer could note that the pests are decreasing, when they may have simply hidden or fled the crop at that time. This is especially true for thrips.

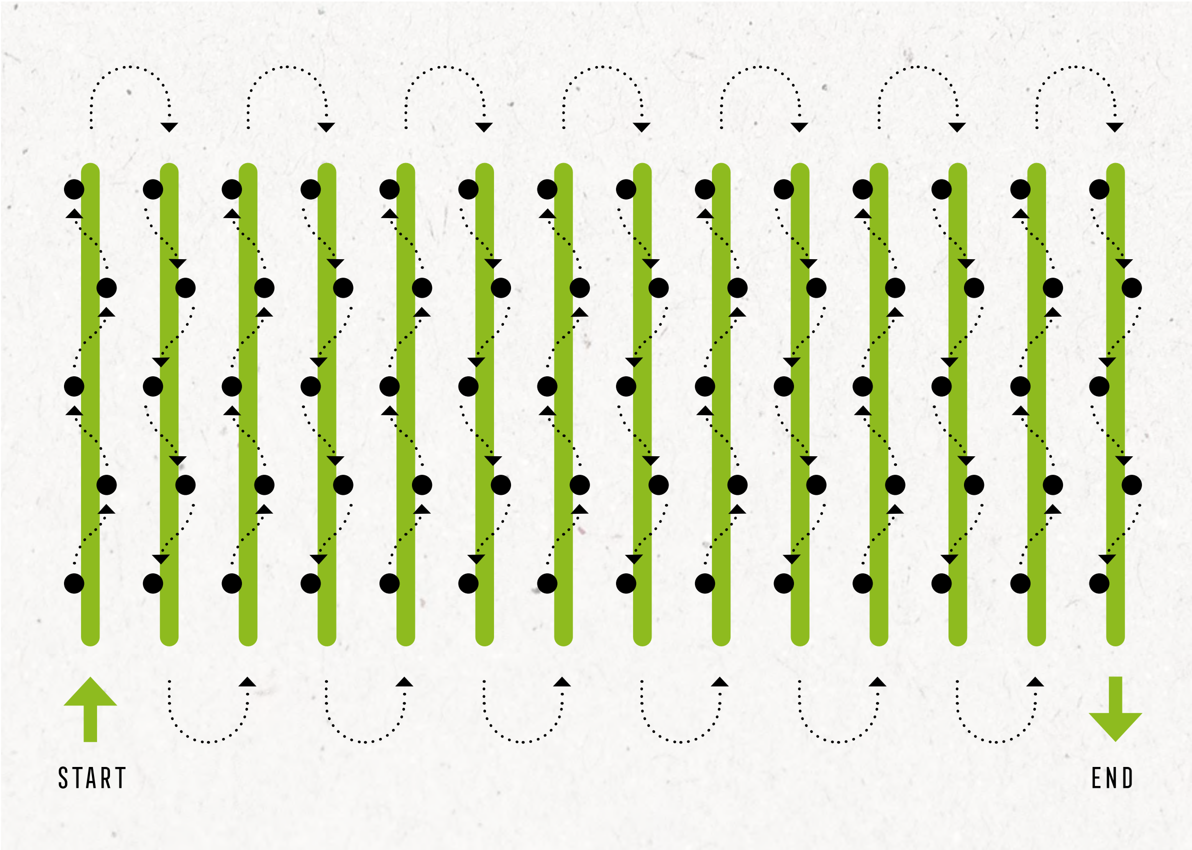


Figure 17 — Monitoring scheme for green bean

Twenty sampling “rows” are chosen at regular intervals from all the lines of the field (see diagram). Rows are aisles between planted lines. Each row is marked and numbered so that data from the same rows can be compared week after week to check the evolution of infestations.

These rows are whole rows and not marked areas in the field. Observation data is generated by moving along each row.

Walk along the path next to the sampling row and stop at five observation points, which you will choose at the plant lines on either side of the path (for example, sampling in a zigzag pattern along the sampling row, as the observer advances towards the end of the row). Distribute the sampling points along the entire length of the line (see diagram).

The zigzag pattern is justified by the fact that, in row crops, one side of the line can receive more sun and heat – or more wind and rain – than the other side, which affects the rate of pests and diseases. Taking samples in a zigzag pattern along the row makes it possible to observe leaves on both sides of the plant lines. The possible differences depending on the side of the lines are thus taken into account in the average.

At each observation point, make the following observations first before taking a leaf from the base and top of the plants for further inspection. At the observation point, note the total number of the following easily visible pests on approximately one square metre of the green bean bed:

- adult miners,
- adult *Diglyphus*,
- adult whiteflies,
- adult *Encarsia*.

Add the numbers from each of the five observation positions on the line and enter the totals on the weekly observation form. The observer may need blank sheets to record the total for each of the five observation points before reporting the line totals on the form.

When the observer has observed, at the various observation points, the above-mentioned pests – which are likely to escape if the leaves are overhandled – they can then collect two leaflets (not a whole trifoliate leaf) from the same zone ((10) in all: (2 leaflets per plant x 5 plants) per sampling row or (200 (10 per row x 20 rows) per block) to count the number:

- of large larvae of greenhouse whiteflies (>L2),
- of black larvae infested with greenhouse whiteflies,
- thrips on the leaves,
- red spiders.

If the crop is still very young and the plants have few leaves, the above observations can be made without taking leaves, simply by turning the lower surface of the leaf upwards. If red spiders are discovered during these checks, they should also be counted in the weekly level of presence of red spiders.

In addition, the observer should look for leaves damaged by red spiders as they walk along the line and inspect these leaves to identify the number of:

- adult *Phytoseiulus*,
- adult *Amblyseius*,
- adult red spiders.

Normally, predators of red spiders are only present when they are numerous (and damage the leaves). This is when the grower will fill in the predator/red spider ratio columns in the weekly reference form.

As soon as flowering begins, the observer begins to look for traces of thrips on the flowers. There is no need to collect the cluster of flowers to inspect it. Place a piece of white paper under the cluster and shake it firmly three times to dislodge the thrips in the flower. Inspect two flower clusters per observation point for thrips in the flowers.

Bean aphid tends to be sporadic. The observer can make observations along the referencing row to detect these pests, the diseases it causes and beneficial insects.

By walking along the entire length of the referencing row, it is easy to observe symptoms of diseases, the presence of grey worms, etc., on all the plants in the line.

- Bean aphid colonies (it is not necessary to count all aphids in the colony. The number of colonies per sampling row will suffice.).
- Total number of aphid predators in each colony (ladybirds, *Aphidius*, syrphids, etc.). It is not necessary to distinguish the various predators. Simply calculate (at the bottom of the column on the referencing sheet) the combined total of predators and aphids versus the number of aphid colonies in each sampling row.
- Total number of caterpillar larvae (leaves damaged, easy to detect).
- Total number of chrysalids.
- Total number of adult butterflies observed.
- Presence of diseases (rust, etc.).
- Presence of grey worms, root-knot nematodes, bean flies, etc.

FINAL CHECKS

When all the sampling rows have been observed, the observer will perform a "final check" by walking along EACH row in both directions in order to comply with the following indications.

- Clearly indicate all new areas significantly attacked by aphids (infestation rate < 10%) with markers and indicate their positions on the block map. These should be treated locally as soon as possible.
- Check all areas that have previously been marked as significantly attacked by aphids. If their infestation rate is greater than 10%, remove the marker.
- Indicate on the block maps the areas susceptible to diseases (bean fat, *Fusarium*, etc.). These guidelines will allow instructions to be drawn up for a localised spraying to control bean fat or a general spray depending on the risks (wet weather and more than four areas per block affected by the disease). *Fusarium* cannot be treated, but sensitive areas will be recorded in the block history to be treated with *Trichoderma* after harvesting and amended with organic matter. Add up the disease-sensitive areas (identify the type of disease) and indicate this number on the front of the referencing card;
- Indicate on the block maps the areas sensitive to red spiders. These will need additional *Phytoseiulus* (introduction rate of at least 1/200). Estimate the total number of red spiders per sensitive area and record this number on the front of the referencing sheet. Collect at least ten leaflets from this area and determine the *Phytoseiulus*/spider ratio. As soon as this ratio falls below 1/10, the problem should soon disappear. Record the data for red spider sensitive areas on a separate referencing sheet and assign a number to each area. These will be referenced weekly until the problem is eradicated.

- Note the presence of live caterpillars observed during the final check (indicate this number on the front of the referencing sheet).
- If necessary, carry out a general spraying of *Bacillus thuringiensis* or other appropriate spraying, as these pests are difficult to spot and should be controlled when they are not too numerous.

7.1.3. USE AND PROMOTION OF NATURAL PEST ENEMIES

Biological control (biocontrol) is a method of controlling a pest by using or promoting its natural enemies, or a disease by promoting its antagonists. Biological control is mainly directed against pests (insects, mites and nematodes). Predatory, parasitoid or infectious organisms (entomophagous fungi, virus diseases) limiting the frequency and severity of crop pests are considered to be natural enemies of crop pests.

At the scale of a farm, the response strategies take various but complementary forms.

THE PRESERVATION AND ENHANCEMENT OF THE ROLE OF INDIGENOUS AUXILIARY ORGANISMS

The development of intensive agricultural practices is generally unfavourable to compliance with these regulatory mechanisms, since the transformation of natural ecosystems usually leads to a reduction in their biological diversity. It is necessary to design a rational management of the parcellal structure of farms in order to reserve safe areas favourable to the maintenance of populations of auxiliary organisms (hedges, grassy devices, shelters, nectariferous plants). It is necessary to limit the use of adverse practices (*e.g.* grubbing of hedges, elimination of fallow land, ploughing, etc.), and plant protection treatments with non-selective products, on refuge areas, at the time of flowering, etc. It is also necessary to preserve the life of the useful organisms in the soil, namely by maintaining a good organic matter content and by disturbing the various layers of the soil as little as possible, for example by avoiding ploughing.

IPM involves the use of crop auxiliaries, such as predators and parasites.

The presence of parasitoid *hymenoptera* can be favoured on a farm by the presence of flowers that supply the adults with useful nectar. For this purpose it is advisable to plant flower strips and/or hedges with gaps between them of maximum 50 m. Hedges need to be multi-tiered and diversified in terms of species to play their full role.

Several umbelliferous plants such as dill and coriander are particularly useful. Several other plant families are useful for promoting the presence of auxiliaries such as syrphs. These include plants of the family *Asteraceae* but also of family *Euphorbiaceae*. Among the *Asteraceae* that are known in tropical environments are *Artemisia*, *pyrethrum*, *Tagetes*, *Bidens pilosa* (medicinal plant), sunflower, etc. For more information consult the COLEAD training manuals "Biodiversity Management" and "Integrated Pest Management".

THE AMPLIFICATION OF THE ROLE OF AUXILIARY ORGANISMS BY FLOOD RELEASES

This strategy, which involves releasing auxiliary organisms in large quantities at the right time and place, uses biological treatment alongside conventional treatments. The recent expertise in the mass production of auxiliary organisms (*e.g.*: mass production carried out on eggs of a surrogate host) has promoted the application of this strategy. In green bean cultivation, the use of *Encarsia formosa* against whiteflies and *Diglyphus* against leaf miners are a case in point.

More information on biological control can be found on page 15 of COLEAD's "Integrated Pest Management" training manual.

7.1.4. ADAPTED CROP PRACTICES

Different practices contribute to pest control. These are generally prophylactic practices aimed at preventing the appearance and spread of a pest or the aggravation of damage. There are practices that avoid the pest, others that disrupt the biological cycle of the pest, others that allow plants to better defend themselves and others that encourage the enemies of the pest.

For example, avoiding setting up a crop near a plot that contains a host plant of a pest avoids the arrival of the pest in the plot or at least reduces and delays its appearance.

A long rotation with non-host crops disrupts the life cycle of a pest; this is particularly true for soil borne diseases. Avoid cultivating in a field recently planted with green beans (a rotation of 3 years is considered a minimum; ideally rotations of at least 5 to 6 years are recommended for soil fungi or nematode-infected land).

Effective crop maintenance (rational fertilisation, regular and adapted irrigation etc.) allows plants to better defend themselves against most pests. The presence of hedges, flower strips and intercropping help to promote the development of most natural enemies of pests.

The practices to be implemented can be classified into 4 distinct groups: the pre-planting choices; the preparation of the plot and its environment; the planting, the maintenance of the crop.

PRIOR CHOICES

SEED QUALITY

Good quality seed will be free of any signs of insects (*e.g.* weevils or wild or dead/living insects in the package or holes in the seed) or disease (*e.g.* powdery mould on the seed). The seeds should have a firm, unshrivelled and stain-free skin.

The grower must either return the seed to the supplier and replace it with better quality seed before planting (if it is not of good quality), or sort the seed and remove the poor quality seed before storing or planting.

Each batch of seed must be accompanied by a certificate of analysis stating the following:

- guaranteed germination percentage,
- the absence of seed-borne pathogens,
- the harvest date,
- the date of expiry.

It is not recommended to buy seeds that do not have a label on their packaging. If the pack of seeds is opened but not used immediately, it must be stored properly and the label must remain with the correct seed batch, so that it can be traced back to the source of the seeds in case of a problem.

If the seeds are not of good quality, they will take longer to germinate. It is important that germination and emergence take place rapidly, because the soil is an environment conducive to infection of young soft tissues with fungal diseases. The longer the emergence process, the longer the time available for infection.

After emergence, the plant no longer depends solely on the food reserves contained in the seed, as it makes new nutrients for its growth from the leaves. It is then better able to resist the attacks of parasites and diseases.

PROPER STORAGE OF BEAN SEEDS

Seed producers dry their seeds after harvest to maintain shelf life. To maintain the guaranteed germination rate, seeds should be stored in airtight containers. The storage time can be reduced by half if the equilibrium moisture increases by only 10%.

Store seed packets in glass or plastic containers with airtight lids. This is very important when the package is opened but not all the content is used immediately.

Store large quantities in a ventilated room, but free of insects and rats, where the temperature will not exceed 20°C.

GERMINATION TEST

Growers can perform their own germination tests before planting seeds.

- Place two sheets of newspaper on a table and slowly wet the paper with a cup of water. Allow the water to be soaked up and squeeze out excess moisture from the paper.
- Open the paper and place 100 seeds evenly on the paper.
- Roll the paper into a tube to enclose the seeds and place it in a plastic bag.
- Leave the test in a warm place (preferably 30°C), away from direct sunlight for 4 days to allow the seeds to germinate. The top of a refrigerator is a suitable warm place.
- Remove the seeds and count the number of seeds that have germinated after 4 days. Record the number of germinated seeds and remove them from the roll.
- Roll up the wet newspaper again with the remaining unsprouted seeds and leave it for another 3 days – note the total number of sprouted seeds.
- This is the germination percentage. It must be greater than 90% (at least 90 out of 100 seeds germinated).

THE SUITABLE VARIETIES

It is best to choose varieties with resistances and/or tolerances to the main crop enemies of the production area. Green bean varieties most often exhibit resistance or tolerance to: *anthracnose*, common mosaic, rust, *Pseudomonas bacteriosis*.

THE QUALITY OF IRRIGATION WATER

Water can be contaminated with nematodes, bacteria and fungi that can cause disease in green beans. River water is the most contaminated source of irrigation water. Drilling water is the least contaminated source.

If possible, river water should be pumped into a holding tank to allow nematodes and microbes to settle to the bottom before pumping water from the upper layers of water. Ideally, water can be filtered before use, but it requires a lot of energy and investment in equipment.

PLOT PREPARATION

A good preparation of the plot and the landscaping of its immediate environment will ensure good growth conditions for the crop (better defence of plants against aggressions), avoid favourable conditions for pests, strengthen the action of antagonists and other natural enemies and hinder the entry of certain pests. Two examples are given below.

DRAINAGE

Roots need air in the soil to breathe and grow properly. Excess water in the soil fills the spaces with water instead of air and hampers root growth. This will not only affect yield, but also promote root infection by soil borne diseases such as *Fusarium* and *Pythium*.

SOIL PH

Soil analysis tells the grower what the pH of the soil is. Beans need an optimal pH close to 6.5. Lime should be applied to acidic soil (pH less than 4.5) to raise the pH to 6.5. Soil analysis will give an indication of the amount of lime needed. Lime application should only be necessary every 3 years. It takes about 12 months for the applied lime to change the pH of the soil. Try not to apply more than 2 tonnes of lime per hectare each time. If more is needed, try applying it over several growing cycles. Be careful, excessive use of DAP fertiliser will make soils acidic.

PLANTING

At this stage, some adapted practices allow seeds to be sown in good germination conditions and plants to develop optimally while allowing easy applications of PPPs and avoiding conditions favourable to pests. Below are some examples of these practices.

SEEDING DENSITY AND DEPTH

The distance between plants affects not only the final yield per unit area, but also the length of time the leaves remain moist after rain or spraying. If the plants are close to each other, the air circulation in the foliage is reduced, and the leaves remain moist for longer. Long periods of leaf moisture promote leaf diseases such as angular spot.

Recommended distances between seeds along a line range from 12 to 18 cm (5 to 7 inches) and between rows range from 25 to 30 cm (10 to 12 inches) – depending on the bean variety.

Since monthly rainfall can vary predictably with the season, it may be wise to reduce plant density for crops that will be developing during the rainy season. This will allow more air to circulate and dry the leaves faster – thus reducing the pressure of diseases.

The grower can change either the distance between seeds in the same row or the distance between rows. A simple on-farm experiment, with some of these variations, will quickly help the grower observe the most profitable plant spacing. Optimal distances vary depending on variety, soil type and season.

Seeds should be planted to the optimum depth for the soil type; see under point 5.2. If they are planted too deep, the seedling will take longer to emerge and the stem will be thinner. This will produce a weaker plant and will also increase the time available for soil-borne diseases, such as *Fusarium*, to infect the seedling. Seeds that are planted too deep and receive too much water to promote germination will be prone to "seedling melt", a disease caused by infection of seedlings by soil pathogens such as *Pythium* and *Phytophthora*.

MAINTENANCE

Proper maintenance of the crop until the end of the harvest avoids the excessive development of several pests. Some examples are given below.

IRRIGATION

The irrigation method is of great importance for the control of pests. For example, not wetting the leaves (by gravity-fed irrigation or drip irrigation) limits the risk of developing diseases that need water on the leaves to grow (*Xanthomonas*, *Alternaria*, etc.). On the other hand, it provides ideal conditions for the development of other enemies (*Tetranychus*, *Bemisia*, aphids, etc.). Gravity-fed irrigation also has the disadvantage of transmitting enemies such as *Fusarium* and *Meloidogyne* through irrigation channels.

The highest risk of soil-borne diseases will occur if the grower is not able to control the amount of irrigation water applied to the crop. Furrow irrigation is the least controllable irrigation method and drip irrigation is the most controllable method.

Drip irrigation is the preferred method of irrigation, and kits for small farmers can be purchased or manufactured by the grower. Dripper lines should be placed with the holes facing skywards and in line with the rows of plants.

Spray irrigation is a potential problem because it makes the leaves wetter than other application methods and increases the risk of leaf diseases such as rust. Spray irrigation also causes soil splashes on the leaves and can increase infection by spores of fungi present in the soil such as angular spot.

Drip irrigation can be used to apply biofertilisers, fertilisers and biopesticides directly to plant roots and is therefore a cost-effective system.

FERTILISATION

If the crop does not receive enough fertiliser or receives too much fertiliser, it will be stressed. Stressed plants will have nutrient deficiencies or toxicities and will not produce high yields. Crops that have received too much nitrogen fertiliser will be very attractive to sap-sucking pests such as thrips, aphids, whiteflies and miners. Adult females will lay more eggs in the thick, fleshy leaves and crops will suffer from higher pest levels. Diseases will also proliferate in crops that receive too much fertiliser.

CROP WASTE MANAGEMENT

Crop waste contains the history of the plant's pests and diseases. Any pest or disease that has invaded the crop during growth and harvest will potentially still be there, continuing to develop, even if all beans have been harvested. As a result, the disease or pest will continue to accumulate and create greater problems for subsequent crops planted in or near the same soil. Several measures must be taken to avoid this situation.

REMOVAL OF ATTACKED PLANTS OR PARTS OF PLANTS

During the growing season, if plants are severely infected with diseases such as *Sclerotium*, *Fusarium* or angular spot, they must be removed. This means grubbing the dying plant and putting it in a bag to transport it out of the field to be composted or destroyed. If the dead plant is not carried in a bag, the infected soil or plant material can spread through the field. In some cases, it is necessary to eliminate only the attacked parts of the plant; for example the pods attacked by caterpillars.

RAPID REMOVAL OF OLD CROPS

As soon as the crop has been harvested, crop debris must be removed and composted or otherwise destroyed. This is particularly important if the crop was infested with whiteflies, thrips or aphids, which can fly off to adjacent crops if the old crop begins to dry out.

All these flying pests are cold-blooded and need the heat of the sun to warm their bodies and give them the energy they need to fly and disperse into adjacent crops. If crops are removed at dusk, when temperatures are cooler, there will be fewer whiteflies and other pests able to fly to adjacent crops.

If the crop is not intended to be composted, the crop debris must be incorporated deep into the soil at the same time as the crop is grubbed. In doing so, the pests will be buried and die. Severely diseased plants, however, must be removed first (for example, if infected with sclerotiniosis, angular spot) as these diseases are transmitted through the soil and survive if buried. Diseased plants must be composted correctly or destroyed in some other way (deep burial in holes; fed to animals, to be avoided for diseases such as *Fusarium* if the manure of these animals is then used for sensitive crops).

COMPOSTING

Crop debris removed from the field is cut into small pieces before being stacked to a height of approximately one metre. In the pile, layers of green plant matter (fresh bean plants) and brown matter (dry grass, brown banana stems, etc.) must be alternated. A composting accelerator such as *Trichoderma asperellum* can be applied. For more information on composting, see the COLEAD manuals on "soil management" and "organic production" as well as COLEAD's technical brochure on composting techniques.

7.1.5. RATIONAL USE OF PPPs

When control involves the use of PPPs, a certain balance, often complicated to achieve, must be maintained between the pests and their natural enemies. It must be remembered that the complete eradication of the pest in the plot will reduce the resource available for the maintenance of its natural enemies, which constitute a fundamental element contributing to the resilience of the system. The objective is therefore to "manage pest control to the point where natural predation functions in a balanced manner and crop losses to pests are maintained at a minimum acceptable level" (FAO).

On the other hand, the use of plant protection products (conventional or biocontrol) should always be considered as a last resort when the other measures taken do not allow sufficient control of the various pests.

The products and their use should minimise adverse effects on human health and the environment.

Applications of PPPs based on a pre-established treatment schedule should be avoided. It is preferable to intervene on the basis of regular observations to establish the phytosanitary status of the crop.

For pests where an intervention threshold (tolerance threshold, threshold of harmfulness) is available, treatments should be carried out when this threshold is reached or exceeded, taking into account the presence of natural enemies. For pests without a threshold, treatments should be applied when the risks are medium or high for the area in which the crop is located.

THE QUALITY OF PPP APPLICATIONS IS VERY IMPORTANT TO ENSURE EFFICIENCY

It is important to understand that knowledge of the life cycle and behaviour of pests optimises the effect of PPP applications. It is notably important to carry out the applications at the best time of the day to ensure contact with the pests, and to apply PPPs in a way adapted to the different stages of the pests' life cycle. For example, in some areas, thrips are found to collect outside the flowers and on the upper surface of the leaves approximately between 7.30 and 8.30 a.m. and between 4.30 and 5.30 pm; it is at these times of the day that it is best to spray.

Sprayed PPPs should be applied in a way that best reaches their targets. Many pests (whiteflies, spider mites, etc.) are located on the underside of the leaves; the applied solution must therefore be able to reach the underside of the leaves and this is particularly true for substances that act by contact and ingestion and that are not systemic (this is the case with virtually all biocontrol products).

For products acting by suffocating the target, this is even more important, the case for maltodextrin for example, for which optimal conditions of application are necessary in order to ensure effectiveness (method of application, volume of solution, humidity, heat, etc.). Indeed, the death of the targets is due to the adhesive properties of the substances, properties appearing only in the case of rapid drying. In addition, the product must not only come into contact with its targets, but must also cover them completely. The two main factors of success are the drying speed and the quality of the application: drying must be completed within a few hours of treatment (1 to 2 hours); the application volume must be high and reach the runoff limit, and the application must allow excellent coverage of the targets, including the underside of the leaves. To monitor this parameter, it is useful to use water-sensitive papers during the first applications in order to check whether the processing equipment, the settings and the application volume are suitable. Each water-sensitive paper must be impinged on at least 90% of its surface.

Proper sprayer calibration is essential to apply the recommended product dose per hectare and the optimum amount of solution.

If a backpack sprayer is used, the grower usually follows the advice of the label on the amount of product to apply per 15-litre sprayer and the optimal concentration of the solution (these doses are based on a theoretical volume of solution of 1,000 litres per hectare on a crop in full vegetation). For lance sprayers, the number of sprayers to be applied will normally depend on the stage of crop development if the solution is not applied unnecessarily to bare soil. The volume of solution to be applied to young plants is significantly lower than the volume of solution to be applied to growing plants (fewer leaf surfaces, therefore less product needed). If the grower applies too many sprayers for a given crop area at a given stage per hectare, there is a risk of "over-applying" the product (risk of burns and economic loss through overconsumption of product) or "under-applying" if the number of sprayers is insufficient (reduced efficiency and economic loss due to the risk of damage of the pest on the crop). It is therefore very important that the grower is perfectly familiar with the volumes of water required at each cultivation stage. This can be determined by doing blank sprays (water spray only).

The choice of sprayer type is also important. In some cases it will be preferable to use atomiser sprayers to ensure better penetration of the solution into the foliage and better coverage of the underside of the leaves.

COMPLIANCE WITH NATIONAL REGULATIONS ON THE USE OF PPPs

In ACP countries, green bean cultivation is mainly an export crop to the EU. EU importers have very specific guidelines on the PPPs they allow to be used on the purchased production. Customer-approved PPPs lists must be followed, but the producer may only use PPPs that have market authorisations in the country of production of the crop, in accordance with authorised uses and licensed doses.

PPPs, which are used for green beans, must take into account:

— Mandatory precautions for use (period of application, pre-harvest intervals, maximum permitted dose, existence or not of untreated areas, protective equipment) and possible restrictions on use.
— The existence of a Maximum Residue Limit (MRL) on the food for the substance. Account must be taken of the MRL in force in the market where the production will be distributed (national MRL, harmonised European MRL or even Codex Alimentarius MRL).

Compliance with the specific GAPs for each use allows the producer to comply with the MRL to be observed according to the final market of the production. The GAP includes product usage rate, maximum number of applications, minimum application interval, and pre-harvest interval (PHI). Any modification of one or more elements of these GAPs (for example: increase in dose, frequency of application and number of applications, and/or last application before harvest not within the pre-harvest interval (PHI)) may result in residues exceeding the recommended MRL. These GAPs are not calendar treatments to be applied as such. In practice, the frequency of treatments must take into account the extent of the attacks and the real risk of damage at local level.

PPP labels should normally provide sufficient information so that the grower does not apply more product than is necessary or permitted at a particular stage of growth. The label normally clearly indicates on which crops the product can be used and what the PHI will be for each different crop. The PHI indicated relates to the MRL of application in the country for which the label is intended. For example, a product sold in Kenya would normally be required to have a label approved by the country's pesticide registration system.

The label may also specify the stage of growth at which a product may be used, such as:

— use only before planting (for example, some nematicides);
— use only before flowering (for example, some dimethoate labels).

If the label limits the stage of growth at which a product can be used, it is very important that this information is followed to the letter – otherwise there is a very high risk that use of the product after this period will leave a residue above the permitted level.

COLEAD'S CROP PROTECTION DATABASE PROVIDES INFORMATION ON GOOD AGRICULTURAL PRACTICES

It was put online in 2018 and is accessible to all its members and beneficiaries. To date, it is the only database of its kind to provide information specifically dedicated to supporting the horticultural sector in ACP countries. The GAP data are obtained from a combination of sources, including COLEAD field PPP trials, PPP manufacturer data and scientific literature.

The Crop protection database brings together the MRLs set by the EU and Codex Alimentarius for key horticultural crops in ACP countries. It also brings together good agricultural practices (dose, interval between treatments, pre-harvest interval, etc.) that ensure compliance with these MRLs. Additional information such as the pesticide type, the authorisation status of the active substance in the EU and ACP countries, the classification recommended by the World Health Organisation (WHO) and the resistance group (FRAC code for fungicides); IRAC classification for insecticides) are also available.

The COLEAD database, Crop Protection Database, can be accessed on our website: here.

RECOMMENDED SUBSTANCES

Appendix 3 contains a list of the substances recommended against the main pests. The list is based on the approvals of the PCPB in Kenya; including arthropods for release, and other sources that are listed in the Appendix. We have only mentioned substances that are authorised in the EU (at the time of writing) as it is a crop mainly earmarked for export to the EU (EU Pesticide Database); with the exception of substances considered to fall under biocontrol which were still listed. It should be noted, however, that it is possible to use other locally registered products subject to compliance with the MRLs of the target market (local or international) often regulated by THE CODEX Alimentarius.

It is up to the user to check whether products containing these substances are authorised in the country of production of the crop, whether the GAP are compatible with the target market (compliance with MRLs) and whether these substances are authorised by the private standards of the buyers of the crops.

TRACEABILITY

As with other crop operations, it is very important to keep a complete documentation of plant health measures, recording for each treatment at least:

- the enemy of the crop to control,
- the date of application (+ number of days after sowing, + days before the planned harvest),
- the crop development stage,
- the product used (full name, supplier, formulation, batch number, etc.),
- the actual dose used,
- the volume of solution,
- the type of application (device, nozzle, volume/ha, working width, speed, wind, etc.).

7.2. MAIN PESTS AND DISEASES

This part presents the main pests of green beans in ACP countries. The stages at which the various pests can cause damage and the potential extent of this damage are first summarised under point 7.2.1, followed by the potential impact on yield and crop quality.

The main pests are then presented individually; first insects, then mites, nematodes, fungi and bacteria.

For each pest the following points are developed:

— **Scientific name**

— **Life cycle**

A good knowledge of the biological cycle of the pest ensures a better understanding of the different control methods to be put in place and the favourable conditions to avoid.

— **Description/identification**

- Other host plants

  The list given on the other host plants of the pest is not exhaustive. It is given as an indication for the main plants.

- Description of the pest organism

  The description is given to be able to identify insects and mites oneself. Only specialists have the capacity to identify nematodes, fungi and bacteria and it is advisable to consult them for correct identification.

- Affected crop stages

  This indicates at what level the main stages of cultivation are potentially affected by the pest. Four levels are possible: 0 = generally not affected, + = little affected, ++ = moderately affected, +++ = very affected. Affected means the presence of the pest and damage.

- Symptoms and damage

  They are described for the different organs of the affected plant.

- Impact on yield and quality

  Descriptions and explanations are given for 3 types of impact: loss of plants, loss of yield per plant, reduction in crop quality.

— **Quarantine organism**

In the case of exports to the EU, it is important to know if the organism is a quarantine pest because the control must make it possible to completely avoid the presence of the pest on the harvested pods.

European legislation on quarantine organisms is constantly evolving and it is important to check it regularly by visiting https://ec.europa.eu/food/plants/plant-health-and-biosecurity/legislation_fr.

The information given here has been collected on the site https://www.favv-afsca.be/professionnels/productionvegetale/legislation/reglementue/fichesdorientationtechnique/.

- **Conditions conducive to infestation**

  The main conditions (climate, weather conditions, season, soil (type, humidity, etc.) etc.) conducive to the development of the pest in a plot are given.

- **Monitoring**

  This outlines the best way of performing the monitoring. References are sometimes made to a more detailed description under point 7.1.2.

- **Control through good agricultural practices**

  The recommended actions are classified according to 4 types: prior choices, plot preparation, planting and maintenance of the crop. A justification and/or description and the expected effect are given for each action. The expected effects are of 4 types: avoids the pest, disrupts its life cycle, improves the plant's defence against the pest and strengthens the action of natural enemies.

- **Organic control**

  A difference is made between two types of biological control: the promotion and conservation of natural enemies present on the farm, the introduction of natural enemies from breeding. Recommendations are given for both types of control where information is available.

- **Control using Plant Protection Products**

  Information is given for the following different aspects of this control: periods, times of day and methods of application; resistance management; choice of substances with emphasis on biocontrol products.

  The user should check whether there are products registered in their country for the intended use and whether the substances are authorised by the buyers of the production (specifications).

  Care should always be taken to alternate substances from different resistance groups; consult IRAC for insecticides (www.irac-online.org) and FRAC for fungicides (https://www.frac.info/).

- **Other control methods**

  The special methods of control are presented.

7.2.1. SUMMARY OF THE MAIN PESTS AND DISEASES AFFECTING THE CROP

The main pests described in this document and the impact levels at the different stages of cultivation are listed below.

Table 16 — Main pests and impact levels at different stages of cultivation

PESTS	SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
Bean fly	0	++	+++	++	+	0
Bean seed fly	0	+++	+++	++	+	0
Aphids	0	+	++	+++	+++	0
Whiteflies	0	+	+++	++	+	0
Leaf miner	0	0	+++	++	+	0
Thrips	0	+	++	+++	++	+
Moth (*Helicoverpa*)	0	0	+	+++	+++	+
Bean pod borer	0	0	0	+++	+++	+
Armyworms	0	0	+	+++	+++	+
Loopers	0	0	++	+	+	0
Blister beetles	0	0	0	+++	+	0
Spider mites	0	0	++	+++	++	0
Meloidogyne	0	+	+++	+++	++	0
Pratylenchus	0	+	++	++	+	0
Fusarium	+	++	+++	+++	+	0
Macrophomina	+	+++	+++	++	+	0
Pythium	0	+++	+++	++	+	+
Rhizoctonia solani	+++	+++	+++	++	+	+
Sclerotium	0	+	++	+++	+++	0
Alternariasis	0	0	0	+	++	+
Anthracnose	+	+	++	++	+++	+
Angular spots	+	+	+	+++	++	+
Rust	0	0	++	+++	++	+
Graisse (Pseudomonas savastanoi and Xanthomonas axonopodis)	++	++	++	+++	++	+
Common *bacteriosis*	++	++	++	+++	++	+

Caption: 0 = no impact; + = low impact; ++ = medium impact; +++ = high impact

Below are the types of impact on yield and crop quality.

Table 17 — Main pests and types of impact on yield and crop quality

PEST	PLANT LOSS	LOSS OF YIELD PER PLANT	REDUCTION IN QUALITY	EU QUARANTINE ORGANISM*
Bean fly	+++	++	+	No
Bean seed fly	+++	++	0	No
Aphids	+	+++	+	No
Whiteflies	0	+++	+	YES for *Bemisia tabaci*
Leaf miner	+	+++	0	YES
Thrips	0	+++	+++	YES for *Thrips palmi*
Moth (*Helicoverpa*)	0	+++	+++	YES
Bean pod borer	0	+++	+++	No
Armyworms	0	+++	+++	YES for *Spodoptera frugiperda*
Loopers	0	+	0	No
Blister beetles	0	++	0	No
Spider mites	0	+++	+	No
Meloidogyne	+	+++	+	No
Pratylenchus	0	++	0	No
Fusarium	+++	++	0	No
Macrophomina	+++	+++	0	No
Pythium	+++	+++	+	No
Rhizoctonia solani	+++	+++	++	No
Sclerotium	++	+++	0	No
Alternariasis	0	0	+	No
Anthracnose	+	++	++	No
Angular spots	0	++	+	No
Rust	+	+++	+	No
Fat	+	++	+	No
Common *bacteriosis*	+	++	+	No

*source: https://www.favv-afsca.be/professionnels/productionvegetale/legislation/reglementue/fichesdorientationtechnique/
Caption: 0 = no impact; + = low impact; ++ = medium impact; +++ = high impact

7.2.2. THE INSECTS

7.2.2.1. BEAN FLY

SCIENTIFIC NAME

There are three species of the genus *Ophiomyia*: *Ophiomyia spencerella*, *O. phaseoli* and *O. centrosematis*.

They belong to the order Diptera, and to the family Agromyzidae.

LIFE CYCLE OF THE PEST

STAGE	DESCRIPTION
Egg	They are laid in the leaves of young plants, near the petiole or in the hypocotyl (germinating seedling stem) depending on the species
Larva	The small white larvae tunnel through the leaf, through the petiole and into the stem.
Pupa	The larvae pass through the stem and pupate inside it, near the base of the plant.
Adult	Adult flies emerge from the pupae in the stem. Adult flies are more active in the late evening or early morning.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

O. phaseoli is the most devastating species in this group, attacking a wide range of legumes (*O. phaseoli* family) including common bean (*Phaseolus vulgaris*), soybean (*Glycine max*) and cowpea (*Vigna unguiculata*). *O. spencerella* also attacks the common bean (*P. vulgaris*) as well as the rice bean (*Vigna umbellata*), Lima bean (*Phaseolus lunataus*) and other *O. phaseoli*. *O. centrosematis* also has a wide range of hosts, including the common bean (*P. vulgaris*), the butterfly pea (*Centrosema pubescens*) and the cowpea (*V. unguiculata*).

DESCRIPTION OF THE INSECT

STAGE	DESCRIPTION
Egg	White and oval
Larva	Yellow white colour and 3 mm in length
Pupa	Barrel-shaped with a length of 2 to 3 mm. Initially yellow with dark coloured ends before turning dark brown (*O. phaseoli*), shiny black (*O. spencerella*) or orange red (*O. centrosematis*).
Adult	Metallic bluish black in colour and with a size of about 2 mm, so much smaller than the adult of the bean seed fly which is 1 cm.

Figure 18 — Larva in a stem. AM Varela, ICIPE

Figure 19 — Adult on a leaf. AM Varela, ICIPE

AFFECTED CROP STAGE(S)

Young plants are the most susceptible, although older plants can also be infected.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	++	+++	++	+	0

SYMPTOMS AND DAMAGE

The main damage results from the attack of the plant stems.

LEAVES	Yellow spots that may indicate that the bean fly is feeding or laying eggs. N.B. But it may also be the first signs of feeding by the leaf miner *Liriomyza*.
STEM	Often it thickens and splits at the base lengthwise.
WHOLE PLANT	The larvae of the bean fly that feed in the main stem cause yellowing of infected plants and retarded growth. Affected young plants usually die

Figure 20 — Upper stem attacked by the larva of the bean fly. J. Wessels. Queensland Government

IMPACT ON YIELD AND QUALITY

The bean fly (*Ophiomyia* spp.) is the main pest insect limiting the yield of common beans in Africa.

TYPE OF IMPACT	DESCRIPTION
Plant loss	Galleries in the stem cause the death of seedlings and early infestation can lead to complete crop loss.
Loss of yield per plant	Older plants can tolerate bean fly attack to some extent, but yields will be lower.
Reduction in quality	No specific loss of pod quality except a possible reduction in size due to weakening of the plants.

QUARANTINE ORGANISM

These are not EU quarantine insects.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Dry weather	Plants are weakened because of damage in the stem that reduces the passage of the sap
	First sunny days after a rainy period.	Higher presence of flies.
Positioning of the plants in the field	Outer edge of the plantation.	Plants more exposed to attack.
Planting period	Late planting.	Stronger infestation.
Time of year	In Kenya, the damage tends to be most severe in December and January.	Sowing should be avoided during this period.

MONITORING

Recently planted crops should be carefully monitored for signs of egg laying on leaves. Wilted and stunted plants will also indicate the presence of bean fly larvae. In fact, these plants harbour the next – larger – generation of bean flies, and measures need to be taken quickly.

The stems and leaves of seedlings should be inspected twice a week, starting 2 to 3 weeks after germination, to observe the following:

- yellowing, stunting, wilting and wasting of young plants at the 2-3-leaf stage;
- translucent traces of laying on leaves;
- larval grazing galleries in the leaves, petioles and stems;
- bulging and cracking stem, especially at the base;
- presence of pupae in the stems;
- presence of adult flies on the plants.

The following intervention thresholds are recommended.

- Direct control measures should be undertaken when the plant infestation rate reaches 5-10%. (CABI BioProtection Portal, 2020).
- Consider taking action when you see 3 to 5 dying plants per row or per square meter. (Plantwise, 2015).
- Consider action if more than one maggot or maggot tunnel per plant or 3-4 adults per plant/square metre. (Plantwise, 2015).

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	Avoid planting in the vicinity of other legume crops that host the bean fly.	Reduction of new infestations by adults.
Take into account the preceding crop	Crop rotation must be ensured with crops that are not attacked by the bean fly.	Disruption in successive cycles.
Soil type	Choosing light to medium-heavy soils allows rapid emergence and rapid growth of young plants.	Plants are more resistant to attack.
FIELD PREPARATION		
Tillage	Work the soil intensively before sowing.	Decreases the population of bean fly pupae possibly inherited from the preceding crop.
Intercropping	Setting aside space to interpose strips of corn helps reduce the level of attack.	Adults move less easily which reduces the level of attack.
Installation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
Creation of hedges	Hedges serve as a refuge for predators such as birds and ground beetles	Control by auxiliaries is reinforced.
PLANTING		
Sow superficially (maximum depth of 3 cm)	Allows rapid emergence and rapid growth of seedlings.	Plants are more resistant to attack.
CROP MAINTENANCE		
Mound the young plants 2 to 3 weeks after emergence of the crop	When the bean fly larva reaches the base of the stem, the plant tissue swells and the stem can split. This affects the normal growth of lateral roots, but encourages the plant to form adventitious roots where the stem has split. Mounding allows these roots to better colonise the soil. It also helps to reduce the number of adult flies that emerge from pupae, since they are enclosed in the mounds of earth.	The attacked plants regain vigour and the number of flies that can hatch decreases.

Ensure good crop fertilisation and irrigation from the outset	The damage is more severe in plants growing under adverse conditions, such as infertile soils and drought.	Plants are more resistant to attack.
Mulching	It makes it possible to ensure good growing conditions for the plants.	Plants are more resistant to attack.
Grubbing and destruction of affected plants	Plants that have succumbed to an attack should be carefully removed from the crop, so that flies do not hatch and re-infect the crop.	Neighbouring and successive crops are less subject to attack as a result of the disruption in the cycle.
Grubbing of plants that have reached the end of production	Harvested crop residues must be quickly buried in the soil, given to livestock or burned.	Dispersal of the fly is avoided by disrupting the cycle.

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

There are parasitoid *hymenoptera* of the genus *Opius* (*Braconidae*), which kill the larvae of the bean fly, but it is often too late to save the plant. However, the presence of these parasitoids slows the spread of the pest from one generation to the next.

These natural enemies can only be conserved if the grower does not use broad-spectrum pesticides such as pyrethroids, organophosphorus and carbamates. Their presence may be reinforced by the presence of flower strips and hedges and in general by greater biodiversity on the farm, see under point 7.1.3.

BY RELEASE OF AUXILIARIES

Natural predators and parasitoids to control the bean fly are not mass bred for availability as a means of commercial control.

CONTROL USING PLANT PROTECTION PRODUCTS

When infestations are severe, consideration should be given to using insecticides to control bean fly.

APPLICATION PERIODS

It is easier to control this pest in a preventive way by applying an insecticide to the seeds if the seeds are not purchased already treated. Savings can be achieved by treating seeds only during times of the year and in areas where the highest number of bean flies is expected.

If the seeds are not treated, then the seedlings are usually treated about 3 to 4 days after emergence, and if the bean fly infestations are severe, the treatment is repeated after 7 days, and possibly after 14 days. In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market. It should be noted that repeated application of broad-spectrum insecticide can lead to invasions of miners and spider mites as a result of the elimination of natural enemies.

