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Best4Soil

Boosting 4 BEST practices for SOIL health in Europe

Deliverable 9 “20 fact sheets published” / WP 3

The writing and layout process for the Best4Soil fact sheets is finished and are published on the website which is already available for the project partners and facilitators.

Date 1-9-2020

Deliverable 3.4

Fact Sheets




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BEST4SOIL Partners

1. Delphy BV
2. FIBL Austria
3. 7Reasons Medien
4. Teagasc
5. Berner Fach Hochschule
6. Landbrug & Fodevarer
7. IFAPA
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Document summary

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Project coordinator: Delphy BV

Description of work

In order to give additional information on the topics covered in the videos respective fact sheets were written by the authors in English. Special attention was paid not to simply repeat the information in the videos, but to go into more detail and, where possible, provide practical information. Therefore the fact sheets should be seen as a complement to the video material.

The specialists (Harm Briks, Delphy BV (DEL); Vincent Michel (Eidgenössisches Department für Wirtschaft, Bildung und Forschung (WBF); Saskia Houben, DEL; Leendert Molendijk, Wageningen University & Research (WUR); Alfred Grand, Landwirtschaft Grand (GRAND); Michaela Schalthoelter, P.H. Petersen Saatzucht Lundsgraard (PHP); Miguel de Cara, IFAPA-Almería at Junta de Andalucia (IFAPA) and Michael Gaffney, Teagasc (TEAG)) started writing the fact sheets after the completion of the storyboards.

After termination they were translated into the other 21 European languages - resulting in 18.420 English words to translate. The coordination of the translators took place within the soil-health-community to ensure the correctness of the translation of the technical terms: Petya Pencheva (Bioselena, Bulgarian), Jan Trávníček (Institut pro ekologické zemědělství a udržitelný rozvoj krajiny, Czech), Marian Damsgaard Thorsted (SEGES, Danish), Saskia Rouben (DEL) and Leendert Molendijk (WUR, Dutch), Eva Tuusis (Estonian University of Life Sciences/EMU, Estonian), Finnish (7reasons), Bruno Häller (Berner Fachhochschule) and Vincent Michel (WBF, French), Iris Haubner (7reasons, German), Kypros Filokyprou (Lacon Institute, Greek), Jade Ducretot (ÖMKi/Hungarian Research Institute of Organic Agriculture, Hungarian), Maria Grazia Tommasini (Centro Ricerche Produzioni Vegetali/CRPV, Italian), Lāsma Ozola (Crop Production Division Latvian Rural Advisory and Training Center, Latvian), Atanas Ronis (LAMMC Žemdirbystės institutas / Institute of Agriculture, Lithuanian), Piotr Chohura (Wroclaw University of Environmental and Life Sciences/Department of Horticulture, Polish), Brankica Tanovic (Institute of Pesticides and Environmental Protection Laboratory of Phytopathology, Serbian), Magdaléna Lacko Bartošová (Slovak University of Agriculture in Nitra, Slovak), Miguel de Cara (IFAPA, Spanish), Olle Sahlin (Sahlins språktjänster, Swedish), Cristian Gazdac (Romanian), José Carlos Marques (Universidade da Madeira, UMA/Centro de Ciências Exactas e da Engenharia, Portuguese), Aljaž Ravnjak (external translator, Slovenian).

Also in the case of the fact sheets some reminders for the deadlines were sent. Once translated the fact sheets were sent back to 7reasons.

In close cooperation with the authors, the graphic designer (7reasons) created a general layout for all the material (e.g. fond, color scheme, background graphics etc.) as well as for each individual fact sheet, including e.g. graphics or photos and their positions. Their final versions were then transformed from word-docs into pdfs, which were sent back to the translators for a final review. After some minor adjustments the web-designer (7reasons) put the files online via the web page (www.best4soil.eu). Up to now 18 fact sheets in 22 languages and one additional information sheet on the taking of a representative compost sample are online. The information about the database can be accessed as an extra page within the website. The missing fact sheet 20 will be published after the final conference 2021.



START OF BEST4SOIL, THE NETWORK OF PRACTITIONERS FOR SHARING KNOWLEDGE ON PREVENTION AND CONTROL OF SOIL BORNE DISEASES

Healthy soils are of major importance for the future of the European horticultural and agricultural crop production. Especially in intensive production systems, **soil borne diseases** are a major factor with a negative impact on soil health. Newly developed best practices and sound crop rotations permit to maintain, improve or re-establish **soil health** in Europe.