THE SUBSTANCES

The substances recommended for the control of bean flies are listed in Appendix 3; they are few in number, so control using PPPs is difficult.

Azadirachtin products or neem extracts are reported to be effective means of biocontrol. (Plantwise, 2015, Infonet Biovision, 2021, Crop Pest Surveillance System – Online Plant Clinic, 2021).

Artisanal preparations made from garlic, onion and chilli are also believed to be effective (Plantwise, 2015).

OTHER CONTROL METHODS

The removal of leaves bearing egg-laying marks reduces the number of larvae produced and thus reduces the number of adults that can lay eggs, which would otherwise have appeared in the stem in the second generation.

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7.2.2.2. BEAN SEED FLY

SCIENTIFIC NAME

Delia platura.

It belongs to the order Diptera, and to the family Anthomyiidae.

LIFE CYCLE OF THE PEST

There may be 3 to 6 generations per year depending on temperatures and food availability.

STAGE	DESCRIPTION
Egg	Females lay about 50 eggs each. Eggs are laid near the surface of moist soils rich in decaying organic matter.
Larva	Larvae feed on seeds and seedlings for one to three weeks.
Pupa	It forms near the surface of the soil.
Adult	Adult flies hatch in the ground.

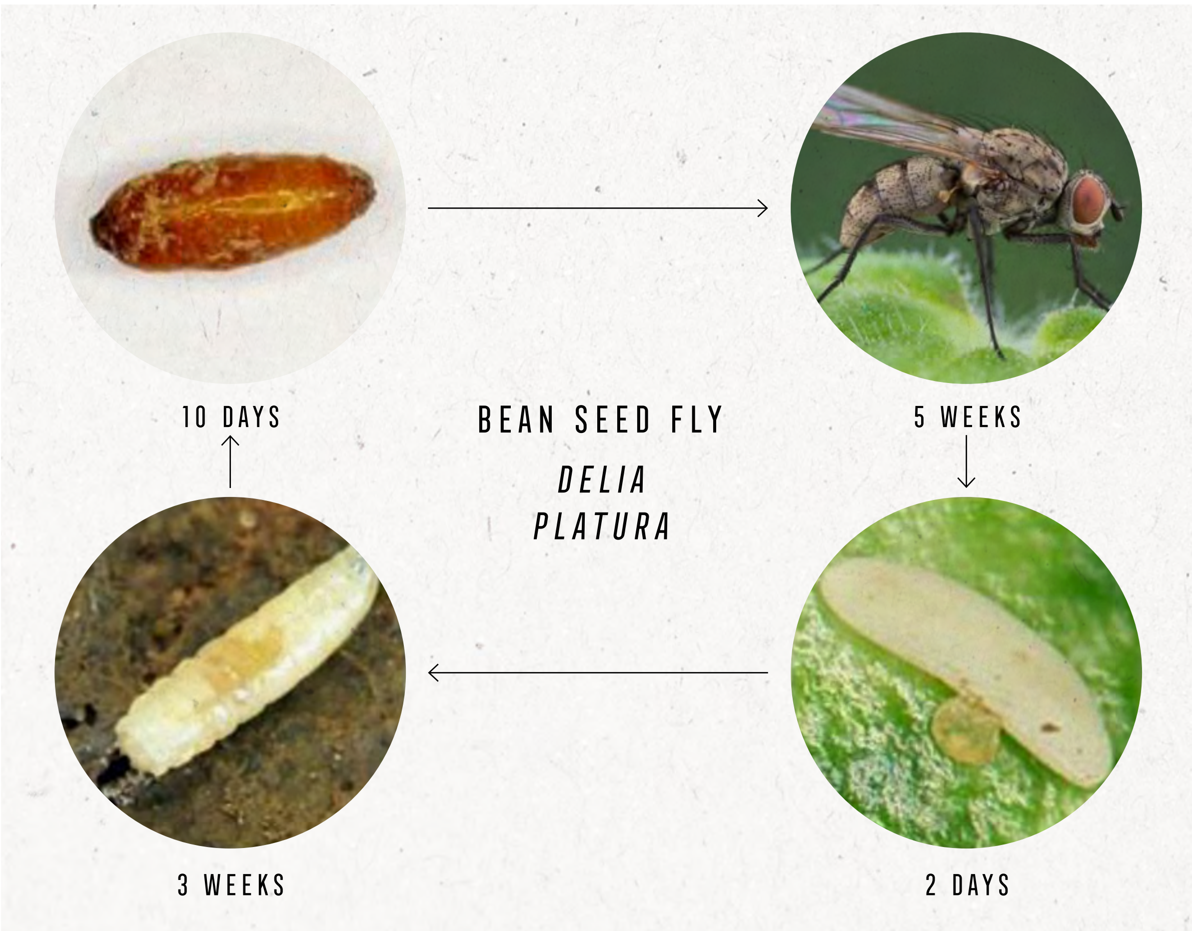

Figure 21 — Life cycle of *Delia platura* over one year with mean durations of each stage of development Boquel *et al.* (2018). Centre de Référence en Agriculture et Agroalimentaire du Québec, 2019).
Taken from https://matheo.uliege.be/bitstream/2268.2/8670/1/Rekinger-M%C3%A9lanie_TFE.pdf

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

It is a very polyphagous insect that attacks more than 40 different plants such as cabbage, onion, peas, potato, radish, cauliflower, sunflower, melon, cucumber, spinach, asparagus, tomato, cereals, corn and tobacco.

DESCRIPTION OF THE INSECT

STAGE	DESCRIPTION
Egg	Pearly white in colour, it is elongated and measures approximately 1 mm in length. The surface is decorated with superficial carvings and a ventral groove that extends over a third of the length.
Larva	White, it is 5 to 8 mm long at full development; the last segment is truncated obliquely.
Pupa	Red-brown in colour, it is about 5 mm in length.
Adult	Grey fly from 3 to 6 mm in length. Its yellowish grey thorax and abdomen are decorated with a brownish median longitudinal band, its legs are black.

Figure 22 — The different stages of the insect and symptoms.
Art Cushman, USDA Systematics Entomology Laboratory, Bugwood.org

AFFECTED CROP STAGE(S)

Germinating seedlings are the most affected. As the plant matures, the stems become too hard for larvae to feed on. Plants are generally safe from attack when they are 3 to 4 weeks old.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+++	+++	++	+	0

SYMPTOMS AND DAMAGE

As a result of the absence of emergence or death of young plants, holes appear in the crop.

SEED	The larvae feed on germinating seeds, often coring them completely.
SEEDLING	The seedlings wilt and die before emerging from the soil or die after emergence.
WHOLE PLANT	Plants that have survived show stunted growth.

Figure 23 — Damage to a seedling caused by seed attack. AM Varela, ICIPE

Figure 24 — Damage to a young bean plant
Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

In Africa the pest is reported only in East Africa, North Africa and South Africa, as well as Madagascar.

TYPE OF IMPACT	DESCRIPTION
Plant loss	Plants wilt and die before emerging from the ground.
Loss of yield per plant	Older plants can tolerate an attack to some degree, but yields will be lower.
Reduction in quality	/

QUARANTINE ORGANISM

This is not an EU quarantine insect.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Soil	High content of decaying organic matter and recently ploughed. High soil moisture, for example in areas where water stagnates.	Flies are attracted to this type of soil to lay on it. A host plant is not required to encourage laying, as the larva can feed on decaying animal or plant material.
Positioning of the plants in the field	Outer edge of the crop.	Plants more exposed to attack.

This insect actively develops in a wide range of temperatures from 11 to 33°C.

MONITORING

Bean seed flies are easily detected by examining the areas in which the plants have not grown. Damaged seeds contain a white larva. However, monitoring is not of much use to trigger treatments, since it is then too late to intervene because the damage is already done.

Monitoring with blue or yellow traps with an attractant is more useful in order to estimate the fly population and its dynamics. This type of trap can be bought off the shelf. However, due to their similarities, they can be confused with flies of the genus *Delia* and sticky traps cannot distinguish them. Indeed, since the insects are trapped in the glue, the morphological characteristics allowing their identification are not all visible.

The use of yellow bowl traps can be a good alternative. These contain water with a few drops of soap (dishwashing liquid) to eliminate surface tension and cause the insects to float on the surface. This makes it possible to recover practically intact specimens if the traps are surveyed on a frequent basis: a survey frequency of 2 to 3 times a week seems to be optimal. It should be noted that the presence of adults in traps does not necessarily mean that larval damage will be observed.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Soil type	Choosing light to medium-heavy soils allows rapid emergence and rapid growth of young plants.	Plants are more resistant to attack.
FIELD PREPARATION		
Limited tillage	Intensive tillage before sowing allows the pupae to be exposed to the surface and mechanically destroyed. However, tillage and incorporation of cover crops results in disturbed soils rich in decaying organic matter, which attracts female flies to lay their eggs. Fields in soil conservation agriculture are less likely to experience bean seed fly problems because surface organic matter is less attractive to female flies than decomposing organic matter in soil.[1] On the other hand, they generally have higher levels of predator activity.	Reduced egg laying by lies. Control by auxiliaries is reinforced.
Fully incorporate the organic matter under the soil surface, before sowing.	Less decaying organic matter in the first cm of the soil.	Reduced egg laying by flies.
Creation of hedges	Hedges serve as a refuge for predators such as birds and ground beetles.	Control of larvae and pupae by auxiliaries is strengthened.
PLANTING		
Sow superficially (maximum depth 3 cm)	Allows rapid emergence and rapid growth of seedlings.	Plants are more resistant to attack.
Apply a biofertiliser, biostimulant or phosphate fertiliser to the seed	By ensuring rapid germination and growth, the duration of the growth stage vulnerable to bean seed fly attack is reduced.	Plants are more resistant to attack.
Sow at high density	This makes it possible to compensate for the emergence losses caused by the larvae.	Loss compensation.
CROP MAINTENANCE		
Grubbing and destruction of affected plants	Rapid detection and removal of severely affected plants will reduce the number of subsequent generations.	Dispersal of the fly is avoided by disrupting the cycle.

1 (Harsimran Kaur Gill, Gaurav Goyal, and Jennifer L. Gillett-Kaufman, 2019) and (Rekinger M, 2020).

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

Much of the life cycle of the bean seed fly occurs underground, in a protected environment; it does not seem to have many natural enemies. Predators include spiders, ants, beetles (Staphylinidae and Carabidae), and birds; however, their impact is small.

Reduced tillage systems (conservation agriculture) generally have higher levels of predator activity than conventionally ploughed fields.

The activity of natural predators can be favoured by the presence of semi-natural environments of high density at the edge of the crop (hedge, edge of wood, etc.).

BY RELEASE OF AUXILIARIES

There are no mass-bred and marketed natural enemies to control this pest.

CONTROL USING PLANT PROTECTION PRODUCTS

Seed treatment is the cheapest and most effective treatment for bean seed fly control. Alternatively, the products can be applied in the sowing furrow.

If this practice is very expensive, savings can be made by treating only during the periods of the year when the highest number of bean seed flies are expected.

THE SUBSTANCES

The substances recommended for the control of bean flies are listed in Appendix 3; they are few in number, so control using PPPs is difficult.

Chemical control against *Delia platura* was generally based on the application of active substances such as lindane, carbofuran, diazinon, aldrine or chlorpyriphos. However, these active substances are no longer authorised within the European Union or even at international level because they present risks for human health and the environment. They can be replaced by substances such as spinosad, tefluthrin or cyantraniliprole.

Larvae pupate in the soil and most of the life cycle takes place in the soil. This makes them very susceptible to infection by commercial entomo-pathogenic fungi, such as *Metarhizium* and *Beauveria*.

If applying organic matter, mix it beforehand with an entomopathogenic fungus such as *Metarhizium*.

OTHER CONTROL METHODS

Checking plants that do not germinate and removing damaged seeds and larvae prevent the development of fifty more flies per seed eliminated.

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7.2.2.3. APHIDS

SCIENTIFIC NAME

Aphis fabae and *Aphis craccivora*.

They belong to the order Hemiptera, and to the family Aphididae.

LIFE CYCLE OF THE PEST

In hot climates, aphids multiply by parthenogenesis: reproduction takes place without fertilisation. Eggs are produced directly by the adult female. Females give birth to larvae after hatching the egg inside the body.

Aphid colonies gather around the growing points of the plants. Aphids can grow rapidly, since the entire cycle lasts about 11 days.

In the event of outbreak, the adults ensure the dissemination from one field to another.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Aphis fabae is highly polyphagous and is found on virtually all vegetable crops. *Aphis craccivora* is particularly fond of *O. phaseoli*, especially *Arachis hypogaea* (peanut) and *Vigna* spp. But it is also found on many families of vegetable crops: Malvaceae, Solanaceae, *Cucurbitaceae*, etc.

DESCRIPTION OF THE INSECT

The wingless female of *Aphis fabae* are 1.5 to 2.9 mm long and are black to blackish brown, often with whitish wax spots on the abdomen. The antennas are shorter than the body. Winged adults are 1.8 to 2.7 mm long and black in colour, with visible white wax spots.

Figure 25 — Colony of *Aphis fabae*. Mourad Louadfel, Homemade, Bugwood.org

The colour of *A. craccivora* aphids can vary from pink for larvae to black for adults. 2 mm long, the female has 2 black cornules and a cauda, the antennae are shorter than the body. The ends of the legs are brown.

Figure 26 — Colony of *Aphis craccivora*. Clemson University – USDA Cooperative Extension Slide Series, Bugwood.org

AFFECTED CROP STAGE(S)

All crop stages but especially at flowering and the formation of pods.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+	++	+++	+++	0

SYMPTOMS AND DAMAGE

Aphid colonies can attack young shoots, lower leaf surfaces, petioles, flowers, pods and seedlings.

SEEDLING	Plants can be stunted if the attack is early and sometimes young plants die.
YOUNG SHOOT	They can be damaged if large colonies of aphids are present.
LEAF	They wilt and curl up.
FLOWER	During flowering there may be abortion and dripping of flowers.
POD	Presence of honeydew and/or sooty mould.
WHOLE PLANT	Highly infected plants struggle to grow. The damage is also due to the production of honeydew, which is a sweet, rich and sticky substance secreted by aphids. It is found as a deposit on plants after they have been attacked by a high number of aphids. Honeydew promotes the growth of a black saprophytic fungus (sooty mould).

Figure 27 — Heavy black aphid attack on the bean (*Aphis fabae*). A.M. Varela, ICIPE

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	Young plants can die in case of significant early infestation.
Loss of yield per plant	The concentration of aphid colonies on the plant's growing points leads to a decrease in crop yield due to the direct damage these parasites cause by sucking plant sap. The presence of sooty mould impedes chlorophyll production and the respiratory function of the plant and thus disrupts its growth.
Reduction in quality	Pods infected with honeydew or sooty mould lose their value.

Aphids are also important vectors of viral diseases (*A. craccivora* transmits more than 30 viruses and many host plants constitute aphid reservoirs, since these insects are polyphagous). Bean mosaic virus (BMV) is one of the viruses transmitted by aphids and infects many *Phaseolus* spp.

QUARANTINE ORGANISM

These are not EU quarantine insects.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Temperature fluctuating between 24 and 28°C and a humidity close to 65%.	Rapid population development.
	Dry period or with low rainfall.	Aphids generally do not survive in the field in extremely rainy conditions.
Water availability for the plants	Water stress of the plants.	The metabolism of the plant, and more particularly the reduced transfer of hydrocarbon, influences the development of winged aphids, which then prefer to attack plants suffering from water stress.
Entomofauna	Aphids often live in symbiosis with ants.	The presence of ants promotes infestation by aphids.

Table 18 — Population dynamics of aphids in Senegal – RADHORT (2012)

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Niayes	++	++	+++	+++	+++	++	++	+	+	+	+	++
Vallée du Fleuve	++	++	++	++	0	0	0	0	0	0	+	++

In Kenya, *Aphis craccivora*, is more present in low-lying areas. (Infonet biovision, 2021).

MONITORING

Aphids are easily visible on the plants, especially on the leaves and buds. It is essential to detect them as soon as possible to avoid significant aphid infestations on plant organs.

The edges of new plantations must also be monitored very carefully to detect early aphid invasions, which often occur at the edge of fields. This makes it possible to apply control methods in time when the aphid population is small and the foliage of the crop is not yet very dense (which would otherwise hinder the penetration of sprays).

The monitoring methods are proposed in detail under point 7.1.2.

CONTROL THROUGH CROP PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	Care should be taken not to place consecutive plantations of fine beans in the wind direction of older crops, which could be heavily infested by aphids.	Avoids the arrival of winged aphids.
PLOT PREPARATION		
Intercropping	Intercropping with chives or garlic is thought to help repel aphids. (Infonet Biovision, 2021).	Avoids the arrival of winged aphids.
Intercropping	Intercropping with *sorghum* strips. See below biological control through conservation.	The presence of ladybirds is reinforced on the plot.
Creation of grassy strips or flowery hedges	The creation of hedges and flower borders provides refuge and food for useful wildlife, as does a row of unharvested and untreated beans left along the edge of the field. See below biological conservation control	Control by auxiliaries is reinforced.
PLANTING		
Avoid excess plant density	Aphid colonies will be better reached by PPPs sprays if the vegetation is less dense; but this may induce a drop in yield.	Population decline following insecticide applications.
CROP MAINTENANCE		
Ensure regular weeding of the plot and its surroundings	The presence of too many weeds can prevent good vegetation cover by PPPs sprays and alternative hosts are reduced.	Population decline following insecticide applications. Avoids sources of winged aphids.
Rational irrigation	In dry weather, regular watering by sprinkling disturbs aphid populations	The population shrinks.
Good management of nitrogen fertilisation	By limiting excessive inputs, the susceptibility of plants to aphid attacks will be limited.	Slows down the multiplication of populations.
Grubbing and destruction of crop residues	Grubbing must be followed immediately by destruction (deep burial, burning or animal feed).	Elimination of sources of infestation for neighbouring crops.

BY CONSERVATION OF THE AUXILIARIES PRESENT

Several natural enemies of aphids occur naturally on farms. These can be the parasitoid *hymenoptera*, for example those of the genera *Aphidius* and *Aphelinus*, Syrphae, Chrysopidae, Anthocoridae and ladybirds.

"For ladybirds, intercropping with *sorghum* can promote their presence because this plant can host the grain aphid (*Rhopalosiphum maidis*) on which ladybirds larvae feed. This specific grain aphid is a source of food for ladybirds and does not attack green beans (Source Bio Savane). " (D. Blancard (INRA); A Berton (CA Guyane), 2021).

The presence of parasitoid *hymenoptera* may be promoted on a farm by the presence of flowers which provide nectar useful to adults see under point 7.1.3.

Integrated aphid control programmes should include PPPs that have minimal impact on crop auxiliaries (see tables on pesticide susceptibility in Appendix 4).

The grower can accelerate the activity of auxiliaries by collecting aphid predators and parasitoids from older crops on the farm and placing them in the new crop. It is however essential to detect aphid colonies as soon as they appear and to introduce useful insects in these "sensitive" places as quickly as possible.

Entomopathogenic fungi of the genus *Metarhizium* are naturally present in aphid colonies, however they often develop too late to allow satisfactory control of aphids; the damage to the culture has already been done.

BY RELEASE OF AUXILIARIES

Parasitoid *hymenoptera* are particularly useful biological control agents, since they lay many eggs inside the body of many aphids which will then be parasitised by the larvae. Pupation occurs inside the aphid's body, where the larva weaves a cocoon. The host aphid does not die immediately and remains attached to the leaf where it feeds.

Sometimes hyperparasites attack a developing *Aphidius* inside the mummified aphid and lay their eggs in the larvae of *Aphidius*. A mummified aphid that has been "hyperparasited" can only be identified when it is opened: when hyperparasited, a tear is visible in the aphid's body instead of a perfectly circular opening resembling a hatch. In Kenya, the native parasitic *hymenoptera*, *Aphidius transcaspinus*, is registered as a biological control agent. It is mass-bred in Kenya for commercial purposes.

Figure 28 — *Aphidius sp.* David Cappaert, Bugwood.org

Figure 29 — Mummified aphids. Nick Dimmock, University of Northampton, Bugwood.org

APPLICATION PERIODS

It is important to carry out a rapid control against early infestations by aphids, because the longer it takes to respond, the more colonies will develop and the more difficult the control will be, especially in the run up to harvesting. Sampling will determine the relative "auxiliary / aphid" ratios in the crop. If the ratio of auxiliaries to aphids is less than one to twenty (i.e. for twenty aphids there is one aphid predator or parasitoid), it may be advisable to use a PPP to rapidly decrease the aphid population. However, if aphids are detected at an early stage, PPPs may be less necessary, even if the ratio of auxiliaries to aphids is less than one in twenty. This is because there is still enough time before flowering (the most sensitive stage) to allow this ratio to evolve favourably under the effect of auxiliaries.

If the risk of transmission of viral disease is high in the growing area, it is preferable not to tolerate any presence of aphids at the beginning of the growing season. Applications of PPPs on the seeds should then be considered as a preventative measure. Systemic active substances kill the aphid effectively, but it still has time to feed and transmit viruses before dying. In this case, products with a repellent effect or an immediate effect are preferable.

RESISTANCE MANAGEMENT

Aphids can become resistant to chemical PPPs if used repeatedly without alternating substances belonging to different resistance groups. For example, resistance to pyrethroids has been detected.

THE SUBSTANCES

It is extremely important to be aware of the harmfulness of PPPs on crop auxiliaries because everything must be done to conserve them. For example, a pyrethroid can kill up to 75% of the natural enemies of aphids and this harmful effect can be maintained for up to 10 weeks after application. The least harmful PPPs will therefore be preferred even if their cost of use per hectare is higher.

Recommended substances for the control of aphids are listed in Appendix 3.

Many biocontrol products allow effective control. These include the following substances: fatty acid, maltodextrin, azadirachtin, oxymatrine, pyrethrin, *Beauveria bassiana*, *Metarhizium anisopliae*, *Paecilomyces fumosoroseus*, *Verticilium lecanii*, paraffin oil, orange essential oil, citric acid.

OTHER CONTROL METHODS

No information available.

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7.2.2.4. WHITEFLIES

SCIENTIFIC NAME

Bemisia tabaci (tobacco whitefly) and *Trialeurodes vaporarium* (greenhouse whitefly). They belong to the order Hemiptera, and to the family Aleyrodidae.

LIFE CYCLE OF THE PEST

The cycle of these two pests is very fast so a population can grow rapidly if nothing hinders their survival. *Bemisia tabaci* and *Trialeurodes vaporarium* have similar cycles and control techniques will be the same for both species. Between 11 and 15 generations are possible per year. The entire growth cycle of the whitefly can be close to 32 days at a temperature of 20 to 25°C and is favoured when the temperature is around 25°C.

STAGE	DESCRIPTION
Egg	The eggs are attached to the underside of the leaves and hatch seven to ten days later.
Larva	There are 4 larval stages (L1, 2, 3 and 4). L1 – this stage, called "mobile larva", is the only mobile phase of the young insect. It moves only a short distance, inserts its needle-shaped mouthparts into the leaf and begins to feed on the sap of the plant, after which it no longer moves. L2 and L3 – the larva remains fixed and feeds on the plant sap, each stage lasting three to four days depending on the temperature. L4 – In the fourth stage – a resting stage, the insect turns into a pupa (puparium).
Puparium	It does not feed during this stage. About a week later, the adult whitefly emerges from the puparium, usually in the morning.
Adult	Although adults can fly up to 15 metres for a 24-hour period, most remain within 2.5 – 3 metres of their hatching site. Adults are very active and are easily disturbed during the day. They feed on the lower surface of the leaves, where they lay their eggs, but they can also place themselves on other areas of the host plant. Adult whiteflies begin laying eggs on the leaf during the day, about one to three days after emerging from the puparium. Each female can lay up to 160 eggs after 5 to 9 days at 30°C depending on temperature and humidity.

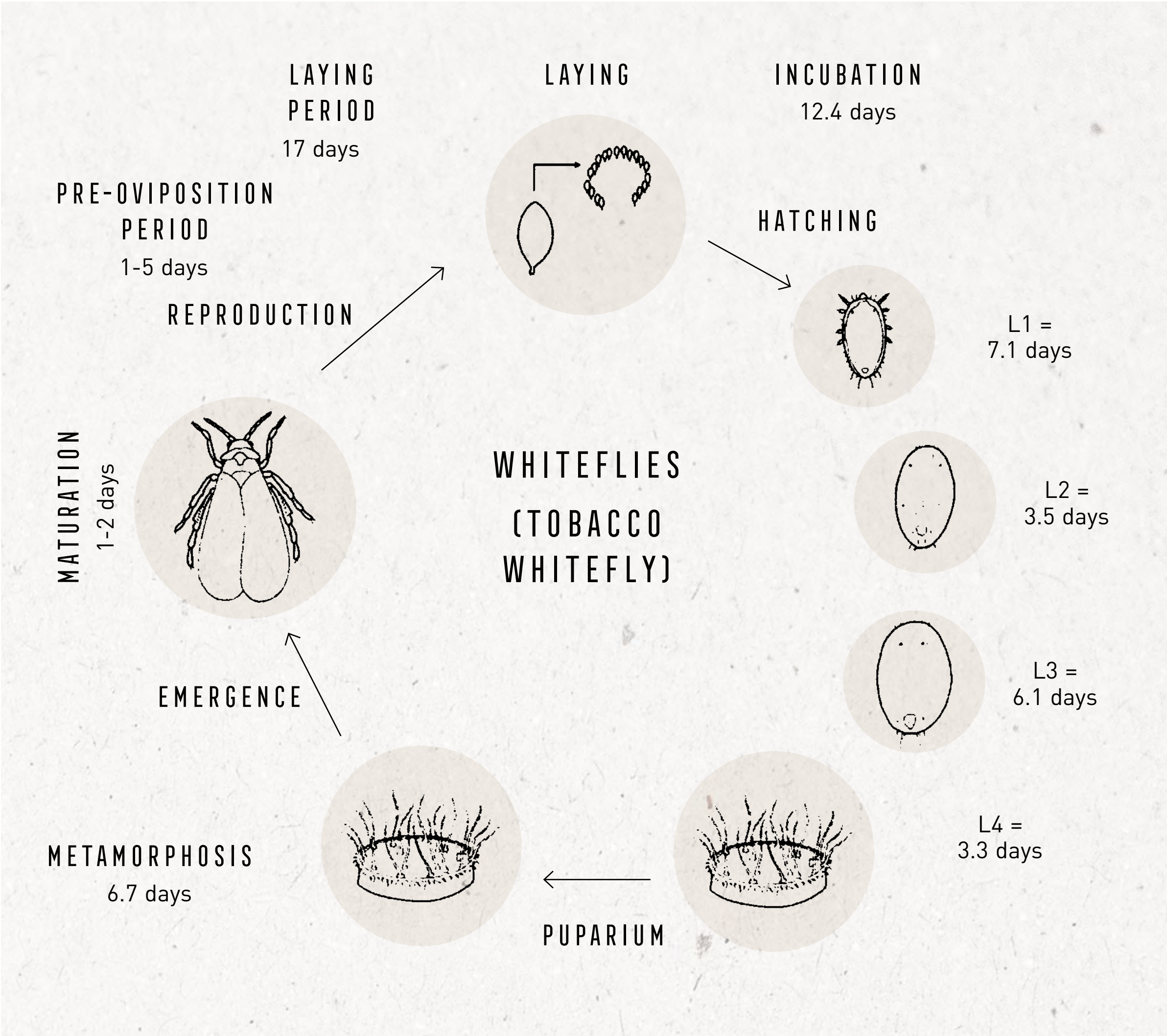

Figure 30 — Duration of the development stages of *Bemicia tabaci* on tomatoes at 20°C.
J. Poidatz (Koppert). (2015). http://ephytia.inra.fr/fr/C/19694/Biocontrol-Biologie

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

The tobacco whitefly has a wide choice of host plants and attacks many crops around the world. For example, the following families are attacked: *Brassicaceae*, *Cucurbitaceae*, *O. phaseoli*, Malvaecae, Solanaceae.

The greenhouse whitefly attacks 249 plant genera from 84 plant families.

DESCRIPTION OF THE INSECT

STAGE	DESCRIPTION
Egg	The eggs, which are white and then gradually turn brown, are held in place by a thin peduncle produced by the female. Mature whitefly eggs are grey in colour. *Bemisia* tend to lay their eggs randomly on the leaf surface, while *Trialeurodes* lay their eggs in semicircles.
Larva	L1: Transparent cuticle, 0.25 mm. They have legs and antennas. After exploring the leaf, they settle there, retract their legs and antennae partially and begin to feed. L2: flat body, 0.3 mm. L3: larger larva (about 0.5 mm), but still has the same shape. L4: wider and flat.
Puparium	The L4 changes shape to become almost round (about 0.8 mm long and 0.6 mm wide). The puparium sometimes has an irregular and lobed contour, depending on the hair length and leaf structure of the host plant. At this stage, the red eyes of the insect are very clearly visible. As the cuticle of the puparium is transparent, the yellow colour of the whitefly can be seen. Laterally, we can see the white wings in development.
Adult	Adults are about 1 mm long and have a yellow body and white wings. *Trialeurodes* and *Bemisia* can be distinguished as follows at the adult stage. The wings of adult *Bemisia* are on their roof-shaped bodies and their yellow abdomen is more visible.

Figure 31 — *Trialeurodes* eggs (COLEAD, 2012. Green bean crop protocol)

Figure 32 — Larva of Bemisai *tabaci*.
INRA-Versailles, Institut National de la Recherche Agronomique, Bugwood.org

Figure 33 — Puparium of *Bemisia tabaci*.
Central Science Laboratory, Harpenden, British Crown, Bugwood.org

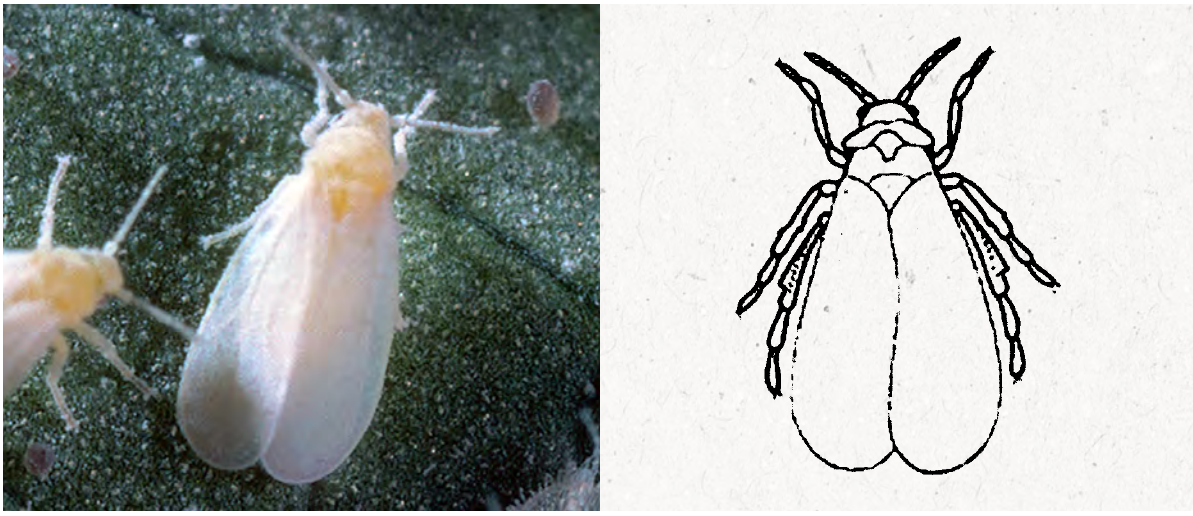

Figure 34 — *Trialeurodes* (COLEAD, 2012. Green bean crop protocol)

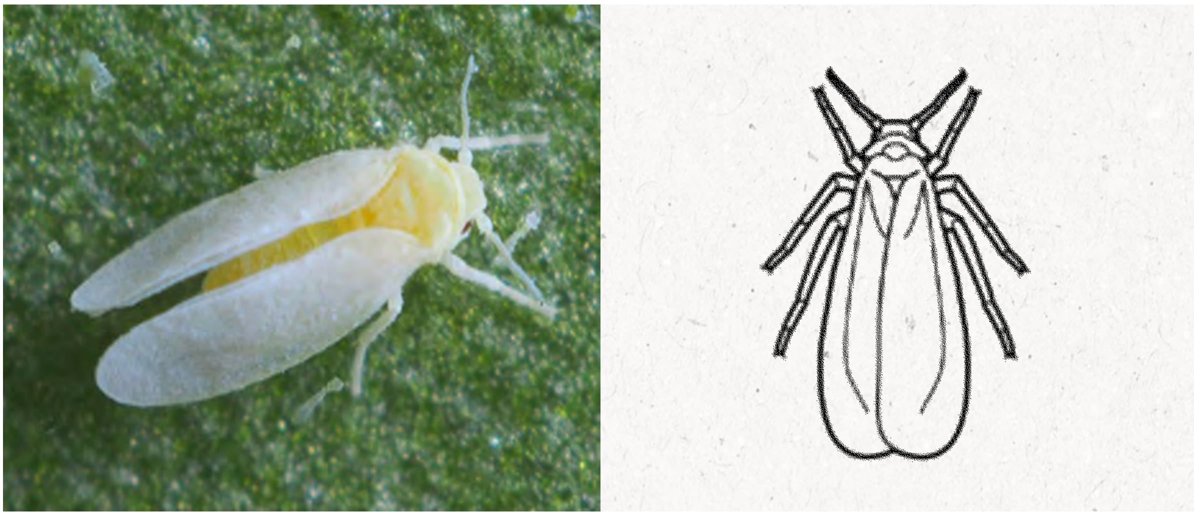

Figure 35 — *Bemisia* (COLEAD, 2012. Green bean crop protocol)

AFFECTED CROP STAGE(S)

The insect can be present on the plant at all stages but more particularly from emergence to flowering through vegetative growth. The early presence of the insect after emergence is the most damaging.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+	+++	++	+	0

SYMPTOMS AND DAMAGE

LEAF	Presence of larvae, puparium and adults mainly on the underside. Damage directly related to the feeding of the larvae and adults leads to the appearance of chlorotic spots on the upper side of the leaves. Depending on the extent of colonisation, these spots can merge until the leaf yellows completely. If whiteflies are not controlled and their feeding is excessive, the leaves can become brittle and eventually dry out and fall.
WHOLE PLANT	Since whitefly larvae suck leaf sap, excess sweet sap flows from their bodies onto the leaf surface below the leaves they feed on. Sooty mould grows easily on this sweet substance, thus causing the characteristic black sooty mould.

Figure 36 — Whitefly (*Bemisia tabaci*) on a green bean leaf. A.M. Varela, ICIPE

IMPACT ON YIELD AND QUALITY

This insect only has a significant direct effect on yield if large populations develop at the beginning of the crop before flowering. Later infestations have little impact on yield. This parasite has a relatively large impact in Africa.

TYPE OF IMPACT	DESCRIPTION
Loss of yield per plant	A decrease in yield is possible due to the direct damage that these parasites cause by sucking the sap of the plants but also due to reduced photosynthesis resulting from deterioration of the leaves. The presence of sooty mould impedes chlorophyll production and the respiratory function of the plant and thus disrupts its growth.
Reduction in quality	Pods infected with honeydew or sooty mould lose their value.

Bemisia tabaci is also a very harmful insect given its transmission of many viruses (Geminivirus, Closterovirus, Nepovirus, Carlavirus, Potyvirus), which cause the appearance of different symptoms depending on the infected species. A virus can cause one or more of the following symptoms: infection of leaf veins, yellow leaves, yellow mosaic on leaves, curling and thinning of leaves, etc.

If the whiteflies are also carriers of a virus, it may even be unprofitable to maintain the crop in the area in question.

QUARANTINE ORGANISM

Bemisia tabaci is considered an EU quarantine pest, which means that it cannot be imported on products destined for the EU. However, this is unlikely to occur with green beans, as the presence of whitefly larvae or pupariums on harvested beans is extremely rare.

Trialeurodes vaporarium is not an EU quarantine pest.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	A moist and sheltered biotope. It is adverse to dry winds.	The insect develops especially during the periods following a rainy season.
	The optimal temperature for the development and survival of the population of *Bemisia tabaci* is 25 to 30°C while for *Trialeurodes vaporarium* it is 20 to 25°C.	In Kenya, *Trialeurodes* vaporariorum is found mainly in the cooler-climate of the highlands and is currently the predominant species affecting beans. However, *Bemisia tabaci* has expanded its presence and is more common than before in the highlands.

The table below gives the periods of high infestation of *Bemisia tabaci* in Senegal.

Table 19 — Population dynamics of *Bemisia tabaci* in Senegal – RADHORT (2012)

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Niayes	++	+	+	+	+	+	+	+	++	+++	+++	+++
Basse Casamance	/	/	/	/	/	/	/	/	/	+++	+++	+++

MONITORING

In the absence of viruses, a certain level of whiteflies on a leaf can be tolerated, as long as the honeydew they secrete does not cause the excessive development of sooty mould. Since dwarf green beans mostly remain in the field for only 10 weeks, whitefly populations do not develop as much as, for example, in climbing green bean crops, which stay in the field for twenty weeks and have three times as many leaves.

BY DIRECT OBSERVATION OF PLANTS

The "economic intervention threshold", must be determined by each grower by observing the crop at a given time (for example, vegetative vigour and quality of leaves, level of sooty mould, etc.) and taking into consideration the remaining time before harvesting.

Methods of monitoring plants by direct observation in the field are proposed in detail under point 7.1.2.

BY TRAPPING

It is also possible to monitor populations with traps to observe general trends in pest populations in the fields. Since adult whiteflies are strongly attracted to yellow, sticky traps can be made using yellow plastic covered with glue or other sticky substances, such as fat. However, these traps should not be used regularly and in large quantities, as they also catch and kill useful insects, such as *Diglyphus* (leaf miner parasitoid) and *Encarsia*, which attack whitefly. These sticky traps should only be used as a monitoring method and not as a means of control. Yellow sticky traps attract thrips, aphids and leaf miners to varying degrees.

CONTROL THROUGH CROP PRACTICES

The following practices contribute to pest control. Crop rotation is difficult to implement given the high number of hosts of this insect.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	It is advisable to plant new crops in the opposite direction of the wind from older crops.	This will reduce the migration of adults from older crops to younger crops, in the direction of the wind.
PLOT PREPARATION		
Plant windbreaks between plots	Windbreaks reduce the movement of whiteflies from one plot to another.	New infestations are reduced.
Plant repellent plants such as coriander or Mexican marigold (*Tagetes minuta*) on the edges of the plots. (Plantwise, 2021)	Repellent plants will reduce the entry of the whitefly into the plot and these plants are also useful to preserve auxiliaries such as parasitoid *hymenoptera*.	New infestations are reduced and control by auxiliaries is strengthened.
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
PLANTING		
Avoid excess plant density.	Whiteflies will be better targeted by PPPs sprays if the vegetation is less dense; but this can induce a drop in yield.	Population decline following insecticide applications.
Use insect nets in areas at risk of virus infection. (Plantwise, 2021).	Cover seedlings with insect nets (mesh 400 µm). The net can then be removed.	Nets prevent the transmission of viruses by adults in young crops.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
CROP MAINTENANCE		
Ensure regular weeding of the ground	Weeds growing along or between seed rows and crop residues may harbour populations of whitefly. Therefore, it is essential to weed the field and remove residues before sowing and during the growing period.	Avoids adult sources.
Grubbing of plants that have reached the end of production	In Kenya, at high altitudes, night temperatures can drop rapidly from 15 to 5°C. At this low temperature, adult whiteflies cannot fly and crops can be removed without disturbing adult whiteflies. If a heavily infested crop is removed during the day, when it is hot, the adult whiteflies are very active and fly away, in "clouds", to adjacent young crops.	This almost completely eliminates the migration of whiteflies from old crops to young crops.
	Grubbed crop residues must be quickly buried in the soil, given to livestock or burned to avoid dispersal of whiteflies.	Elimination of sources of infestation for neighbouring crops.
	Treat plants before grubbing in the presence of high pest populations so as not to contaminate nearby host crops.	Elimination of sources of infestation for neighbouring crops.
Balanced nitrogen fertilisation	Open-structure foliage allows PPP sprays to better reach their targets on the underside of the leaves. Excess fertilisation (especially nitrogen) will produce foliage that is too dense. An excess of nitrogen also makes the leaves more attractive to whiteflies, leaf miners and thrips.	Population decline following insecticide applications. Arrival of new adults reduced.

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

Several natural enemies of whiteflies are present on farms. For example: parasitoid *hymenoptera* such as *Eretmocerus* spp. and *Encarsia* spp.; predatory mites such as *Amblyseius* spp. and *Typhlodromus* spp.; predatory thrips; Chrysopidea, Staphylinus and ladybirds.

Their presence should be conserved using PPPs compatible with crop auxiliaries (see tables on pesticide susceptibility in Appendix 4).

Encarsia, lays its eggs in the puparium of the whitefly. When a whitefly puparium is parasitised, it turns black, which facilitates monitoring of infestation rates as part of an integrated pest management programme.

Figure 37 — Adult *Encarsia* laying an egg in a whitefly larva. (COLEAD, 2012. Green bean crop protocol)

Figure 38 — Whitefly larvae turn black when parasitised by *Encarsia*. David Cappaert, Bugwood.org

The presence of parasitoid *hymenoptera* can be encouraged on a farm by the presence of flowers that provide useful nectar to adults. See under point 7.1.3.

BY RELEASE OF AUXILIARIES

The action of natural enemies can sometimes be too slow and too late. It is then advisable to introduce auxiliaries available off the shelf.

Natural enemies like *Encarsia Formosa* are available in some ACP countries like Kenya.

It is possible to design a prophylactic whitefly control programme using adult *Encarsia* for open field crops. Introduction rates of *Encarsia* are based on an estimate of the number of whitefly puparium that could be present on each trifoliate leaf, if no other control is used and natural migration of the pest occurs smoothly (worst case scenario).

After some time, if control is effective, the rate of natural migration of the whitefly to the crop shortly after planting is likely to decrease and, as a result, the required rates of introduction of*Encarsia* also decrease.

An efficient sampling system allows the grower to measure the control carried out by estimating the average number of whitefly puparium and adult whitefly puparium per leaf after a certain period of time.

It is possible to integrate the use of adult *Encarsia* into the application schedule of other compatible fungicides and insecticides. Sprays of PPPs must ensure that adult *Encarsia* are not killed. *Encarsia* are also highly susceptible to fungicides (see Appendix 4 for pesticide susceptibility).

For more details on *Encarsia* see Appendix 5.

CONTROL USING PLANT PROTECTION PRODUCTS PPP

Whitefly control is difficult for several reasons.

- Repeated application of insecticides against whiteflies has led to the development of resistance to many substances worldwide. When resistance develops due to insecticide abuse, whitefly populations grow dramatically and can become uncontrollable. It is therefore essential to alternate different classes of substances to avoid the appearance of resistance.
- Most of the PPPs available do not kill whitefly eggs or pupariums (because they do not feed at these stages). It is mainly adults and young larvae that are targeted by the treatments.
- The stages sensitive to PPPs are mostly hidden at the lower part of the leaves which are more difficult to reach by spraying.