The Best4Soil project has started at 12. November 2018 and is now in the phase of creating factsheets, data bases, videos and network activities. With Best4Soil we are building a **community of practice network** across Europe by inter-connecting growers, advisers, educators and researchers. This network promotes **knowledge ready for practice on 4 best practices** (fig. 1, 2, 3, 4) for the control of soil borne diseases. Therefore we build a website and organize meetings and events in 20 European countries where we exchange knowledge on soil health with our communities of practice. The main objective of the Best4Soil thematic network is to maintain, improve or re-establish soil health in Europe. We provide open-access databases with information on the range of pathogens and nematodes that affect vegetable, arable and cover crops to help practitioners to build appropriate **crop rotations** and innovative **control strategies**.

Fig. 1: Compost/ organic amendments

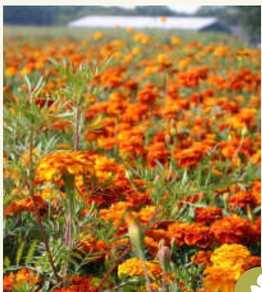

Fig. 2: Green manures / cover crops

Fig. 3: Anaerobic disinfestation (ASD)

Fig. 4: (Bio)solarisation

Innovative control strategies are provided through easily understandable tutorial videos and through factsheets which give more in-depth information. All information is edited in 22 EU languages, will be freely accessible and highly comprehensible to guarantee a smooth knowledge transfer from research to practice.

BEST4SOIL PROPOSES THREE APPROACHES FOR OPTIMAL SOIL HEALTH:

- the adaptation of **optimised crop rotation** as a basis to prevent build-up of soil borne diseases, which is specific to the needs and situation of each individual grower
- the implementation of best practices that have a preventive effect, such as the use of **compost, organic amendments, cover crops and green manures**.
- the implementation of best practices which reduce soil borne diseases after they occur, in order to reduce inoculum levels, such as **(bio)solarisation and anaerobic disinfestation (ASD).**

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WWW.BEST4SOIL.EU

We aim to launch our website in January 2020. The website will provide **highly comprehensible information**, a blog and chatroom and **two open access databases** on the range of pathogens (soil borne fungi and nematodes) affecting host plants, which will help the practitioners to build appropriate crop rotations and innovative control strategies.

A **decision support tool** will be developed to aid growers and advisers to plan appropriate crop rotations and the use of green manures/cover crops beneficial for soil health. This support tool will extract tailor made information that is relevant for a particular grower.

EU WIDE NETWORK

With this information, growers can innovate their **soil health management strategies**. Besides the website and databases we create **communities of practice** (CoP) to deal with **specific regional soil health issues**, which we interconnect through our network.

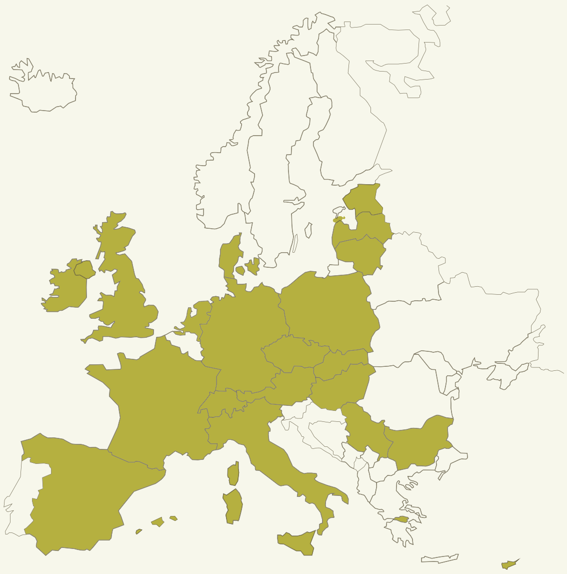
Best4Soil will deploy **local facilitators** to set up the network with active communities of practice. The facilitators in different European regions are organized in **4 subnetworks**, based on the EPPO climatic zones and actively disseminate the knowledge and collection of feedback from practice. The consortium of Best4Soil includes advisers, breeder, communicators, educators, growers, and researchers from eight European countries. Together with facilitators in twelve more EU countries, the network will interconnect an important part of the European growers, advisers and educators, the main stakeholders of Best4Soil.

To get involved or for more information you can contact us by e-mail:

- Info@Best4Soil.eu

THE BEST4SOIL NETWORK IN 20 COUNTRIES

Austria, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Serbia, Slovakia, Spain, Switzerland and United Kingdom.



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Authors: Leendert Molendjik, Johnny Visser
(Wageningen University and Research, The Netherlands)

ANAEROBIC SOIL DISINFESTATION (ASD): PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on Anaerobic Soil Disinfestation (ASD): Practical information

Anaerobic soil disinfestation (ASD) is an alternative for chemical soil treatments (fig. 1). ASD reduces a wide range of soil borne diseases, pests and weeds. The method requires incorporation of easily degradable organic material into the soil, after which the soil is covered with an airtight plastic sheet to prevent the inflow of oxygen which creates an anaerobic environment. All oxygen is used by soil micro-organisms while degrading the organic material. For some organisms these anaerobic conditions alone are already lethal. The organic material degrades further through fermentation, by which volatile fatty acids are being released that are lethal to many other species of soil organisms. Many useful species survive both anaerobia and these volatile compounds, so there is no question of sterilization.

Fig. 1: Anaerobic Soil Disinfestation in a glance (from top to bottom):
Incorporation fresh organic matter
Closing the surface
Wetting the soil
Covering with virtually impermeable film (VIF)

HOW DOES IT WORK?

The Best4Soil video Anaerobic Soil Disinfestation: Practical information (link##) shows the principle of anaerobic soil disinfestation (ASD). ASD is an alternative for chemical soil disinfestation. Figure 2 gives an overview of the steps to take for successful application of ASD (at the top) and their effect (at the bottom).

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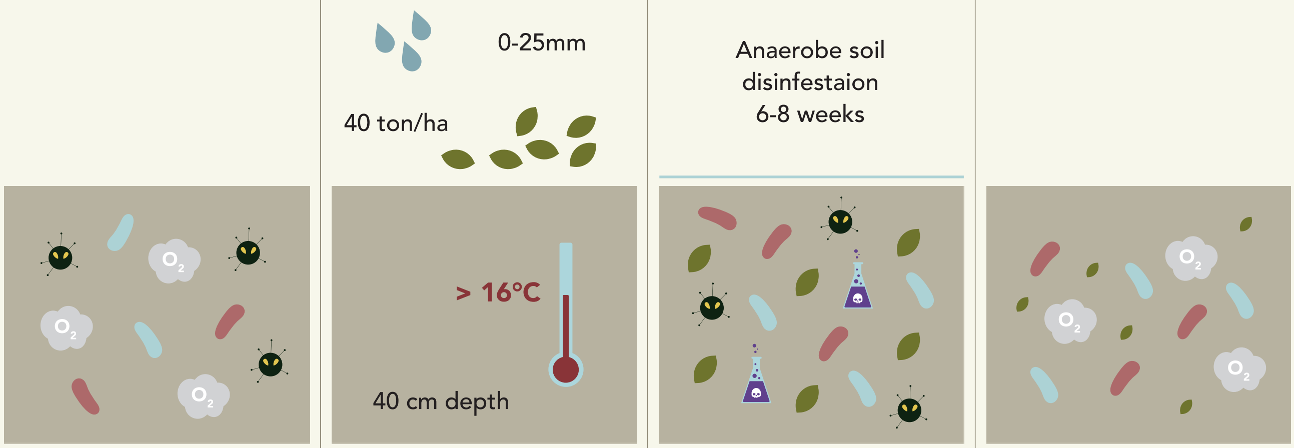
MANAGEMENT:	• Incorporate organic materials (fresh, chopped small) • press soil • wet soil	• airtight cover • prevent damage • repair holes	• grow a crop to prevent leaching of nutrients
BASELINE	**PREPERATIONS**	**ASD**	**RESULT**



What happens belowground: Before start oxygen is in the soil. Pathogens parasi-tes and beneficial Mircoor-ganisms live together.	• Soil is reaching field capacity. • Fresh organic material is coming in.	• Microorganisms de-grade organic material • O_2 gets depleted • Toxic compounds are released and kill pa-thogens and pests	• O_2 returns • Composition of soil life changed • soil life restored • Organic residues and nutrients • anaerobe sensitive organisms parished

pathogen/parasite/weed · Organic matter · Oxygen · Micro-Organism · Toxic agents · Airtight plastic

Figure 2: ASD steps (top) operating mechanism (bottom)

STEP 1: THE RIGHT MATERIALS AND CONDITIONS

Organic materials
It is important that the organic materials are easily degra-dable for the soil micro-organisms. Basically any source of fresh plant material will do, e.g.:

- Fresh crop residues
- Fresh grasses
- Fresh cover crops and green manures
- Protein rich residual flows

When grown in the same location, it is preferable that the organic material is from a non-host plant, to prevent the multiplication of unwanted nematodes or pathogens. The material should be fresh, so composted material, straw or sludge are not suitable. When external organic matter is brought in, it should be free of pathogen/pests and seeds.