APPLICATION PERIODS

A regular application of PPPs against whiteflies is often essential to control adults and larvae as they develop. However, it is recommended to carry out preventive control treatments at the beginning of the growth cycle until flowering only if the risk of virus transmission is known. If there is no risk of virus transmission, the field should be sampled and treated only when necessary.

APPLICATION TIMES

It is best to spray crops overnight, late afternoon/early evening, or early morning, before the temperature is high enough for the whitefly to fly. In cold weather, the whitefly will not fly during spraying (possibly to other plots) and the sprays will reach them more easily.

THE SUBSTANCES

The recommended substances are listed in the summary table in Appendix 3.

Many biocontrol products allow effective control. These include the following substances: *Metarhizium anisopliae*, *Beauveria bassiana*, *Paecilomyces fumosoroseus*, *Verticilium lecanii*, azadirachtin and neem extracts, pyrethrins, citric acid, sweet orange essential oil, flour and starch, oxymatrine, *Chromobacterium subtsugae* strain PRAA4-1 fatty acids.

OTHER CONTROL METHODS

Adult whitefly may be attracted to sticky yellow traps. These can be used in certain circumstances to reduce the number of flying adults. However, sticky traps can also trap and kill important parasitoid *hymenoptera* of the whitefly and leaf miner, so care should be taken when using this method.

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7.2.2.5. LEAF MINER

SCIENTIFIC NAME

Liriomyza trifolii (American serpentine leaf miner or California miner fly), *L. Huidobriensis* (South American Leaf Miner), and other *Liriomyza* spp.

Liriomyza belong to the order Diptera, and to the family Agromyzidae.

LIFE CYCLE OF THE PEST

There are several different species of leaf miner, but their life cycle, behaviour and control methods are the same. Several generations per year are possible. In Kenya, the total cycle time varies between 24 and 28 days between December and January.

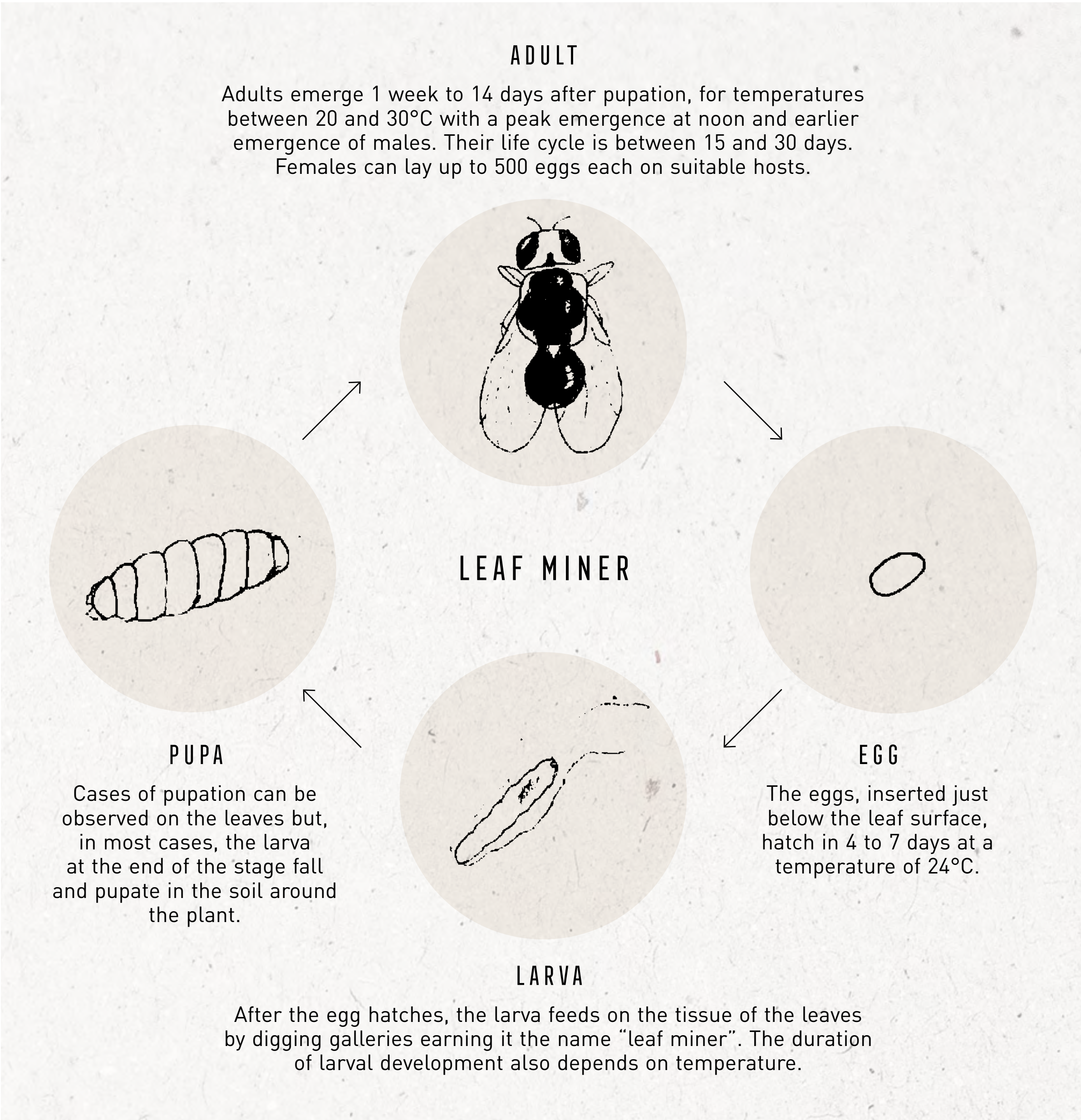

Figure 39 — Life cycle of the leaf miner. COLEAD. (2016). Guide to good phytosanitary practices for aubergine cultivation (*Solanum melongena* (*Solanum melongena*, *Solanum* aethiopicum, *Solanum* macrocarpon)

OTHER HOST PLANTS

The *O. phaseoli* and Solonaceae are the most important hosts in terms of the richness of *Liriomyza* species and their relative abundance. Other important host plants are for example: *Cucurbitaceae* (cucumber), *Gossypium* (cotton) and also various weeds.

DESCRIPTION OF THE INSECT

STAGE	DESCRIPTION
Egg	They are oval in shape and cream in colour.
Larva	Initially transparent and 0.5 mm in length then yellowish and 2.5-3.5 mm in length
Pupa	Barrel shaped and variable colour (yellow to dark brown).
Adult	Adults are black and yellow, which makes them visible when they circle around the host plant and over the leaves. They are 2.5 to 3.5 mm long.

Figure 40 — Larva of *Liriomyza trifolii.*
Photograph by Lyle J. Buss, University of Florida

Figure 41 — Pupa of *Liriomyza* sp.
Charles Olsen, USDA *APHIS* PPQ, USDA *APHIS* PPQ, Bugwood.org

Figure 42 — Adult of *Liriomyza trifolii.*
Central Science Laboratory, Harpenden, British Crown, Bugwood.org

AFFECTED CROP STAGE(S)

From the seedling stage to the first harvest through vegetative growth, flowering and fruiting.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	+++	++	+	0

SYMPTOMS AND DAMAGE

SEEDLING	Severely attacked seedlings are stunted and may eventually die.
LEAF	Numerous chlorotic nutritional bites observed on the limbus and performed by females with their ovipositor. Larval feeding damage appears in the form of galleries (0.13 to 0.15 mm in diameter) on the upper side of the leaves. The shapes of these galleries vary depending on the infested plant, but they are long, linear and shallow when the leaf area is sufficient. They are generally greenish to white. Severely mined leaves can turn yellow and fall off.

Figure 43 — Galleries on a bean leaf. AM Varela, ICIPE

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	Severely attacked seedlings may eventually die.
Loss of yield per plant	The photosynthetic activity of plants, their growth and yields can be greatly reduced in case of heavy infestations.

QUARANTINE ORGANISM

Liriomyza bryonae, *Liriomyza huidobriensis* and *Liriomyza trifolii* are EU quarantine pests (Annex II, Part B of Regulation (EU) 2019/2072).

Interceptions in the EU affect mangetout peas rather than green bean pods, as galleries are not frequently observed on green bean pods, perhaps because their growing period is much shorter than the peas.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Climate	Hot and dry. But when the temperature exceeds 40°C, the leaf miner lays fewer eggs.	They are found at any altitude in some countries such as Kenya, but it is in temperate environments at high altitude (2,000 m at the equator) that they cause the most damage. In Kenya, L. huidobrensis is dominant at high altitudes. (C N Foba, D Salifu, Z O Lagat, L M Gitonga, K S Akutse, K K M Fiaboe, 2015). In Senegal, in the Niayes region, infestations peak from November to July, the dry season. Infestations decrease sharply in the rainy season. (RADHORT, 2012).

MONITORING

A detailed observation methodology is given under point 7.1.2.

BY DIRECT OBSERVATION OF PLANTS

A sampling system will determine the ratio between *Diglyphus* and adult leaf miners. If this ratio is at least "one to three" (i.e. one adult *Diglyphus* for three adult leaf miners), the leaf miner is controlled and no action is required.

Field sampling should be done primarily from emergence to the beginning of harvest. See under point 7.1.2. for more details.

BY TRAPPING

The use of yellow glue traps placed near the crop is a very effective method of sampling and estimating infestation. However, it is not advisable to use these routine traps for the mass trapping of the leaf miner because they also catch *Diglyphus* which is a very effective parasitoid that controls the leaf miner without the need for pesticides, except in case of very serious infestation.

The leaf miner prefers horizontal surfaces to vertical surfaces to land and it is therefore more efficient to lay traps horizontally. On the other hand, it is preferable to position the traps above the crop to increase the probability of capture.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	It is advisable to avoid cultivating on land with a preceding crop that is under attack or that is close to a crop that is under attack.	Avoids the arrival of new adults.
PLOT PREPARATION		
Deep ploughing	Since the leaf miner pupifies in the ground, deep ploughing can bury the pups and prevent them from hatching. However, care must be taken to ensure that the topsoil is sufficient to carry out this operation without bringing soil from the subsoil to the surface. On the other hand, this practice is contrary to the principles of soil conservation agriculture.	Disrupts the pest cycle.
Install barriers in the form of hedges around and between plots	Adult leaf miners are insects that have difficulty flying and barriers about 50 cm high can reduce migration into crops.	Avoids the arrival of new adults.

Plant trap plants	Some crops are much more attractive to leaf miners than green beans. For example, fava beans can be used as "trap plants" of leaf miners. But the leaf miner needs to be controlled in the trap crop, so that it does not become a bigger problem in the cultivation of green beans later on.	Avoids the arrival of new adults.
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
CROP MAINTENANCE		
Ensure regular weeding of the ground and surrounding areas	It is recommended to destroy host weeds growing along cultivated fields, unless biological control methods are used, in which case the natural predator will migrate to weed-covered areas and kill all leaf miner larvae present there.	Avoids the arrival of new adults.
Collect and destroy heavily mined leaves	Heavily mined leaves are no longer very useful to the plant because photosynthesis is reduced. It is best to tear them out and destroy them before the larvae leave them to turn into pupae.	Disrupts the pest cycle.
Grubbing of plants at the end of production	If there has been a strong infestation by leaf miners, it is necessary to destroy (for example by deep burying) the crop residues quickly after harvest, in order to prevent the miners from completing their cycle up to the pupation stage. However, crop residues are not always a problem. In fact, if biological control has been carried out correctly, it is possible that a higher number of *Diglyphus* than leaf miners hatch from the crop residues (see below on biological control).	Disrupts the pest cycle. Elimination of sources of infestation for neighbouring crops.

ORGANIC CONTROL

Parasitoid *hymenoptera* of the families *Braconidae*, *Eulophidae* and *Pteromalidae* are important natural enemies of leaf miners and, in the absence of insecticides, generally maintain this insect at low levels of abundance.

The parasitoid *hymenoptera*, *Diglyphus isaea* of the family *Eulophidae*, is the best way to control leaf miners, since it lays its eggs in abundance and flies actively in search of leaf miner larvae to lay its eggs. The eggs are laid next to the leaf miner larvae in the leaf. To feed, the parasitoid larva sucks the body contents of the leaf miner's larva, which eventually dies, and *Diglyphus* pupifies in the leaf and the adult emerges later.

Diglyphus migrate naturally into crops if they are not sprayed with insecticides toxic to *Diglyphus*. The presence of *Diglyphus isaea* in a culture can be observed by short galleries visible on leaves containing dead leaf miner larvae.

In Kenya, *Diglyphus* is found in the wild but is also registered as a crop protection agent and is mass-bred locally.

Managing natural populations of the parasitoid is probably the most effective way to control the leaf miner. At the end of cultivation, instead of being destroyed, the residues are collected and placed in cardboard boxes. Transparent plastic jars are inserted into the side faces of these boxes and emerging *Diglyphus* are attracted to the light. These jars are removed and emptied up to twice a day to "harvest" the *Diglyphus* individuals, which are then released into the green bean fields. To exploit this parasite to the full, individuals must be released into a young crop, because if the crop is old, wasps will not have time to exert a significant impact on the population of leaf miners. For more information, consult the COLEAD training manual entitled "Integrated Pest Management".

Figure 44 — Adult *Diglypus* ((COLEAD, 2012). Green bean crop protocol)

In Senegal, five native whiteflies (larval parasitoids), plus five other rare parasitoids, frequently parasitise leaf miners. The most important parasitoids are *Hemiptarsensus semialbiclava*, which dominate in the second half of the dry season, and two *Chrysonotomyia* spp. Which are more abundant during the rainy season. (P. Neuenschwander, S. T. Murphy & E. V. Coly, 2008).

CONTROL USING PLANT PROTECTION PRODUCTS

Usually, infestations on green beans are quite low but the application of PPPs is necessary when the attack is severe, especially on young plants. Heavy infestations are often a consequence of a non-rational use of PPPs that eliminated natural enemies without reaching the pest.

Control through the application of PPPs is very problematic for several reasons:

- the larvae are endophytes (they develop inside the leaves) and are therefore protected from insecticides, the truly effective substances have a translaminar action that allows the larvae in the leaf to be reached;
- truly effective products are very rare and it is essential to avoid those that harm natural enemies (for example cyromazine and azadirachtin are compatible with *Diglyphus*);
- resistance to substances can appear quickly.

APPLICATION PERIODS

Treatments should be applied before the harvest period, in preventive or remedial conditions, according to intervention thresholds.

THE SUBSTANCES

The recommended substances are listed in the table in Appendix 3.

Biocontrol substances with good effectiveness on the leaf miner include in particular azadirachtin and neem extracts as well as paraffin oil.

OTHER CONTROL METHODS

No information available.

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7.2.2.6. THRIPS

SCIENTIFIC NAME

Many species of thrips can attack beans. In Kenya the main species are *Megalurothrips sjostedti*, *Frankliniella occidentalis* and *Frankliniella schultzei*.

In Africa, other bean thrips worth mentioning are *Sericothrips occipitalis* and *Thrips tabaci*, and more rarely *Thrips palmi*.

Thrips belong to the order *Thysanoptera*, and to the family *Thripidae*.

LIFE CYCLE OF THE PEST

The development cycle comprises 6 stages: egg, two larval stages, two pre-pupal stages and adult; its duration varying as a function of the temperature and of the host plant (by way of example, for *F. Occidentalis*, it fluctuates from 34 days at 15°C to 13 days at 30°C).

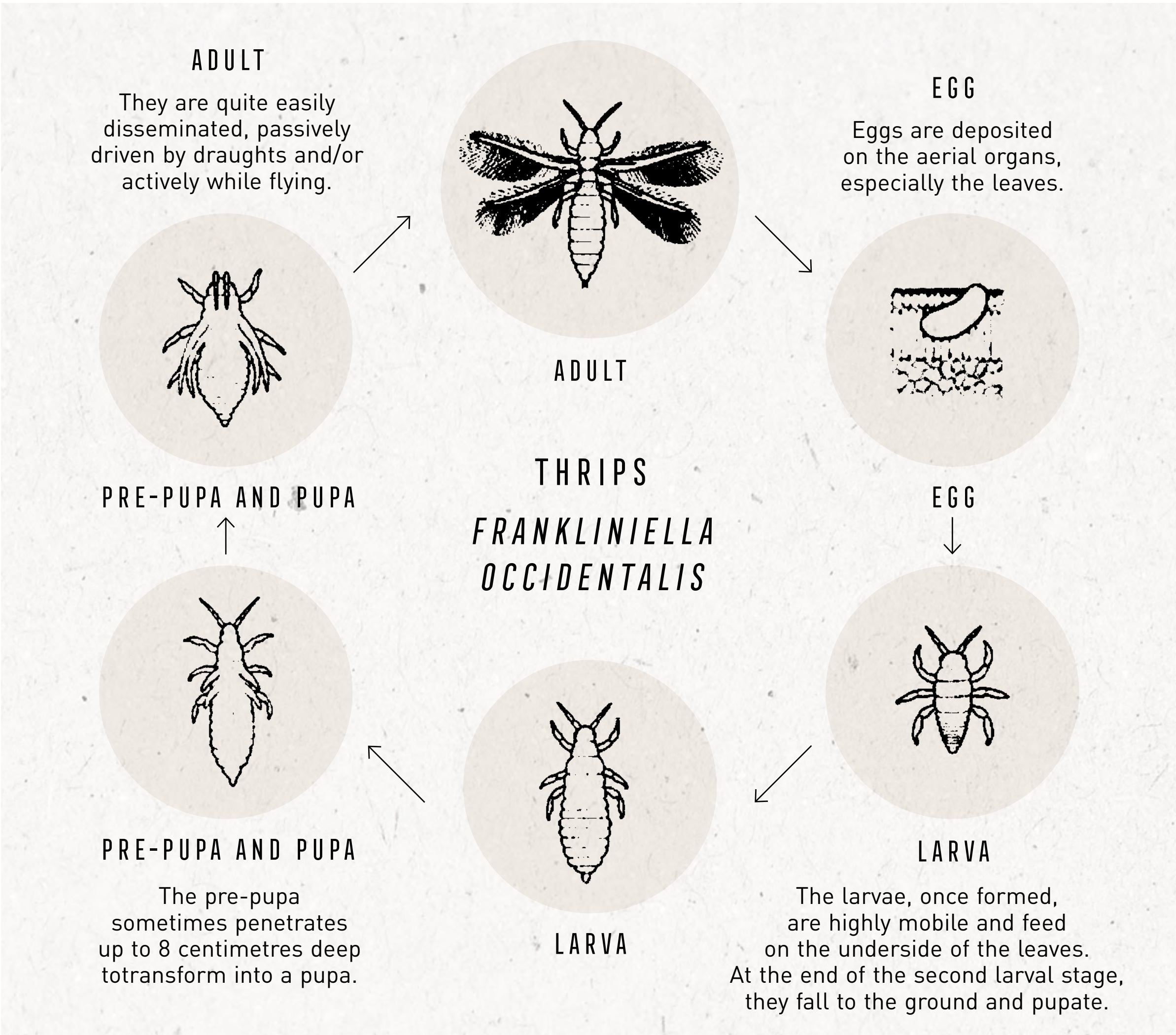

Figure 45 — Life cycle of thrips. COLEAD. (2016). Guide to good phytosanitary practices for aubergine cultivation (*Solanum melongena* (*Solanum melongena*, *Solanum* aethiopicum, *Solanum* macrocarpon)

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Megalurothrips sjostedti mainly attacks legumes such as peanuts, peas, cowpeas and Angole peas.

Both species of *Frankliniella* feed on a wide variety of plants.

DESCRIPTION OF THE INSECT

They are very small insects (1 to 2 mm long). It is therefore difficult to distinguish between species in the field.

STAGE	Description
EGG	They are kidney-shaped.
LARVA	Larvae are similar to adults but have no wings and are usually pale yellow to almost white in colour.
PRE-PUPA	The first prepupal stage is characterised by the appearance of wing blanks. The second, clearer prepupal stage also shows larger wing blanks and long antennae curved towards the back of the body.
ADULT	Adults are cylindrical or cigar-shaped and pale yellow to black in colour. They have two pairs of narrow wings with a fringe of long bristles.

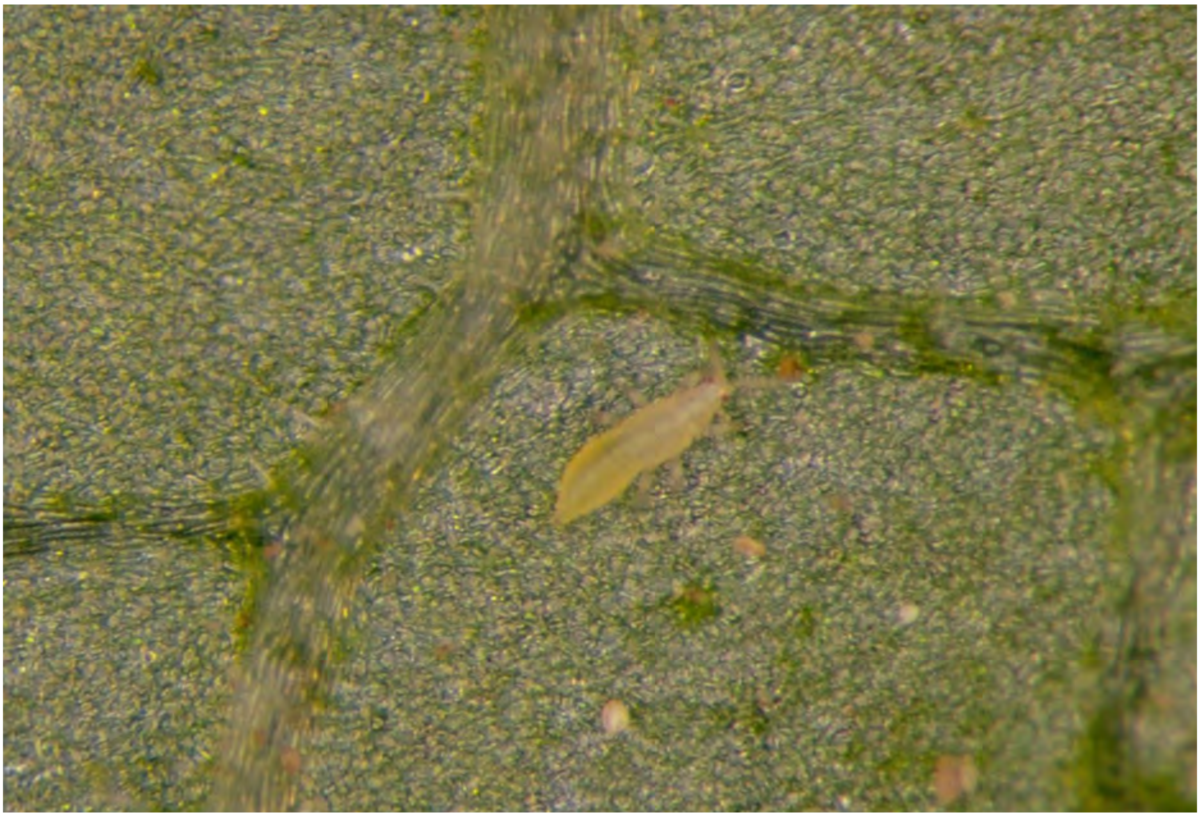

Figure 46 — Larva of *Thrips tabaci*. Frank Peairs, Colorado State University, Bugwood.org

Figure 47 — Adults of *Frankliniella occidentalis*: one male (the smallest) and two females.
P.M.J. Ramakers, Applied Plant Research, Bugwood.org

AFFECTED CROP STAGE(S)

From the seedling stage to flowering. From flowering, thrips are found mainly in buds, flowers and young pods.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+	++	+++	++	+

SYMPTOMS AND DAMAGE

Thrips feed by sucking on the contents of epidermal cells, causing damaged tissue to quickly become necrotic.

LEAF	Numerous and tiny silver lesions, even irregular size and shape ranges; they gradually become necrotic and take on a beige hue. Affected leaves and leaflets tend to become chlorotic and become dull.
FLOWER	Whitish lesions appear. Significant damage is characterised by malformation, deformation and discolouration of flowers.
POD	Silvery, even suberized, more or less extensive alterations are observed

Figure 48 — Feeding damage by thrips. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 49 — Thrips on a flower. Ko Ko Maung, Bugwood.org

Figure 50 — Heavily attacked pods Gerald Holmes, Strawberry Center, Cal Poly San Luis Obispo, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	Generally plants do not die.
Loss of yield per plant	The number of pods produced decreases following abscission of the buds and abortion of the flowers. Thrip bites also cause weakening and wilting of plants that reduce yields.
Reduction in quality	Stains and lesions on pods making them unmarketable.

QUARANTINE ORGANISM

Note that *Thrips palmi* is an EU quarantine pest and observers must be trained to identify this species.

The other species on green beans are not EU quarantine pests.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Climate	The warm climate (25-30°C) of tropical and Sahelian countries is well adapted to this pest.	The two species, *Megalurothrips sjostedti* and *Frankliniella occidentalis*, have virtually the same ecological requirements, however, under hot and dry conditions the second takes over while the first is more abundant during cool and rainy periods and in high altitude areas. In Kenya, thrips are primarily of commercial importance during the dry seasons, almost half of the year.

MONITORING

The crop must be monitored regularly and especially as soon as the flower buds appear. This monitoring makes it possible to trigger treatments in time and avoid making too many PPP applications. However, thrips are not easily detectable due to their small size.

It is suggested that insecticides should only be applied after an average density of three thrips per flower has been observed. (J.H. Nderitu, M.J. Kasina, G.N. Nyamasyo, C.N. Waturu and J. Aura, 2008).

Infestations should be assessed by direct observation of plants in the field. Randomly check the damage caused by thrips to the extremities of plants before the flowering stage. Look for thrips early in the morning (i.e. before 9 a.m.) as they tend to hide inside the flowers or under the leaves when temperatures are high. For more details on the methodology to be followed see under point 7.1.2.

Populations of thrips can also be monitored using yellow or blue glue traps.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choice of tolerant varieties	Paulista	Less incidence of attacks
Choose an appropriate site for the plot	It is advisable to avoid cultivating on land with a preceding crop that is under attack or that is close to a crop that is under attack.	Avoids the arrival of new adults.
Clean the farm	If the populations of thrips are large, this means refraining from growing susceptible plants for at least 1 year.	Reduction of populations by disrupting the cycle.
PLOT PREPARATION		
Deep ploughing	Provided that the depth of the topsoil is adequate, deep ploughing of plots heavily infested by thrips can bury those who pupify in the ground. Do not plough deep if you risk bringing soil from the subsoil to the surface, as this will reduce subsequent yields. However, this practice is contrary to the principles of soil conservation agriculture.	Reduction of populations by disrupting the cycle.
Soil solarization	Solarization can kill pupae present in the soil but this practice is contrary to the principles of soil conservation agriculture because solarization destroys various useful organisms present in the soil.	Reduction of populations by disrupting the cycle.
Intercropping strips	Sunflower and corn harbour *Orius* spp. auxiliaries that feed on thrips.	Control by auxiliaries is reinforced.
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
CROP MAINTENANCE		
Ensure regular weeding of the ground and surrounding areas	It is recommended to destroy host weeds that grow in and along cultivated fields.	Reduces sources of reinfestation.
Grubbing of plants at the end of production	Remove and destroy infested plant debris and crop residues.	Dispersion is avoided by disrupting the cycle.

BY CONSERVATION OF THE AUXILIARIES PRESENT

Several natural enemies of thrips occur naturally on farms. For example: predatory thrips; *Phytoseiidae* mites and anthocorids, *Orius* spp.

Their presence should be conserved by using PPPs compatible with crop auxiliaries (see tables on pesticide susceptibility in Appendix 4).

The most common natural enemies in Kenya are the predatory anthocorid *Orius albidipennis* and the parasitoid *Ceranisus menes* (*Hymenoptera*: *Eulophidae*).

The presence of parasitoid *hymenoptera* such as *Ceranisus* can be encouraged on a farm by planting flowers that provide useful nectar to adults. See under point 7.1.3.

Intercropping green beans with corn is believed to increase the presence of *Orius* and *Ceranisus* and reduce damage to pods. Source: J.O. Nyasani, Rainer Meyhöfer, Sevgan Subramanian, Hans-Michael Poehling. (2012). *Effect of intercrops on thrips species composition_and_population_abundance_on_French_beans_in_Kenya.* Entomologia Experimentalis and Applicata 142(3): 236-246. Accessed on 19.05.2021 at https://www.researchgate.net/publication/235886898.

Figure 51 — Adult *Orius* feeding on young larvae of thrips (COLEAD, 2012. (Green Bean Crop Protocol)

BY RELEASE OF AUXILIARIES

In Kenya, the predatory mite *Amblyseious cucumeris* is authorised for the control of thrips but not on green bean crops. The same is true for *Macrochelis robustulus* and *Hypoaspis miles*, which attack thrip pupae present in the soil.

CONTROL USING PLANT PROTECTION PRODUCTS

Thrips are difficult to control with insecticides because they hide and feed in the flowers, where they are sheltered. However, thrips of the genus *Megalurothrips* are easier to reach with insecticides than thrips of the genus *Frankliniella*. It is therefore important to know the type (species) and degree of thrip infestation before taking control measures.

APPLICATION PERIODS

Freshly emerged young bean leaves are very attractive for thrips. Since there are several generations in the life of a crop, it is important to put in place a strategy to control thrips from the first weeks of the crop, in order to avoid the exponential increase of the population in the crop. Late onset of interventions can lead to less effective controls and increase the risk of pesticide residues and damage to harvested pods. Subsequently, insecticide applications against bean flower thrips should be carried out mainly during the period from the development of flower buds to the beginning of flowering. Threshold-based spraying are considered more cost-effective than scheduled observations. A threshold of 3 thrips per flower is recommended in Kenya.

APPLICATION TIMES

In some areas, thrips have been observed to occur outside the flowers and on the upper surface of the leaves approximately between 7.30 and 8.30 a.m. and between 4.30 and 5.30 p.m. These are the best times of day for spraying because it is thus possible to use contact insecticides instead of systemic organophosphorus compounds. After very severe droughts, thrips are very thirsty and the feeding damage will increase on the plant because they scrape moisture from leaves and petals. If, during the drought, a heavy shower occurs in the late afternoon, thrips often place themselves on the surface of leaves and flowers during the evening. In this case, the time is right to spray them, because more thrips will be killed.

RESISTANCE MANAGEMENT

Chemical resistance is also a common problem when it comes to thrips. An integrated control programme and a robust resistance management strategy are needed. It will be necessary to:

- alternate substances belonging to different groups;
- not apply the same substance more than once in a row;
- only apply the products at the recommended doses.

THE METHOD OF APPLICATION

Good spray coverage is essential, as thrips hide during the day in the flowers and in the armpit or lower part of the leaves.

THE SUBSTANCES

The recommended active substances are listed in the table in Appendix 3. However, preference should be given to products that are most compatible with the preservation of the natural enemies of the pest.

Some commercial biopesticides have been successfully mixed with chemicals to achieve a synergistic effect in thrip control, as well as a strategy for managing resistance to important active substances such as spinosad.

Biocontrol substances include:

- Entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria bassiana*.
- Products based on azadirachtin or neem extracts.
- Pyrethrins.
- *Chromobacterium subtsugae* strain PRAA4-1.
- Mineral oils.
- Fatty acids.

OTHER CONTROL METHODS

Place blue glue traps over plants to reduce thrips.

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7.2.2.7. COTTON BOLLWORM

SCIENTIFIC NAME

Helicoverpa armigera (*Heliothis armigera*)

It is part of the order Lepidoptera, and of the family Noctuidae.

LIFE CYCLE OF THE PEST

STAGE	DESCRIPTION
Egg	Eggs are deposited separately on young shoots, near buds, on flowers, fruits or leaves. These eggs hatch after 3 days when temperatures average 25°C.
Larva	The first larval stages are the most mobile and move by walking. The caterpillars are often aggressive and cannibal.
Pupa	Pupation takes place in the ground.
Adult	The moths fly at night and at dusk where they feed on nectar or drops of water from their host plants. The adult life cycle is around 3 weeks. A female can lay up to 3,000 eggs throughout its life cycle.

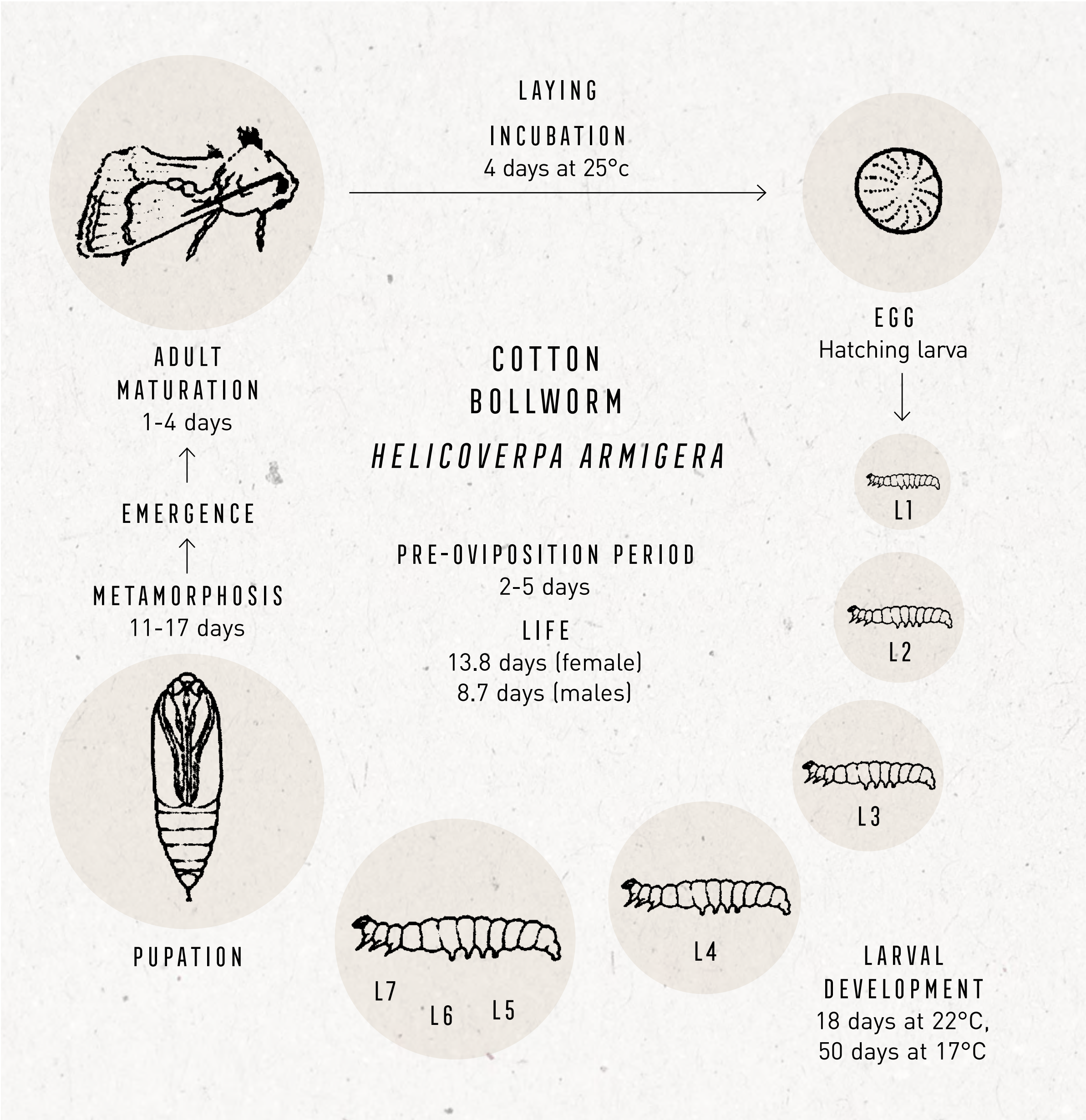

Figure 52 — Development cycle of *Helicoverpa armigera*.
J. Poidatz (Koppert) (2014) http://ephytia.inra.fr/fr/C/19706/Biocontrol-Biologie

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Its mobility, polyphagia, rapid reproductive capacity and diapause make it particularly suitable for artificial ecosystems such as crops. *H. armigera* is a major pest in most parts of the world for several crops such as: *Gossypium* (cotton), *Lycopersicon esculentum* (tomato), *Solanum tuberosum* (potato), *Sorghum*, *Arachis hypogaea* (peanut), *Brassicaceae* (crucifers), *Cucurbitaceae*, *Allium*, *Citrus*, *Capsicum annuum* (chilli), *Pennisetum glaucum* (millet), *Phaseolus*, *Pisum sativum* (peas), *Solanum melongena* (aubergine), etc.

DESCRIPTION OF THE INSECT

STAGE	DESCRIPTION
Egg	Spherical with flattened base, about 0.5 mm in diameter. They are initially bright yellowish white, becoming brown just before hatching.
Larva (caterpillar)	Yellowish white to reddish brown head with dark spots. The head of older larval stages is spotted. Their bodies are marked with three broad dark stripes and many lighter wavy lines. Their colour is extremely variable, and can be green, straw yellow, black or pinkish, or even reddish brown. At the end of development, they measure between 30 and 40 mm in length.
Pupa (chrysalis)	The chrysalides are between 14 and 18 mm long and have a smooth brown body surface.
Adult (butterfly)	Adult females are robust butterflies, brownish orange, measuring about 18 to 19 mm and with a wingspan of 40 mm. They are larger than males that have a grey-green colouring. The forewings are bordered by a line of black spots and the hindwings of both sexes are cream in colour, with a dark brown band along the outer border.

Figure 53 — Caterpilllar of *Helicoverpa armigera* (COLEAD, 2012. Green bean crop protocol)

Figure 54 — Chrysalis of *Helicoverpa armigera* (COLEAD, 2012. Green bean crop protocol)

Figure 55 — Helicoverpa armigera Butterfly. W. Billen, Pflanzenbeschaustelle, Weil am Rhein, Bugwood.org

AFFECTED CROP STAGE(S)

From setting to the harvest through the stages of vegetative growth. Adults can lay eggs on the pods. Damage can therefore appear after harvest in the export crates because eggs and young caterpillars are not easily visible during sorting.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	+	+++	+++	+

SYMPTOMS AND DAMAGE

LEAF	The caterpillar consumes foliage.
FLORAL BUDS	They can also be destroyed by the caterpillar.
POD	The caterpillar perforates the pods and devours the seeds. It is most often found outside the pod but sometimes inside.

Figure 56 — Damage to pod. Droppings near the caterpillar. A.M. Varela, ICIPE

IMPACT ON YIELD AND QUALITY

Its predilection for flower buds and fruiting organs (pods, seeds etc.) of cultivated plants with high added value (cotton, tomato, bean, etc.) gives it major economic importance and a significant socio-economic cost, especially in subsistence agriculture.

TYPE OF IMPACT	DESCRIPTION
Loss of yield per plant	Rarely because of severe defoliation. Loss of flower buds and therefore pods.
Reduction in quality	Perforated pods unsuitable for sale.

QUARANTINE ORGANISM

Helicoverpa armigera is considered an EU quarantine pest, which means that it cannot be imported on products destined for the EU. It is therefore essential to properly sort the pods, in order to remove those that are damaged or carrying caterpillars, in the processing rooms before packing.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Vegetation	Availability of food (sucrose, nectar) for butterflies.	The longevity of butterflies depends on the availability of food (sucrose, nectar). For this reason, cotton bollworms tend to form populations after the rains in Kenya, when adults come out of the chrysalids in the soil and it is highly likely that suitable host plants have grown after the rains.
Time of year	In countries such as Senegal, this pest is dangerous all year round and, in the Niayes region, especially in the cool dry season from December to April-May and its development is favoured by the succession of host crops: tomatoes, beans, aubergine, cotton, etc.	Green beans are grown for export in a period favourable to this pest.

MONITORING

Because of the high egg-laying capacity of this pest, it is important to anticipate its arrival in a crop and to begin a preventative spraying campaign before having a large pest population.

BY TRAPPING

"Pheromone traps are commercially available for *Helicoverpa armigera*. Use these traps to identify the arrival and general trends in the evolution of pest populations on the farm. Do not attempt to use pheromone traps to monitor pest levels in small individual fields, as this could give false information about the overall risk on the farm. The trap density is 5 per hectare." (Plantwise – CABI, 2016).

BY DIRECT OBSERVATION OF PLANTS

This monitoring is useful in order to determine the moment when the economic intervention threshold is reached and exceeded so that control measures are taken. It is difficult to obtain precise data on this threshold, some are based on the number of eggs, others on the number of caterpillars (one egg per 2 plants, 2 caterpillars per 18 plants, 2 eggs per row of 1 m). "Other sources indicate a threshold of 1 to 2 caterpillars per m^2 for crops such as cotton, corn and *sorghum*. ' (Plantwise – CABI. 2016).

The observation of eggs is difficult, so it is better to search for caterpillars instead. Those that feed can be observed on the surface of leaves, buds, flowers or pods but are sometimes hidden in flowering and fruiting organs. It is possible to detect their presence by observing organic waste outside the pods, due to the nutrition of the caterpillars. In case of doubt, it is necessary to open the perforated pods to ensure the presence of the caterpillar. For green beans produced for export, as it is an EU quarantine pest, the tolerance must be practically zero caterpillar during the harvest period.

It is advisable to monitor the plots 1 to 2 times a week from the appearance of the flower buds until the end of the harvest. During the observation, note the number of small (<1.5 cm) and large (>1.5 cm) caterpillars.

CONTROL THROUGH CROP PRACTICES

Control via crop practices is difficult for this pest because new populations can suddenly appear as a result of butterfly migrations that can come from far away.

Nevertheless, the following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLOT PREPARATION		
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
Creation of hedges	Gives shelter to several useful insects and insectivorous birds	Control by auxiliaries is reinforced.
Intercropping with trap crops*	"Research in Ethiopia has indicated that lupine, Angole pea, hyacinth beans, corn and sunflower attract significantly higher numbers of this pest and divert them from the main crop, beans (Dejen and Tesfaye 2002). Corn grown in strips at 10 m intervals has been reported to reduce damage to pods in beans (Ahmed and Damte 2002)." (Infonet Biovison, 2020).	Less egg-laying on green bean crops.
CROP MAINTENANCE		
Remove the attacked pods from the field and then destroy them	This prevents caterpillars from turning into chrysalids and then into a butterfly	Disrupts the cycle.
Grubbing of plants at the end of production	This prevents caterpillars from turning into chrysalids and then into a butterfly	Disrupts the cycle.
Balanced nitrogen fertilisation	Open-structure foliage allows PPP sprays to better reach their targets on the underside of the leaves. Excess fertilisation (especially nitrogen) will produce foliage that is too dense.	More caterpillars are affected by insecticides.

* Companion plants have certain limitations, because they can promote the multiplication of caterpillars, unless they are inspected thoroughly and regularly and the caterpillars present are removed by picking them off or by spraying them with an insecticide. A single eliminated Caterpillar prevents the development of several hundred second generation caterpillars (since an adult can lay up to 3,000 eggs).

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

Several natural enemies of *Helicoverpa armigera* occur naturally on farms. For example: egg parasitoid *hymenoptera* such as *Trichogramma* spp. or caterpillars such as *Bracon* spp.; tachinids (larval parasitoid Diptera) and predators such as: lacewings, ants, anthocorids, mirids and ladybugs.

"Spraying insecticides can harm natural enemies. This is particularly damaging at the beginning of the season, as natural enemies that could have grown and removed the pest are killed. Replacing broad-spectrum PPPs with selective biopesticides such as Bt, nuclear polyhedrosis viruses (NPV) and plant extracts (*e.g.* neem) to control this and other pests; can allow early establishment of natural enemies and contribute to pest control. To achieve better results, a joint effort involving local growers and farming communities at the regional level would be needed." (Infonet Biovision, 2020).