- You need about 40 tons/ha fresh organic material to disinfest 40 cm depth of soil.
- The smaller the organic material is chopped, the better: it makes it easier for bacteria to colonize and the O_2 depletion takes place faster.

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Plastic cover material
Not all plastic is suitable for ASD because it needs to be strong enough to prevent it from being damaged, and it should be airtight. Suitable plastics are Virtually Impermeable Films (VIF) or thick polyethylene with a 0.20 to 0.40 mm thickness (often used for silage). Other plastics are generally not sufficiently airtight.

Conditions
Soil moisture and temperature conditions are other important factors for a successful application of ASD:

- The micro-organisms need a soil temperature above 16°C to break down the organic material quickly. The refore anaerobic soil disinfestation should be applied when temperatures are above 16°C. The higher the temperature, the better.
- Make sure that the soil is wet. For best results, the soil moisture should be at field capacity. If not, then irrigation is needed for a good result. Field capacity is defined as the soil moisture 2 days after the soil was water saturated (e.g. after a heavy rainfall), when all the tall and medium size pores do not contain water anymore. In general irrigating 20mm will do.

STEP 2. INCORPORATION OF THE MATERIALS

- ASD is possible on most soils, on sandy soils however it performs better in general and is easier to apply than on clay soils.
- The organic material should be well distributed/incorporated into the upper 0-20 or if required 0-40 cm soil depth.
- The working depth depends on several factors. Generally, ASD occurs in the layer where the organic matter is homogeneously mixed with the soil.
- In case of pathogens infecting the entire root system, it is necessary to treat the soil over the entire rooting depth.
- Adjust the amount of materials to the operating depth: 40 tons/ha for a 40 cm operating depth, up to 80 tons/ha for an 80 cm operating depth.

STEP 3. SOIL CONDITIONS AND COVERAGE

- Make sure that the soil is wet before you cover it with the sheet.
- Preferably the soil is compacted with a roller or by driving track to track with a tractor after incorporation of the fresh organic material. This closes big soil pores and increases the concentration of toxic volatile compounds in the soil atmosphere.
- Use VIF (VIF: virtually impermeable film) or thick polyethylene with a 0.15 to 0.20 mm thickness (silage). Other plastics are generally not airtight enough.
- Make sure the soil surface is flat, preventing clods and residues from puncturing the plastic. In the case of clay soil it helps to have a wet soil.
- Covering the soil with plastic can be done mechanically. In the video with practical information on ASD you can see how a special machine is covering the field with the airtight plastic
    - Prevent wind damage by adding bags with sand on top of the plastic sheet.
    - Prevent damage by animals by chasing or setting up a fence. Make sure no seeds or other attractive food under the sheet is visible for birds.
    - Check the sheets frequently and repair holes a.s.a.p. to maintain an O2 free atmosphere underneath the plastic.
- Apply ASD for a duration of 6-8 weeks, during a period with temperatures above 16°C.

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ANAEROBIC SOIL DISINFESTATION (ASD): ADVANTAGES AND DISADVANTAGES

This factsheet contains complementary information to the Best4Soil video on Anaerobic Soil Disinfestation (ASD): Advantages and disadvantages

Anaerobic soil disinfestation (ASD) is an alternative for chemical soil treatments (fig. 1). The method is described in details in the Best4Soil factsheet "Anaerobic soil disinfestation (ASD): Practical information".

Fig. 1: Anaerobic Soil Disinfestation in a glance (from top to bottom):
Incorporation fresh organic matter
Closing the surface
Wetting the soil
Covering with virtually impermeable film (VIF)

Anaerobic soil disinfestation reduces a wide range of important soil borne diseases, pests and weeds (table 1).

Table 1. Effectivity of ASD against diseases, pests and weeds (source: Wageningen University & Research, Field Crops, Lelystad). Effectivity: - none, + reasonable, ++ good, +++ very good.

PROBLEM ORGANISM	EFFECTIVITY ASD
Fungi	
Fusarium oxysporum	++
Phytophthora fragariae	+
Pythium	++
Rhizoctonia solani AG3	+++
Rhizoctonia tuliparum	+++
Rhizoctonia solani AG2	-
Sclerotinia sclerotiorum	+++
Synchytrium endobioticum	+
Stromatinia	+
Verticillium dahliae[1]	+++
Bacteria	
Ralstonia solanacearum	++
Fauna	
Pseudocentipedes (Symphyla)	+++
Remainings from previous crop	
Volunteer potato seedlings	++
Nematodes	
Ditylenchus dipsaci[1]	+++
Globodera pallida	++

[1]These species are well controlled on light soils but less easy on heavy soils

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PROBLEM ORGANISM	EFFECTIVITY ASD
Nematodes	
Meloidogyne fallax	+++
Meloidogyne chitwoodi	+++
Meloidogyne incognita	+++
Pratylenchus penetrans	+++
Pratylenchus fallax	+++
Trichodoridae	+
Weeds	
root-spreading weeds in general (depending on species)	++
Cyperus esculentus	+++
Cirsium arvense	++
Convolvulus arvensis	++
Tussilago farfara	++
Elytrigia repens	++
Persicaria amphibium	-
Sonchus oleraceus	++
Sonchus arvensis	++
Fallopia convolvulus	++
seed-spreading weeds in general (depending on species)	-
Echinochloa crus-galli	-
Poa annua	-
Stellaria media	+++

COSTS

Direct costs are the purchase and application of the plastic material (depending on the location approx. 4000 €/ha). Since ASD should be applied at temperatures above 16°C a limited number of summer crops can be grown in the temperate zone. Additional costs are irrigation, incorporation of the material, management during the application period (preventing damage of the sheet) and removing the plastic. Although its feasibility depends on local circumstances and the value of the main crop, in several field experiments benefits were found to be higher than the costs.

ADDITIONAL EFFECTS

The biological processes bring positive and negative additional effects such as nutrients from the degraded material but also a risk on phytotoxicity. By postponing sowing/planting for one week after retrieval of the plastic minimises this risk. ASD is not sterilizing the soil, such as steaming. Many beneficial organisms will survive ASD and will recover within days and some of them even in hours after removing the VIF. Unfortunately, earthworms, springtails and some antagonists are known to be killed by ASD. Disappearance or removal of benign organisms could diminish soil resilience against certain diseases; e.g. resilience against *Fusarium* is known to be unchanged, while the resilience against *Pythium* is temporarily reduced as a consequence of ASD. Therefore the advice is not to grow crops sensitive to *Pythium* in the first season after ASD. Except for *Pythium* no negative experiences have been reported. In the video Anaerobic Soil Disinfestation: advantages & disadvantages [##link##] you can learn more about the advantages versus disadvantages of ASD.

CONCLUSION

Although it is an expensive method ASD is a promising and currently feasible for high value crops. Have a look at our videos [link##] "Anaerobic Soil Disinfestation: practical information" and "Anaerobic Soil Disinfestation: advantages and disadvantages" for practical insights.

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COMPOST PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on Compost Practical Information

INTRODUCTION

Compost is part of the natural cycle. It is a result of microbial decomposition of dead organic matter in the presence of oxygen (aerobic conditions). The repeated application of compost on arable and vegetable fields does increase soil organic matter content as well as the microbial diversity and abundance of the soil. Composts can also increase the suppression of soil borne diseases and increase soil health in general.
Different types of compost can be described as:

Thermophilic compost

When large amounts of organic matter or feedstocks with the right mixture of carbon and nitrogen content and moisture level are put together on a heap, bacteria and fungi start to decompose the material and within a short time, the activity of the microbes produces temperatures of 65 °C or more. Due to the level of these temperatures, weed seeds as well as human and plant pathogens are killed or deactivated. Thermophilic compost has to be monitored frequently to assess when important management steps such as turning, watering, or covering need to occur (fig. 1).

Fig. 1: Homogenizing resources for thermophilic compost production with a compost turner

Vermicompost:

Composting at ambient temperatures is a natural process and therefore part of the natural cycle. Epigeic earthworms (fig. 2) play a major role in vermicomposting. The lack of high temperatures result in a more diverse type of compost. If weed seeds are an issue in the final product, a combination of thermophilic- and vermicomposting can be used.

Fig. 2: Epigeic earthworms in vermicompost

Other composts

Alternative methods like applying the composting feedstock or material directly on the field without prior composting or piled composting (often used, when manure storing capacity is limited) are also possible. If the process is anaerobic (lack of oxygen), it is not composting, but fermentation.

WHY SHOULD WE PRODUCE AND APPLY COMPOST?

Compost application is an easy way to increase soil organic matter, soil microbial diversity as well as soil fertility and soil health. Organic matter is critical for most soil functions like soil structure, water purification and regulation, carbon sequestration and regulation, biodiversity

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and nutrient cycling. The increase of microbial diversity and abundance is important for plants. They communicate, feed and breed microbes e.g. for nutrient mobilization or to suppress soil borne diseases (Bonanomi et al., 2007; Nobel and Coventry, 2005). Trace elements and all other nutrients are all elements of compost whereas with synthetic fertilizer, often only nitrogen, phosphorous and potassium are delivered. This is important to keep plants healthy and reduce the susceptibility of the plants for pests and diseases.