The presence of parasitoid *hymenoptera* can be encouraged on a farm by the presence of flowers that provide useful nectar to adults. See under point 7.1.3.

BY RELEASE OF AUXILIARIES

There are no natural invertebrate enemies available in ACP countries for release.

CONTROL USING PLANT PROTECTION PRODUCTS

On green beans, the damage is generally not significant enough to justify insecticide applications. However, the application of PPPs is necessary for export to the EU because *Helicoverpa armigera* is a quarantine organism and there is no tolerance of the presence of caterpillars on the pods.

Period, time of day and method of application

Preventive control should be preferred to remedial control because green bean consignments may be refused by importing countries in the EU if the presence of caterpillars is detected. In preventive control, it is advisable to treat every week from setting and throughout the harvest period.

Treatment tips:

- Treat as soon as possible, once butterflies are captured in tracking traps: the younger the caterpillars, the more sensitive they are to treatments, whether chemical or biological.
- Treat in the evening because caterpillars and butterflies have nocturnal activity. In addition, many products such as *Bacillus thuringiensis* are sensitive to UV radiation.
- Ensure good leaf cover. The quality of the spray is effectively important because most products act by contact, so enough impacts on the aerial organs are needed for the larvae to ingest the product when feeding.

- Repeat sprays every 8 to 10 days depending on the persistence of product action (a contact product acts for 8 days or less if leached and a systemic product for 15 to 20 days), while alternating the active substances belonging to different groups because resistance could appear. In all cases; these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market.
- Renew the contact treatments after rain of more than 20 mm.

THE SUBSTANCES

The recommended active substances are listed in the table in Appendix 3. However, preference should be given to products that are most compatible with the conservation of the natural enemies of the pest.

The biocontrol products include the following.

- *Bacillus thuringiensis* var. *Kurstaki* or *Bacillus thuringiensis* var. *aizawai*.
- Baculoviruses such as nucleopolyhedrovirus.
- Entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria bassiana*.
- Products based on azadirachtin or neem extracts.
- Oxymatrine.

RESISTANCE MANAGEMENT

Resistance of this pest to chemical pesticides is often reported around the world and the implementation of an integrated management programme is important to avoid the emergence of resistance. Therefore, care must be taken to alternate substances belonging to different resistance groups defined by the IRAC. The selection pressure exerted by insecticides including pyrethroids led to resistance phenomena in *H. armigera* populations already in the 1980s.

OTHER CONTROL METHODS

Light traps can attract butterflies away from cultivated plants. They can be coupled to water tanks, where adult butterflies struggle and drown.

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7.2.2.8. POD MINER OR BEAN BORER

SCIENTIFIC NAME

Maruca testulalis (*Maruca vitrata*).

It is a member of the order Lepidoptera, and of the family *Crambidae*.

LIFE CYCLE OF THE PEST

STAGE	DESCRIPTION
Egg	The egg stage lasts about 3 days at 24-27°C.
Larva	The presence of flowers at the time of wintering (rainy season) allows the few caterpillars of the first stage, first gathered in groups, to disperse later. Young caterpillars feed on leaves and pods during the 13 to 14 days of the larval stages at 24-27°C.
Pupa	Pupation lasts about a week.
Adult	Adults are inactive during the day and can be found resting on the lower leaves of the plant. Several generations can be observed per year (up to 7).

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

O. phaseoli such as *Cajanus cajan* (Cajun peas) and *Phaseolus lunatus* (Lima bean), etc.

DESCRIPTION OF THE INSECT

M. vitrata is a member of the pod-boring lepidopteran group.

STAGE	DESCRIPTION
Egg	The eggs are yellow white, translucent and have the appearance of fine individual water droplets.
Larva (caterpillar)	The larva has discrete spots along the back and has a dark brown/black head. It spins webs between flowers, stems and pods.
Pupa (chrysalis)	The chrysalis measures between 11.5 and 2.5 mm.
Adult (butterfly)	The adult butterfly is a moth that, at rest, keeps its wings spread out and measures about 25 mm. The adult's wings are brown with white markings. The head is brown.

Figure 57 — Caterpillar in a pod. Ko Ko Maung, Bugwood.org

Figure 58 — Butterfly. Alan Kimber, Bugwood.org

AFFECTED CROP STAGE(S)

Phases of vegetative growth, flowering and fruiting (from setting to harvest).

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	0	+++	+++	+

SYMPTOMS AND DAMAGE

The damage caused resembles that of other pests such as *Helicoverpa armigera*.

FLOWERS	Circular holes at the level of the corolla of the flowers, which transforms the flowers into a brownish mass within 24 hours.
POD	The pods deform because of the larger caterpillars they contain.

Figure 59 — Caterpillar on a flower.
Ko Ko Maung, Bugwood.org

IMPACT ON YIELD AND QUALITY

Yield losses can be very significant on grain beans grown in the rainy season. However, on export green beans grown in drier seasons, the damage is generally not significant.

TYPE OF IMPACT	DESCRIPTION
Loss of yield per plant	Loss of flower buds and flowers therefore pods.
Reduction in quality	Perforated pods unsuitable for sale.

QUARANTINE ORGANISM

This is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

It is widespread in tropical regions especially in West and East Africa. *M. vitrata* is often considered a major legume pest in tropical areas but less so in Kenya for example.

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Strong hygrometric conditions are necessary for this nocturnal lepidopteran.	On green beans, it is quite rare because this crop is rather grown in the dry season.
Availability of host plants	The alternation of the flowering periods of the different host plants according to a South-North gradient influences the migration of *M. vitrata* from the coast to the savannas of West Africa. During this migration, the populations find favourable conditions for their reproduction on different cultivated plants.	This has the consequence of increasing the populations with each new generation. Thus, up to 1,500 adults can be captured per night during the growing season thanks to light traps with capture peaks of 5,000 butterflies per night in northern Benin.

MONITORING

The most effective method of capturing butterflies remains the light trap.

The flowers should be examined for circular holes made by the caterpillars and look for signs of deformation in the pods.

There are also pheromones that can be applied in population tracking traps.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The practices mentioned below help to control the pest, but the use of insecticide is often unavoidable. They are practically the same as for *Helicoverpa armigera*.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLOT PREPARATION		
Creation of hedges	Gives shelter to several useful insects and insectivorous birds	Control by auxiliaries is reinforced.
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
CROP MAINTENANCE		
Remove the attacked pods from the field and then destroy them	This prevents caterpillars from turning into chrysalids and then into a butterfly	Disrupts the cycle.
Grubbing of plants that have reached the end of production	This prevents caterpillars from turning into chrysalids and then into a butterfly	Disrupts the cycle.
Balanced nitrogen fertilisation	Open-structure foliage allows PPP sprays to better reach their targets on the underside of the leaves. Excess fertilisation (especially nitrogen) will produce foliage that is too dense.	More caterpillars are affected by insecticides.

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

Several natural enemies occur naturally on farms. Examples include: larval parasitoid *hymenoptera* such as *Bracon* spp.; tachinids (larval parasitoid Diptera) and predators such as lacewings, ants, anthocorids, mirids and ladybirds.

Spraying insecticides can harm natural enemies. Replacing broad-spectrum PPPs with selective biopesticides such as Bt to control this and other pests may allow early establishment of natural enemies.

The presence of parasitoid *hymenoptera* can be encouraged on a farm by the presence of flowers that provide useful nectar to adults. See under point 7.1.3.

BY RELEASE OF AUXILIARIES

There are no natural invertebrate enemies available in ACP countries for release.

CONTROL USING PLANT PROTECTION PRODUCTS

PERIODS OF APPLICATION

In preventive control in case of risks, treat every week from setting and throughout the harvest period. In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market.

TIMES OF DAY FOR APPLICATIONS

Pod borer larvae are active only at night, moving from flower bud to flower bud. Spraying at night will be more effective.

RESISTANCE MANAGEMENT

Dependence on chemicals to control this pest is decreasing, partly due to resistance phenomena. Therefore, it is advisable to use these only in case of extreme necessity and to recommend alternative control methods.

THE SUBSTANCES

The recommended active substances are listed in the table in Appendix 3. However, preference should be given to products that are most compatible with the conservation of the pest's natural enemies.

Biocontrol products include:

— *Bacillus thuringiensis* var. *Kurstaki* or *Bacillus thuringiensis* var. *aizawai*.

— Entomopathogenic fungi such as *Metarhizium anisopliae*.

— Products based on azadirachtin or neem extracts.

OTHER CONTROL METHODS

No information available.

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7.2.2.9. ARMYWORMS

SCIENTIFIC NAME

Spodoptera exigua (beet armyworm) and *Spodoptera frugiperda* (autumn armyworm). They are part of the order Lepidoptera and the family Noctuidae.

LIFE CYCLE OF THE PEST

SPODOPTERA EXIGUA

Larval development in 6 stages is controlled by a combination of diet and temperature conditions, the temperatures required to move from egg to caterpillar and chrysalis are 13 and 15°C, respectively This development takes between 10 and 12 days at 28°C but can last 35 days at 16°C.

STAGE	DESCRIPTION
Egg	The eggs are deposited overnight on the host plant at the lower surface of the lower leaves.
Caterpillar	It feeds mainly at night and hides during the day. Caterpillars are good walkers, they are able to travel considerable distances and, as a result, caterpillars from the same group of eggs can damage the crop in many places. The young caterpillars live in groups and spin isolated webs on the leaves under which they remain hidden until the third or fourth stage. Older caterpillars spread throughout the crop. At the end of their development, the caterpillars move towards the soil and prepare to pupate.
Chrysalis	Pupation sometimes occurs in the crop, but it usually occurs on the soil surface in a cocoon made up of soil particles, bonded to each other by a sticky secretion.
Adult	Adults emerge from cocoons at night and live between 8 and 11 days.

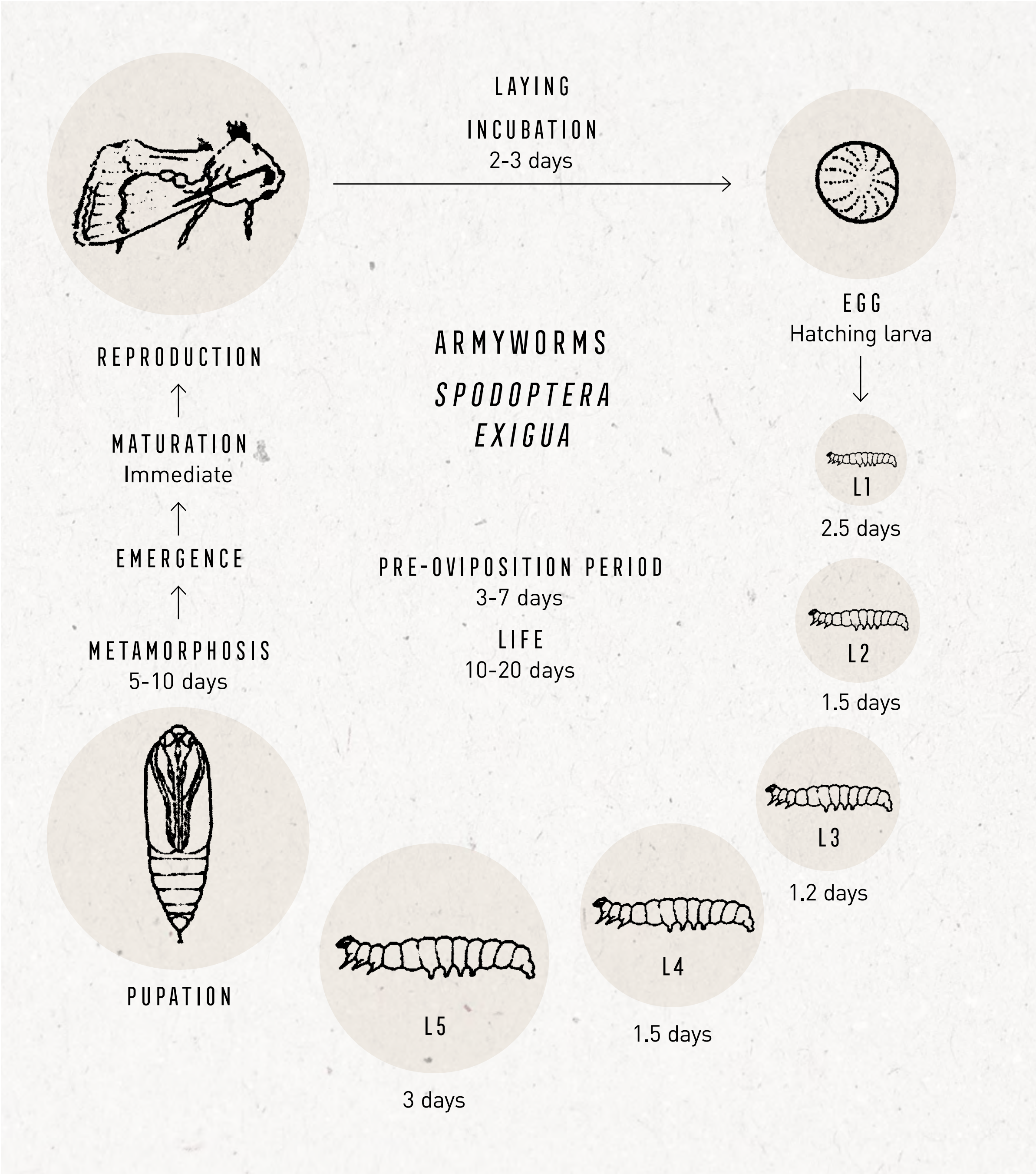

Figure 60 — *Spodoptera exigua* development cycle.
J. Poidatz (Koppert) (2014). http://ephytia.inra.fr/fr/C/19714/Biocontrol-Biologie

SPODOPTERA FRUGIPERDA

In the tropics, breeding can be continuous with four to six generations per year.

STAGE	DESCRIPTION
Egg	The eggs are laid at night on the leaves of the host plant, glued to the underside of the leaves, in tight clusters of 100-300 and sometimes in two layers, commonly covered with a protective layer of hair. Hatching takes 2 to 10 days (usually 3 to 5).
Caterpillar	The first two larval stages feed gregariously on the underside of the young leaves. The rate of larval development through the six stages is controlled by a combination of diet and temperature conditions, and usually takes 14 to 28 days. Larger larvae are nocturnal, unless they enter the armyworm phase to swarm and disperse, seeking other food sources.
Chrysalis	Pupation occurs inside a soft cocoon in a soil cell, or rarely between leaves on the host plant, and 7 to 14 days are needed for development.
Adult	Adults emerge at night and usually use their natural pre-oviposition period to travel several kilometres before settling for laying, sometimes migrating long distances. On average, adults live 11 to 14 days.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

— *Spodoptera exigua*

The beet armyworm has a wide range of hosts and is a major pest of vegetable, field and floral crops. Susceptible vegetable crops include asparagus, beetroot, broccoli, cabbage, cauliflower, celery, chickpea, corn, cowpea, aubergine, lettuce, onion, peas, pepper, potato, radish, spinach, sweet potato, tomato and turnip. Other damaged crops include corn, cotton, peanut, *sorghum*, soybeans and tobacco.

— *Spodoptera frugiperda*

A polyphage pest, it is a tropical and subtropical species with a preference for Poaceae. It is frequently observed on herbaceous grasses and on sugar cane, corn, rice and *sorghum*. It is also reported on *Brassicaceae*, *Cucurbitaceae*, Solanaceae, Onion, *Phaseolus*.

DESCRIPTION OF THE INSECT

— *Spodoptera exigua*

STAGE	DESCRIPTION
Egg	They are grey, sometimes greenish or rosy, laid in bundles, sometimes over several layers. The egg cluster is covered with a mass of white cotton hairs and scales of the adult's body.
Larva (caterpillar)	The caterpillars are of variable colour but often green and measure between 20 and 30 mm at the last stage. They are sometimes brown or even black in colour. Their colour and patterns vary greatly and depend on the host plant, the stage of development, but also the climate. It has sinuous dark lines on the dorsal side and a yellow stripe on each side of the body. Each segment has a black dot above the yellow bands.
Pupa (chrysalis)	Brown, 15 to 20 mm long.
Adult (butterfly)	Wingspan of 17 to 30 mm, long body of approximately 15 mm, brown grey forewings overrun with dark brown or bright black and a yellowish, kidney-shaped design. The white hindwings have a clearly visible nervation, underlined in brown. The head and thorax are brown and the abdomen grey-brown.

Figure 61 — Egg cluster.
John C. French Sr., Retired, Universities: Auburn, GA, Clemson and U of MO, Bugwood.org

Figure 62 — Caterpillar. Russ Ottens, University of Georgia, Bugwood.org

Figure 63 — Butterfly Paul Harris, Bugwood.org

— *Spodoptera frugiperda*

STAGE	DESCRIPTION
Egg	The eggs are gathered in clusters and are cream, grey or white and are covered with a "down".
Larva (caterpillar)	The caterpillars are light green to dark brown with longitudinal stripes. In the sixth stage, the larvae are 3 to 4 cm in length. When they hatch, they are green with black lines and spots, and as they grow, they remain green or become buff-coloured with black dorsal and spiracular lines. Older caterpillars are characterised by an inverted yellow Y shape on the head.
Pupa (chrysalis)	Generally, it is shiny brown in colour and measures 1.3 to 1.7 cm.
Adult (butterfly)	The forewings of the male butterfly have white spots at their lower end and the hindwings are white with dark veins.

Figure 64 — Egg cluster.
David Jones, University of Georgia, Bugwood.org

Figure 65 — Caterpillar. Russ Ottens, University of Georgia, Bugwood.org

Figure 66 — Butterfly William Lambert, University of Georgia, Bugwood.org

AFFECTED CROP STAGE(S)

All stages from emergence to harvest.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	+	+++	+++	+

SYMPTOMS AND DAMAGE

Larvae of both species can damage developing leaves, buds and pods.

LEAF	The young caterpillars feed on the superficial layer of the leaves and often leave intact the epidermis and large veins causing a characteristic skeleton or “windowing” effect. The caterpillars at a later stage of their development make irregular holes in the leaves and the caterpillar at its full development devours the foliage completely, leaving only the main veins.
BUD AND FLOWER	They can also be destroyed.
POD	Caterpillars can make holes in them.

Figure 67 — Moderate damage on leaf. Infoagro.com

Figure 68 — Intense damage on leaf. https://keys.lucidcentral.org/keys/sweetpotato/key/Sweetpotato%20Diagnotes/Media/Html/TheProblems/Pest-LeafChewingInsects/ArmyWorms/Armyworm-damage-A_Vera.jpg

IMPACT ON YIELD AND QUALITY

The highest risk concerns the possible presence of caterpillars on the pods in the export boxes.

TYPE OF IMPACT	DESCRIPTION
Loss of yield per plant	Yield losses may be observed following significant defoliation. Bigger losses may be due to damage to flowers and pods.
Reduction in quality	Perforated pods unsuitable for sale. The presence of caterpillars in harvested beans can lead to the rejection of batches by processors or buyers.

QUARANTINE ORGANISM

— *Spodoptera exigua*

This is not an EU quarantine organism.

— *Spodoptera frugiperda*

Considered as an EU quarantine pest (Appendix II, Part A of Regulation (EU) 2019/2072) and priority (Regulation (EU)2019/1702). This means that it cannot be imported on products destined for the EU. Itis therefore essential to properly sort the pods, in order to remove those damaged or carrying caterpillars, in the processing rooms before packing.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Climate	Sub-tropical and tropical for both species.	The optimum temperature for caterpillars is 28°C. At lower temperatures, activity and development cease and, during cooler conditions, all stages are killed.

Table 20 — Population dynamics of Spodopetra *exigua* on vegetable crops in Senegal in the Niayes region. RADHORT (2012)

JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
+	++	++	++	++	+	0	0	0	0	0	+

MONITORING

These pests are detected by searching for feeding damage caused by the caterpillar and by pheromone or light traps.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLOT PREPARATION		
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
Creation of hedges	Gives shelter to several useful insects and insectivorous birds	Control by auxiliaries is reinforced.
CROP MAINTENANCE		
Grubbing of plants at the end of production	This prevents caterpillars from turning into chrysalids and then into a butterfly	Disrupts the cycle.
Balanced nitrogen fertilisation	Open-structure foliage allows PPP sprays to better reach their targets on the underside of the leaves. Excess fertilisation (especially nitrogen) will produce foliage that is too dense.	More caterpillars are affected by insecticides.

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

Many native natural enemies have adapted to these pests. Among the most common parasitoids are *Braconidae hymenoptera* and Tachinidae Diptera. Predators frequently attack eggs and small larvae; among the most important are Anthocoridae, Geocoridae and Nabidae. Pupae are prone to attack, especially by ants. The main mortality factors vary across crops and geographic regions.

Spraying insecticides can harm natural enemies. Replacing broad-spectrum PPPs with selective biopesticides such as Bt to control these and other pests may allow early establishment of natural enemies.

The presence of parasitoid *hymenoptera* can be encouraged on a farm by the presence of flowers that provide useful nectar to adults. See under point 7.1.3. for more information.

BY RELEASE OF AUXILIARIES

There are no natural invertebrate enemies available in ACP countries for release.

CONTROL USING PLANT PROTECTION PRODUCTS

RESISTANCE MANAGEMENT

In the case of autumn armyworms, frequent resistance to many classes of pesticides, including synthetic pyrethroids, is noted. Treating successive generations of the autumn armyworm with the same active substance should be avoided. It is therefore advisable to alternate products that have active substances with different modes of action every 30 days. In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market. In tropical climates, the autumn armyworm completes its life cycle in 30 to 40 days.

THE SUBSTANCES

The activity of natural enemies should be maximized in the first place, avoiding broad-spectrum insecticides that are toxic to insects, arachnids and predatory mites as well as parasitoids.

The recommended active substances are listed in the table in Appendix 3.

Biocontrol substances include:

- *Bacillus thuringiensis* var. *Kurstaki* or *Bacillus thuringiensis* var. *aizawai*.
- Baculoviruses such as nucleopolyhedrovirus.
- Pyrethrins.
- Oxymatrine.
- The entomopathogenic fungus *Metarhizium rileyi* strain PHP1705.
- Azadirchtin.

OTHER CONTROL METHODS

No information available.

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7.2.2.10. CABBAGE LOOPER

SCIENTIFIC NAME

Trichoplusia ni.

It is part of the order Lepidoptera, and the family Noctuidae.

LIFE CYCLE OF THE PEST

STAGE	DESCRIPTION
Egg	The eggs are deposited individually on the lower edge of the upper leaves of the plants. The eggs hatch 3 to 4 days after laying.
Caterpillar	There are 5 larval stages. The normal duration of the larval stage is 2 to 4 weeks.
Chrysalis	Pupation occurs in woven cocoons, often on the lower part of host plants. It lasts 2 weeks.
Adult	The butterfly is able to disperse widely, reaching distances of up to 200 km. They fly at night and can survive for 10 to 12 days.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

It is essentially a pest that attacks cruciferous plants, its favourite host, but it can also be found in crops such as tomato, pepper, some *cucurbitaceae*, soy, sesame and cotton.

DESCRIPTION OF THE INSECT

STAGE	DESCRIPTION
Egg	The eggs have a spherical shape, the flattened part being attached to the leaf, and are yellowish white or greenish in colour.
Larva (caterpillar)	They are green, usually with a narrow white band on each side and several narrow lines on the back. Loopers can be distinguished from most other common caterpillars by their distinctive looping movement.
Pupa (chrysalis)	They have a green colour and then take on a coffee brown colour when they are close to adulthood.
Adult (butterfly)	Grey-brown marbled colour with a silver eight-shaped pattern on the forewings.

Figure 69 — Caterpillar. David Cappaert, Bugwood.org

AFFECTED CROP STAGE(S)

All stages and more particularly that of vegetative growth.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	++	+	+	0

SYMPTOMS AND DAMAGE

The caterpillars feed on the leaves, which leads to the appearance of large irregular holes on their surface.

IMPACT ON YIELD AND QUALITY

The impact on yield is generally small and can only be significant in case of very strong infestations which are rare.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

No information available.

MONITORING

Methods of detection of *T. ni* vary with the stage of development of the insect. Like most defoliators, caterpillars can be sampled by inspecting the leaves in the field. However, at least some knowledge of the spatial distribution of larval stage characteristics is required. This sampling will make it possible to set the intervention threshold.

It is also possible to sample adults using pheromone traps.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

New infestations can come from far away, so there are few really effective practices.

Residues from the bean crop as well as those from a neighbouring crop potentially host to *T. ni* must be destroyed in order to avoid creating refuge areas for the butterfly.

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

There are many species of *T. ni* parasitoids with particular attention to trichograms that kill eggs and thus prevent larval damage.

Many other natural enemies exist in the fields. For example, predators frequently attack eggs and small larvae; among the most important are the Ichneumonidae, Geocoridae, Anthocoridae (*Orius* spp.) and the Nabidae.

Spraying insecticides can harm natural enemies. Replacing broad-spectrum PPPs with selective biopesticides such as *Bacillus thuringiensis*to to control this and other pests may allow early establishment of natural enemies.

The presence of parasitoid *hymenoptera* can be encouraged on a farm by the presence of flowers that provide useful nectar to adults. See under point 7.1.3 for more information.

BY RELEASE OF AUXILIARIES

There are no natural invertebrate enemies available in ACP countries for release.

CONTROL USING PLANT PROTECTION PRODUCTS

The active substances recommended against *Helicoverpa* and armyworms are generally as effective against *Trichoplusia ni.*

Biocontrol products include:

- *Bacillus thuringiensis* var. *Kurstaki* or *Bacillus thuringiensis* var. *aizawai*.
- Baculoviruses such as nucleopolyhedrovirus.
- Azadirachtin and neem extracts.
- Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium rileyi* strain PHP1705.

It is also possible to reintroduce insect vectors of *T. ni* virus, but it implies the possibility of collecting dead insects attacked by viruses, mixing them, filtering them and then spraying the viral particles in the field.

OTHER CONTROL METHODS

No information available.

REFERENCES

- RADHORT. (2012).
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  Accessed on 12.05.2021 at
  http://www.fao.org/3/az781f/az781f.pdf

7.2.2.11. SPECIES OF THE GENUS MYLABRI

SCIENTIFIC NAME

Mylabris spp.

They are part of the order Coleoptera, and the family Meloidae.

LIFE CYCLE OF THE PEST

STAGE	DESCRIPTION
Egg	Eggs are laid in the soil in groups of at least 100 and hatch after 2 weeks.
Larva	Larvae live underground and feed on locust and grasshopper eggs.
Pupa	Pupation also takes place in the ground.
Adult	Adults emerge shortly after flowering of bean plants, gather at the level of flowering organs and live for 2 weeks.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Arachis hypogeae (peanut), *Sorghum* (*sorghum*), Solanaceae (tomatoes, chillies, etc.), *Cucurbitaceae* (cucumber), etc.

DESCRIPTION OF THE INSECT

The adult insect measures between 25 and 35 mm in length. It is blackish with wide yellow or reddish transverse bands on the elytra. The tips of the antennas are also yellow or orange.

AFFECTED CROP STAGE(S)

Essentially the flowering stage.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	0	+++	+	0

SYMPTOMS AND DAMAGE

It devours the flowers (which leads to abortion of the pods) and sometimes the leaf blade can be perforated with large holes. As these species occur in large numbers, an entire field can quickly become defoliated.

Figure 70 — Mylabre attacking a flower. AGCD – Coopération Belge. (1989). Maladies et ravageurs des cultures de la région des grands lacs d'Afrique Centrale (No. 24). (232 p.)

IMPACT ON YIELD AND QUALITY

In Africa, Mylabri beetles are not common pests in green bean crops because they are an insect that are mostly present in the rainy season, when green beans are less cultivated.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

Favourable conditions are mainly during wintering and the rainy season, (from August, but also in November and December in Senegal).

MONITORING

Adults can be trapped using yellow pans. Plant monitoring is easy because insects are clearly visible.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The only practice that can contribute to control is tillage that allows the larvae to be exposed to desiccation or death by passing tools and to prevent it from being too wet permanently during the rainy season.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

In general, it is difficult to undertake because these insects show a high degree of resistance to insecticides and therefore require the use of more potent active substances and high dosages, which is contraindicated on plants whose production is intended for consumption.

Pyrethroids and organophosphorus compounds are generally effective.

OTHER CONTROL METHODS

It is possible to carry out a manual harvest of insects, especially if there is an abundant workforce.

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https://cgspace.cgiar.org/handle/10568/75398

7.2.3. MITES

7.2.3.1. RED SPIDER MITES OR TWO-SPOTTED SPIDER MITES

SCIENTIFIC NAME

In tropical regions we can mention *Tetranychus*. Urticae (= *T. cinnabarinus*), *T. Neocaledonicus*, *T. glover* I, *T. evansi*. These species are very similar and can only be identified by specialists.

They are part of the order Trombidiformes, and the family Tetranychidae.

LIFE CYCLE OF THE PEST

Spider mites go through 5 stages of development: egg, Hexapod larva, protonymph, deutonymph and adult. The duration of the cycle varies depending on the temperature and is about 9 days in tropical conditions.

<table>
<tr><th>STAGE</th><th>DESCRIPTION</th></tr>
<tr><td>Egg</td><td>Eggs are laid mainly on the underside of the leaves.</td></tr>
<tr><td>Larva</td><td rowspan="4">The pest often appears on the tissue of older leaves, before migrating upwards, colonising the newer leaves towards the top of the plant and secreting a silk thread to hang in the air currents.
Dispersal is by wind, by travel on the ground, by people, equipment and tools or by plants.</td></tr>
<tr><td>Protonymph</td></tr>
<tr><td>Deutonymph</td></tr>
<tr><td>Adult</td></tr>
</table>

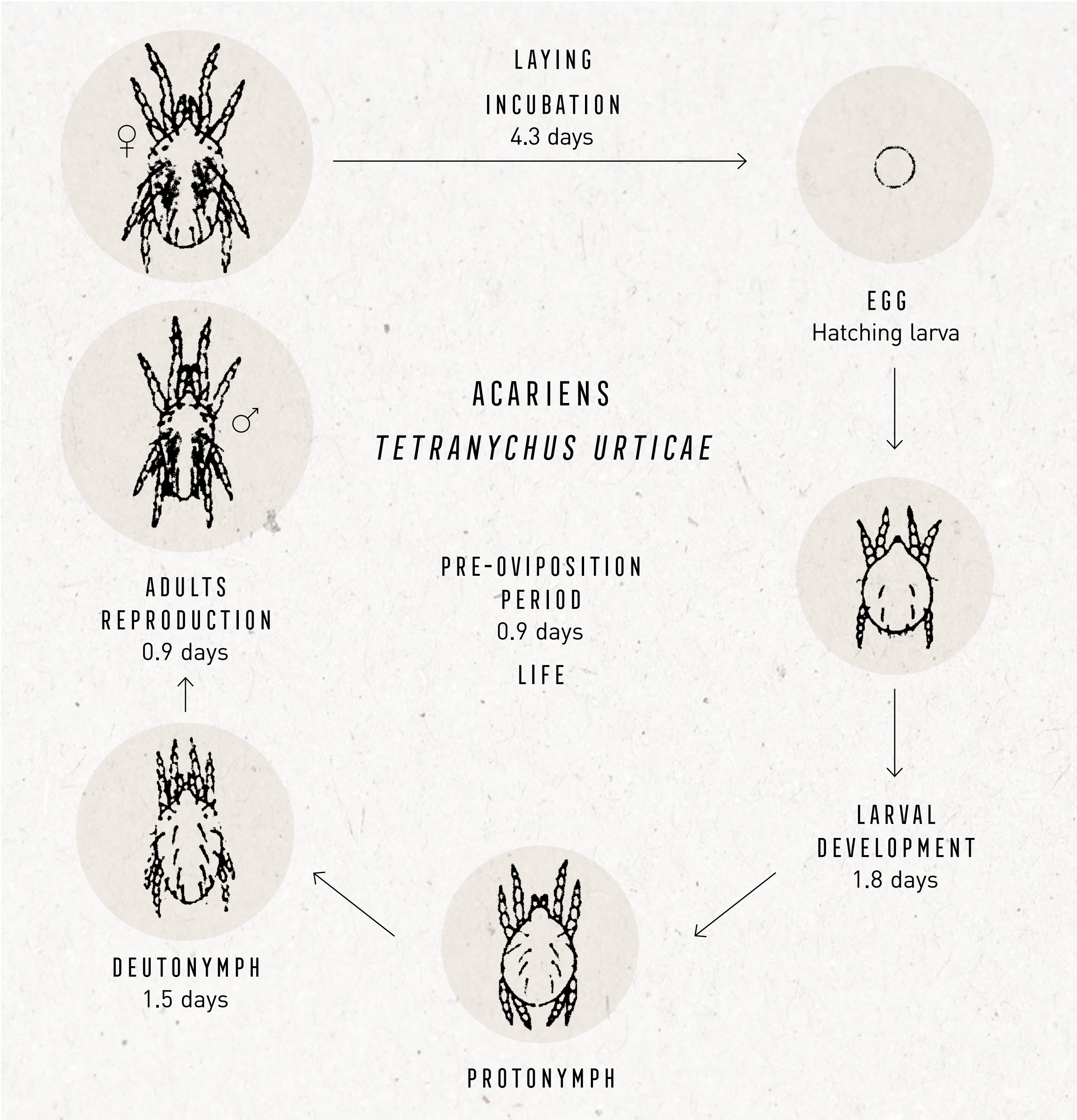

Figure 71 — Development cycle of *Tetranychus urticae* at 25°C, 55 to 85% RH, in a rose crop. J. Poidatz (Koppert) (2021)
http://ephytia.inra.fr/fr/C/24345/Tropileg-Araignees-rouges-Tetranychus-spp

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Highly polyphagous, they grow on several hundred cultivated and uncultivated hosts, including most vegetable crops, including tomato, aubergine, *cucurbitaceae* and beans. Other host plants include *Gossypium* (cotton), *Citrus*, *Abelmoschus esculentus* (gombo), *Carica papaya* (papaya) and *Solanum tuberosum* (potato).

DESCRIPTION OF THE PEST

STAGE	DESCRIPTION
Egg	The eggs are spherical (0.15 mm in diameter), translucent at first, then take on a pearl appearance, sometimes pink.
Larva, protonymph, deutonymph	The larvae are beige and, as they feed, two black spots appear on their abdomen (hence one of their common names). These spots are actually their intestines that fill with sap, which is dark green when concentrated and eventually becomes black. The two spots may become one if the spider mite has fed in excess. Each larval stage has eight legs except the first stage which has 3 pairs of legs.
Adult	Adults are 0.3 to 0.5 mm long and have an oval-shaped body.

Figure 72 — Eggs, larvae and adults. Whitney Cranshaw, Colorado State University, Bugwood.org

The spider mites turn red if they are subjected to any constraint. This occurs when the mites are present in large numbers on a plant. This overpopulation weakens the plant and the nutritional quality of the sap decreases, which stresses the spider mites, because it is their only source of food. They turn red because they slow down their development in line with the quality of the sap.

AFFECTED CROP STAGE(S)

Before flowering and especially when flower buds appear at harvest.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	++	+++	++	0

SYMPTOMS AND DAMAGE

Symptoms can be observed on the leaves.

Yellowish/whitish spots appear on the upper surface of the leaf while, on the lower surface, spiders can be observed which come across as small mobile red balls (about 0.4 mm). A very fine web appears when they are present in large numbers. If the attack is significant, the plant struggles to grow. The leaves are deformed and can fall. The infestation manifests itself in foci, often from closely attacked neighbouring crops.

Figure 73 — Symptoms on the upper side of a leaf.
Whitney Cranshaw, Colorado State University, Bugwood.org

Figure 74 — Web spun by spider mites.
John C. French Sr., Retired, Universities: Auburn, GA, Clemson and U of MO, Bugwood.org

IMPACT ON YIELD AND QUALITY

Beans are very sensitive to spider mite attacks.

TYPE OF IMPACT	DESCRIPTION
Loss of yield per plant	A reduction in plant growth, flowering and number of pods can be observed. Damage is more severe when mites attack young plants.
Reduction in quality	Reduction in pod length.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Hot and dry weather (in Senegal, especially from March to August) unlike heavy rains that quickly reduce outbreaks.	Red spider mites develop very quickly, especially at high temperature: about 9 to 12 days at 30°C.

Table 21 — Population dynamics of spider mites in Senegal on vegetable crops. RADHORT (2012)

ZONE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Niayes	+	+(+)	++	+++	+++	+++	+++	++	+	+	+	+
Vallée du Fleuve	0	++	+++	+++	+++	+++	+++	+++	+	0	0	0
Basse Casamance	++	+++	+++	+++	+++	+++	++	+	+	+	+	+

MONITORING

It is possible to detect spider mites by observing the symptoms on the leaves, but it is best to locate them accurately before the symptoms appear. Regular sampling of the leaves is essential and should be examined with a magnifying glass or microscope.

Methods of monitoring plants by direct observation in the field are proposed in detail under point 7.1.2.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	It is recommended to avoid planting beans in or near fields that have previously been severely infested by spider mites or near sensitive trees (papaya, etc.). Since the spider mites move with the wind, it is essential to ensure that the new crop is laid in the opposite direction of the wind to the earlier infested crops.	Reduction of the migration of spider mites by the wind to new crops.
PLOT PREPARATION		
Creation of grassy strips or flowery hedges	See below biological control through conservation.	Control by auxiliaries is reinforced.
Creation of hedges	Windbreak hedges reduce wind speed in the plot.	Reduction of the migration of spider mites by the wind to new crops.
CROP MAINTENANCE		
Ensure regular weeding of the ground and surrounding areas	Properly carried out, weed control will allow a more effective penetration of the sprayed product to the underside of the leaves of the crop. Many weeds can also harbour spider mites.	Decline in populations following acaricide applications. Avoids sources of spider mites.
Sprinkler irrigation	Spider mites do not like the presence of water on the leaves.	The mechanical action of the sprinkling causes them to drop off the leaf.
Balanced nitrogen fertilisation	Open-structure foliage allows PPP sprays to better reach their targets on the underside of the leaves. Excess fertilisation (especially nitrogen) will produce foliage that is too dense. An excess of nitrogen also makes the leaves more attractive to spider mites.	More caterpillars are affected by insecticides.

Grubbing of plants at the end of production	If spider mite infestation has been heavy, crop residues should be harvested and burned immediately after harvest. However, if biological control has been used, it is essential to check the leaves at the end of a crop cycle before destroying them, as they may contain more *Phytoseiulus* than spider mites and could therefore be used to transfer *Phytoseiulus* to other crops. For this purpose, it is important to use a magnifying glass, as the leaves can show serious damage due to feeding spider mites, but it can simply be old damage, since the number of spider mites can be low if the*Phytoseiulus* population has grown in this crop. The grower can even decide to leave the crop in place, or even water the crop, in order to allow the population of *Phytoseiulus* to grow in such a way that it is largely preponderant compared to the number of spider mites.	Disrupts the pest cycle. Eliminates sources of infestation for neighbouring crops.

ORGANIC CONTROL

BY CONSERVATION OF THE AUXILIARIES PRESENT

Several natural enemies feed on mites. The main natural enemies are predatory mites (*e.g.* Phytoseids), predatory beetles such as small staphylinids (*Oligota* spp) and ladybirds, lacewings, predatory thrips, anthocorids (*Orius* spp), mirids and predatory flies such as cecydomyiids. Natural predators are in most cases able to control two-spotted spider mite infestations, provided that natural enemies are not disturbed by the intensive use of broad-spectrum pesticides – and that the crop is properly irrigated. A compatible chemical spraying programme must therefore be used if the grower wants to take advantage of these biological controls.

Before considering the application of PPPs, it is advisable to evaluate the presence of auxiliaries in the crop. Methods are proposed in Appendix 7 of the COLEAD Sustainable Management of Biodiversity Training Manual "Examples of methods for assessing the presence of auxiliaries present in the crop for some pests".

BY RELEASE OF AUXILIARIES

Some natural enemies are mass produced for introduction into the fields. In Kenya, the two main available natural enemies are two predatory mites: *Phytoseiulus persimilis* and *Amblyseius californicus*.

— ***Phytoseiulus persimilis***

Phytoseiulus is a predatory mite, larger than the spider mite. It can live up to 26 days. In the absence of prey, they are carnivorous and eat each other.

It is light red/orange and shiny with a pear- or avocado-shaped body. It has longer legs and is more active than the spider mite, because it has to look for food while the mites only suck the sap.

The young *Phytoseiulus*, which hatch from the egg, are pink-orange in colour and very bright. Young larvae have 3 pairs of legs and develop 4 pairs in later stages.

Eggs will be laid only near the colonies of spider mites, so that they can hatch and start feeding immediately.

Figure 75 — *Phytoseiulus persimilis.* Biobest

- **Tips for release of *Phytoseiulus***

Appropriate release rates and periods vary depending on the crop.

If the grower can obtain enough *Phytoseiulus* at a reasonable cost, it is possible to introduce enough predatory mites to "clean" a crop and reduce the population of spider mites to an acceptable level.

Phytoseiulus are available either as a freshly harvested product on leaves or in a plastic bottle containing vermiculite.

Order *Phytoseiulus* only when you are ready to apply them and after planning your application, making sure that you have not recently sprayed *Phytoseiulus*-toxic PPPs and that you do not intend to do so within two weeks of applying *Phytoseiulus* (see tables on pesticide sensitivity in Appendix 4).

Never store the *Phytoseiulus*; use them as soon as they arrive at the farm. If you need to store them, place them in a domestic refrigerator at 5°C for up to 24 hours.

Extreme caution should be exercised when transporting *Phytoseiulus* to the crop. If the vial containing vermiculite becomes too hot, the vermiculite will dry or even dehydrate the *Phytoseiulus* in the vial, and they will die. If condensation forms in the bottle, the *Phytoseiulus* contained in the bottle will drown.

- **Release strategies**

Always release *Phytoseiulus* as a preventative measure at an early growing stage, regardless of whether or not samples reveal the presence of spider mites in the crop. If the introduction is done late and spider mites are already a problem; a large amount of *Phytoseiulus* will be needed and this may not be cost effective.

It is necessary to perform at least two separate applications of two to four weeks. Each application must include a minimum of 15,000 *Phytoseiulus* per hectare.

If the risk of spider mite development is high (hot weather forecast), the introduction strategy should be modified as follows:

— reduce the interval between applications (separated by one to two weeks);

— continue applications until sampling reveals that the ratio is less than one in five (*Phytoseiulus* to spider mites). See under point 7.1.2.

- **Application methods**

It is essential to apply predators as evenly as possible. If predators are not applied homogeneously in a crop, spider mites present on plants located between those that received *Phytoseiulus* will not be protected until the predators have eaten all the spider mites present on the original treated plants. This can lead to the formation of pockets of red spider mites, which will be more difficult to remove by biological means.

The predator must therefore be applied every metre along the row, but it is recommended to apply additional *Phytoseiulus* in areas previously detected as having already suffered more attacks by the spider mites.

Care must be taken to place the leaves containing *Phytoseiulus* in such a way that the underside of the transfer leaf faces the soil, so that the eggs of *Phytoseiulus* do not dry in the sun, and also to wedge the transfer leaves between the stems of the plant, low enough in the foliage, so that they do not fly away until the *Phytoseiulus* have left the transfer leaves to spread into the crop.