CHALLENGES WITH COMPOST

With all the benefits of compost production and application, some challenges have to be considered also. Sometimes the quantity and quality of resources for compost production are not sufficient, or technology and knowledge of the production and application of compost is not readily available. Additionally, national and regional regulations for production and application of composts have to be considered. The quality of the compost, heavy metal content, contamination from plastic or other debris, as well as pesticide residues and other quality factors have also to be considered, and therefore knowing the provenience of the starting feedstock is important.

Additional information on compost are published as an EIP-AGRI minipaper:

https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/2_eip_sbd_mp_organic_matter_compost_final.pdf

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Bonanomi G., Antignani V., Pane C., Scala F. 2007. Suppression of soilborne fungal diseases with organic amendments. Journal of Plant Pathology 89, 311-324

Nobel R., Coventry E. 2005. Suppression of soil-borne plant diseases with composts: A review. Biocontrol Science and Technology 15, 3-20.

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COMPOST: VERMICOMPOST

This factsheet contains complementary information to the Best4Soil video on Compost: Vermicompost

INTRODUCTION

Compost is part of the natural cycle. It is a result of microbial decomposition of dead organic matter under the influence of oxygen (aerobic conditions). Apart from thermophilic compost, which can generate temperatures of 65 °C and more, vermicompost is produced at ambient temperatures using epigeic earthworms (fig. 1), key organisms for the production of high quality compost. This method mimics nature and results in a compost with a diverse microbial community, which would otherwise be killed through the temperatures occurring in thermophilic compost heaps.

Fig. 1: Epigeic earthworms in vermicompost

Difference to thermophilic compost

While turning is a key step in the process to produce thermophilic compost, mechanical disturbance is not allowed for vermicomposting (Dominguez and Edwards, 2010) as the action of the worms aerates the material. These composts differ in both production systems and in the characteristics of the materials produced. Vermicompost usually is higher in total nutrients (because of increased volume reduction during processing), but also has a higher proportion of plant available nutrients. The microbiome (community of microbes) is more diverse than in thermophilic compost, because the high temperature kills a lot of organisms in the compost heap. Vermicompost contains significant amounts of phytohormones (like auxin, gibberellin and cytokinin), which are e.g., produced by bacteria of the genus Pseudomonas spp., and promoting e.g. root growth. This can easily be seen in practice, when observing roots growing in earthworm burrows in a soil pit. Vermicompost is also considered to contain a range of plant growth promoting rhizobacteria (PGPR) (Vijayabharathi et al., 2015).

Production methods and technology

The vermicompost process does not kill weed seeds, therefore, it is critical to either avoid having seeds in the input material, or to use a combination of thermophilic and vermicomposting methods for production. In temperate areas, vermicomposting can be done outdoors, but if harsh weather conditions (cold or hot) occur, the method should be conducted indoors and (because of the higher costs) in a continuous flow process (fig2), which is much more efficient than ground heaps. Continuous flow methods feed on one side (most often on top) and harvest from the bottom. Epigeic earthworms stay in the upper 15-20 cm if suitable, so when harvesting takes place at the bottom, earthworms do not have to be separated from end product.

Fig. 2: Continuous flow, indoor vermicomposting facility, Austria.

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Resources, mixtures, and environmental conditions

Input material (feedstock) for vermicomposting is critical. If the earthworms don't like their food/environment, they don't perform and eventually disappear. This is the number one reason why this technology has not been adopted more widely. Composting earthworms have some environmental requirements: Temperature 15-30°C, moisture content 60-80%, pH-level 6-8, fully aerobic conditions and enough food (C/N ratio 25:1) with loose structure. Most of the time, mixes from different resources have to be altered /diluted/ supplemented to fit the required quality.

Quality control and regulations

Control of quality is critical, either with compost produced on farm, or purchased. Sometimes earthworms may have not fully processed the organic resources. Compost and organic fertilizer production is not yet regulated by the European Union, therefore each country has its own national legislation and regulations. In some countries, vermicompost is considered compost, some countries regulate it as organic or organic-mineral fertilizer and some countries even have special regulations for vermicompost.

Usage and application

Due to the high input of time and resources into its production, the price for vermicompost does not compare to compost produced in the thermophilic manner. Therefore, application rates are much lower and should be reserved for high value crop production. Nowadays, research is being undertaken to use vermicompost or compost extracts from vermicompost for seed coating and other micro application methods, reducing the application rate of vermicompost to one liter per hectare. Use in seed drills, as an amendment for soil substrates, or when planting orchards (fig. 3) and vineyards is also common practice.


Fig. 3: Vermicompost is a valuable organic amendment and should be used in first line for high value crops such as orchards or vineyards.

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Vijayabharathi R., Arumugam S., Gopalakrishnan S. 2015. Plant growth-promoting microbes from herbal vermicompost. IN: Egamberdieva D., Shrivastava S., Varma A. (eds.), Plant-growth-promoting rhizobacteria and medicinal plants. Springer, Cham, Switzerland, pp. 71-88. DOI 10.1007/978-3-319-13401-7_4

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COMPOST: THERMOPHILIC COMPOST

This factsheet contains complementary information to the Best4Soil video on Compost: Thermophilic Compost

INTRODUCTION

Compost is part of the natural cycle. It is the result of microbial decomposition of dead organic matter in the presence of oxygen (aerobe conditions). Thermophilic compost, also known as hot rotting compost or windrow compost, is the most common compost, which is produced in medium to large quantities worldwide. Thermophilic compost has to be actively managed mostly by turning the material to extend the temperature over all parts of the compost heap. It does reach 65°C or greater, which ensures weed seeds as well as plant and human pathogens are killed or deactivated.

PRODUCTION

Regulations and location

Producing compost from different resources or feedstock needs a location or site, which is suitable in regard to local regulations (e.g. environmental protection); but is also appropriate to the composting process. In most countries composting, from a regulation perspective, is split into two different types of operation. Either (1) only resources from the farm may be used or (2) input material from waste processing are utilised. More rigorous legislation can be expected for composts and processes involving collected waste. Accessibility during bad weather conditions, collection of run-off water and other characteristics have to be forseen, before making a decision on the location of a composting area. A central location for reduced transport costs, anyway from neighboring dwellings reducing any potential issues with smell, noise or vermin, should be selected.

Resources and mixtures

While some manures, especially if mixed with bedding, can be composted alone, most waste has to be mixed with other resources to balance the carbon (C) to nitrogen (N) ratio (C/N). Good starting mixes tend to have a C/N ratio of 25-35 to 1. If the amount of carbon is too little, resources for the microbial community can be a limiting factor. When carbon is lacking, the excess nitrogen will result in problems with bad odours and anaerobic conditions within the compost heap. This will ultimately reduce the quality of the final material. If nitrogen is missing, the bacteria cannot compete with fungi to utilize the carbon and therefore the compost heap may fail to attain the temperatures necessary to produce a good compost. Apart from the correct C/N ratio, the starting mixes need to have a good structure to guarantee sufficient air flow in the entire heap and the appropriate moisture level is also important. The water or moisture level can be easily checked with a 'fist test'. A handful of homogenized material is squeezed in the hand. A few drops of water should appear. When the hand is opened the material should stay compacted. If there is no water visible and the material falls apart, it is too dry. If water is readily running out from the material when squeezed, the moisture content is too high (see also in the Best4Soil factsheet on compost quality).

Technology

Composting is, by definition, an aerobic process, therefore airflow and the availability of oxygen is critical. These conditions have to be achieved through a loose structure on one side, but also through frequent turning on the other side. Front end loaders alone are not appropriate to provide proper homogenization of the heap, therefore tractor/PTO driven compost turners (fig. 1) or self-propelled large compost turners (fig. 2) have to be used for good quality composts. A failure to turn a compost heap or windrow will likely result in a poor quality, poorly homogenized and insufficiently heated compost. Covering a compost with a fleece prevents leaching of mineral nutrients as well as preventing the material drying out and is a good procedure to achieve a high quality compost (fig. 3).

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Fig. 1: tractor/PTO (power take-off) driven compost turner.

Regulations

Compost does contain nitrogen and other nutrients. For this reason, environmental protection regulations are in force in each country within Europe.

Technology

Compost application requires heavy equipment (fig. 4), which is not always available on farm. Therefore, contractors can be hired to apply compost to the field. Often, they offer not only to spread the compost, but also to turn the heaps frequently with professional equipment.

Fig. 2: Self-propelled, commercial compost turner.

Fig. 4: Spreading big volumes of thermophilic compost needs expensive equipment. If this is lacking on the farm, contractors can do the work.

Fig. 3: Compost fleece prevents leaching and drying out.

Quality control

Either self-produced or purchased,all compost should go through quality control. Depending on the input material, this should include lab analysis for nutrients, heavy metal, pathogens as well as maturity and or stability. More information on compost quality assessment can be found in the Best4Soil video and factsheet on compost quality.