- **Compatible spraying programmes**

If a biological pest control programme is adopted, all prophylactic sprays against spider mites must be removed from the programme immediately. Otherwise, the acaricides will kill the *Phytoseiulus*.

Other spray products, including fungicides, can also kill some *Phytoseiulus*. Keep in mind that even a "safe" pesticide is likely to kill 25% of *Phytoseiulus* (see Appendix 4 for *Phytoseiulus* sensitivity to pesticides).

MONITORING OF THE EFFECTIVENESS OF BIOLOGICAL CONTROL

Biological control success can be measured by weekly monitoring of leaf samples to determine the ratio of predators to parasites. For the observation methods see under point 7.1.2.

By keeping the weekly data, the grower can measure the evolution of the relationship (between the *Phytoseiulus* and the spider mites) over a certain period and thus evaluate the success of the releases.

After their introduction, the *Phytoseiulus* will actively search for spider mites. Therefore, during monitoring, check only the leaves with damage due to spider mites: it is in these places that the spider mites are located and that is where the *Phytoseiulus* will be.

Red pigment, which points to spider mites under stress, deters potential predators in search of food and it is important to take this into consideration if the farmer uses biological means of control against this pest, as *Phytoseiulus* may not be as effective when red spider mites predominate.

— ***Amblyseius californicus***

Another predatory mite is registered in Kenya as a biological control agent against spider mites. *Amblyseius* are native to Kenya and offer the advantage of being generally more resistant to pesticides than *Phytoseiulus*. Moreover, they can survive longer without the presence of spider mites, since they can also feed on pollen. In the absence of spider mites, the *Amblyseius* attack very young thrips.

CONTROL USING PLANT PROTECTION PRODUCTS

Generally, spider mite infestations are low if the environment is not disturbed by non-rational applications of PPPs.

PERIODS OF APPLICATION

Control with PPPs should be preventive or curative, in the vegetative phase, so as to start harvests with very low levels of infestation.

RESISTANCE MANAGEMENT

The use of acaricides can lead to the appearance of resistance phenomena among spider mites. There is a rapid development of resistance over a relatively small number of generations and cross-resistance to other acaricides. Therefore, these should be carefully selected and used only when necessary. An anti-resistance strategy proposed by the IRAC (International Resistance Action Committee) consists of the use of active substances belonging to different chemical families in order to prolong their effectiveness.

THE SUBSTANCES

Spider mites are often poorly controlled by insecticides that also have an acaricidal action (dimethoate being a good example) and moreover these products are generally harmful to the auxiliaries. By treating indiscriminately with these kinds of products, the result obtained is opposite to that targeted and the populations of spider mites, now rid of their natural enemies, explode. It is preferable to use specific acaricides against spider mites with little or no impact on auxiliaries.

The recommended active substances are listed in the table in Appendix 3. However, preference should be given to products that are most compatible with the conservation of the pest's natural enemies.

Biocontrol products include:

- Matrine (oxymatrine).
- Products based on essential sweet orange oil.
- Products based on *Beauveria bassiana*.
- Products based on azadirachtin or neem extracts.
- A product based on farnesol and nerolidol (parapheromones that attract males) and geraniol and citronellol (substances with acaricidal action).
- Maltodextrin-based products, which is the result of the hydrolization of starch.
- Preparations based on starch or flour (10% w/v).
- Horticultural soaps (fatty acids) may be recommended for mites. Be sure to check for burns when spraying soap and never spray in hot weather.

- Sprayable wettable sulphur, in addition to being a recognised fungicide, has an acaricidal effect. Do not use in hot weather (above 25°C).
- *Chromobacterium subtsugae* strain PRAA4-1.
- Citric acid
- Paraffin oil.

The number of biocontrol solutions is significant. However, good coverage under the leaves is necessary for these products to have an effect.

OTHER CONTROL METHODS

No information available.

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7.2.4. NEMATODES

7.2.4.1. ROOT-KNOT NEMATODES

SCIENTIFIC NAME

Meloidogyne spp. Mainly *M. incognita* and *M. javanica*.

They belong to the order Tylenchida, and the family *Heteroderoidae*.

LIFE CYCLE OF THE PEST

The *Meloidogyne* is a sedentary endoparasite nematode, which means that it does not move very far in the soil and must live inside a plant.

STAGE	DESCRIPTION
Egg	A mass of eggs (500 to 1,000) protected by a mucilaginous sheath is produced by a large female which is found inside each root knot. The egg mass is released outside the root knot.
Juvenile larvae	Juveniles hatch from the eggs. This is the free life stage, which moves very short distances through the soil to infect new roots. It can only live two weeks outside the roots, looking for a new host plant. Juvenile nematodes die if they do not find a new host within two weeks.
Larvae	Juvenile nematodes enter the tip of the roots and remain at one location of the root for their entire lives. They are sexually differentiated into males and females once inside the root. Males are rare.
Adult	When the female begins to form, its presence in the root causes the enlargement of neighbouring plant cells, creating a powerful "well" for the plant's nutrients. She dies after laying her eggs.

Storage	*Meloidogyne* remain for several years in the soil in the form of egg masses protected by a mucilaginous sheath, but also thanks to a large number of cultivated and uncultivated plants which ensure their multiplication and conservation.
Dissemination	Passive dissemination of eggs and larvae occurs through runoff, drainage and irrigation water. Larvae actively move short distances in moist soils. Dissemination is possible via soil dust, contaminated plants, tillage tools and agricultural machinery.

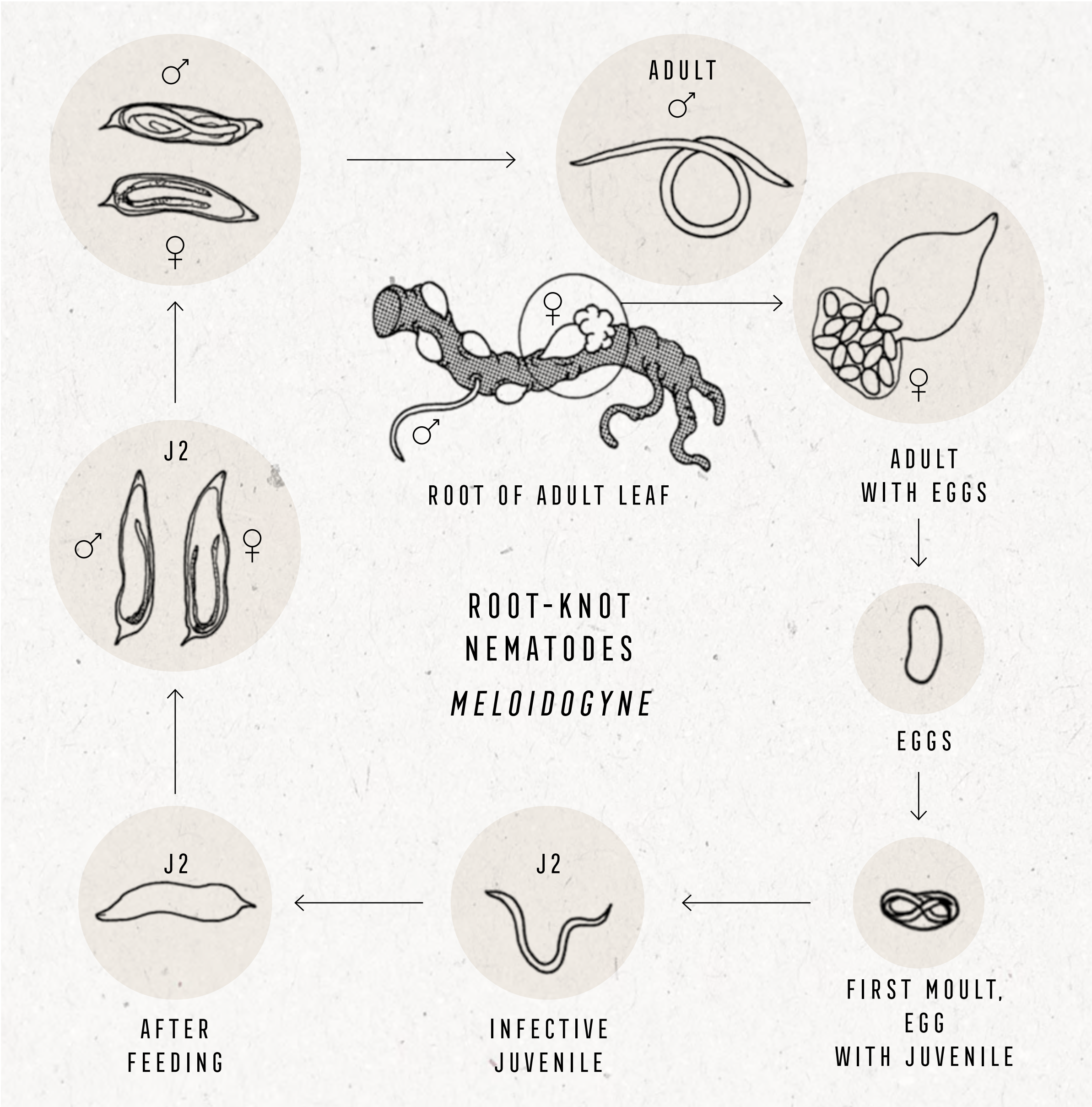

Figure 76 — Life cycle of the root-knot nematode. (2016)
https://www.promusa.org/Root-knot+nematodes

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Many crops host *Meloidogyne*, *e.g. Arachis hypogaea* (peanut), *Musa* spp. (Banana), *Oryza sativa* (rice), *Solanum tuberosum* (potato), *Lycopersicon esculentum* (tomato) and almost all vegetable crops except onion, mint, strawberry, garlic and leek.

DESCRIPTION OF THE PEST

The root-knot nematode is a very small worm, invisible to the naked eye. It "hijacks" nutrients from the plant to create large bulges in the roots, where it lives and feeds. These swellings are the characteristic "knots" of the roots, hence its name.

AFFECTED CROP STAGE(S)

From emergence to harvest but the most damaging attacks are those that take place from emergence to flowering.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+	+++	+++	++	0

SYMPTOMS AND DAMAGE

ROOT	Larvae penetrate the roots and attach themselves near the vascular area, causing bulges or knots. The shape, size and appearance of the knots vary with age, number, host plant, extent of the attack, the *Meloidogyne* species involved, and environmental conditions. In case of strong infestation, the roots can be reduced to the state of swollen stumps. The root-knot nematode is often mistaken for normal nodulation of legumes by nitrogen-fixing *Rhizobium* bacteria. The nodules formed by *Rhizobium* are round and attached to the outside of the root, while that of the root nematode is swelling inside the root itself. The interior of nodules formed by *Rhizobium* is often pink if they actively fix nitrogen. *Rhizobium* nodules are easily detached from the root, unlike root-knot nematodes.
WHOLE PLANT	Plants attacked early remain stunted and sometimes turn yellow, wilt or die. The damage often appears in the form of patches in a field because the distribution of nematode populations is not homogeneous over the entire surface of the plot.

Figure 77 — Root knot of *Meloidogyne* spp. on Tamya bean.
Christian Chabrier. (2014). COLEAD/PIP. Root-knot nematode control solutions in Senegal.
Report of mission to Senegal from 26 January to 6 February 2014. Page 14

Figure 78 — *Rhizobium* nodosis on beans. E-phytia – INRA

Figure 79 — Poor growth of attacked plants. (COLEAD, 2012. Green bean crop protocol)

Figure 80 — *Meloidogyne* spp. damage in a Tamya bean plot; SOCAS Senegal. Christian Chabrier. (2014). COLEAD/PIP. Root-knot nematode control solutions in Senegal.
Report of mission to Senegal from 26 January to 6 February 2014. Page 14

IMPACT ON YIELD AND QUALITY

The reduction of the root system and metabolic disorders due to the presence of *Meloidogyne* result in poor plant development and a gradual decrease in yields.

Damage is sometimes considerable on farms where crop rotation management and soil health quality are below standard.

In addition, by injuring the roots, *Meloidogyne* also facilitate the penetration of phytopathogenic microorganisms (*Pythium*, *Fusarium*, *Rhizoctonia*) which further impacts the yields.

QUARANTINE ORGANISM

M. incognita and *M. javanica* are not EU quarantine pests. They are not found on the pods in any case.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Hot period, with cardinal temperatures of 14°C-28°C-32°C). Activity is thought to be blocked at more than 38°C.	At very high temperatures (over 29°C), the cycle takes approximately 3 weeks but for low temperatures it can take up to 3 months.
Soil humidity	Saturating irrigation promotes the spread of root-knot nematodes.	Juveniles need open water to move and infect the roots.
Soil	Sandy, light, low in organic matter and clay.	Juveniles move more easily in this type of soil and the attacks are therefore heavier. Juvenile migration decreases as clay content in soil increases.
	Compacted or slightly moist, a nutritional deficiency.	More severe damage.

MONITORING

The relative levels of nematodes in the soil per plot should be checked to identify those with high levels and to apply appropriate treatment.

If samples taken from the soil are too dry or are not stored properly before being sent to the laboratory for the assessment of nematode levels, incorrect information about the levels may be provided. This is due to the fact that, in order to extract nematodes from the soil sample, they must be alive to leave the earth and head to the water. The nematodes in the water are then counted and identified.

If beans are grown in a warm climate and crops are far away from laboratories, it may be useful to train staff in simple extraction methods so that water containing nematodes can be sent for analysis instead of soil samples. This would provide more accurate data and reduce costs, as the laboratory will not need to perform the extraction.

Root diagnosis for root-knot nematodes involves carefully sampling the root systems of plants and recording a root-knot index (RI) on a scale of 0 to 10 to estimate the level of infestation of the plot. Root analysis can be performed by growers themselves or the agricultural advisor. The rating scale used is the Zeck scale, described below.

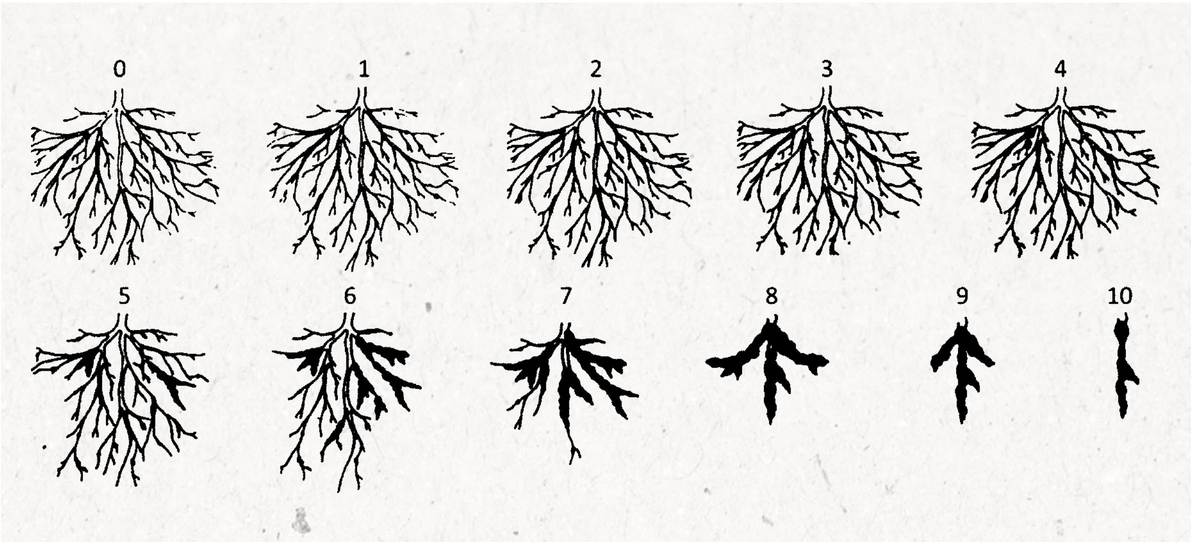

Figure 81 — Zeck scale indexing *Meloidogyne* nematode attacks on plant roots (Zeck, 1971). Taken from[2]

To facilitate its in field application among growers and determine the level of vigilance required, in France the 'Gedubat' project team adapted and grouped this Zeck scale into 3 main classes; see table below.

2 GIS PICLég – Scientific interest group for integrated production in vegetable crops. (2018). Les nématodes à galles *Meloidogyne* spp. Hors-Série Infos Ctifl, 2018. Fiche n°1 – Le diagnostic racinaire et l'analyse nématologique. https://www.picleg.fr/content/download/3994/38866/version/1/file/Fiche+n%C2%B01+Diagnostic+racinaire+et+analyse+n%C3%A9matologique.pdf

Table 22 — Description of the Zeck scale and grouping in class following the work of Gedubat (GIS PICLég – Scientific Interest Group for Integrated Production in Vegetable crops, 2018)

<table>
<tr><th>IG</th><th>DESCRIPTION ACCORDING TO THE ZECK SCALE</th><th colspan="2">ADAPTATION PRODUCED BY GEDUBAT</th></tr>
<tr><td>0</td><td>complete and healthy root system; no infestation</td><td rowspan="4">0 to 3</td><td rowspan="4">Healthy roots or presence of some small knots.
No impact on the plant.</td></tr>
<tr><td>1</td><td>very few small knots</td></tr>
<tr><td>2</td><td>small knots more easily detectable</td></tr>
<tr><td>3</td><td>many small knots; root tufts still complete</td></tr>
<tr><td>4</td><td>many small knots; some large knots; root system still functioning</td><td rowspan="3">4 to 6</td><td rowspan="3">Many small knots. The root system works only partially.
More or less visible impact on the plant</td></tr>
<tr><td>5</td><td>25% of the root system have knots and no longer functioning</td></tr>
<tr><td>6</td><td>50% of the root system have knots and no longer functioning</td></tr>
<tr><td>7</td><td>75% of the root system have knots and no longer functioning</td><td rowspan="4">>6</td><td rowspan="4">Extremely affected roots: a bundle of large knots, almost no more fine roots. the plant can no longer feed
significant impact on the plant</td></tr>
<tr><td>8</td><td>near absence of fine roots; bundles of large knots on the main roots; the plant can no longer feed</td></tr>
<tr><td>9</td><td>reduced root system and filled with large knots preventing the plant from feeding</td></tr>
<tr><td>10</td><td>dead plant and roots</td></tr>
</table>

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to pest control.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	It is recommended to avoid planting beans in a field that has previously experienced severe infestations with root-knot nematodes.	Avoids a source of infestation.
Management of the irrigation water source	Use drilling water for irrigation in preference to river water, as the latter can carry a large number of nematodes. If this is not possible, decant the river water into a tank before using it and allow the nematodes to flow to the bottom of the tank. Use a floating pump to extract water only from the top of the water volume – where there are fewer nematodes.	Avoids a source of infestation.

Avoid preceding crops sensitive to *Meloidogyne*	Brassica crops are not a host for the root-knot nematode and can be used in rotation with legumes In addition, Brassica crop residues contain a substance similar to some nematicides, which is released into the soil when they decompose. If Brassica crop waste is chopped, dried for two days and then incorporated into the soil, this will reduce the level of nematodes in the soil. This is what is known as biofumigation. Other good preceding crops for green beans are: corn, onion, garlic, sesame or fodder crops such as *Paspalum notatum*, *Eragrostis curvula*, *Panicum maximum*, *Chloris gayana*, *Sorghum sudanense* and *Digitaria decumbens*.	Disrupts successive cycles.
Grow a green fertiliser and bury it in the ground	The green fertiliser is cut and the cut is left on the ground for 2 days before burying it. For green beans, it is advisable to avoid using green fertilisers from the legume family. Examples of usable plants (scientific names are given to avoid confusion with vernacular names which may vary from country to country): *Tagetes patula*, *Tagetes erecta*, *Tagetes minuta*, *Chrysanthemum coronarium* and *Thitonia diversifolia*. The recommended seed quantity for the *Tagetes* is 4 to 12 kg/ha with 25 cm row spacing. A larger spacing gives the same result but the suppressive effect is less rapid. The crop must remain on site for at least 45 days after emergence but it must be avoided until the presence of seeds to prevent the plant from becoming invasive. However, the results obtained with these plants are variable, depending on the pathotypes of *Meloidogyne* present locally on the one hand, and the varieties of plants with nematicidal effects on the other hand; but also depending on the organic matter content of the soil and the presence of other organisms such as nematode antagonistic fungi.	This practice reduces soil infestation.
Choose a plot that is flooded in the rainy season or deliberately flood the plot	The soil must be flooded for several months.	Asphyxia of larvae.
Avoid the presence of host trees and shrubs of *Meloidogyne*	The windbreaks that can be hosts (*Euphorbia*, *Prosopis*) and intercropping with other host plants with different cycles (papaya, etc.) are to be avoided.	Avoids a source of infestation.

PLOT PREPARATION		
Leave the soil bare but irrigated for 2 weeks*	Before sowing the beans, it is possible to kill juvenile mobile nematodes in the soil (hatching from eggs as a result of water in the soil) by removing all weeds and host plants from the area for 2 weeks. They will die if they cannot enter a host within 2 weeks.	Disrupts the life cycle at the juvenile stage.
Cleaning of agricultural equipment	Equipment used in the field (ploughs, etc.) can move nematodes into the fields and must be cleaned, for example with water, after and before use.	Avoids a source of infestation.
Rational use of organic matter	Infestation can be reduced by applying abundant, well-decomposed organic matter to the seed row. Organic matter slows down the rise of nematodes that are deep in the soil. On the other hand, input of organic matter can modify the microflora and mesofauna and promote the development of various *Meloidogyne* antagonists.	Physical barrier around the roots. Control by antagonists is reinforced.
Bury certain organic matter in the soil just before planting	Coffee pulp, cakes made from *Azadirachta Indica* or *Ricinus communis*.**	Nematicide plus organic matter effect.
Creation of hedges	Windbreak hedges help reduce the risk of new infestations because nematodes can be spread by the wind via soil particles. Hedges also reduce the risk of rain water runoff, which is a method of dissemination of juvenile nematodes.	Barrier to new sources of soil infestation.
CROP MAINTENANCE		
Mound the plants	This helps to promote the development of adventitious roots that can compensate for possible knot roots.	Compensation for attacked roots.
Grubbing and destruction of plants at the end of production	Regular grubbing, with all roots, will reduce the level of nematode eggs in the soil.	Reduction of inoculum in soil.
Tillage at the end of the crop	Root nematodes can be removed by drying the soil with the aid of disking operations (30 cm deep), after removal of the infested crop. Part of the root nematode egg deposits, which had remained in the soil after crop removal, will be killed by drying out.	Disrupts successive cycles.

* N.B. this technique is not recommended in the case of conservation agriculture that recommends never leaving bare soil.

** Crop tests in real conditions are required to fine tune knowledge of the effectiveness of these organic materials and to define a method of use that is accurate and compatible with the technical and economic requirements of production.

ORGANIC CONTROL

Various organisms, present in soils, attack nematodes. Predatory fungi (*Arthrobotrys* spp.) trap nematodes and feed on them. Other fungi (*Paecilomyces* spp. and *Verticilium* spp.), kill nematode eggs. Nematodes can also be parasitised by various fungi with adhesive spores. Mycorrhizae, fungi associated with plant roots, protect the plant against nematodes. Bacteria (*Pasteuria penetrans*) also parasitise nematodes. Other microorganisms produce nematicidal toxins.

It is therefore necessary to take all possible measures to avoid stopping the action of this natural activity, which is a decisive, indeed essential, element in the regulation of populations of crop pests.

Maintaining a high organic matter content in the soil plays an important role in promoting useful microflora.

CONTROL USING PLANT PROTECTION PRODUCTS

STRATEGY

The application of nematicides, to be used only as a last resort, is done over the entire surface or localised during preparation of the land or about ten days after planting using a localised method.

"The use of chemicals against nematodes poses very serious problems: safety for applicators (risk of poisoning in contact with nematicides), consumers (risk of residues) and the environment (poisoning of the environment, destruction of non-target organisms including auxiliaries, etc.), loss of efficacy (following the selection of tolerant individuals or the selection of organisms capable of rapidly degrading the active ingredient in the soil), direct and indirect costs." (Christian Chabrier, 2014).

"To limit the number of treatments on a farm, a better knowledge of nematodes and their infestation levels is needed. This implies having an ad hoc laboratory to extract and count nematodes from the soil before each planting. It is also necessary to have the elements needed to assess the intervention thresholds at which nematicide applications are required. These thresholds will depend on the pathogenesis of the species, which also involves evaluating the latter and knowing the life cycle characteristics (survival capacities, reproduction method, dissemination, etc.) of the main pathogenic species. When this knowledge is sufficient, it is sometimes possible to combine alternative methods that allow high yields to be achieved without plant protection products. (Christian Chabrier, 2014).

THE SUBSTANCES

Most conventional chemical nematicides are now banned in the EU. The recommended active substances are listed in the table in Appendix 3.

"It is desirable to substitute conventional products with bionematicides, which are generally less toxic. However, these products pose additional constraints related to logistical risks (they are often more labile than chemical pesticides) and, for those containing living organisms, ecological risks (risk of introduction of an invasive organism). Some may work well against *Meloidogyne*, but these products often work poorly when infestations are significant." (Christian Chabrier, 2014).

Biocontrol products include:

— *Paecilomyces lilacinus*.

— *Trichoderma asperellum* (also root growth stimulator).

— Garlic extracts.

— Azadirachtin and neem extracts.

OTHER CONTROL METHODS

SOLARIZATION

Soil solarization is a technique in which transparent polyethylene tarpaulins are laid on moist soil for a period of six to 12 weeks to heat uncultivated soils to temperatures that are lethal to nematodes and other soil-borne pathogens. The most successful use of soil solarization appears to occur in heavier soils (loamy to clayey) rather than sandy; but these are also the least infested naturally. Soils with low water retention capacity and rapid drainage can significantly inhibit heat transfer to deeper soil horizons. However, this practice is not recommended in a cultivation system that advocates greater biodiversity in soils because solarization also kills many soil organisms that are useful, apart from *Trichoderma* (useful saprophytic fungi) that are conserved.

RHIZOBIUM

Strong root colonisation by *Rhizobium* competes with colonisation by root-knot nematodes. *Rhizobium* seed treatments are commercially available. *Rhizobium* colonisation also occurs naturally but may be too slow or insufficient to have a suppressive effect on nematodes.

WATER TREATMENT

Electromagnetic treatment of irrigation water is thought to reduce nematode damage (Aqua4D 2021). *Sustainable, Chemical-free Nematode Control in Senegal.* Accessed on 28.05.2021 at https://www.aqua4d.com/news/sustainable-chemical-free-nematode-control-in-senegal/).

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7.2.4.2. MIGRATORY ENDOPARASITIC NEMATODES

SCIENTIFIC NAME

Some *Pratylenchus* species can attack green beans, including *P. brachyurus*.

They belong to the order Tylenchida, and the family *Pratylenchidae*.

LIFE CYCLE OF THE PEST

Pratylenchus species are internal parasites with migratory capacity. All larval stages can invade the roots and can move from roots to roots. Most species reproduce by parthenogenesis. This is faster at high temperatures (27-32°C) with an optimum at 26°C. The period necessary to create a new generation varies from 14 weeks at 15°C to 4 weeks at 30°C. A temperature of 20°C is necessary for both root and parasite development.

These pests can survive for several months (up to 22 months) without the presence of the host plant. They survive exposure to high soil temperatures especially in very dry soils.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Very polyphagous: Poaceae, Solanaceae (tomato, potato), *Cucurbitaceae*, *Arachis hypogeae* (peanut), *Zea mays* (corn), tobacco, pineapple, sweet potato...

DESCRIPTION OF THE PEST

It is a small worm (0.4 to 0.5 mm long), invisible to the naked eye.

AFFECTED CROP STAGE(S)

All stages, but more impact from emergence to flowering.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+	++	++	+	0

SYMPTOMS AND DAMAGE

ROOT	Brown, reddish or blackish necrosis.
WHOLE PLANT	Growth arrest, decreased vigour, foliar necrosis and chlorosis, defoliation.

IMPACT ON YIELD AND QUALITY

The above-mentioned symptoms may induce a decrease in yield. However, on green beans the impact is significantly less important than for *Meloidogyne* nematodes.

QUARANTINE ORGANISM

It is not an EU quarantine organism. It is not found on pods in any case.

CONDITIONS CONDUCIVE TO INFESTATION

The rate of development and cycle depend on the host plant and environmental conditions.

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Soil temperature is optimal for eggs at 35°C.	Very present in tropical and subtropical climates.
Soil humidity	Saturating irrigation promotes the dissemination of nematodes.	Juveniles need open water to move and infect the roots.
Soil	Acidic pH.	Populations decrease as pH increases.
	Presence of certain fungi such as *Rhizoctonia solani*, *Pythium*, Phytophtora, *Fusarium*.	Conditions are favourable for the installation and development of the nematode.

MONITORING

Attacked plants may exhibit poor growth, as well as chlorosis and defoliation. Affected plant areas are found in the field. The presence of root lesions are signs of the presence of the nematode. Such plants should be carefully removed for examination of the lesions. For further determination, a detailed examination of the morphology of nematodes extracted from roots or other parts of the plant under attack should be carried out.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The main practices contribute to pest control. Crop rotation is not really effective in preventive control of this pest because of the great diversity of hosts.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choose an appropriate site for the plot	It is advisable to avoid planting beans in a field that has previously been severely infested with these nematodes.	Avoids a source of infestation.
Management of the irrigation water source	Use drilling water for irrigation in preference to river water, as the latter can carry a large number of nematodes. If this is not possible, decant the river water into a tank before using it and allow the nematodes to flow to the bottom of the tank. Use a floating pump to extract water only from the top of the water volume – where there are fewer nematodes.	Avoids a source of infestation.
Choose a plot that is flooded in the rainy season or deliberately flood the plot	The ground must be flooded for several months.	Asphyxia of larvae
PLOT PREPARATION		
Cleaning of agricultural equipment	Equipment used in the field (ploughs, etc.) can move nematodes into the fields and must be cleaned, for example with water, after and before use.	Avoids a source of infestation.
Rational use of organic matter	Infestation can be reduced by applying abundant, well-decomposed organic matter to the seed row. Organic matter slows down the rise of nematodes that are deep in the soil. On the other hand, input of organic matter can modify microflora and mesofauna and encourage the development of various antagonists.	Physical barrier around the roots. Control by antagonists is reinforced.
CROP MAINTENANCE		
Mound the plants	This helps to promote the development of adventitious roots that can compensate for possible root knots.	Compensation for attacked roots.
Grubbing and destruction of plants at the end of production	Regular grubbing, with all roots, will reduce the level of nematode eggs in the soil.	Reduction of inoculum in soil.

ORGANIC CONTROL

Refer to the text for *Meloidogyne* nematodes.

CONTROL USING PLANT PROTECTION PRODUCTS

Refer to the text for *Meloidogyne* nematodes.

OTHER CONTROL METHODS

Refer to the text for *Meloidogyne* nematodes.

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7.2.5. FUNGAL DISEASES

7.2.5.1. *FUSARIUM* WILT OF THE NECK, *FUSARIUM ROOT ROT* OF THE BEAN, DRY ROOT ROT OF BEANS, BEAN ROOT ROT

SCIENTIFIC NAME

Fusarium solani f. sp. *Phaseoli*

LIFE CYCLE OF THE FUNGUS

It is a soil borne fungus.

STORAGE	Stays for about 2 to 3 years in the soil especially on plant debris thanks to its chlamydospores.
INOCULUM SOURCES	Conidia, chlamydospores and mycelium present in the soil. *Fusarium* can also be transmitted through seeds.
INFECTION	The spore germinates and begins to colonise the plant by the roots.
DEVELOPMENT, SPORULATION	Once inside the plant, the fungus will proliferate in its vascular system, where much of the plant's nutrients move. The growth of *Fusarium* inside the plant blocks the movement of water and the typical symptoms of wilting appear. When the plant dies, the spores of the *Fusarium* return to the soil via the crop debris and the cycle begins again.
DISSEMINATION	Pathogenic spores are disseminated through irrigation water, crop waste, and even agricultural tools.

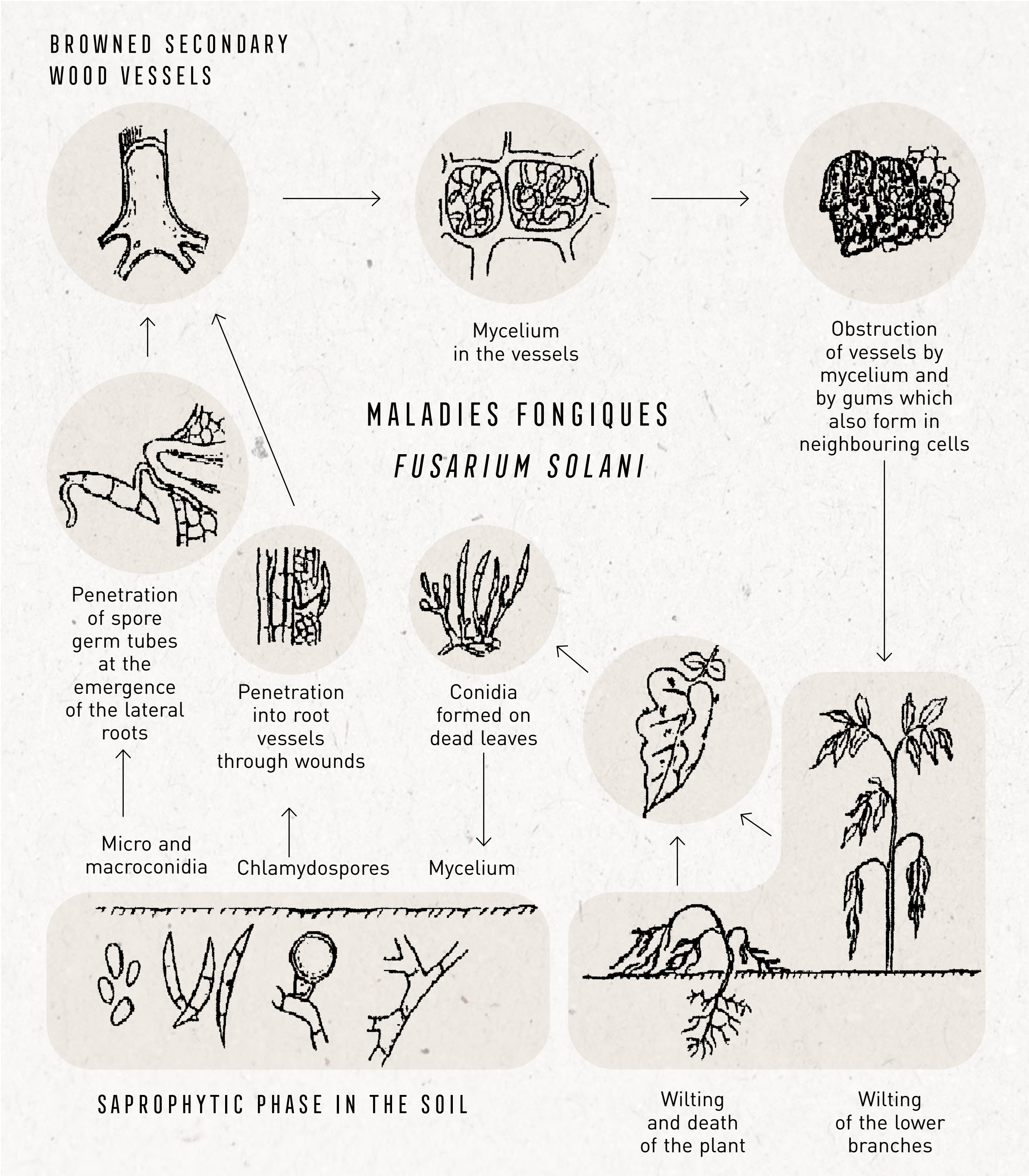

Figure 82 — Infectious cycle of *Fusarium solani* (Agrios, 1997)
https://agronomie.info/fr/fusarium-solani/

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Species of the genus *Phaseolus*.

AFFECTED CROP STAGE(S)

From the seedling stage to the appearance of flower buds.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
+	++	+++	+++	+	0

SYMPTOMS AND DAMAGE

SEEDLING	The affected plants are stunted and the seedlings wilt.
ROOT	The roots are necrotic and the main root is reddish. Adventitious roots do not develop.
STEM	Longitudinal and reddish lesions on the base of the stem (neck).
LEAF	Primary leaves are often yellow, then become necrotic.
WHOLE PLANT	It is common for infected plants to show no symptoms until flowering, when the water requirements of plants increase for pod production. At this point, the plants can suddenly collapse, because the development of *Fusarium* wilt causes an obstruction of the vessels of the plants, which therefore do not receive enough water.

Figure 83 — Withered and dried young plant. (COLEAD, 2012. Green bean crop protocol)

Figure 84 — Symptoms on young plants. Bruce Watt, University of Maine, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	As a result of wilting, plants die.
Loss of yield per plant	Root rot can lead to severe yield losses, especially when adverse environmental conditions (such as moisture and soil compaction) persist after planting and during flowering.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Temperatures between 20 and 28°C (32 to 104°F)	Rapid development of the fungus.
Soil	Compacted soil, water-soaked soil or drought.	Factors that prevent good rooting, weaken infected plants and strengthen the development of the disease.
	Salinity	Promotes infection.
	Presence of *Pratylenchus penetrans* or *Meloidogyne* and fungi of the genus *Pythium*.	Accentuates the severity of the disease.

MONITORING

Identification of this fungus is done by monitoring the wilting of the plant in the field, taking samples from infected plants and cultivating tissue samples. Since there are no effective fungicides for *Fusarium*, it is important to note the fields and the different areas of the fields in which *Fusarium* has been detected.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

Adequate cultivation practices are the most effective means of control. The main ones are listed below.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Seed selection	It is important to use clean, certified seed free from *Fusarium* infection. The seed label must indicate this. Some countries insist that imported seeds be treated with a fungicide for this reason. The use of self-produced seeds may increase the risk of *Fusarium*-infected seeds.	Prevent infected seeds from introducing *Fusarium* into a healthy site, as the disease can remain in the soil for many years.
Selecting the type of soil	Compact soils and uneven surfaces, where water can accumulate and weaken plants, should be avoided.	Less effect of the disease on plant growth.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Avoid sensitive preceding crops	Crop rotation is very important because the fungus is very specific and cannot infect crops other than *Phaseolus*. If beans are planted on the same plot without rotation, this can cause *Fusarium* to accumulate in the soil. On a heavily infested plot, a rotation of at least 3 years and preferably 6 to 8 years without *Phaseolus* should be performed.* The history of the field crops is a useful means of identifying areas or fields in which bean crops should not be included in the crop rotation plan. In fields where *Fusarium* infections are widespread, the ideal strategy would be to have at least one corn or cruciferous crop before the next bean crop.	Decreases the inoculum in the soil by disrupting successive cycles.
PLOT PREPARATION		
Good use of agricultural equipment	Contaminated soil on machines used to till the soil can displace pathogens from the soil. Make sure that severely infected fields are the last to be passed through during the day and wash farm machinery thoroughly after use to prevent infected soil from being moved around the farm.	Avoids a source of infestation.
Enrich the soil with organic matter	If the soil organic matter content is actively managed to conserve between 3 and 5% organic matter – through the application of composted manure or crop residues – this allows the development in the soil of useful microbes, such as *Trichoderma*, which have an antagonistic effect on *Fusarium*.	Control by antagonists is reinforced.
Tillage	It is necessary to till the soil carefully beforehand, in order to ensure proper drainage and aeration of the soil.	Less effect of the disease on plant growth.
Ensure proper soil drainage	Use raised beds, to improve drainage of soils that are too moist.	Less effect of the disease on plant growth.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
CROP MAINTENANCE		
Selecting the irrigation system	Plants that experience water stress (too much or not enough water) will be more susceptible to *Fusarium* infection. Preferably use drip irrigation to water "little and often".	Less effect of the disease on plant growth.
Practise rational fertilisation	Excess nitrogen in the soil can accelerate the development of *Fusarium* in infected plants. It is essential to carefully establish the fertiliser application programme to avoid excessive fertilisation.	Less effect of the disease on plant growth.
Grubbing and destruction of plants that are visibly diseased or at the end of their production lifetime	Do not leave obviously infected plants in the field. The fungus will continue to grow in the dying plant and will increase the potential inoculum of disease spores in the soil for subsequent crops. Carefully remove the plants with their roots; place them in a bag to take them out of the field, bury the infected plant material or chop it and compost it properly.	Reduces the inoculum in the soil.
Tillage at the end of the crop	Plough deeply to bury bean debris after harvest.	Reduction of inoculum in the upper part of the soil.
Rational use of crop waste	Do not feed livestock with late-production plants if manure is to be used in bean fields, as this can be a source of infestation.	Avoids a source of infestation.

* In the tropical zone, where two and a half crops can be grown over a 12-month period, it may not be necessary to apply such a long rotation. If the rotation of non-host crops, for example corn and cabbage crops, is interposed between the bean crops, it is possible to cultivate the bean again within 18 months, depending on the severity of an infestation previously occurring in the field.

ORGANIC CONTROL

F. solani has several natural enemies, for example: antagonistic fungi such as *Trichoderma viridens* and *Gliocladium virens*; bacteria of the subgroup *Pseudomonas fluorescens* which have a pathogenic effect on this fungus; antagonistic bacteria such as *Bacillus subtilis*. These beneficial microorganisms develop in the soil when there is a high content of organic matter. In some countries, they are also available as "biopesticides".

CONTROL USING PLANT PROTECTION PRODUCTS

The treatment of bean seeds with thiram is the main chemical means of controlling this disease, but thiram is no longer authorised in the EU. Other substances exist for seed treatment and are listed in the table in Appendix 3.

There is no effective chemical treatment to be applied after germination, so it will not be useful to treat after emergence.

Seeds can be treated with *Trichoderma*, which can help protect crops against *Fusarium*. Alternatively, organic matter previously enriched in *Trichoderma* may be applied to the planting line of the crop about 3 weeks before sowing the beans. The organic matter must be kept moist during this pre-planting period – to allow *Trichoderma* to grow on the organic matter.

However, *Trichoderma* itself is a fungus and advice should be sought on the simultaneous use of *Trichoderma* and fungicides applied to soil or seeds. It is also possible to apply *Trichoderma* using drip irrigation (see label). *Trichoderma* also act on several other soil diseases such as (*Pythium*, *Rhizoctonia*, *Sclerotinia*, *Phytophthora*, etc.).

A *Streptomyces* K61 (*Streptomyces griseoviridis*) preparation applied at the seedling stage in moist soil grows rapidly and colonises the available spaces around the root system of the host plants, thus preventing the pathogenic fungi from feeding and growing. In addition, the bacterium secretes various enzymes and metabolites that prevent the growth of pathogenic fungi.

OTHER CONTROL METHODS

No information available.

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7.2.5.2. NECROSIS OF THE STEMS OR ROT OF THE ROOT OF THE BEAN

SCIENTIFIC NAME

Macrophomina phaseolina (*Rhizoctonia bataticola*)

LIFE CYCLE OF THE FUNGUS

It is a soil borne fungus.

CONSERVATION	*M. phaseolina* survives as sclerotia on plant debris between 16 and 18 months. Survival and germination of sclerotia are favoured by dry soils, with a high carbon/nitrogen ratio in their amendments and oxygen concentrations above 16%. Conservation is also done at the seed level.
INOCULUM SOURCES	The main infectious agent for most hosts is black microsclerotia contained in soil or plant debris.
INFECTION	Soil inoculum colonises roots as soon as they come into contact with them.
DEVELOPMENT, SPORULATION	Hyphal growth occurs along the junction lines of epidermal cells.
DISSEMINATION	*M. phaseolina* rarely produces spores. The propagation is therefore mainly by the displacement of soil or plant debris containing sclerotia, and by seeds.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Very polyphagous soil borne fungus (more than 500 known hosts) including for example: *Arachis hypogaea* (peanut), *Cucumis sativus* (cucumber), *Solanum tuberosum* (potato).

AFFECTED CROP STAGE(S)

Stages of seedling, flowering, fruiting, grain formation and vegetative growth.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
+	+++	+++	++	+	0

SYMPTOMS AND DAMAGE

The entire plant as well as leaves, buds, roots and seeds can be attacked by the fungus but the attack mainly targets the stems and roots. Necroses have an edge and appear as concentric circles. Many small sclerotia or pycnids form on the margins of the lesions and several areas of the field can be affected.

SEED	Dry, carbonaceous or ashy rots.
SEEDLING	At the level of the seedling, the first symptoms appear as a fine and irregular lesion of blackish colour at the boundary between the surface and the soil at the level of the stem. Dry rot that may appear at the cotyledons, growth point and neck in the form of blackening. These lesions occur before or just after the emergence of the young seedling. After emergence, the infection spreads from the initial necrosis. The lesions widen, fuse, become necrotic and can lead to the death of the young seedling.
ROOT	More or less brown mycelium reminiscent of that of *Rhizoctonia solani*.
WHOLE PLANT	Wilting, chlorosis and leaf fall are more noticeable on one side of the plant.

Figure 85 — Bean seedlings with blackish lesions on the stem.
Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 86 — Necrosis on stem (COLEAD, 2012). Green bean crop protocol)

IMPACT ON YIELD AND QUALITY

The impact is major, especially in areas that experience hot and dry conditions during the growing period of the plant.

TYPE OF IMPACT	DESCRIPTION
Plant loss	Death of seedlings.
Loss of yield per plant	Attacked plants do not produce, or produce less.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Warm temperatures (30-40°C) and low relative humidity. Infection is maximal at 35°C and 76% relative humidity.	More severe diseases.
Concomitant presence of other pests.	Presence of nematodes.	Infection favoured. A synergistic relationship is established between the nematode (*Heterodera*, *Meloidogyne*, *Rotylenchus*) and the fungus.
Water availability	Water stress.	Predisposition to infection.

MONITORING

Ensure monitoring from germination to full harvest and treat with fungicides when necessary.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The control of *M. phaseoilina* focuses on the management of microsclerotia populations in the soil. The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Seed selection	It is important to use certified seeds	Prevents the fungus from being introduced into a healthy site.
PLOT PREPARATION		
Enrich the soil with organic matter	For example with compost or neem cake.	Control by antagonists is reinforced.
Cleaning of agricultural equipment	The equipment used in the field (ploughs, etc.) may move microsclerotia in the fields and should be cleaned, for example with water, after and before use.	Avoids a source of infestation.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
CROP MAINTENANCE		
Ensure regular irrigation	Plants are predisposed to infection because of water stress.	Less plant infection.
Ensure rational fertilisation in nitrogen	Excess nitrogen in the soil can accelerate the development of the disease.	Slower development of the disease.
Grubbing and destruction of plants that are visibly diseased or at the end of their production lifetime	Do not leave obviously infected plants in the field. The fungus will continue to grow in the dying plant and will increase the potential inoculum of disease spores in the soil for subsequent crops. Carefully remove the plants with their roots; place them in a bag to take them out of the field, bury the infected plant material or chop it and compost it properly.	Reduction of inoculum in soil.

ORGANIC CONTROL

M. phaseolina has, like *F. solani*, several natural enemies, such as antagonistic fungi and bacteria. A good organic matter content in the soil promotes the activity of its microorganisms.

CONTROL USING PLANT PROTECTION PRODUCTS

Treating bean seeds with thiram is the main chemical means of controlling this disease, but thiram is no longer authorised in the EU. Other alternative substances exist and are listed in the table in Appendix 3.

With regard to alternative PPPs, *Trichoderma harzanium* is an effective agent for controlling *M. phaseolina*. Infestation rates can be substantially reduced by applying this antagonist to soil. This fungus can also be used in seed treatment to effectively control *M. phaseolina*. Products based on *Streptomyces* are also usable.

OTHER CONTROL METHODS

No information available.

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7.2.5.3. DAMPING OFF OR BLACK FOOT OR *PYTHIUM* ROOT ROT

SCIENTIFIC NAME

Pythium aphanidermatum.

It belongs to the oomycetes and is related to species of the genus *Phytophthora*.

LIFE CYCLE OF THE FUNGUS

This fungus is a member of the oomycetes family. Oomycetes produce oospores, sexual spores that serve as a dormant structure and a means of survival under adverse conditions.

CONSERVATION	Oospores are the primary survival structures: they are resistant to desiccation and can survive in soils for long periods (11 months) in the absence of the appropriate host or organic substrate that allows them to survive as saprophytes. If conditions are not met for infection, the zoospores encydate and, as long as the soil moisture and temperature are adequate, they remain in the soil for at least 7 years.
INOCULUM SOURCES	In the presence of certain nutrients and at high relative humidity, sporangia are stimulated to produce mobile zoospores, the main infectious agents.
INFECTION	Oospores germinate directly or form sporangia. Sporangia can also germinate directly, but can also produce swarm spores, zoospores. In the presence of open water, zoospores are attracted to the seeds and roots they penetrate. Zoospores germinate and infect seedlings, often at the boundary between soil and air.
DEVELOPMENT, SPORULATION	Long hyphae pierce the epidermis of the plant. The fungus can produce new sporangia within a few days. Plant cells are killed by substances excreted by mould, which causes decay.
DISSEMINATION	The pathogen is dispersed when infected plant debris is transported to non-infested areas and when there is sufficient soil moisture to allow zoospores to swim freely.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

P. aphanidermatum is fond of a wide variety of host plants, including cucumber, cereals, cabbage varieties, beans, tomato, peanut, aubergine and potato.

AFFECTED CROP STAGE(S)

Stages of emergence, germination, vegetative growth and post-harvest.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+++	+++	++	+	+

SYMPTOMS AND DAMAGE

SEEDLING	After sowing, seedlings have difficulty emerging and those that emerge have necrotic brown to black roots. The plants wilt abruptly and softening and moist rot are observed on the roots, the collar and sometimes on the stems. On the attacked parts the epidermis is easily detached by scratching it off.
ROOT	Maroon lesions appear on the roots which, attacked by moisture, become black. Lateral roots and apices rot, and the entire root system is sometimes putrefied.
STEM	Brown lesions appear on the stems.
LEAF	Foliar symptoms are nutritional deficiencies due to the condition of the roots.
PODS	After harvest, under conditions of high humidity, a fragile white mycelium can develop on the pods in the export boxes.

Figure 87 — Seedlings with symptoms. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 88 — White and downy masses on pods affected by aqueous rot.
David B. Langston, University of Georgia, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	Early attacks in favourable conditions often lead to the death of seedlings by damping off.
Loss of yield per plant	Sometimes, once the plant has emerged and started to grow, infections by the pathogen are no longer lethal, but they can still have a significant impact on plant growth and yield.
Lower quality	Fragile white mycelium may develop on pods in export boxes.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	High soil moisture and mild or hot temperatures (soil temperature between 32 and 37°C) with a great deal of luminosity.	Ideal conditions for oospore germination.
Soil	pH greater than 7.	Soil pH is an important element in the infection of the field by the phytopathogenic fungus because it influences its ecology (oospore germination) and pathogenicity. For pH values between 5 and 6, the saprophytic activity of the fungus in the field is greatly reduced.

MONITORING

Since some other phytopathogenic fungi cause similar damage, the diagnosis should be confirmed by isolating and identifying the pathogen.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Avoid sensitive preceding crops	Because of the many hosts of this fungus, crop rotation does not fully control the pathogen, but there are some rotation practices that reduce the inoculum load. Fungi of the genus *Pythium* are known to be pathogens for which it is difficult to find resistant hosts. But there are examples of tolerant plants such as ginger and corn and some bean species.	Population densities of *P. aphanidermatum* in soils after harvest can be reduced by a rotation of 2 to 3 years.
Choice of irrigation system and water source	Avoid furrow irrigation. Zoospores can also be present in river water and spread through irrigation systems that use river water. Using drilling water is preferable.	Prevents the fungus from being introduced into a healthy site.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLOT PREPARATION		
Enrich the soil with organic matter	A high level of organic matter in the soil allows a structure that is properly aerated and promotes the development of antagonistic microorganisms	Control by antagonists is reinforced. Dispersion of zoospores more difficult.
PRIOR CHOICES		
Tillage	It is necessary to till the soil carefully beforehand, in order to ensure proper drainage and aeration of the soil.	Well-drained soil not only limits the dispersal of zoospores, but also prevents plants from becoming predisposed to the fungus.
Ensure proper soil drainage	Use raised beds, to improve drainage of soils that are too wet.	Well-drained soil not only limits the dispersal of zoospores, but also prevents plants from becoming predisposed to the fungus.
Practise rational fertilisation	Excess nitrogen in the soil can accelerate the development of the disease. It is essential to carefully establish the fertiliser application programme to avoid over-application.	Slower development of the disease.
Ensure a rational amendment	Different mixtures or organic and inorganic compounds are known to reduce the incidence of the disease. This ability to control the pathogen lasts about 25 days after application of the amendment and urea appears to be the most effective component against the pathogen. The mechanism of fungus suppression is related to a direct effect of mineral fertilisers and an indirect effect of the mixture that reduces pH and stimulates soil microbial activity.	Control by antagonists is reinforced. Toxicity on the fungus.
CROP MAINTENANCE		
No excessive irrigation	The permanent presence of abundant free water promotes the dispersion of zoospores.	Less dispersal and infection.
Grubbing and destruction of plants that are visibly diseased or at the end of their production lifetime	Do not leave obviously infected plants in the field. The fungus will continue to grow in the dying plant and will increase the potential inoculum of disease spores in the soil for subsequent crops. Carefully remove the plants with their roots; place them in a bag to take them out of the field, bury the infected plant material or chop it and compost it properly.	Reduction of inoculum in soil.

ORGANIC CONTROL

Good agricultural practices and the introduction of organic matter into the soil increase the natural presence of *Trichoderma* and other microorganisms in the soil that are *Pythium* antagonists.

CONTROL USING PLANT PROTECTION PRODUCTS

Several commercial fungicides have been developed for soil and seed treatment and for preventive treatment against *P. aphanidermatum*. Thiram is the most recommended fungicide for the treatment of bean seeds but is no longer authorised in the EU. Other substances exist for seed or soil treatment and are listed in the table in Appendix 3.

PPPs based on biological control microorganisms exist to control *Pythium*, such as: *Bacillus amyloliquefaciens* (formerly *subtilis*) strain QST 713, *Gliocladium catenulatum*, *Gliocladium virens*, *Streptomyces* K61 (*Streptomyces griseoviridis*), *Streptomyces lydicus* WYEC 108 and *Trichoderma harzianum*.

OTHER CONTROL METHODS

No information available.

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7.2.5.4. DAMPING OFF OR BLACK SCURF

SCIENTIFIC NAME

Rhizoctonia solani

LIFE CYCLE OF THE FUNGUS

This fungus produces basidiospores and is therefore part of the basidiomycetes.

CONSERVATION	On crop residues and soil organic matter in the form of mycelium or pseudo-sclerotia (several years). It can also be found on and inside seeds. Sometimes present in some substrates and composts.
INOCULUM SOURCES	Contaminations via mycelium already present in the soil or originating from sclerotia. They can also take place via basidiospores derived from its sexual reproduction.
INFECTION	Penetration of mycelium into tissues directly through the cuticle or through various wounds. Rapid inter- and intracellular invasion of tissues thanks to lytic enzymes.
DEVELOPMENT, SPORULATION	Formation of mycelium travelling on tissues and on the ground, and reaching other healthy organs. The mycelium grows on the surface of the plant and forms infection cushions that will then infect the entire plant. Sometimes, basidiospores formed on basidia present on the surface of the hymenium are produced.
DISSEMINATION	Rarely by basidiospores transported by the wind over quite large distances. Transmission also takes place by soil contaminated by mycelium and sclerotia via tillage, soiled tilling tools and equipment; or by water via splashes during irrigations or rains.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Polyphagous fungus, it grows on many crops such as: corn, tomato, chilli, aubergine, potato, cucumber, crucifers, legumes...

AFFECTED CROP STAGE(S)

The most sensitive stage is the seedling stage up to 21 days after sowing. Early infections lead to seed degeneration and post-emergence wasting.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
+++	+++	+++	++	+	+

SYMPTOMS AND DAMAGE

The fungus affects the roots, stems, but also leaves and fruits if they are close to the ground.

SEED	Seed degeneration
SEEDLING	Damping off, weakening and yellowing or wilting of seedlings
ROOTS	Dry necrosis of the pivot and the rootlets
NECK	Reddish-brown and indented cankers, which extend longitudinally.
LEAVES	Leaf yellowing or wilting related to tissue alteration. Grey mould on leaves touching the ground*
PODS	Small, concave, moist cankers sometimes appear on the pods during harvest. Grey mould on pods touching the ground*

* Attacks in very humid equatorial or tropical climates.

Figure 89 — Root rot of bean seedlings caused by Corticium *rolfsii* (left), and *Rhizoctonia solani* (right)
AGCD – Coopération Belge. (1989). Maladies et ravageurs des cultures de la région des grands lacs d'Afrique Centrale (No. 24). (232 p.). Accessed on 04.06.21 at http://www.nzdl.org/cgi-bin/library?e=d-00000-00---off-0tulane--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-help---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&cl=CL1.4&d=HASH017effd0ae3acd4ea49da90e.5.10&x=1

Figure 90 — Symptoms on young plants. Edward Sikora, Auburn University, Bugwood.org

Figure 91 — Grey mould on leaves. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 92 — Grey mould on pods. Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

R. solani is a pathogen whose damage is of economic importance for some African countries such as Senegal.

TYPE OF IMPACT	DESCRIPTION
Plant loss	Due to lack of emergence or seedling wasting.
Loss of yield per plant	Due to weakening of the affected plants.
Reduction in quality	Due to the presence of stains on the pods.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

Growing plants are less sensitive than others that are weakened or grow irregularly.

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Soil	Humidity	Good condition for mycelium conservation.
	Lack of antagonistic microorganisms	No natural impediment to the expansion of the fungus.
	Compaction.	Lengthens the emergence phase and encourages the expression of symptoms.
	Salinity	Promotes infection.
	Clayey-sandy	Promotes infection.
Weather conditions	High relative humidity. Heavy rains.	Promote infection.
	Temperatures above 24-26°C. Optimum of 27°C.	Promote infection.
Irrigation	By excessive spraying.	Promotes infection.
Foliage	High density.	High relative humidity near the ground, under dense foliage, can promote infections.

MONITORING

No information available.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease. Any measure that promotes rapid emergence and good seedling establishment limits the impact of this pathogen.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Seed selection	It is important to use clean, certified seed free from *Rhizoctonia* infection.	Prevents the fungus from being introduced into a healthy site.
Avoid sensitive preceding crops	The preceding crop should not be the potato because this crop is an important host of this fungus. Long rotations (3 to 6 years) are required.	Decreases the inoculum in the soil by disrupting successive cycles.
Choice of water source	Avoid water that is too salty.	Less effect of the disease on plant growth.

Avoid shaded plots	Soil and plants stay wet longer in shady areas.	Limited infection.
Avoid compacted and asphyxiating soils	This type of soil does not allow good plant growth and is conducive to infection with the fungus.	Not only limits infection, but also prevents plants from becoming predisposed to the fungus.
PLOT PREPARATION		
Enrich the soil with organic matter	A high level of organic matter in the soil provides a well aerated structure and encourages the development of antagonistic microorganisms.	Control by antagonists is reinforced. Less effect of the disease on plant growth.
Tillage	It is necessary to till the soil carefully beforehand, in order to ensure proper drainage and aeration of the soil.	Not only limits infection, but also prevents plants from becoming predisposed to the fungus.
Ensure proper soil drainage	Use raised beds, to improve drainage of soils that are too wet.	A well-drained soil not only limits infection, but also prevents plants from becoming predisposed to the fungus.
PLANTING		
Sowing superficially (maximum depth 3 cm)	Allows rapid emergence and rapid growth of seedlings.	Plants are more resistant to attack.
Avoid planting seeds too close together	Reduces relative humidity and temperature under vegetation and increases evapotranspiration and penetration of the sun's rays	Avoids conditions conducive to infection.
CROP MAINTENANCE		
No excessive irrigation	Soil that is too moist is conducive to infection.	Avoids conditions conducive to infection.
Selecting the irrigation system	Drip irrigation reduces the risk of spreading the pathogen.	Prevents the fungus from being introduced into a healthy site.
Use leaf fertilisers	This makes it possible to compensate for the difficulties of feeding the plant by the roots.	Plants are more resistant to attack.
Grubbing and destruction of plants that are visibly diseased or at the end of their production cycle	Grubbing must be followed immediately by destruction (deep burial, burning or animal feed).	Avoids increased inoculum potential. Avoids contamination of neighbouring plots.

ORGANIC CONTROL

Fungi of the genus *Trichoderma* are antagonists of *Rhizoctonia solani*.

Good agricultural practices and input of organic matter in the soil increase the natural presence of *Trichoderma* and other useful microorganisms in the soil.

CONTROL USING PLANT PROTECTION PRODUCTS

Coating seeds with a fungicide provides effective protection.

Soil fumigation may be carried out before sowing using metam sodium in combination with seed treatment with iprodione, but iprodione is no longer authorised in the EU.

Other substances exist for seed or soil treatment and are listed in the table in Appendix 3.

Control of *Rhizoctonia solani* with biocontrol products is largely based on the use of the antagonist *Trichoderma* spp. *Bacillus amyloliquefaciens* (formerly *subtilis*) strain QST 713, *Streptomyces* K61 (*Streptomyces griseoviridis*) and *Streptomyces lydicus* WYEC 108 are also effective. Another method entails using *Gliocladium virens* and *Gliocladium catenulatum*.

It is also possible to use fungal antagonists and organic amendments in combination for better control of *R. solani*.

OTHER CONTROL METHODS

The seed can be treated with hot water (about 52°C) for 30 minutes. This type of treatment eliminates fungal contamination from the seed.

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7.2.5.5. NECK ROT, SOUTHERN BLIGHT OF VEGETABLES AND MELONS

SCIENTIFIC NAME

Sclerotium rolsfii (*Corticum rolfsii – Athelia rolfsii*)

LIFE CYCLE OF THE FUNGUS

CONSERVATION	In the form of sclerotia in the soil for several years (5 years in dry soil). The mycelium is able to survive for 6 months in dry soil.
INOCULUM SOURCES	The main source of inoculum is a black microsclerotia in the soil or plant debris of host plants.
INFECTION	Sclerotia, exposed to temperatures above 26-27°C, germinate, and emerging hyphae grow and penetrate stems and other plant structures that come into contact with the soil surface. It can penetrate healthy tissue without creating lesions.
DEVELOPMENT, SPORULATION	Once *Sclerotium rolfsii* takes hold in plant tissue, it develops a white mycelium from the site of infection, which eventually forms a fan pattern that continues to advance towards the roots. The pathogen invades the stem and roots and destroys the cortex. If the temperatures reach at least 27-35°C, the mycelium becomes compacted, and between 4 and 7 days after infection, it forms sclerotia which rapidly change in colour from white to brown. Occasionally, *S. rolfsii* has a sexual fruiting stage that develops on the edges of lesions and in places that are in the shade of the sun. This stage is not frequently observed in the field and is not thought to be of primary importance in the transmission of the disease.
DISSEMINATION	The sclerotia are slightly heavier than the spores, so they are less likely to be transported by wind. However, they can be scattered from field to field by contaminated water, animals and ploughs.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

This fungus is highly polyphagous and particularly prevalent in warm tropical and subtropical regions.

It can attack and persist on some 500 plants, cultivated or not, belonging to a hundred botanical families. Vegetables include: tomato, chilli, aubergine, various salads, melon, cucumber, watermelon, beetroot, carrot, cauliflower, celery, garlic, onion, radish, turnip, sweet potato. It also attacks: corn rice, peanut *sorghum*, potato.

AFFECTED CROP STAGE(S)

From emergence to fruiting phase.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	+	++	+++	+++	0

SYMPTOMS AND DAMAGE

ROOT	THEY ROT.
Neck	Wet rot at the base of the neck just above the ground line.
Stem	A thick white mycelium with spherical sclerotia (1 mm diameter), first white and then beige, develops on the stem at the base of the plant and spreads all around the organic matter of the soil and roots. This is observable during hot and humid periods and disappears at times of drought.
Leaf	Yellowing of the edges of the lowest leaves is observed early. The upper leaves then begin to turn yellow and fall.
Whole plant	The plant gradually wilts and dies.

Figure 93 — Plants with brown sclerotia on the stem
Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 94 — Wilting of plants (basic IT source)

IMPACT ON YIELD AND QUALITY

The impact can be significant only in very humid and hot growing conditions; this is rarely the case for green beans intended for export.

TYPE OF IMPACT	DESCRIPTION
Plant loss	By wasting.
Loss of yield per plant	By weakening of the affected plants.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Soil	Humidity	Promotes infection.
	Acidic soils, its mycelial growth being optimal between pH 3 and 5; germination of sclerotia occurs between pH 2 and 5. The latter appears to be inhibited above pH 7.	Promotes infection.
	Lack of well decomposed organic matter.	Less active antagonists.
	Nitrogen deficiency	Less active antagonists.
	The more clay content in the soil decreases, the more the disease increases.	Infection promoted.
Weather conditions	High relative humidity. Heavy rains.	Promote infection.
	Temperatures above 26-27°C	Favourable to the germination of sclerotia.
	Warm temperatures (between 26 and 35°C) and relative humidity between 20 and 40%	Allow sclerotia to survive in soils.

MONITORING

No information available.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Avoid sensitive preceding crops	It is advisable to carry out crop rotations every 3 years at most and especially not to plant successive crops that share this parasite. *	Decrease of the inoculum in the soil by disrupting successive cycles.
Shaded plots should be avoided	Soil and plants stay wet longer in shady areas.	Limited infection.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLOT PREPARATION		
Enrich the soil with well decomposed organic matter	A high level of organic matter in the soil allows a structure that is properly aerated and encourages the development of antagonistic microorganisms	Control by antagonists is reinforced. Less effect of the disease on plant growth.
Soil liming	Helps to raise the pH in soils that are too acidic.	Limited infection.
Ensure proper soil drainage	Use raised beds, to improve drainage of soils that are too wet.	A well-drained soil not only limits infection, but also prevents plants from becoming predisposed to the fungus.
PLANTING		
Correct seed density	A dense canopy increases soil moisture. Increasing plant spacing can help reduce this moisture.	Reduced infection.
CROP MAINTENANCE		
No excessive irrigation	Soil that is too moist is conducive to infection.	Avoids conditions conducive to infection.
Ensure regular weeding of the field	The presence of weeds keeps soil moisture longer.	Avoids conditions conducive to infection.
Ensure good nitrogen fertilisation, rich in calcium	The application of nitrogen helps control the disease and increases yield. Calcium helps raise the pH of the soil.	Less effect of the disease on plant growth. Limited infection.
Grubbing and destruction of plants that are visibly diseased or at the end of their production cycle	Grubbing must be followed immediately by destruction (deep burial, burning or animal feed).	Avoids increased inoculum potential. Avoids contamination of neighbouring plots.

* Although crop rotation is a traditional and preferred method of controlling the disease, it is not very effective in controlling *S. rolfsii* due to its wide range of hosts and the ability of sclerotia to survive in soil.

ORGANIC CONTROL

The lack of organic amendments or poorly decomposed organic matter or a nitrogen deficiency in the soil decreases the activity of antagonistic microorganisms, such as *Bacillus subtilis* and *Trichoderma*, and therefore promotes the development of the fungus.

CONTROL USING PLANT PROTECTION PRODUCTS

Currently, seed treatment with fungicides is the most successful method of controlling this pathogen.

Before sowing, soil fumigation can be carried out using metam sodium.

Other substances exist for seed or soil treatment and are listed in the table in Appendix 3.

Among the biocontrol products the following are thought to have some effectiveness when applied to soil: *Trichoderma harzianum*, *T. viride*, *Bacillus subtilis*, *Penicillium* spp., *Streptomyces lydicus* WYEC 108, *Gliocladium virens* and *Gliocladium catenulatum*.

OTHER CONTROL METHODS

The application of ginger juice at 20g / l at the rate of 100 ml / plant (application to the neck and the surrounding soil) is reported to be effective. Repeated application, at least three times at a fortnightly interval during the bean development cycle, appears to be necessary. (NDRIAMIARISOA Lovaniaina Dinanirina, 2014).

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7.2.5.6. ALTERNARIOSE

SCIENTIFIC NAME

Alternaria spp. of which *A. alternata*.

LIFE CYCLE OF THE FUNGUS

CONSERVATION	The fungus survives on soil plant debris and weeds.
INOCULUM SOURCES	The primary inoculum (infectious spores) can be found in the field where the plants are grown.
INFECTION	In order for spores to infect a leaf, it must remain wet for about four hours.
DEVELOPMENT, SPORULATION	Although symptoms appear on adult pods at the end of the growing season, evidence indicates that infections develop earlier on flowers, young pods and leaves. The fungus remains inactive after premature infection until natural senescence of the plant begins.
DISSEMINATION	The spores it produces can be transported, by wind or rain, from decaying plant debris to the leaves, flowers and pods of snap beans.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Alternaria alternata can infect a broad range of hosts, *Phaseolus* spp., *Pisum sativum* (pea), *Solanum melongena* (aubergine)...

AFFECTED CROP STAGE(S)

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	0	+	++	+

SYMPTOMS AND DAMAGE

Species of the genus *Alternaria* are latent parasites that enter through natural openings and only show symptoms after a latency period. They are responsible for infections on pods that can sometimes already occur in the field, but which are mainly found post-harvest.

LEAVES	Symptoms are most often limited to primary leaves that show brownish spots, roughly rounded, bordered by a darker ring, or a large number of small uniformly black spots, depending on the pathogen involved. In conditions of high humidity, these symptoms can also spread to the oldest trifoliate leaves.
PODS	Orange, reddish or brownish speckles.

Figure 95 — Symptoms on leaves and pods.
Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Reduction in quality	Due to the presence of stains on the pods that sometimes appear only after harvest.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Cool (15 to 23°C) and humid weather that keeps the leaves wet for 24 hours or more.	Causes spore germination and infestation.
Nutritional deficiency	Nutritional deficiency of nitrogen and/or potassium.	Higher sensitivity.

MONITORING

Monitor during sensitive phenological stages and treat with fungicides if necessary.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

Control measures are rarely justified, but the practices mentioned below can contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Avoid sensitive preceding crops	It is recommended to apply a minimum of three cycles of non-host plants or one crop rotation over three years to avoid disease development in a field.	Decreases the inoculum in the soil by disrupting successive cycles.
Choosing the site of the plot	It is recommended not to plant green beans near other crops infested with fungal diseases that could infest them in turn.	Avoids a source of infestation.
Shaded plots should be avoided	Plants stay wet longer in shaded areas.	Limited infection.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLANTING		
Adapted seed density	A dense canopy increases the persistence of moisture on the foliage. Increasing plant spacing can help reduce this moisture.	Reduced infection.
CROP MAINTENANCE		
Ensure good nitrogen fertilisation, rich in potassium.	Less susceptibility of plants to disease.	Less effect of the disease on plant growth. Limited infection.
Grubbing and destruction of plants that are visibly diseased or at the end of their production cycle	Grubbing must be followed immediately by destruction (deep burial, burning or animal feed).	Avoids increased inoculum potential. Avoids contamination of neighbouring plots.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

It is particularly important to apply effective fungicides when pods are small to avoid infections that will occur later when the pods are mature.

The recommended substances are listed in the table in Appendix 3.

The biological control methods applied against fungi of the genus *Alternaria* include bacilli, enterobacteria and the antagonist fungus *Trichoderma viride*.

OTHER CONTROL METHODS

No information available.

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7.2.5.7. BEAN *ANTHRACNOSE*

SCIENTIFIC NAME

Colletotrichum lindemuthianum (*Gleosporium lindemuthianum*)

LIFE CYCLE OF THE PATHOGEN

CONSERVATION	The fungus can survive as a resting mycelium especially in infected seeds and to a lesser extent on debris such as vines and pods for more than 2 to 5 years depending on environmental conditions.
INOCULUM SOURCES	Primary contamination is carried out by the propagules of the fungus carried by the seed or, to a lesser extent, in bean straw. Secondary contamination occurs via conidia produced on already infected plants.
INFECTION	It occurs via propagules or via conidia produced on free conidiophores in acervules. A conidium germinates in 6 to 9 hours under favourable environmental conditions.
DEVELOPMENT, SPORULATION	The time between infection and visible symptoms varies from 4 to 9 days, depending on temperature.
DISSEMINATION	The fungus is disseminated over long distances by infected seeds. Propagation over short distances takes place by mechanical contact, splashing water or wind, especially in cool, humid weather.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Only legumes such as: Lima bean (*P. lunatus*), Spanish bean (*P. multiflorus*), Mungo bean (*P. aureus*), cowpea (*Vigna sinensis*), broad bean (*Vicia faba*), *Cajanuscajan* (*Cajanus cajan*), pea (*Pisum sativum*).

AFFECTED CROP STAGE(S)

Pre-emergence, vegetative growth, flowering and fruiting stages.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
+	+	++	++	+++	+

SYMPTOMS AND DAMAGE

Symptoms can be observed on any part of the plant but most often on the leaves.

SEED	Infected seeds discolour and turn yellow, then brown and black.
SEEDLING	Pale brown and indented spots may appear on cotyledons.
STEM	The lesions are elongated and indented.
LEAF	Dark brown and elongated lesions, first on the veins on the underside of the leaves. The disease then spreads laterally into light brown lenticular spots bordered by a darker brown, visible on the upper side. The disease can affect large areas of the limbus, which often takes on a creased appearance.
POD	Indented rounded spots with brown-reddish protruding edges, forming acervuli in humid weather that appear as rosy gummy droplets. These lesions penetrate deep into the pods and can cause young pods to wilt.

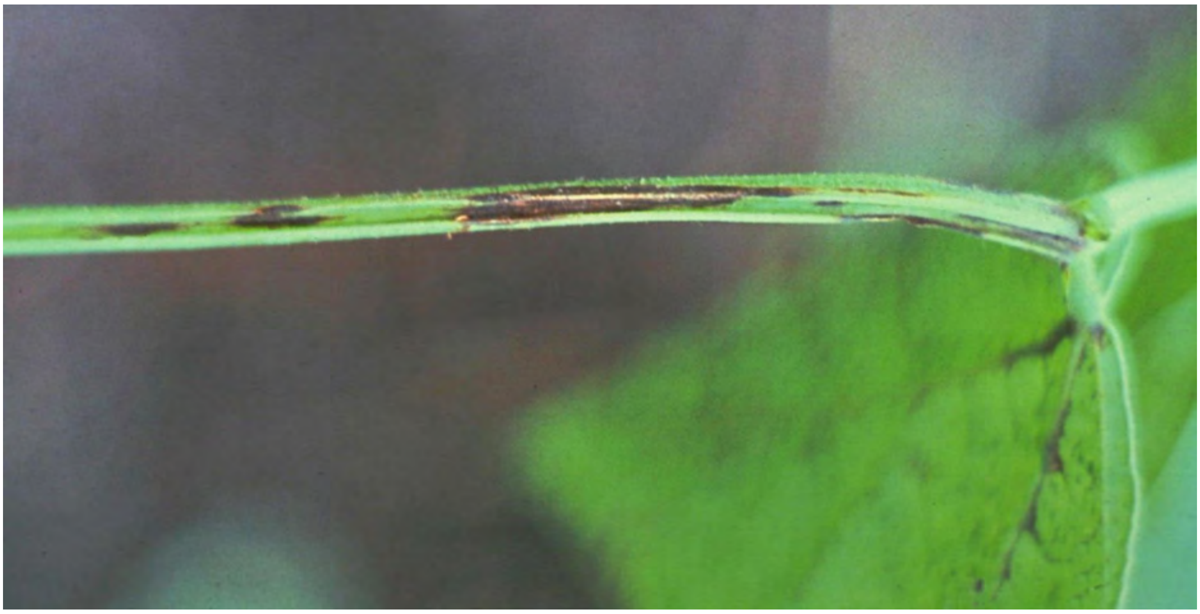

Figure 96 — Symptom on petiole. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 97 — Symptom on veins of a leaf. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 98 — Symptom on pod.
Elizabeth Bush, Virginia Polytechnic Institute and State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	Early attack can lead to the death of seedlings of susceptible cultivars as a result of attacks on the hypocotyl.
Loss of yield per plant	Damage to foliage can lead to loss of yield.
Reduction in quality	Due to the presence of stains on the pods.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

The disease is more common in temperate zones than in the tropics. In the tropics, *anthracnose* prevails in cold regions, at high altitudes (1,600 – 2,000 m). *Anthracnose* development is unlikely on seeds produced in semi-arid areas, which have little precipitation and high temperatures during the growing season.

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Moderate rain at regular intervals, especially when accompanied by wind and a splash effect.	Dissemination of favoured conidia implies the development of severe epidemics.
	Average temperatures between 13 and 26°C with an optimum ranging from 17 to 20°C.	Infection favoured.
	Relative humidity greater than 92% during all stages of conidial germination, incubation and sporulation	Infection favoured.

MONITORING

No information available.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Seed selection	It is important to use clean, certified seed that is free of fungal infection.	Prevents the fungus from being introduced into a healthy site.
Choice of resistant varieties	For example, Paulista and Amy amid others (see point 3.2.).	Limited infection.
Avoid sensitive preceding crops	Legume-free 2-3-year crop rotations are often recommended because the fungus can survive on infected debris for more than 2 years.	Decreases the inoculum in the soil by disrupting successive cycles.
Choose an appropriate site for the plot	It is advisable not to plant green beans near other crops infested with fungal diseases that could infest them in turn.	Avoids a source of infestation.
Shaded plots should be avoided	Plants stay wet longer in shaded areas.	Limited infection.
PLANTING		
Adapted seed density	A dense canopy increases the persistence of moisture on the foliage. Increasing plant spacing can help reduce this moisture.	Reduced infection.
CROP MAINTENANCE		
Limit the activity and movement of workers in the field	When the foliage is wet after rain there is a risk that workers' clothes will be contaminated by rubbing on the leaves and that new plants will be contaminated.	Avoids dispersing the fungus.
Regular weeding of the plot	Allows better aeration of the plants and therefore less moisture on the plant.	Reduced infection.
Avoid sprinkling irrigation.	Excess water may be conducive to the development of the disease.	Reduced infection.
Grubbing and destruction of plants that are visibly diseased or at the end of their production cycle	Grubbing must be followed immediately by destruction (deep burial, burning or animal feed).	Avoids increased inoculum potential. Avoids contamination of neighbouring plots.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

As *anthracnose* is a minor problem for green beans in the tropics, the application of fungicides is often not justified.

PERIOD OF APPLICATION

Bean seeds are usually treated with fungicides against various fungal diseases and this will help control *anthracnose* during germination. During the growth cycle, treatments are carried out, if necessary, after the appearance of the first leaves and until the pods form. In infested areas it is advisable to carry out at least 3 treatments during vegetation (appearance of 1st trifoliate leaf, 1st flower buds and appearance of pods). In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market.

THE SUBSTANCES

The recommended substances are listed in the table in Appendix 3.

Biological control methods include *Trichoderma viride*, *Trichoderma harzianum*, *Gliocladium virens*, *Streptomyces lydicus* WYEC 108, neem extracts and copper.

OTHER CONTROL METHODS

No information available.

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7.2.5.8. ANGULAR LEAF SPOT DISEASE

SCIENTIFIC NAME

Pseudocercospora griseola (*Isariopsis griseola – Phaeoisariopsis griseola*)

LIFE CYCLE OF THE FUNGUS

CONSERVATION	The fungus survives as spores in the plant debris of infected plants and soil for several months (up to 19 months).
INOCULUM SOURCES	Plant debris, seeds and natural or wild host plants.
INFECTION	Infection takes place via the stoma.
DEVELOPMENT, SPORULATION	The intracellular development phase is responsible for necrosis. Fruiting bodies are produced on the lesions and in wet weather many conidia appear.
DISSEMINATION	The splash effect of rain can promote spore dissemination but dry winds are the main agents of dissemination. Dissemination also takes place via seeds.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

O. phaseoli such as cowpea, soybean, *Desmodium* and *Dolichos lablab*.

AFFECTED CROP STAGE(S)

From flowering to the end of the harvest period.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
+	+	+	+++	++	+

SYMPTOMS AND DAMAGE

Lesions are visible on stems, leaves and pods.

STEM	The lesions on the stems are elongated and brown.
LEAF	On the first leaves, the spots are circular, but on trifoliate leaves, the characteristic angular spots are observed. The disease manifests itself on the lower leaves of the plant in the form of angular spots, first grey, then brown, limited by leaf veins. The lesions may also be surrounded by a chlorotic halo with no coloured border. On the underside of the leaves, small tufts of dark colour can be distinguished. The angular shape of the spots is a characteristic of the symptoms. The affected leaves turn yellow and fall prematurely.
POD	Lesions on the pods are less frequent than on the leaves. They are oval to circular in shape, initially superficial, with black borders and a red-brown centre. The width of the spots varies but they then grow to merge and cover the whole pod. The symptoms are similar to those of *anthracnose*.

Figure 99 — Angular spots on leaf. (basic IT source)

Figure 100 — Spot on pod. Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Loss of yield per plant	Due to falling leaves.
Lower quality	Spots on the pods make them unsellable.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/ EXPLANATION
Weather conditions	A long (1 to 2 days), warm (16 to 28°C with an optimum at 24°C) period with persistent humidity associated with a primary inoculum source. These conditions must alternate with dry and windy periods for spore dispersal.	Development of infection.

MONITORING

Regularly inspect the fields for early onset of angular spot and determine when the fungicide is to be applied.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Seed selection	It is important to use clean, certified seed that is free of fungal infection.	Prevents the fungus from being introduced into a healthy site.
Avoid sensitive preceding crops	2-year legume-free crop rotations are often recommended because the fungus can survive on infected debris for up to 19 months.	Decreases the level of inoculum in the soil by disrupting successive cycles.
Choose an appropriate site for the plot	It is advisable not to plant green beans near other crops infested with fungal diseases that could infest them in turn.	Avoids a source of infestation.
Shady plots with a microenvironment that is too humid should be avoided	A crop that is too dense, shaded or associated with corn will remain moist longer.	Limited infection.
PLANTING		
Adapted seed density	A dense canopy increases the persistence of moisture on the foliage. Increasing plant spacing can help reduce this moisture.	Reduced infection.
CROP MAINTENANCE		
Reduce the activity and movement of workers in the field.	When the foliage is wet after rain there is a risk that workers' clothes will be contaminated by rubbing on the leaves and that new plants will be contaminated.	Avoids dispersing the fungus.
Regular weeding of the plot	Allows better aeration of the plants and therefore less moisture on the plant.	Reduced infection.
Grubbing and destruction of plants that are visibly overattacked or at the end of production	Grubbing must be followed immediately by destruction (deep burial, burning or animal feed).	Avoids increased inoculum potential. Avoids contamination of neighbouring plots.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

PERIOD OF APPLICATION

Seed treatment and leaf spraying help combat angular spot disease.

Apply a fungicide at the beginning of flowering (when 10-30% of the flowers are blooming) when conditions are conducive to an outbreak of the disease. Consider performing a second fungicidal treatment seven days later at the end of flowering (when 50-70% of flowers are out) if conditions conducive to the outbreak and spread of the disease occur between the beginning and the end of flowering or are expected after the end of flowering. In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market.

Fungicides are effective when applied before flowering and during the formation of pods. It is sometimes possible to avoid treatments, as fungal attacks often occur late in the crop cycle and therefore have very little effect on crops.

THE SUBSTANCES

The recommended substances are listed in the table in Appendix 3.

Biocontrol methods include copper and sulphur.

OTHER CONTROL METHODS

No information available.

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7.2.5.9. BEAN RUST

SCIENTIFIC NAME

Uromyces appendiculatus. Formerly *Uromyces phaseoli*.

LIFE CYCLE OF THE FUNGUS

STORAGE	In the form of teleutospores that are able to ensure the survival of the parasite from one year to the next.
INOCULUM SOURCES	Nearby host plants.
INFECTION	When bean foliage develops, it is susceptible to infection by wind-borne spores. Spores germinate on the leaf and penetrate through the stomata, feeding on leaf material. Symptoms appear within 5 days.
DEVELOPMENT, SPORULATION	As it matures, the fungus forms a reddish-brown pustule that erupts across the leaf surface.
DISSEMINATION	Spores are disseminated by air or by mechanical means (hands of harvesters and agricultural equipment) or via animals including insects. Some types of spores are specially adapted for survival and have thick dark walls; they can survive long periods in the air and travel great distances.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Mainly species of the genus *Phaseolus*

AFFECTED CROP STAGE(S)

Seedlings at the end of the harvest period

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
0	0	++	+++	++	+

SYMPTOMS AND DAMAGE

Although the disease mainly affects the leaves, it also affects petioles and pods and, in severe cases, the stem.

STEM	Same symptoms as on leaves but rarer.
LEAF	The damage appears, especially on the underside of the leaves, in the form of small (1 to 2 mm in diameter) yellow pustules, rapidly becoming masses of brown-red spores in the middle of a yellow spot. The yellow halo does not appear in some varieties, so the symptoms are more discreet. On heavily attacked plants, the leaves dry out and fall. As the very affected leaves wilt, heavily diseased plants quickly take on a tapered appearance.
POD	Pods are sometimes attacked. "Green islands" appear around the pustules.

Figure 101 — Spots on the bottom and top side of leaves. (basic IT source)

Figure 102 — Heavily attacked foliage. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 103 — Rust stains on pod. Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	If infection begins in the early stages of vegetative growth, the plant may die.
Loss of yield per plant	Photosynthesis decreases as a result of leaf damage. Rust has a maximum effect on yield if it infects beans between the stages of the third trifoliate leaf, pre-flowering and early flowering.
Reduction in quality	The presence of spots on the pods depreciates the crop.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Humid conditions (about 95% relative humidity) and temperatures of 20 to 25°C. Spore germination reaches a maximum at temperatures between 17 and 22°C with a lower percentage for spores and pustules that had invaded the oldest leaves. The disease is reduced by high temperatures.	Promote the development of the pathogen. In Senegal, in the Niayes region, the period favourable to rust is from December to March.
Fertilisation	Excessive nitrogen manure and lack of potassium	Promote the development of the disease.

MONITORING

The symptoms induced by this fungus are easily recognisable and it is possible to diagnose the disease in the field. See under point 7.1.2 for guidance on methodology to be followed.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Choice of resistant varieties	See point 3.2	Limited infection.
Avoid sensitive preceding crops	Legume-free 2-3-year crop rotations are often recommended because the fungus can survive on infected debris for more than 2 years.	Decreases the level of inoculum in the soil by disrupting successive cycles.
Choose an appropriate site for the plot	It is advisable to avoid growing in troughs where fog persists for a long time in the morning, as this provides adequate humidity and temperature conditions for infection. It is recommended that green beans not be planted near other crops infested with rust, which may infest them in turn.	Avoids a source of infestation.
Plant corn, cereals or sunflower between green bean plots	Minimises the spread of wind-borne diseases, such as bean rust.	Limited infection.
Shaded plots should be avoided	Plants stay wet longer in shaded areas.	Limited infection.
PLANTING		
Adapted seed density	A dense canopy increases the persistence of moisture on the foliage. Increasing plant spacing can help reduce this moisture.	Reduced infection.
CROP MAINTENANCE		
Regular weeding of the plot	Allows better aeration of the plants and therefore less moisture on the plant.	Reduced infection.
Avoid sprinkling irrigation in the evening or at night	Excess water may be conducive to the development of the disease.	Reduced infection.
Ensure well-balanced nitrogen and potassium manure	Allows the development of antagonistic microorganisms and increases the resistance of the plant.	Less effect of the disease on plant growth.
Grubbing and destruction of plants that are visibly too diseased or at the end of production	After removal, destruction (deep burial, burning or animal feed) of crop residues.	Avoids sources of primary inoculum. Avoids contamination of neighbouring plots.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

PERIOD OF APPLICATION

Recommended treatments include weekly preventive application of fungicides during the period between flower bud formation and flowering, or curative treatments performed as soon as the first brown spots are detected. In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market. Early detection of symptoms is essential, which requires proper training of farm personnel (farm workers, supervisors).

THE SUBSTANCES

The recommended substances are listed in the table in Appendix 3.

As regards biocontrol products, bacteria such as *Bacillus amyloliquefaciens* (*subtilis*) *strain QST 713*, copper, sulphur, make it possible to control the fungus.

OTHER CONTROL METHODS

No information available.

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7.2.6. BACTERIAL DISEASES

7.2.6.1. BEAN FAT OR HALO *BACTERIOSIS*

SCIENTIFIC NAME

Pseudomonas savastanoi pv. *phaseolicola* or *Pseudomonas syringae* pv. *phaseolicola*

LIFE CYCLE OF THE BACTERIUM

Bean fat is a necrotic bacterium that kills cells as the lesion develops and at the same time colonises dead tissue. Its development cycle (from contamination to symptom onset) is rapid, at less than 7 days under optimal conditions.

CONSERVATION	The pathogen survives in infested seeds. Bean fat will also remain in crop residues littering the soil.
INOCULUM SOURCES	Seeds, organic waste and already infected host plants. Weeds and some non-host species can also serve as a source of primary inoculum because the bacteria can live on them epiphytically and without symptoms.
INFECTION	When the weather is very humid, the pathogen enters the plant through lenticels, stomata or wounds.
DEVELOPMENT	After entering the leaves, the bacterium multiplies at an exponential rate in the intercellular spaces. Symptoms develop with 6 to 10 days.
DISSEMINATION	The disease can spread from leaf to leaf and from plant to plant through rain splashes and irrigation water. It can spread up to 26 metres from the main focus. If affected agricultural material is left in situ, on the ground, or dragged over the rest of the cultivated area, it is likely to spread the disease. Transmission via insects is also possible.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Natural infections have been recorded in several other legume species, including all members of *Phaseoleae* except *Desmodium* spp. and *Pisum sativum*.

DESCRIPTION OF THE PATHOGEN

It is a Gram-negative, aerobic, rod-shaped bacterium that measures 0.5 to 1.0 by 1.5 to 4.0 µm, and that is propelled by a polar flagella.

AFFECTED CROP STAGE(S)

Pre-emergence, vegetative growth, flowering and fruiting stages.

SEED	GERMINATION – EMERGENCE	YOUNG PLANTS	FLORAL BUDS AND FLOWERING	DEVELOPMENT OF PODS	POST-HARVEST
++	++	++	+++	++	+

SYMPTOMS AND DAMAGE

The bacteria can attack the whole plant, leaves, buds, pods and seeds.

SEED	They can be wizened.
SEEDLING	General chlorosis, stunting and distortion of growth. If there is any doubt about the identification of the disease in seedlings, cut the stem and dip the cut end into a glass of water. If it is a bacterial infection, a white bacterial seepage will flow from the cut end into the water. This will not happen if it is a disease caused by a fungus, such as *Fusarium*.
STEM	On young plants, lesions on the stem are in the form of reddish streaks that can crack and release bacterial exudate in wet weather.
LEAF	The first symptoms on the leaves are very small (0.5 cm in diameter) spots "soaked with water". Leaf tissues initially appear translucent and saturated with water as a result of extrusion of water into intercellular spaces. The necrosis which then appears is sometimes surrounded by a chlorotic halo (2 to 3 cm in diameter) induced by the diffusion of a toxin responsible for the death of plant cells. The confluence of these halos results in a more or less generalised chlorosis of the limbus. If temperatures are very high, the halo may not appear at all. Careful examination of the centre of the spots reveals bacterial exudate, which is usually light cream or silver in colour.
POD	Dark green, greasy spots appear, which become partially reddish brown. They are either circular or extend along the sutures. There is no halo around the spots.

Figure 104 — Chlorosis and isolated lesions. Howard F. Schwartz, Colorado State University, Bugwood.org

Figure 105 — Symptoms on young leaves. (basic IT source)

Figure 106 — Greasy spots on pod. Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Plant loss	The bean plant may eventually die.
Loss of yield per plant	Damage to the leaves can cause a drop in yield.
Reduction in quality	Pod lesions are particularly important for the green bean industry because they make the pod unacceptable to the fresh fruit and vegetable market and processors.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

Major bacterial disease of the common bean (*Phaseolus vulgaris*) in temperate regions and above middle elevations in the tropics.

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Low temperatures, (16 to 24°C), overcast and humid weather (saturating humidity). Symptoms develop within 6-10 days but may be delayed when temperatures are high. Heavy rains.	Rapid development of the disease.

MONITORING

It is important to identify and eliminate affected plants as soon as they appear in the field in order to slow the spread of the disease. A bag should be placed over the affected plant to enclose it before removing it from the field. When it is observed that young plants are diseased, a localised application of a copper-based product can be carried out.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

The following practices contribute to the control of the disease.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PRIOR CHOICES		
Seed selection	It is important to use clean, certified seeds that are free from bacterial infection. The use of self-harvested seeds increases the risk of introducing bean fat into the growing area.	Prevents the bacteria from being introduced into a healthy site.
Choice of resistant or tolerant varieties	For example Paulista, Tania and Emelia	Limited infection.
Avoid sensitive preceding crops	Rotation of crops aged 3 years or more with cereals (corn) is recommended.	Decreases the level of inoculum in the soil by disrupting successive cycles.
Shaded plots should be avoided	Plants stay wet longer in shaded areas.	Limited infection.
PLOT PREPARATION		
Cleaning of agricultural equipment	Equipment used in the field (ploughs, etc.) can disseminate the bacteria in the fields and should be cleaned, for example with water, after and before use.	Avoids a source of infestation.

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT
PLANTING		
Adapted seed density	A dense canopy increases the persistence of moisture on the foliage. Increasing plant spacing can help reduce this moisture.	Reduced infection.
CROP MAINTENANCE		
Limit the activity and movement of workers in the field.	When the foliage is wet after rain there is a risk that workers' clothes will be contaminated by rubbing on the leaves and that new plants will be contaminated.	Avoids the dispersion of the bacteria.
Regular weeding of the plot	Allows better aeration of the plants, therefore less moisture on the plant, and the elimination of potential sources of infestation.	Reduced infection.
Avoid sprinkling irrigation.	Drip irrigation is recommended to curb the spread of the disease, as it helps reduce moisture in the foliage and does not wet the leaves.	Reduced infection.
Make sure infested crop debris is quickly and completely incorporated into the ground immediately after harvesting.	Since the pathogen can survive for 12 months on dry leaves exposed to a temperature of 24°C, it is essential to compost or bury plants removed from the field. Discarded plants can be used as animal fodder as long as crop debris does not contain pesticide residues.	Avoids increased inoculum potential.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

Copper-based pesticides are widely used to control bean fat, despite the fact that they are generally not very effective against bacterial diseases. Spraying can be performed with cupriferous chemicals every seven to ten days after the first symptoms are observed. In all cases, these recommendations will have to be adapted according to the recommendations provided by the manufacturer of the product used and the GAP will have to be adapted in order to comply with the MRLs of the target market.

OTHER CONTROL METHODS

No information available.

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7.2.6.2. COMMON *BACTERIOSIS*

SCIENTIFIC NAME

Xanthomonas axonopodis pv. *Phaseoli* or *Xanthomonas campestris* f.sp. *Phaseoli*.

LIFE CYCLE OF THE BACTERIUM

The cycle is similar to that of the bean fat bacterium.

DESCRIPTION/IDENTIFICATION

OTHER HOST PLANTS

Other naturally infected legumes include *P. lunatus*, *Vigna aconitifolia* and *V. radiata*.

DESCRIPTION OF THE PATHOGEN

Xanthomonas campestris pv. *phaseoli* is a Gram-negative, aerobic, straight rod-shaped bacterium that measures 0.4 to 0.7 by 0.7 to 1.8 µm, and is propelled by a single polar flagella. On agar medium, the colonies appear mucous, convex, yellow and shiny.

AFFECTED CROP STAGE(S)

Same as bean fat.

SYMPTOMS AND DAMAGE

SEED	On white-seed varieties, yellow or brown spots may appear on the integument, especially near the hilum area.
SEEDLING	Stem rings may develop at the cotyledonary node.
STEM	Infection of the stems is less common. It begins with a water-soaked spot, which becomes a reddish-brown lesion, usually without chlorosis. The bacterium can invade the xylem, and wilting can occur if a sufficient number of bacteria develop in the xylem.
LEAF	The disease begins with small spots with a water-soaked appearance, visible on the underside of the leaves. A narrow halo of bright lemon-yellow tissue often develops around dried necrotic lesions, which can be found in the interveinal areas and along leaf edges. The spots enlarge, merge and become necrotic, forming brownish, irregular, flaccid areas on the upper surface of the limbs, limited by a golden yellow border. With age, these lesions dry out, turn light brown, marked with sinuous dark brown lines, and the yellow border fades. Heavy attacks can cause considerable leaf fall.
POD	Development of circular and water-soaked areas that may also have yellow masses of bacteria on the lesions. Later, the spots on the pods turn reddish brown and become sunken. Early infection of pods results in small, wizened and discoloured seeds.

Figure 107 — Discolouration of attacked seeds. V.R. Wallen, Agriculture and Agri-Food Canada, Bugwood.org

Figure 108 — Symptoms on leaf. Howard F. Schwartz, Colorado State University, Bugwood.org

IMPACT ON YIELD AND QUALITY

Same as bean fat.

The disease can cause significant losses in tropical, subtropical and temperate climates. This disease is more severe in tropical conditions with high temperatures and precipitation.

QUARANTINE ORGANISM

It is not an EU quarantine organism.

CONDITIONS CONDUCIVE TO INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT/EXPLANATION
Weather conditions	Hot and humid temperatures, air temperature 28° to 32°C.	The greatest damage to bean plants

MONITORING

Same as bean fat.

CONTROL THROUGH GOOD AGRICULTURAL PRACTICES

Control measures are similar to those recommended for halo *bacteriosis*.

ORGANIC CONTROL

No information available.

CONTROL USING PLANT PROTECTION PRODUCTS

Same strategy and same products as for halo *bacteriosis*.

OTHER CONTROL METHODS

Seeds can be disinfected by heating them at 60°C for 23 to 32°C with a relative air humidity of 45 to 55%.

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7.3. KEY POINT CHECKLIST

7.3.1. MAIN PESTS BY CROP STAGE

The main pests to be taken into account by crop development stage are listed below.

It is recalled here that monitoring and control measures are to be applied only if the pest is known to be problematic in the growing area.

THE SEED

It must be free of the following microorganisms to avoid losses during germination, emergence and growth of plants

- *Fusarium solani f. sp. Phaseoli*
- *Macrophomina phaseolina*
- *Rhizoctonia solani*
- *Colletotrichum lindemuthianum*
- *Pseudocercospora griseola*
- *Xanthomonas axonopodis pv. Phaseoli*
- *Pseudomonas savastanoi pv. phaseolicola*

GERMINATION AND EMERGENCE

Germinating seed in the soil is a rich source of food for insect larvae, nematodes and fungi that live in the soil. The losses caused, loss of plants, can be very significant, in particular following attacks by the following pests

- *Ophiomyia spp.*
- *Delia platura*
- *Meloidogyne spp.*
- *Fusarium solani f. sp. Phaseoli*
- *Macrophomina phaseolina*
- *Rhizoctonia solani*
- *Sclerotium rolsfii*
- *Pythium aphanidermatum*
- *Pseudomonas savastanoi pv. phaseolicola*
- *Xanthomonas axonopodis pv. Phaseoli*

As soon as the seedlings emerge from the ground they can be attacked by aerial pests such as

- *Ophiomyia spp.*
- *Aphis spp.*
- *Bemisia tabaci (risk of virus transmission)*
- *Thrips*
- *Colletotrichum lindemuthianum*
- *Pseudomonas savastanoi pv. phaseolicola*
- *Xanthomonas axonopodis pv. Phaseoli*

YOUNG PLANTS AND THE VEGETATIVE PHASE

Foliar diseases may be more evident during the further development of the canopy of beans, due to the ageing of the plant that becomes more sensitive and the density of the canopy that promotes the development of diseases. However, diseases begin to develop much earlier in the life of a crop and it is at this point that they must be avoided by adopting preventive measures (cultural practices or PPP applications). Indeed, once the symptoms appear, curative control becomes difficult and pre-harvest intervals may apply to PPPs. The diseases to be taken into consideration are

- *Colletotrichum lindemuthianum*
- *Pseudocercospora griseola*
- *Uromyces appendiculatus*
- *Pseudomonas savastanoi pv. phaseolicola*
- *Xanthomonas axonopodis pv. Phaseoli*

Insect and mite attacks during this stage may not cause much immediate damage but now is the time to control them to prevent them from developing and causing losses when starting harvesting, the period when the use of PPPs becomes more problematic due to the risks of pesticide residues on production. The pests to be taken into account are

- *Aphis spp.*
- *Bemisia tabaci*
- *Thrips*
- *Liriomyza trifolii*
- *Tetranychus spp.*

Root and neck attacks at this stage will be the most damaging to the crop. It is from the beginning of this period that it is necessary to implement preventive measures (crop practices or applications of PPPs) to avoid their development. Pests and diseases to consider are

- *Meloidogyne spp.*
- *Fusarium solani f. sp. Phaseoli*
- *Macrophomina phaseolina*
- *Rhizoctonia solani*
- *Sclerotium rolsfii*
- *Pythium aphanidermatum*

THE APPEARANCE OF FLOWER BUDS, FLOWERING AND DEVELOPMENT OF PODS

During this growth phase, these 3 stages appear successively on a plant. But at certain times these 3 stages coexist on a plant, that is to say that we can observe, at the same time, pods ready to be harvested, new flower buds and flowers.

This period is very attractive for pests that feed on pollen and flowers of green beans and those that feed on pods. Those to be controlled are more particularly

— Thrips
— *Helicoverap armigera*
— *Spodoptera* spp. (attacks mainly the foliage but can also be found on pods

During this phase, the pests and foliar diseases cited for the vegetative phase may continue to develop or appear and require control. These are

— *APHIS spp.* (can sometimes also appear on pods)
— *Bemisia tabaci* (may indirectly cause damage to pods by honeydew)
— *Tetranychus spp.*
— *Colletotrichum lindemuthianum* (can sometimes also appear on pods)
— *Pseudocercospora griseola* (can sometimes also appear on pods)
— *Uromyces appendiculatus* (can sometimes also appear on pods)
— *Pseudomonas savastanoi pv. phaseolicola*
— *Xanthomonas axonopodis pv. Phaseoli*

Root and neck pests can continue to develop during this phase but no control is possible to avoid damage. They must be controlled in the previous stages.

HARVEST AND POST-HARVEST

The presence or absence of pests or diseases on the pods during the harvest and post-harvest stages results from the effectiveness of their control during cultivation. A good sorting avoids having pods that could be rejected by buyers and, for EU quarantine organisms (QOs), be destroyed by the control authorities at the expense of the exporter, following the presence of the following organisms

- Thrips (QO)
- *Liriomyza trifolii* (rarely on pods, QO)
- *Helicoverpa armigera* (QO)
- *Spodoptera frugiperda* (QO)
- *Colletotrichum lindemuthianum*
- *Pseudocercospora griseola*
- *Uromyces appendiculatus*
- *Pseudomonas savastanoi pv. phaseolicola*
- *Xanthomonas axonopodis pv. Phaseoli*
- Fumagin (following heavy attacks of aphids or whiteflies)

7.3.2. REMINDER OF THE MAIN ENVIRONMENTAL CONDITIONS FAVOURABLE TO CROP ENEMIES

The main environmental conditions favourable to the development of pests are summarised below in tables. They are classified into two main categories: weather conditions and soil.

This summary makes it possible to identify favourable conditions that are common to several pests. Those that are common to the greatest number of pests will obviously be those that should be avoided as a priority.

The weather table shows which pests are most abundant during periods without rain (or light rain) and which are favoured by rain.

The table also shows the effect of temperature on the abundance of pests. Some are more adapted to relatively cool temperatures (conditions that are found especially at altitude in tropical zones); such as: *Trialeurodes*, *Megalurothrips sjostedti*, alternariosis, *anthracnose*, rust and bacterial fat. Others are more adapted to higher temperatures such as: *Bemisia*, *Frankliniella occidentalis*, spider mites, *Meloidogyne*, *Macrophomina*, *Sclerotium*, common *bacteriosis*.

The optimum relative humidities for the development of the various pests are also indicated.

7.3.2.1. WEATHER CONDITIONS

Table 23 — Favourable weather conditions

	Period without rain	Rainy season	Optimum temperatures in °C																									Optimum relative humidity
			16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Bean fly	+		No availability of detailed information, but it is a subtropical and tropical climate insect, therefore with relatively high optimum temperatures.																									
Bean seed fly			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Aphids	+										■	■	■	■	■													65%
Whiteflies (*Bemisia*)												■	■	■	■	■	■											High
Whiteflies (*Trialeurodes*)							■	■	■	■	■	■																
Leaf miner	+		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■											
Thrips – *Frankliniella occidentalis*	+											■	■	■	■	■	■											
Thrips – *Megalurothrips sjostedti*		+						■	■	■	■	■	■															
Moth (*Helicoverpa*)												■																
Bean pod borer		+	No availability of detailed information, but it is a tropical climate insect, so with relatively high optimum temperatures.																									Very high
Armyworms															■													
Blister beetles		+	No availability of detailed information, but it is a tropical climate insect, so with relatively high optimum temperatures.																									Very high
Spider mites	+											■	■	■	■	■	■	■	■	■	■	■						
Meloidogyne		+													■	■	■	■	■									
Pratylenchus		+																				■						
Fusarium							■	■	■	■	■	■	■	■	■													
Macrophomina	+																■	■	■	■	■	■	■	■	■	■	■	Relatively low
Pythium		+																	■	■	■	■	■	■				Very high
Rhizoctonia solani		+												■														75-80%
Sclerotium		+											■	■	■	■	■	■	■									Very high
Alternariasis		+	■	■	■	■	■	■	■	■																		Very high

	Period without rain	Rainy season	Optimum temperatures in °C																									Optimum relative humidity
			16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Anthracnose		+		■	■	■	■																					>90%
Angular spots		+									■																	Very high
Rust							■	■	■	■	■	■																+/- 95%
Fat		+	■	■	■	■	■	■	■	■	■																	Very high
Common *bacteriosis*		+													■	■	■	■	■									Very high

7.3.2.2. SOIL

Soil characteristics have an impact mainly on soil borne organisms attacking plant roots and necks.

Table 24 — Soil characteristics favourable to the development of pests

	Decomposing organic matter buried at a shallow depth	Persistent high humidity	Lack of water	Sandy	Poor in organic matter	Poor in clay	Low in nitrogen	Light	Compacted	Low pH (acid)	High pH	Presence of other soil borne pathogens
Seed fly	+	+										
Aphids			+									
Meloidogyne		+	+	+	+	+		+				
Pratylenchus		+								+		
Fusarium		+	+						+			+
Macrophomina			+									+
Pythium											+	
Rhizoctonia solani		+							+			
Sclerotium	+					+	+			+		
Alternariasis							+					

7.3.3. THE MAIN GOOD CROP PRACTICES CONTRIBUTING TO THE CONTROL OF PESTS

The crop practices which contribute to the control of pests are summarised below in tables. They fall into 4 main categories:

1. Prior choices
2. Plot preparation
3. Planting (sowing)
4. Crop maintenance

This summary makes it possible to identify practices that are useful for the control of several pests. Those that are common to the greatest number of pests will obviously be those that will have to be implemented as a priority while taking into account in priority the main pests known to be problematic in the growing area. It will also be necessary to ensure that the practices put in place do not risk encouraging pests hitherto considered as minor in the production area.

The type of effect expected from the different practices is also described in these tables.

7.3.3.1. PRIOR CHOICES

Table 25 — Crop practices for the control of pests, to be taken into account during the prior choices

CROP PRACTICE		CERTIFIED HEALTHY SEED	RESISTANT / TOLERANT VARIETIES	AVOID PROXIMITY TO A PLOT WITH HOST PLANT	ROTATION WITH NON-HOST CROP	PREFER LIGHT TO MEDIUM-HEAVY SOIL	AVOID COMPACTED OR ASPHYXIATING SOIL	PLOT WITHOUT TROUGHS	AVOID A CONTAMINATED WATER SOURCE	AVOID WATER THAT IS TOO SALTY	GREEN FERTILISER IN PRECEDING CROP	PLOT FLOODED BEFORE CULTIVATION	NO PRESENCE OF HOST TREES	PLOT NOT TOO SHADED
TYPE OF EFFECT	AVOIDANCE	√	√	√			√	√	√	√			√	√
	DISRUPTS THE PEST CYCLE				√						√	√		
	IMPROVES THE PLANT'S DEFENCE		√			√	√			√				
Bean fly				+	+	+								
Bean seed fly						+								
Aphids				+										
Whiteflies				+										
Leaf miner				+										
Thrips			+	+	+									
Spider mites				+										
Meloidogyne					+		+		+		+	+	+	
Pratylenchus					+				+			+		
Fusarium		+			+	+		+						
Macrophomina		+												
Pythium					+			+	+					
Rhizoctonia solani		+					+	+		+				+
Sclerotium					+									+
Alternariasis				+	+									+
Anthracnose		+		+	+									+
Angular spots		+		+	+									+
Rust			+	+	+									+
Fat		+	+		+									+
Common *bacteriosis*		+	+		+									+

7.3.3.2. PLOT PREPARATION

Table 26 — Crop practices for the control of pests; to be taken into account when preparing the plot

CROP PRACTICE		HEAVY TILLAGE (DEEP PLOUGHING)	LIMITED TILLAGE*	RAISED BEDS / DRAINAGE	ORGANIC MATTER INCORPORATED COMPLETELY UNDER THE SEEDBED	WELL DECOMPOSED ORGANIC MATTER BURIED IN THE FIRST CM OF THE SOIL	SOIL LIMING	CLEANING OF AGRICULTURAL EQUIPMENT	SOLARIZATION	FALLOW AND IRRIGATED PLOT FOR 2 WEEKS	INTERCROPPING	FLOWER STRIPS	HEDGES	WINDBREAKS (BARRIERS)
TYPE OF EFFECT	AVOIDANCE		√	√	√	√	√	√		√	√			√
	DISRUPTS THE PEST CYCLE	√							√					
	IMPROVES THE PLANT'S DEFENCE				√	√								
	REINFORCES THE ACTION OF AUXILIARIES		√		√	√				√	√	√	√	
Bean fly		+									+	+	+	
Bean seed fly			+		+	-							+	
Aphids											+	+		
Whiteflies											+	+		+
Leaf miner		+									+	+		+
Thrips		+							+		+	+		
Moth (*Helicoverpa*)											+	+	+	
Bean pod borer											+	+	+	
Armyworms												+	+	
Blister beetles		+												
Spider mites												+		+
Meloidogyne					+			+	+	+				
Pratylenchus					+			+						
Fusarium				+		+		+						
Macrophomina						+		+						
Pythium				+		+								
Rhizoctonia solani				+		+								
Sclerotium				+		+	+							
Rust											+			
Fat								+						
Common *bacteriosis*								+						

* Soil preparation recommended in conservation agriculture (no tillage)

7.3.3.3. PLANTING

Table 27 — Crop practices for the control of pests; to be taken into account when planting

CROP PRACTICE		SOW TO THE RIGHT DEPTH	SEED COATING WITH FERTILISER AND/OR STIMULANT	SOW AT HIGH DENSITY	SOW AT LOW DENSITY	COVER WITH A NET AFTER SOWING
TYPE OF EFFECT	AVOIDANCE			√		√
	DISRUPTS THE PEST CYCLE					
	IMPROVES THE PLANT'S DEFENCE	√	√			
	IMPROVES THE ACTION OF SPRAYED PPPs				√	
Bean fly		+				
Bean seed fly		+	+	+		
Aphids					+	
Whiteflies					+	+
Rhizoctonia solani		+			+	
Sclerotium					+	
Alternariasis					+	
Anthracnose					+	
Angular spots					+	
Rust					+	
Fat					+	
Common *bacteriosis*					+	

7.3.3.4. CROP MAINTENANCE

Table 28 — Crop practices for the control of pests; to be taken into account during the maintenance of the crop

CROP PRACTICE		MOUNDING OF PLANTS	GOOD FERTILISATION	BALANCED NITROGEN MANURE	FOLIAR FERTILISATION	SUFFICIENT AND REGULAR IRRIGATION	SPRINKLER IRRIGATION	DRIP IRRIGATION	MULCHING	REGULAR WEEDING	AVOID ENTERING WET FIELDS	GRUBBING OF AFFECTED PLANTS*	ELIMINATION OF HEAVILY INFESTED ORGANS	GRUBBING OF PLANTS AT THE END OF PRODUCTION*	SOIL DISKING AFTER CLEANING THE GROUND	DEEP PLOUGHING AFTER LAST HARVESTS
TYPE OF EFFECT	AVOIDANCE			√			√	√		√	√					
	DISRUPTS THE PEST CYCLE	√					√					√	√	√	√	√
	IMPROVES THE PLANT'S DEFENCE	√	√		√	√			√							
	IMPROVES THE ACTION OF SPRAYED PPPs			√						√						
Bean fly		+	+			+			+			+		+		+
Bean seed fly												+				
Aphids				+		+	+			+				+		
Whiteflies				+						+				+		
Leaf miner													+	+		+
Thrips										+				+		+
Moth (*Helicoverpa*)				+									+	+		
Bean pod borer				+									+	+		
Armyworms				+										+		
Loopers														+		
Blister beetles																+
Mites				+			+			+				+		
Meloidogyne		+												+	+	
Pratylenchus		+												+		
Fusarium				+		+		+				+*		+*		+
Macrophomina				+		+						+		+		
Pythium			+	+		+		+				+		+		
Rhizoctonia solani					+	+		+				+		+		
Sclerotium				+		+				+		+		+		

Crop practice	Mounding of plants	Good fertilisation	Balanced nitrogen manure	Foliar fertilisation	Sufficient and regular irrigation	Sprinkler irrigation	Drip irrigation	Mulching	Regular weeding	Avoid entering wet fields	Grubbing of affected plants*	Elimination of heavily infested organs	Grubbing of plants at the end of production*	Soil disking after cleaning the ground	Deep ploughing after last harvests
Type of effect: Avoidance			√			√	√		√	√					
Type of effect: Disrupts the pest cycle	√					√					√	√	√	√	√
Type of effect: Improves the plant's defence	√	√		√	√			√							
Type of effect: Improves the action of sprayed PPPs			√						√						
Alternariasis		+	+								+		+		
Anthracnose							+		+	+	+		+		
Angular spots									+	+	+		+		
Rust		+	+				+		+		+		+		
Fat							+		+	+	+		+		+
Common *bacteriosis*							+		+	+	+		+		+

* Do not feed to animals as fodder because the fungus may pass into the manure

7.3.4. STRATEGIES FOR THE APPLICATION OF PPPs

The periods of control by PPPs for the different pests according to the crop development stages and whether they must be preventive, curative on the basis of surveillance (observations in the field) or preventive on the basis of surveillance (trapping or favourable weather conditions) are summarised below.

Table 29 — Periods of control against insects and mites

CROP ENEMY	SOIL	SEED	SEEDLING DAYS AFTER EMERGENCE 3-4	YOUNG PLANTS DAYS AFTER EMERGENCE 10	VEGETATIVE DEVELOPMENT DAYS AFTER EMERGENCE 17 AND MORE	FLOWERING	POD DEVELOPMENT AND HARVESTING PERIOD
Bean fly		P	P	C/S	C/S		
Bean seed fly	P	P					
Aphids		P	P or C/S	C/S	C/S	C/S	
Whiteflies		P	P or C/S	C/S	C/S	C/S	
Leaf miner			P or C/S	C/S	C/S	C/S	
Thrips			P or C/S	C/S	C/S	P or C/S	C/S
Moth (*Helicoverpa*)						P/S	P/S
Bean pod borer						C/S	C/S
Armyworms						C/S	C/S
Loopers				C/S	C/S		
Blister beetles						C/S	
Spider mites					C/S	C/S	C/S

Table 30 — Periods of control against nematodes, fungi and bacteria

CROP ENEMY	SOIL	SEED	SEEDLING	YOUNG PLANTS	VEGETATIVE DEVELOPMENT	FLORAL BUDS	FLOWERING	POD APPEARANCE	POD DEVELOPMENT AND HARVESTING PERIOD
Meloidogyne	P		P	P	P				
Fusarium	P	P							
Macrophomina	P	P							
Pythium	P	P							
Rhizoctonia solani	P	P							
Sclerotium	P	P							
Alternariasis									C/S
Anthracnose		P			C/S	C/S	C/S	C/S	
Angular spots		P				P/S	P/S	P/S	P/S
Rust						C/S	C/S	C/S	
Fat				C/S	C/S	C/S	C/S	C/S	C/S
Common *bacteriosis*				C/S	C/S	C/S	C/S	C/S	C/S

Caption:
P = preventive
C/S = curative on the basis of surveillance
P/S = preventive on the basis of surveillance

Observation on seed treatment: The fungicidal effects of seed treatment will only last about 2 to 3 weeks, with some of the newer products offering up to 3 to 4 weeks of protection. This protective window begins at planting time. Therefore, if it takes two weeks for the crop to emerge in a cool period, treatment may only protect the seedlings for one week after emergence.

7.3.5. THE MAIN BIOCONTROL PRODUCTS

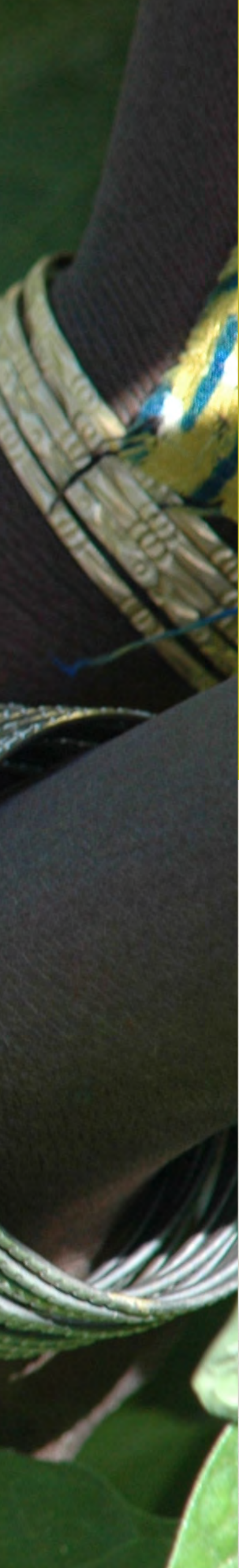
The main biocontrol products that can be used (taken from Appendix 3) are listed in the following two tables.

Table 31 — Main biocontrol products against insects and mites

	AZADIRACHTIN OR NEEM EXTRACTS	ESSENTIAL ORANGE OIL	OXYMATRINE	PYRETHRIN	*BACILLUS THURINGIENSIS*	BACULOVIRUS	*BEAUVERIA BASSIANA*	*CHROMOBACTERIUM SUBTSUGAE*	*METARHIZIUM ANISOPLIAE*	METHARIZIUM *RILEYI*	*PAECILOMYCES FUMOSOROSEUS*	*VERTICILLIUM LECANII*	CITRIC ACID	FATTY ACID	HORTICULTURAL OIL	PARAFFIN OIL	MALTODEXTRIN	FLOUR AND STARCH
Bean fly	√																	
Bean seed fly							√		√									
Aphids	√	√	√	√			√	√	√		√	√	√	√		√	√	
Whiteflies	√	√	√	√			√	√	√		√	√	√	√	√			√
Leaf miner	√															√		
Thrips	√			√			√	√	√					√		√		
Moth (*Helicoverpa*)	√		√		√	√			√									
Bean pod borer	√				√				√									
Armyworms	√		√	√	√	√				√								
Loopers	√				√	√	√			√								
Spider mites	√	√	√				√	√					√	√		√	√	√

Table 32 — Main biocontrol products against nematodes, fungi and bacteria

	AZADIRACHTIN OR NEEM EXTRACTS	GARLIC EXTRACTS	*BACILLUS AMYLOLIQUEFACIENS*	*BACILLUS SUBTILIS*	COPPER	*GLIOCLADIUM SPP.*	*PAECILOMYCES LILACINUS*	*PENICILLIUM SPP.*	SULPHUR	*STREPTOMYCES K61*	*STREPTOMYCES LYDICUS*	*TRICHODERMA ASPERELLUM*	*TRICHODERMA SP.*	*TRICHODERMA HARZIANUM*	*TRICHODERMA VIRIDE*
Meloidogyne	√	√					√					√			
Fusarium										√			√		
Macrophomina														√	
Pythium			√			√				√	√			√	
Rhizoctonia solani			√			√				√	√		√		
Sclerotium				√		√		√			√			√	√
Alternariasis															√
Anthracnose	√				√	√					√			√	√
Angular spots					√				√						
Rust			√		√				√						
Fat					√										
Common *bacteriosis*					√										



8

HARVESTING

According to the bean types and varieties and depending on the destination markets, yields vary around 4-6 tonnes of beans/ha for extra fine to fine and French filet and 9 to 12 -14 tonnes for bobby beans.

COMMERCIAL QUALITY

The commercial quality of harvested beans depends on the specifications imposed for each variety produced. Thus, depending on the destination markets, the parameters of size, length, diameter, turgor and colour of the pod are specified.

It is these criteria required by importers and mass distribution under a label, a given brand, that facilitate the marketing and the negotiation of good selling prices.

HARVEST PERIOD

In West Africa, harvests start in early December and continue until April of the following year. On the other hand, as explained earlier, in Kenya the beans are harvested all year round because of the spread of production in different areas of the country and according to the seasons.

The frequency of harvest will be adapted to the type of bean exported and the method of shipment. Extra-fine beans (Kenya) are harvested every day. For bobby beans, a harvest every two to three days is recommended and every two days for the French filet bean. It is necessary to keep these harvesting frequencies throughout production to avoid penalising commercial yields due to large sorting differences.

The harvest lasts from 20 to 25 days, depending on the varieties and the area and period of cultivation.

HARVEST METHOD

In sub-Saharan Africa, beans are usually harvested by hand in the early morning to prevent plants from suffering from the mid-day heat. The harvesters survey the planting lines to pick the pods of turgid beans, with the peduncle and put them in agricultural crates. The latter must be well ventilated and stackable to prevent the beans housed in a crate from being subjected to the weight of those of the upper crates.

Harvesting of export beans is almost always done manually in ACP countries and is usually carried out exclusively by women.

However, on farms oriented towards canning production, plants with grouped and upright production can be harvested by machines, but beans cannot be marketed with the label early fresh green beans (the mechanical threshing of the crop causes the freshness and turgor of the products to be lost).

The pods must be harvested according to the size expected for the product's sale. Size is determined by the maximum width of the pod measured perpendicular to the split.

Table 33 — Classification of sizes according to the type of green bean desired

TYPE	SIZE
extra fine	maximum 6 mm
very fine	maximum 8 mm
fine	maximum 9 mm
"fine bobby"	maximum 9 -10 mm
medium	maximum 12 mm "Medium" French filet beans cannot be classified in the "Extra" Class
large	over 12 mm

WORKFORCE

To respect the above, the workforce must be trained and aware of the importance of the harvest. It must be supervised. It can harvest from 5 to 10 kg per hour per person, depending on size, type, time in season and number of harvests.

9

POST-HARVEST

HANDLING IN THE FIELD

On a regular basis (ideally every 10 minutes) the harvested pods must be placed under a shaded and ventilated shelter while awaiting evacuation to a processing station (in Kenya under charcoal cooler, in West Africa under Crinting shelter, a panel of braided bamboo)

It is advisable to quickly evacuate the crates of beans to the processing centre (ideally every 30-45 minutes or at the latest one to two hours after harvest).

In case of delayed sorting/packaging, cool the harvested pods. A "charcoal cooler", made of charcoal surrounded by backyard wire mesh, is useful if there is no electricity. It must be designed in such a way as to ensure that the air circulating inside passes through the charcoal (no space in the layers of charcoal). Charcoal should be moistened to enhance the cooling effect. This humidification can be achieved by placing a drainage line at the top of the charcoal pile, fed by a water tank on the roof (charcoal cooler). Maintain product traceability throughout all operations, from harvest to storage and shipping.

TRANSPORT

It is advisable for the harvested products to be evacuated to the processing station in covered trucks that are ventilated or refrigerated to preserve the freshness of the products and avoid exposing them to heat or sunlight.

The crops must be placed in the cold store as quickly as possible, including before final sorting and processing if the latter is delayed.

10

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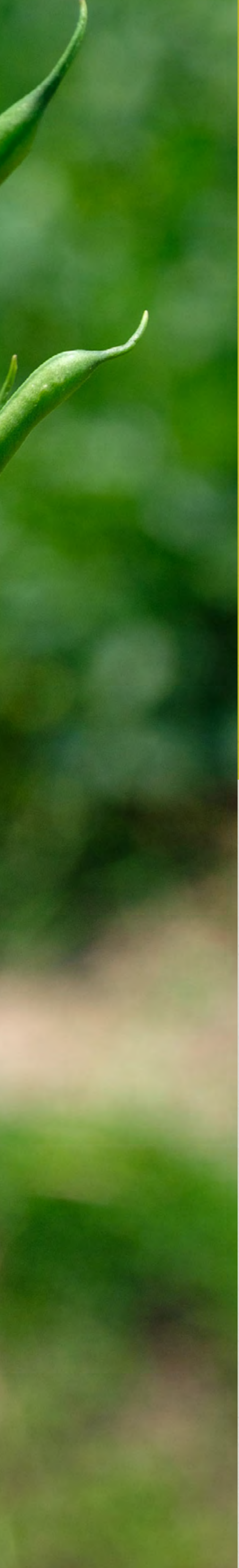

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APPENDICES

APPENDIX 1: FULL BBCH SCALE

PRINCIPAL GROWTH STAGE 0	GERMINATION
00	Dry seed
01	Initiation of seed imbibition
03	Seed imbibition completed
05	Radicle emergence from seed
07	Emergence of hypocotyl with cotyledons from the seed
08	Hypocotyl and cotyledons move towards the soil surface
09	Emergence: cotyledons break through the surface of the soil
PRINCIPAL GROWTH STAGE 1	**LEAF DEVELOPMENT**
10	Cotyledons fully unfolded
12	First pair of true leaves visible
13	3 leaves unfolded (first leaf trifoliate)
1.	And so on...
19	9 or more unfolded leaves (2 simple leaves and 7 or more trifoliate leaves)
PRINCIPAL GROWTH STAGE 2	**SIDE SHOOTS FORMATION**
21	The first side shoot is visible
22	2 side shoots are visible
23	3 side shoots are visible
2.	And so on...
29	9 or more side shoots are visible
PRINCIPAL GROWTH STAGE 5	**APPEARANCE OF THE INFLORESCENCE**
51	The first flower buds are visible, protruding from the leaves
55	The first individual, but still closed, flower buds are visible, extending beyond the leaves
59	The first petals are visible, the flower buds are numerous but still closed.
PRINCIPAL GROWTH STAGE 6	**FLOWERING**
60	The first flowers open (sporadically)
61	Beginning of flowering[2]
62	20% of flowers are open[1]
63	30% of flowers are open[1]
64	40% of flowers are open[1]

65	Full flowering: 50% of flowers open[1] Main flowering period[2]
67	Flowering is coming to an end: most of the petals have fallen off or dried out[1]
69	End of flowering: first pods visible[1]
PRINCIPAL GROWTH STAGE 7	**FRUIT DEVELOPMENT**
71	10% of pods have reached their final length[1] Beginning of pod development
72	20% of pods have reached their final length[1]
73	30% of pods have reached their final length[1]
74	40% of pods have reached their final length[1]
75	50% of pods have reached their final length, seeds begin to fill the pod[1] Main period of pod development[2]
76	60% of pods have reached their final length[1]
77	70% of pods have reached their final length, the pods break cleanly[1]
78	80% of pods have reached their final length[1]
79	The pods have reached their final length, the beans can be seen individually[1]
PRINCIPAL GROWTH STAGE 8	**FRUIT AND SEED RIPENING**
81	10% of pods are ripe (sheaths are hard)[1] Beginning of seed ripening[2]
82	20% of pods are ripe (sheaths are hard)[1]
83	30% of pods are ripe (sheaths are hard)[1]
84	40% of pods are ripe (sheaths are hard)[1]
85	50% of pods are ripe (seeds are hard)[1] Main ripening period[2]
86	60% of pods are ripe (sheaths are hard)[1]
87	70% of pods are ripe (sheaths are hard)[1]
88	80% of pods are ripe (sheaths are hard)[1]
89	Fully ripe: the pods are ripe (the seeds are hard)[1]
PRINCIPAL GROWTH STAGE 9	**SENESCENCE**
97	The plant is dead
99	Product after harvest

1 For varieties with a limited flowering period.
2 For varieties with an unlimited flowering period.

APPENDIX 2: EXAMPLES OF WEEKLY AND SUMMARY SHEETS FOR PHYTOSANITARY MONITORING

WEEKLY MONITORING SHEET (TO BE COMPLETED WEEKLY)

FARM	BLOCK	CROP AGE (WEEKS)	OBSERVATION DATE	NAME OF THE OBSERVER	OBSERVATION TIME

ROW	adult *Diglyphus* on 5 observation points per row	adult leaf miners on 5 observation points per row	thrips on five leaves per row	thrips in five flowers per row	total adult whiteflies on five observation points per row	total adult *Encarsia* on ten lower leaves per row	whitefly larvae >L2 on ten lower leaves per row	blackened larvae on ten lower leaves per row	number of aphid biocontrol agents in aphid colonies per row	number of aphid colonies in the row	adult lepidopteran observed flying over the field during inspection (indicates eggs laid)	number of caterpillar larvae in the entire row	has pupation begun? (number of pups seen per row)	Total adult *Phytoseiulus* on 5 red spider mite infested leaves per row	Total adult *Amblyseius* on 5 red spider mite infested leaves per row	total adult spider mites on 5 infested leaves per row	background level of adult red spider mites on 5 randomly selected leaves in the row	mouche des haricots	vers gris	nématode à galle	rouille	tache angulaire	pourritures des racines	graisse	*Ascochyta*	autres maladies	autres problèmes
																		PRESENCE/ABSENCE IN THE ROW									
1																											
2																											
3																											
4																											
5																											
6																											
7																											
8																											
9																											
10																											
11																											
12																											
13																											
14																											
15																											
16																											
14																											
18																											
19																											
20																											
TOTAL																											
avg per row																		COMMENTS									
RATIO					%P				RATIO					RATIO													

Use data from individual ROWS to perform early point treatments of pests and diseases in certain rows before the problem becomes widespread. Transfer the data from the blackened boxes to the weekly summary to measure the effect of the crop protection measure week after week. Mark all red spider mite hot spots in the field and on the field map – treat quickly with predatory mites (check hot spots weekly to ensure predator proliferation). Bean flies and been seed flies are normally a problem only for the first five weeks and especially in outer rows or in wetter areas of the field in dry weather. For the section from "bean fly" to "other problems", enter the total number of rows where there are pests or diseases. Comments box: severity of diseases, identification of root rot, indication of water saturated regions, etc. Indicate the recommended treatment.

SUMMARY SHEET
(TRANSFER AVERAGES WEEKLY TO SEE PROGRESS)

FARM	BLOCK	CROP AGE (WEEKS)	OBSERVATION DATE	OBSERVER NAME (PRINTED)	OBSERVATION TIME

data transferred from black boxes of weekly forms. crop age (weeks)	Dig:	LM	weekly avg. per row of thrips on five leaves per row	weekly avg. per row of thrips on five flowers per row	weekly avg. per row of adult whiteflies at 5 observation points per row inspected	weekly avg. per row of adult *Encarsia* at 5 observation points per row	weekly avg. per row of whitefly larvae >L2 on ten lower leaves per row	weekly percentage infestation (% blackened larvae on ten lower leaves per row)	total ratio of aphid biocontrol agents per row/ total number of aphid colonies	weekly total adult lepidopteran observed flying over the field during the inspection	weekly total of caterpillar larvae throughout the row	weekly total pupae per row	ratio of predators to red spider mites on infested leaves (if applicable)	weekly avg. of the basic level of red spider mites per row	bean fly	grey worm	root-knot nematode	rust	angular spot	root rot	fat	*Ascochyta*	other diseases	autres problèmes	pesticides and biocontrol agentsapplied (and on what date)
1									:				:												
2									:				:												
3									:				:												
4									:				:												
5									:				:												
6									:				:												
7									:				:												
8									:				:												
9									:				:												

Notes: To obtain the *Diglyphus*/leaf miners ratio (should be less than 1:5 for good control), divide the total number of adult leaf miners by the total number of adult *Diglyphus* each week.

It is essential to assess the presence of thrips on the leaves before the flowers appear, so crop protection is applied when contact is easier (on the leaves). Control of thrips in flowers is difficult and has constraints on the pre-harvest interval.

The oldest, largest whitefly larvae (in which an *Encarsia* can grow) will be found only on the lower leaves. The weekly percentage infestation of whitefly larvae is calculated from the number of blackened larvae divided by (total blackened larvae plus larger whitefly larvae >L2) = %P (do not count small larvae as they cannot be parasitised).

To obtain the aphid biocontrol agent/aphid colony ratio, divide the total number of aphid colonies observed in all rows each week by the total number of aphid biocontrol agents. *Bacillus thurigiensis* only gives good results on young caterpillars that are difficult to find. If there are adult lepidopterans, they will lay eggs and Bt should ideally be applied quickly after this period. When most of the caterpillars have become chrysalids, pesticides have no effect on this stage of life and should be allowed to hatch before applying crop protection to the next generation. For the section from "bean fly" to "other problems" – enter the total weekly number of rows with problems.

APPENDIX 3: RECOMMENDED ACTIVE SUBSTANCES AND AUXILIARY ARTHROPODS

Auxiliary substances and arthropods against insects, mites and nematodes. COLEAD stresses the importance of respecting the instructions indicated on the label of PPPs. In addition, before applying any product, it is advisable to consult the latest regulatory changes in the EU databases on pesticides and the Codex Alimentarius and ensure compliance of applied GAP to the demands of the target market (MRLs and buyer specifications). Information on GAP to meet EU and Codex Alimentarius MRLs is available in the COLEAD Crop Protection Database.

ACTIVE SUBSTANCE	BEAN AND BEAN SEED FLY	APHIDS	WHITEFLIES	*LIRIOMYZA* MINER	THRIPS	MOTH	POD BORER	LEGIONARIES	SPIDER MITES	NEMATODES
abamectin				×	×				×	× 21
acetamiprid	×	×	×		×					
citric acid		×	×		×				×	
fatty acids (potassium salt, soap)		×	× 22.29		×				× 14.22.29	
garlic (extract)										×
Ambyseius *californicus*									×	
Aphidius transcaspinus		×								
azadirachtin	× 17	×	×	×	×	×	× 5	× 16	× 10	×
Bacillus thuringiensis var. *aizawai*						×	×	× 16		
Bacillus thuringiensis var. *kurstaki*						×		× 15.29		
Beauveria bassiana		×	×		×	×		× 16	× 9	
bifenazate									× 7.29	
chlorantraniliprole						×	×	× 15		
Chromobacterium subtsugae strain PRAA4-1		× 28	× 16.28		× 16.28				× 16.28	
cyantraniliprole	× 20	×	×		×			× 15		
cypermethrin		×	×		×			× 15		

ACTIVE SUBSTANCE	BEAN AND BEAN SEED FLY	APHIDS	WHITEFLIES	*LIRIOMYZA* MINER	THRIPS	MOTH	POD BORER	LEGIONARIES	SPIDER MITES	NEMATODES
deltamethrin		×	×		×	×	×			
Digliphus isaea				×						
emamectine benzoate		×			×	×	×	× 15	×	
Encarsia formosa			×							
esfenvalerate					× 29	× 29				
flour and starch (10% solution)			× 1							
fenazaquin									× 7	
fenpyroximate									× 8	
flonicamid		× 23	×		×					
flubendiamide							× 6	× 15		
fluopyram										×
fosthiazate										×
gamma-cyhalothrin		×	×		×					
Geraniol Citronellol Nerolidol Farnesol									× 9	
hexythiazox									×	
paraffin oil		×	×	×	× 16.29				× 9.29	
orange essential oil		× 24	× 2						× 12	
lambda-cyhalothrin		×	×		×	×	×	× 15		
maltodextrin									× 13	
Metarhizium anisopliae		×	×		×		× 5			
Metarhizium rileyi strain PHP1705						× 26		× 26		
methoxyfenozide						×	×	× 16		
Nucleopolyhedrovirus						× 29		× 15		
Paecilomyces fumosoroseus		×	×							
Paecilomyces lilacinus										×

ACTIVE SUBSTANCE	BEAN AND BEAN SEED FLY	APHIDS	WHITEFLIES	*LIRIOMYZA* MINER	THRIPS	MOTH	POD BORER	LEGIONARIES	SPIDER MITES	NEMATODES
Phytoseilus persimilis									×	
pyridaben									× 8	
pirimicarb		×								
pyrethrins	×	×	×		×			× 16		
pyriproxyfen		×	×		×					
sulphur									×	
spinetoram					×	×	×	× 15		
spinosad	× 18			× 3	× 16		× 6	× 16		
spirotetramate		×	×		×				× 11	
sulfoxaflor			×		× 29					
tebufenpyrad									× 7	
tefluthrin	× 19									
Trichoderma asperellum										×
Verticillium *lecanii*		×	×		×					

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AUXILIARY SUBSTANCES AND ARTHROPODS AGAINST FUNGI AND BACTERIA

ACTIVE SUBSTANCE	*FUSARIUM SOLANI*	*MACROPHOMINA PHASEOLINA*	*PYTHIUM*	*RHIZOCTONIA SOLANI*	*SCLEROTIUM ROLFSII*	*ALTERNARIA*	*ANTHRACNOSE*	ANGULAR SPOTS	RUST	HALO BLIGHT	BACTERIAL BLIGHT
benzoic acid							×	×	×		
azoxystrobin				× 4.24	× 6	× 14	×	×	×		
Bacillus amyloliquefaciens (subtilis) strain QST 713			× 5	× 5					× 8		
captan	× 9		× 10	× 4	× 6		× 15	× 29			
copper							×	×	×	×	×
cymoxanil							×	×	×		
cyprodinil							× 17				
difenoconazole				× 24		× 12	×	×	×		
dimetomorph							×	×	×		
dithianon							×	×	×		
fluazinam						× 14					
fludioxonil	× 9		× 1	× 24							
fluopicolide			× 28								
fluopyram							× 16		×		
fluoxastrobin					× 6				×		
fluxapyroxad						× 13					
fosethyl								×			
Gliocladium catenulatum strain J1446			× 20	× 20	× 20						
Gliocladium virens (*Trichoderma virens* strain GL-21)			× 18	× 18	× 19		× 27				
metalaxyl			× 10								
metalaxyl-M (mefenoxam)			× 1								
metam-sodium				× 25	× 6						
neem (extract)							× 7				
penthiopyrad						× 21	× 21	× 21	× 21		
propamocarb-HCl			× 2.10								

ACTIVE SUBSTANCE	*FUSARIUM SOLANI*	*MACROPHOMINA PHASEOLINA*	*PYTHIUM*	*RHIZOCTONIA SOLANI*	*SCLEROTIUM ROLFSII*	*ALTERNARIA*	*ANTHRACNOSE*	ANGULAR SPOTS	RUST	HALO BLIGHT	BACTERIAL BLIGHT
prothioconazole							× 16		× 16		
pyraclostrobin					× 6						
pyrimethanil							×	×	×		
sedaxane				× 24							
sulphur							×	×	×		
Streptomyces K61 (formerly S. griseoviridis)	× 22		× 22	× 22							
Streptomyces lydicus WYEC 108	× 23	× 23	× 23	× 23	× 23	× 23	× 23				
tebuconazole							×	×	×		
tetraconazole									×		
Trichoderma asperellum (str. T34)	×		×	× 26							
Trichoderma harzianum	×	× 30	× 11	× 3			× 27				
Trichoderma viride							× 27				
trifloxystrobin				× 24					×		

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APPENDIX 4: TABLES ON THE SENSITIVITY OF AUXILIARIES TO PESTICIDES

Important note: Some of the products listed below are classified as highly hazardous pesticides and are not recommended for use by COLEAD. However, given that they still have local approval, this table aims to warn about the impact of the use of these products on auxiliary plants.

This table is therefore by no means a recommendation for the use of products but focuses on the theoretical impact of pesticides on auxiliaries.

INSECTICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	RED SPIDER PREDATOR			MITES AND THRIP PREDATOR			RED SPIDER PREDATOR			GENERAL AND THRIP PREDATOR		
		PHYTOSEIULUS PERSIMILIS			*AMBLYSEIUS CALIFORNICUS*			*FELTIELLA ACARISUGA*			*ORIUS LAEVIGATUS*		
		EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=SEMAINE)	EGG	ADULT	PERSISTENCE (W=WEEK)
abamectin	spray.	?	>75%	2w	?	?	?	?	>75%	?	>75%	>75%	3w
acephate	spray.	?	>75%	>3w	?	>75%	>2w	?	>75%	>8w	>75%	>75%	?
acrinathrin	spray.	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?
alphacyperme-thrin	spray.	>75%	>75%	>8w	?	?	?	?	>75%	>8w	>75%	>75%	?
Amblyseius californicus	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
amitraz	spray.	>75%	>75%	3w	?	>75%	0w	?	?	?	?	50-75%	3w
Aphidius transcaspinus	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
azadirachtin	spray.	?	<25%	?	?	?	?	?	?	?	<25%	?	?
azocyclotin	spray.	50-75%	50-75%	3 days	25-50%	25-50%	?	?	?	?	?	25-50%	?
beta cyfluthrin (see cyfluthrin)	spray.	>75%	>75%	>8w	50-75%	50-75%	?	>75%	>75%	>8w	>75%	>75%	>8w
bifenthrin	spray.	>75%	>75%	>8w	?	?	?	>75%	>75%	>8w	>75%	>75%	>8w
BT var kurstaki	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
BT var kurstaki	dust	25-50%	25-50%	0.5w	?	?	?	<25%	?	?	?	?	?
buprofezin	spray.	<25%	25-50%	0w	<25%	<25%	0w	25-50%	<25%	1w	25-50%	<25%	0w
carbaryl	spray.	?	>75%	2w	?	?	?	50-75%	>75%		>75%	>75%	?

INSECTICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	RED SPIDER PREDATOR			MITES AND THRIP PREDATOR			RED SPIDER PREDATOR			GENERAL AND THRIP PREDATOR		
		PHYTOSEIULUS PERSIMILIS			*AMBLYSEIUS CALIFORNICUS*			*FELTIELLA ACARISUGA*			*ORIUS LAEVIGATUS*		
		EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=SEMAINE)	EGG	ADULT	PERSISTENCE (W=WEEK)
carbofuran	spray.	?	>75%	>3w	?	?	?	?	?	?	?	?	?
carbosulfan	spray.	25-50%	25-50%	1w	?	?	?	?	?	?	?	?	?
chlorpyrifos-methyl	spray.	<25%	<25%	0w	?	25-50%	2w	?	>75%	?	>75%	>75%	?
cyfluthrin	spray.	>75%	>75%	>8w	50-75%	50-75%	?	>75%	>75%	>8w	>75%	>75%	>8w
cypermethrin (see also profenofos)	spray.	>75%	>75%	>8w	?	?	?	>75%	>75%	>8w	>75%	>75%	>8w
cyromazine	spray.	<25%	<25%	0w	<25%	<25%	0w	?	>75%	0w	?	<25%	?
cyromazine	drip	<25%	<25%	0w	?	?	?	?		?	?	?	?
deltamethrin	spray.	>75%	>75%	>8w	?	?	?	>75%	>75%	>8w	>75%	>75%	>8w
diazinon	spray.	<25%	<25%	1w	?	25-50%	2w	>75%	>75%	>6w	25-50%	50-75%	?
dichlorvos	spray.	<25%	>75%	1w	?	?	?	?	>75%	<1w	>75%	>75%	1w
dimethoate	spray.	>75%	>75%	8w	?	50-75%	?	50-75%	25-50%	?	>75%	>75%	?
Encarsia formosa	organic												
fenazaquin	spray.	?	?	?	?	?	?	?	?	?	?	?	?
fenitrothion	spray.	?	>75%	?	?	?	?	?	?	?	?	>75%	?
fipronil	spray.	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?	25-50%	25-50%	?
gamma – cyhalothrin	spray.	?	?	?	?	?	?	?	?	?	?	?	?
garlic (see also pyrethrins)	spray.	?	?	?	?	?	?	?	?	?	?	?	?
hexythyazox	spray.	<25%	<25%	?	<25%	<25%	?	<25%	<25%	?	<25%	<25%	?
imidachloprid	spray.	50-75%	50-75%	?	>75%	>75%	5 days	>75%	>75%	?	>75%	>75%	?
imidachloprid	drip	25-50%	25-50%	?	<25%	<25%	?	<25%	<25%	?	25-50%	25-50%	1w
lambda – cyhalothrin	spray.	>75%	>75%	>8w	<25%	<25%	?	>75%	>75%	>8w	>75%	>75%	>8w

INSECTICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	RED SPIDER PREDATOR *PHYTOSEIULUS PERSIMILIS*			MITES AND THRIP PREDATOR *AMBLYSEIUS CALIFORNICUS*			RED SPIDER PREDATOR *FELTIELLA ACARISUGA*			GENERAL AND THRIP PREDATOR *ORIUS LAEVIGATUS*		
		EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=SEMAINE)	EGG	ADULT	PERSISTENCE (W=WEEK)
malathion	spray.	25-50%	25-50%	>1w	?	?	?	50-75%	>75%	2w	>75%	>75%	?
methomyl	spray.	>75%	>75%	2w	>75%	>75%	?	>75%	>75%	?	>75%	>75%	1w
methoxy-fenozide	spray.	?	?	?	<25%	<25%	?	?	?	?	>75%	>75%	?
mineral oils	spray.	?	?	?	?	25-50%	>2w	?	?	?	?	?	?
oxamyl	spray.	>75%	>75%	>8w	?	?	?	>75%	>75%	>8w	>75%	>75%	>8w
oxamyl	drip	<25%	<25%	0w	?	?	?	?	?	?	?	>75%	?
oxydemeton – methyl	spray.	?	>75%	1w	?	?	?	50-75%	>75%	?	?	?	?
parathion methyl	spray.	<25%	<25%	0w	?	?	?	?	?	?	?	>75%	?
pirimiphos-methyl	spray.	>75%	>75%	>2w	?	>75%	?	?	>75%	?	?	?	?
propargitis	spray.	>75%	50-75%	0w	?	50-75%	?	25-50%	<25%	?	?	50-75%	?
pymetrozin	spray.	<25%	<25%	0w	25-50%	25-50%	?	?	?	?	25-50%	25-50%	1w
pymetrozin	drip	<25%	<25%	0w	<25%	<25%	?	?	?	?	<25%	<25%	1w
pyrethrin (+ P.B.O)	spray.	<25%	>75%	1w	?	?	?	?	>75%	>1w	?	?	?
spinosad	spray.	<25%	<25%	0w	<25%	<25%	0w	?	?	?	25-50%	25-50%	3 days
sulphur	spray.	25-50%	25-50%	?	50-75%	50-75%	?	25-50%	25-50%	?	25-50%	<25%	?
teflubenzuron	spray.	<25%	<25%	0w	<25%	<25%	0w	?	?	?	>75%	<25%	?
tetradifon	spray.	<25%	<25%	0w	?	?	?	?	<25%	?	?	?	?
tetradifon + dicofol	spray.	50-75%	50-75%	2w	50-75%	50-75%	?	<25%	>75%	?	<25%	<25%	?
thiamethoxam	spray.	>75%	>75%	?	<25%	<25%	?	?	?	?	>75%	>75%	>2w
thiocyclam	spray.	?	25-50%	0.5s	?	?	?	?	?	?	?	?	?
trichlorfon	spray.	>75%	>75%	2w	?	?	?	?	?	?	>75%	>75%	?

INSECTICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	APHID PREDATOR			APHID PARASITE			WHITEFLY PARASITE			LEAF MINER PARASITE		
		LADYBIRDS			*APHIDIUS COLEMANI*			*ENCARSIA FORMOSA*			*DIGLYPHUS & DACNUSA*		
		LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=SEMAINE)	LALARVA	ADULT	PERSISTENCE (W=WEEK)
abamectin	spray.	?	>75%	1w	?	>75%	?	>75%	>75%	3w	?	>75%	?
acephate	spray.	?	>75%	>6w	?	>75%	?	>75%	>75%	>8w	?	>75%	?
acrinathrin	spray.	>75%	>75%	?	25-50%	>75%	?	>75%	>75%	?	>75%	>75%	?
alphacyper-methrin	spray.	?	>75%	?	?	>75%	?	>75%	>75%	>8w	?	>75%	?
Amblyseius californicus	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
amitraz	spray.	?	50-75%	?	?	?	?	>75%	>75%	3w	?	?	?
Aphidius transcaspinus	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
azadirachtin	spray.	?	?	?	?	?	?	?	?	?	?	?	?
azinphos-methyl	spray.	?	>75%	>6w	?	>75%	?	>75%	>75%	>8w	?	>75%	?
azocycloin	spray.	50-75%	>75%	?	?	?	?						
beta cyfluthin (see cyfluthin)	spray.	50-75%	>75%	>8w	>75%	>75%	?	>75%	>75%	>8w	>75%	>75%	>8w
BT var kurstaki	spray.	?	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
BT var kurstaki	dust	?	<25%	0w	?	?	?	?	?	?	?	?	?
buprofezin	spray.	?	50-75%	1w	<25%	<25%	0w	25-50%	<25%	0.5s	?	<25%	0w
carbaryl	spray.	25-50%	>75%	?	?	>75%	?	50-75%	>75%	4w	?	>75%	
carbofuran	spray.	?	?	?	?	?	?	?	?	?	?	?	?id
carbosulfan	spray.	?	>75%	>8w	?	?	?	?	?	?	?	>75%	?
chlorpyrifos-methyl	spray.	?	?	?	>75%	>75%	?	50-75%	?	>8w	?	>75%	?
cyfluthrin	spray.	50-75%	>75%	>8w	>75%	>75%	?	>75%	>75%	>8w	>75%	>75%	>8w
cyhexatin	spray.	?	<25%	0w	?	>75%		<25%	>75%	2w	?	>75%	
cypermethrin	spray.	?	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w

INSECTICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	APHID PREDATOR			APHID PARASITE			WHITEFLY PARASITE			LEAF MINER PARASITE		
		LADYBIRDS			*APHIDIUS COLEMANI*			*ENCARSIA FORMOSA*			*DIGLYPHUS & DACNUSA*		
		LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=SEMAINE)	LALARVA	ADULT	PERSISTENCE (W=WEEK)
cyromazine	spray.	50-75%	25-50%	0w	?	<25%		<25%	<25%	0w	?	<25%	?
cyromazine	drip	?	?	?	?	<25%		?	<25%	?	?	?	?
deltamethrin	spray.	?	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w
diazinon	spray.	25-50%	25-50%	?	>75%	>75%	?	25-50%	>75%	4-6w	?	>75%	?
dichlorvos	spray.	?	>75%	<1w	?	>75%	?	>75%	>75%	1w	?	>75%	?
dicofol	spray.	?	<25%	0w	?	50-75%	?	<25%	>75%	>1w	?	50-75%	?
dicofol + tetradifon	spray.	?	<25%	0w	?	50-75%	?	<25%	>75%	>1w	?	50-75%	?
Diglyphus isaea	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	>0w	<25%	<25%	0w
dimethoate	spray.	>75%	>75%	?	>75%	>75%	?	>75%	>75%	>8w	?	?	?
Encarsia formosa	organic												
endosulfan	spray.	?	>75%	2w	50-75%	?	?	<25%	>75%	>8w	?	>75%	?
fenitrothion	spray.	?	>75%	?	?	?	?	50-75%	?	>6w	?	?	?
fipronil	spray.	?	?	?	?	?	?	<25%	<25%	?	?	?	?
gamma – cyhalothrin	spray.	?	?	?	?	?	?	?	?	?	?	?	?
garlic (see also pyrethrin)	spray.	?	?	?	?	?	?	?	?	?	?	?	?
hexythyazox	spray.	<25%	<25%	?	<25%	<25%	?	<25%	<25%	?	<25%	<25%	?
imidacloprid	spray.	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?
imidachloprid	spray.	25-50%	25-50%	?	25-50%	25-50%	?	25-50%	25-50%	?	25-50%	25-50%	?
malathion	spray.	>75%	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w
methomyl	spray.	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?	>75%	>75%	?
methoxy-fenozide	spray.	?	?	?	?	?	?	<25%	<25%	?	?	?	?

INSECTICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	APHID PREDATOR			APHID PARASITE			WHITEFLY PARASITE			LEAF MINER PARASITE		
		LADYBIRDS			*APHIDIUS COLEMANI*			*ENCARSIA FORMOSA*			*DIGLYPHUS & DACNUSA*		
		LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=SEMAINE)	LALARVA	ADULT	PERSISTENCE (W=WEEK)
mineral oil	spray.	?	?	?	?	?	?	?	?	?	?	?	?
oxamyl	spray.	50-75%	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w	>75%	>75%	>8w
oxamyl	drip	?	<25%	0w	?	<25%	?	25-50%	<25%	?	?	<25%	?
oxydemeton-methyl	spray.	?	>75%	?	?	?	?	>75%	>75%	>8w	?	?	?
parathion methyl	spray.	>75%	>75%	?	?	?	?	?	>75%	?	?	?	?
pirimicarb	spray.	?	>75%	1w	?	<25%	?	<25%	50-75%	<1w	?	50-75%	<1w
pirimiphos-methyl	spray.	?	<25%	0w	>75%	>75%	?	>75%	>75%	>6w	?	>75%	
propargitis	spray.	?	50-75%	?	<25%	<25%	?	50-75%	50-75%	1w	?	?	?
pymetrozin	spray.	?	?	?	<25%	25-50%	?	<25%	<25%	?	?	?	?
pymetrozin	spray.	?	?	?	<25%	25-50%	?	<25%	<25%	?	?	?	?
pyrethrin (+ P.B.O)	spray.	?	>75%	>2w	?	?	?	25-50%	>75%	2w	?	>75%	1w
spinosad	spray.	?	?	?	?	50-75%	?	?	50-75%	1w	?	?	?
sulphur	spray.	<25%	25-50%	?	25-50%	25-50%	?	<25%	>75%	>4w	?	25-50%	<1w
teflubenzuron	spray.	?	25-50%	?	?	<25%	?	<25%	25-50%	<1w	?	>75%	0w
tetradifon	spray.	?	<25%	?	?	<25%	?	<25%	>75%	<1w	?	<25%	0w
tetradifon + dicofol	spray.	<25%	<25%	?	50-75%	50-75%	?	<25%	>75%	>1w	50-75%	50-75%	?
thiamethoxam	spray.	?	?	?	?	?	?	?	?	?	?	?	?
thiocyclam	spray.	50-75%	25-50%	?	25-50%	>75%	?	<25%	25-50%	<1w	?	>75%	?
trichlorfon	spray.	?	>75%	?	?	>75%	?	<25%	50-75%	?	?	>75%	?

FUNGICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	RED SPIDER PREDATOR			THRIP AND MITE PREDATOR			PREDATOR OF THRIPS AND OTHERS			LEAF MINER PARASITE		
		PHYTOSEIULUS PERSIMILIS			*AMBLYSEIUS CALIFORNICUS*			*ORIUS LAEVIGATUS*			*DIGLYPHUS*		
		EGGS	ADULT	PERSISTENCE (W=WEEK)	EGGS	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)	NYMPH	ADULT	PERSISTENCE (W=WEEK)
azoxystrobin	spray.	<25%	<25%	?	<25%	<25%	?	<25%	<25%	?	?	?	?
benomyl	spray.	<25%	50-75%	>2w	?	?	?	?	?	?	?	<25%	0w
bitertanol	spray.	<25%	<25%	0w	<25%	<25%	0w	25-50%	<25%	?	?	<25%	0w
buprimate	spray.	<25%	25-50%	4d	?	<25%	0w	50-75%	50-75%	0w	?	25-50%	0w
captan	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	?	?	?
chlorothalonil	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	?	<25%	0w
copper oxychloride	spray.	<25%	<25%	0w	<25%	<25%	0w	?	<25%	?	?	?	?
difenoconazole	spray.	?	<25%	?	?	?	?	?	?	?	?	?	?
dithianon	spray.	?	<25%	?	?	<25%	?	?	<25%	?	?	?	?
fosetyl aluminium	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	?	?	?	<25%	0w
garlic (see also pyrethrin)	spray.	?	?	?	?	?	?	?	?	?	?	?	?
hexaconazole	spray.	?	<25%	?	?	<25%	?	?	<25%	?	?	?	?
iprodione	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	?	<25%	0w
mancozeb	spray.	<25%	50-75%	0w	<25%	<25%	0w	25-50%	<25%	0w	?	<25%	0w
metalaxyl (see zoxamide)	spray.	?	50-75%	?	?	?	?	?	?	?	?	?	?
metalaxyl + mancozeb	spray.	<25%	<25%	0w	<25%	<25%	0w	?	?	?	?	?	?
metiram	spray.	?	50-75%	?	?	?	?	<25%	<25%	0w	?	?	?
myclobutanil	spray.	<25%	<25%	0w	<25%	<25%	0w	25-50%			?	?	?
propamocarb	spray.	<25%	<25%	0w	<25%	<25%	0w	?	?	?	?	<25%	0w
propamocarb	spray.	<25%	<25%	0w	<25%	<25%	0w	?	?	?	?	<25%	0w

FUNGICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	RED SPIDER PREDATOR			THRIP AND MITE PREDATOR			PREDATOR OF THRIPS AND OTHERS			LEAF MINER PARASITE		
		PHYTOSEIULUS PERSIMILIS			*AMBLYSEIUS CALIFORNICUS*			*ORIUS LAEVIGATUS*			*DIGLYPHUS*		
		EGGS	ADULT	PERSISTENCE (W=WEEK)	EGGS	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)	NYMPH	ADULT	PERSISTENCE (W=WEEK)
propiconazole	spray.	?	<25%	?	?	?	?	25-50%	<25%	?	?	<25%	0w
Propineb (see also cymoaxa nil)	spray.	50-75%	>75%	1w	?	?	?	?	<25%	?	?	?	?
pyrimethanil	spray.	?	25-50%	?	?	?	?	<25%	?	?	?	?	?
sulphur	spray.	<25%	<25%	0w	?	?	?	25-50%	<25%	?	?	50-75%	<1w
sulphur	powder	<25%	25-50%	1w	?	?	?	?	?	?	?	?	?
sulphur	manure	<25%	25-50%	1w	?	?	?	?	?	?	?	?	?
tebuconazole	spray.	?	<25%		?	?	?	?	?	?	?	?	?
Thiamethoxam (only seed treatment)	seed treatment	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w

FUNGICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	APHID PREDATOR			APHID PARASITE			WHITEFLY PARASITE		
		LADYBIRD			*APHIDIUS*			*ENCARSIA*		
		LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)	LARVA	ADULT	PERSISTENCE (W=WEEK)
azoxystrobin	spray.	?	?	?	<25%	<25%	?	<25%	<25%	?
benomyl	spray.	?	>75%	?	<25%	<25%	0w	<25%	<25%	0w
bitertanol	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
buprimate	spray.	?	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
captan	spray.	?	<25%	0w	?	?	?	<25%	<25%	0w
chlorothalonil	spray.	?	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
copper oxychloride	spray.	<25%	<25%	0w	?	?	?	<25%	50-75%	<1w
difenoconazole	spray.	?	?	?	?	<25%	?	?	<25%	?
dithianon	spray.	<25%	<25%	?	?	<25%	?	<25%	<25%	0w
fosetyl aluminium	spray.	?	<25%	0w	?	?	?	?	<25%	?
garlic (see also pyrethrin)	spray.	?	?	?	?	?	?	?	?	?
hexaconazole	spray.	25-50%	<25%		?	<25%	?	?	?	?
iprodione	spray.	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
mancozeb	spray.	?	2	0w	<25%	<25%	0w	<25%	25-50%	0w
Metalaxyl (see also zoxamide)	spray.	?	?	?	?	?	?	?	<25%	?
metalaxyl+mancozeb	spray.	?	<25%	0w	?	?	?	<25%	<25%	?
metiram	spray.	<25%	<25%	?	<25%	<25%	?	?	>75%	4w
myclobutanil	spray.	?	<25%	0w			?	?	?	?
propamocarb	spray.	?	<25%	0w	?	?	?	<25%	<25%	0w
propamocarb	drip	?	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
propiconazole	spray.	25-50%	?	?	<25%	<25%	?	<25%	<25%	?
propineb (see also cymoaxanil)	spray.	50-75%	>75%	0w	?	<25%	?	<25%	>75%	>4w
pyrimethanil	spray.	?	?	?	?	?	?	?	?	?
sulphur	spray.	25-50%	25-50%		25-50%	50-75%	?	<25%	>75%	>4w
sulphur	powder	?	>75%	>6w	?		?	<25%	>75%	>3w
sulphur	manure	?	?	?	?		?	?	>75%	<1w
tebuconazole	spray.	?	?	?	?	25-50%	?	<25%	25-50%	?
thiamethoxam (only seed treatment)	seed treatment	<25%	<25%	0w						

FUNGICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	RED SPIDER PREDATOR			RED SPIDER PREDATOR			PREDATOR OF THRIPS AND OTHERS			LEAF MINER PARASITE		
		PHYTOSEIULUS PERSIMILIS			*AMBLYSEIUS CALIFORNICUS*			*ORIUS LAEVIGATUS*			*DIGLYPHUS*		
		EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=WEEK)	EGG	ADULT	PERSISTENCE (W=WEEK)
thiophanate-methyl	spray.	25-50%	>75%	>2w	?	?	?	25-50%	?	?	?	<25%	0w
thiram (spraying on crop not allowed)	spray.	?	25-50%		?	?	?	<25%	25-50%	?	?	<25%	0w
thiram (powder on crop not allowed)	powder	50-75%	<25%	>1w	?	?	?	?	?	?	?	?	?
thiram (only seed treatment allowed)	seed	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
triadimefon	spray.	<25%	<25%	0w	<25%	<25%	0w	?	<25%	?	?	<25%	0w
Trichoderma	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
triforine	spray.	<25%	25-50%	0w	?	?	?	?	<25%		?	<25%	0w
zoxamide	spray.	?	?	?	?	?	?	?	?	?	?	?	?

FUNGICIDES (GREEN BEAN) ACTIVE MATERIALS	APPLICATION METHOD	APHID PREDATOR			APHID PARASITE			WHITEFLY PARASITE		
		LADYBIRD			*APHIDIUS*			*ENCARSIA*		
		LARVA	ADULT	PERSISTENCE (W = WEEK)	LARVA	ADULT	PERSISTENCE (W = WEEK)	LARVA	ADULT	PERSISTENCE (W = WEEK)
thiophanate-methyl	spray.	?	<25%	0w	<25%	<25%	?	<25%	<75%	0w
thiram (spraying on crop not authorised)	spray.	?	25-50%	0w	<25%	<25%	?	<25%	50-75%	<1w
thiram (powder on crop not authorised)	powder	?	?	?	?	?	?	<25%	50-75%	<1w
thiram (only seed treatment allowed)	seed treatment	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
triadimefon	spray.	?	<25%	0w	?	?	?	<25%	<25%	0w
Trichoderma	organic	<25%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
triforine	spray.	25-50%	<25%	0w	<25%	<25%	0w	<25%	<25%	0w
zoxamide	spray.	?	?	?	?	?	?	?	?	?

APPENDIX 5: MORE INFORMATION ABOUT *ENCARSIA*

It is possible to design a prophylactic pest control programme using adult *Encarsia* for field crops. Introduction rates of *Encarsia* are based on an estimate of the number of whitefly pupae that could be present on each trifoliate leaf, if NO other control is used and natural migration of parasites occurs smoothly (worst case scenario).

After some time, if control is effective, the rate of natural migration of the whitefly to the crop shortly after planting is likely to decrease and, as a result, the required rates of introduction of*Encarsia* would also decrease.

An effective sampling system for integrated pest management allows growers to measure control by estimating the average number of whitefly pupae and adult whitefly per leaf after a certain period of time.

In Europe and elsewhere, *Encarsia* is normally bought from companies specialised in biological control in the form of black pupae of parasitised whiteflies containing a young *Encarsia* pupa that will give birth to an adult *Encarsia*. This adult *Encarsia* is the biological control agent because it flies away to lay eggs in other whitefly pupae present in the crop. This method has advantages in that the production and distribution of pupae is cheaper than adults and pupae can be stored longer than adults before use. This is suitable for EU growers who produce crops in greenhouses.

The use of *Encarsia* in outdoor crops is very rare. However, adult *Encarsia* are preferred over *Encarsia* pupae (i.e. parasitised whitefly pupae) for outdoor crops in Kenya because, in the fields, *Encarsia* pupae are likely to be eaten by ants, dehydrated or blown away by the wind if introduced alone. On the contrary, adult *Encarsia* will place themselves directly on the underside of the leaves, looking for whitefly pupae to feed on them and on which to lay their eggs.

It is also easier to integrate the use of adult *Encarsia* into the application schedule of other compatible fungicides and insecticides, since the grower knows the exact date the adults were introduced into the crop. If, otherwise, the grower had introduced *Encarsia* at pupae stage, they would not know the exact date on which they emerged from the black pupae. As a result, it would be difficult to schedule further pesticide sprays and ensure that adult *Encarsia* are not killed. *Encarsia* are very sensitive to pesticides and even fungicides. (Refer to Appendix 4 on sensitivity to pesticides) Technical advice should be sought for the use of biological control means for whitefly. However, the following indications will help growers who wish to apply biological control means on outdoor crops. Week-long training courses provide the necessary sampling and management skills to implement these programmes.

"TRADITIONAL" METHOD OF USING *ENCARSIA*

Commercial use of *Encarsia*, the most commonly used parasitic *hymenoptera* against whitefly, is normally limited to protected crops due to the cost of these natural predators, which would not be cost-effective for outdoor crops.

Nevertheless, *Encarsia*, like all other natural predators, comes from the outside! Its effective use outdoors is not prevented by biological reasons, but by economic reasons. In Kenya, the production of *Encarsia* is very cheap and therefore they can be used in much larger quantities than growers in the EU could afford economically.

The traditional method of using *Encarsia* is to buy parasitised whitefly pupae (they are black when parasitised). They are glued on cartons that are hung from plants. Adult *Encarsia* emerge (or not) from these pupae and look for large enough whitefly pupae in the culture, in which they lay an egg. If the *Encarsia* egg is laid in a large whitefly pup, it will grow in the parasitised whitefly pupa and eventually become an adult *Encarsia* (because the large pupa contains enough food). In the absence of large pupae in the crop, *Encarsia* will be forced to lay an egg in a smaller pupa, which will not have enough "flesh" to allow the full development of *Encarsia* to the adult stage. As a result, both the developing *Encarsia* and the pupa die and the population of *Encarsia* present in the culture will not be able to grow. However, the whitefly pupa dies, which is the goal of the grower.

The choice of the date of introduction of *Encarsia*, which must coincide with the presence of large whitefly pupae, determines the success of the method of gradually introducing *Encarsia*. This is the weekly introduction of small but frequent quantities of *Encarsia* at a fixed rate per hectare, which aims to overcome some of the above-mentioned problems. Weekly prophylactic introductions of *Encarsia* generally stop as soon as parasitism is observed in 95% of whitefly pupae (i.e. when 95% of black pupae are detected on the leaves of plants).

PROPHYLACTIC/PREVENTIVE PROGRAMME USING *ENCARSIA*

An intense prophylactic programme is another way to use *Encarsia*. In Europe, for potted ornamental plants (*e.g.* poinsettias), an intense prophylactic programme for the introduction of *Encarsia* is used instead of the low intensity regular weekly programme (the 'gradual' method described above) used for example in tomato crops, since the consumer does not want to buy ornamental poinsettias with black pupae on the leaves. In tomato crops, it does not matter if black pupae are found on the leaves.

For poinsettias, a regular introduction of *Encarsia* is applied before whiteflies lay eggs on the leaves, so that *Encarsia* actually kills the whitefly pupae during their development instead of parasitising them. Indeed, adult *Encarsia* also feed on young pupae (excessive damage due to feeding kills pupae, which then fall off the leaf). Pupae also die if *Encarsia* has laid an egg inside them, even if the pupae are too small to ensure the full development of *Encarsia* larvae. Therefore, the rate of traditional parasitism will not be high and few black pupae will be present in the culture, as the development of the whitefly population in the culture has stopped at stage L2. This technique is called "de-escalation". De-escalation will generally occur when the ratio of adult *Encarsia* to whitefly pupae present in the crop is close to one to thirty (i.e. one adult *Encarsia* to thirty whitefly pupae).

This type of "de-escalation" programme will inevitably use more *Encarsia* than traditional dropper methods and is normally only applied in high-value crops, such as ornamental crops. However, while it is possible to reduce the cost of *Encarsia* by raising them en masse on the farm, the largest quantities of adult *Encarsia* can be used economically.

The general principle of biological control is that the higher the number of useful insects present (or introduced) compared to the number of parasites present, the faster the control will be carried out.

The rate of introduction of *Encarsia* should therefore be related to the number of whiteflies actually present or to the estimated number of whiteflies that can migrate into the crop.

In order to calculate the possible number of *Encarsia* required, the grower must first correctly assess the likely weekly development of whitefly pupae in the crop if NO control means are applied. This assessment may be made either on the basis of the grower's experience with the average number of whitefly pupae on each trifoliate leaf at a given stage of growth of the crop, or by designating an unsprayed parcel in the same field to allow adult whiteflies to migrate into that plot.

Weekly sampling of this plot yields the average number of:

- whitefly pupae per leaf and per week (pupae development),
- leaves per plant per week (leaf growth). (Refer to the table opposite to learn how to use this information.)

The weekly introduction rate of adult *Encarsia* (not of parasitised black pupae) is calculated by dividing the estimated weekly number of whitefly pupae per hectare (*) by 30. This determines the number of adult *Encarsia* required to establish a one to thirty ratio between adult *Encarsia* and whitefly pupae in the foliage of the crop. When this ratio is reached, "de-escalation" should be practised. If the grower can afford to introduce more adult *Encarsia* into the crop, they would ensure an even better control (but it would cost more).

* Estimated total number of whitefly pupae per hectare = (average number of whitefly pupae per leaf x total number of leaves per plant) x total number of plants per hectare.)

Calculations for prophylactic introduction rate (*Encarsia* in fine beans)

This high rate would only be necessary during the period when the plantation's whitefly population was forcibly reduced to a more manageable level. Subsequent introduction rates would be adjusted according to the actual average number of whitefly pupae present (and not according to the high average of 20 pupae per leaf used in the calculation method presented below).

Table 1: Guidance on calculations for the introduction of adult *Encarsia* into outdoor crops of fine beans Plants/ ha = 200,000. Use a rate of 20 pupae per trifoliate leaf to calculate the maximum number of whiteflies per hectare (worst case scenario) for the initial programme.

As long as no spraying of harmful chemicals is applied during this phase and there is no massive invasion of adult whiteflies from an adjacent crop, further introductions of adult *Encarsia* beyond the sixth week should not be required. (Refer to the table on pesticide sensitivity in the appendices).

WEEK AFTER PLANTING	WEEK. 3	WEEK. 4	WEEK. 5	WEEK. 6	WEEK. 7	WEEK. 8	WEEK. 9	WEEK. 10
trifoliate leaves per plant	1	3	9	12	18	22	26	26
Total trifoliate leaves per ha (thousands)	200	600	1,800	2,400	3,600	4,400	5,200	5,200
estimated total pupae per ha	4 million	12 million	36 million	48 million				
introduction rate per ha In thousands of *Encarsia* 1 to 30 ratio (rounded)	14,000	400,000	1.2 million	1.6 million				

The implementation of this technique leads to a certain development of black (parasitised) whitefly pupae, as part of the larvae of the whitefly have developed beyond the L3 stage and can be adequately parasitised by *Encarsia* and become black.

Sampling will determine the need for continued introductions of *Encarsia*. Adult *Encarsia* introductions should continue if weekly sampling reveals:

— the average number of whitefly pupae continues to increase weekly to an unacceptable level, or

— that the parasitism rate of larger pupae on older lower leaves is less than 50%.

The grower must determine if the level of pupae present is "acceptable" (economic threshold). They should take into account the number of weeks the crop is present in the soil and should examine whether the honeydew of the larvae present causes too much damage to the beans or whether the crop does not grow vigorously enough because of the large feeding samples of the whiteflies. However, at 5 pounds sterling per thousand (EU trade cost of parasitised pupae), an introduction of about three million adult *Encarsia* per hectare would cost approximately 150,000 pounds, a cost that is prohibitive.

The only way to do this is to raise *Encarsia* on the farm in order to reduce the cost. It is also possible to destroy whitefly pupae by spraying with detergent, such as Teepol, but again, advice should be sought from pesticide regulatory authorities to determine whether this use should not be registered as a pest control product for agricultural use. In many countries, this type of crop protection agent is exempt from registration because it causes death by physical means, dissolving the epidermis and allowing death of the pupa by dehydration.

Other control agents include substances such as starch, which, when sprayed on a leaf with whitefly pupae, prevents the pupae from hatching because it forms a layer that chokes or dehydrates the pupae due to osmosis. Similar effects can be achieved by spraying vegetable or mineral oils. Again, these types of substances are exempt from registration in other countries because of their physical mode of action. Advice should be sought on local registration requirements.

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