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COMPOST: ADVANTAGES AND DISADVANTAGES

This factsheet contains complementary information to the Best4Soil video on Compost: Advantages and Disadvantages

INTRODUCTION

Compost is part of the natural cycle. It is a result of microbial decomposition of dead organic matter under the influence of oxygen (aerobic conditions). With the use of compost comes a broad range of benefits, but also some disadvantages, which should be considered beforehand. Factors such as the input material or feedstock, composting method, compost storage and application, will all influence the characteristics of the material.

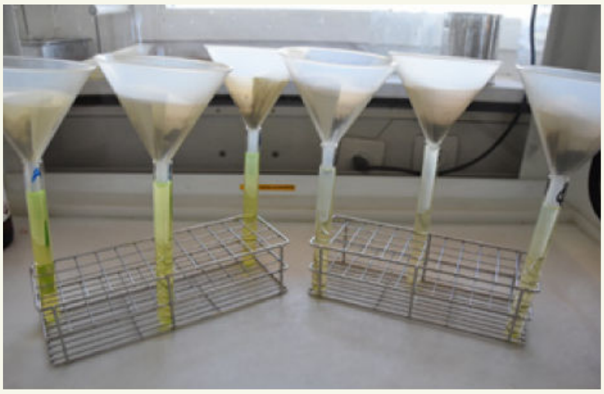

Fig. 1: Soil microbial activity of compost (left side) and soil (right side), measured with the FDA method. The more intense the yellow color of the extract, the higher the soil microbial activity.

ADVANTAGES

Soil organic matter

Compost has a high content of organic matter and can easily raise the organic matter level in soils. This leads to better soil aggregate stability, higher water holding capacity and infiltration rate as well as higher cation exchange capacity. Further information can be found in the Best4Soil video and the factsheet on Soil Organic Matter.

Microbial diversity and abundance

One of the unique characteristics of compost is its microbial diversity and microbial abundance. Since microbes are the main player in the composting process, a huge range of bacteria, archaea, fungi and protozoa is found in compost. This boosts the microbial activity of soils amended with compost (fig. 1). Vermicompost has even higher biodiversity, as there is no heat phase in the process and therefore no microbes are lost due to high temperatures.

Suppression of soil-borne diseases

Microbes play a very critical role in supporting and providing plants with nutrients; but also to suppress soil-borne diseases. Lots of composts have the ability to suppress the activity of pathogens. Direct effects include microbial competition for nutrients, humic substances, toxic volatiles or direct parasitism effects. Indirect effects of composts are vigorous or healthy plant growth, reduced stress, induced resistance and improved soil structure. In general, while compost is not a plant protection agent as such, it can be of great help in reducing pressure from soil-borne diseases.

Nutrient availability

Nutrient availability in compost is also due to microbial activity. Not only are some of the nutrients delivered with compost already plant available, but when incorporated into the soil, compost microbes start to mobilize nutrients from the soil, making them plant available. Plants can control these effects through their root exudates.

Resilience of Soil

In general, all of these positive effects of compost on soil and plants increase the resilience of the plant-soil system. Therefore, negative impacts from outside (severe weather, contamination, compaction, etc.) are better managed and are less stressful for the plants.

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DISADVANTAGES

Availability

Compost is not always available, and availability throughout Europe varies. Farmers and growers are often looking for specific qualities from compost. Because of its weight and volume, compost cannot be transported over long distances either, as this is cost prohibitive.

Quality and contamination

If compost does not have the right quality for a specific application, it is better to reconsider its use, rather than incorporate poor quality compost in the field. Quality can be measured in a range of different ways, taking different characteristics into consideration. This can include unbalanced nutrient content, humic acids, organic and inorganic contamination. A simple test using cress as bioindicator to measure if a compost is plant compatible with the target crop (fig. 2) is presented in the Best4Soil video and factsheet on compost quality tests (link to video 8). Solid debris (plastic, glass, metal, etc.) and especially small debris like micro-plastic, are a specific problem of composts coming from separate waste collection sites (fig. 3). For organic farmers the input material is critical e.g., sewage sludge is not allowed in compost for organic fields. Another quality problem of composts not produced correctly are viable spores of fungal and bacterial pathogens, weed seeds and pathogenic viruses. In such cases, the application of compost will decrease the health of soils by contaminating them with pathogenic microorganisms and weeds.

Fig. 2: Plant compatibility of compost measured with the "open cress test". The second compost from the left is not suitable for growing plants. More information in the Best4Soil video on compost quality tests.

Fig. 3: Solid debris are an important quality problem of a compost.

Costs, equipment

Composting meanwhile is a technology driven process. Heavy equipment is used to process the input material and transport the compost to the fields (fig. 4), which is costly. Often it is cheaper to hire contractors for input preparation (shredding of material), turning, sieving, transport and application.

Fig. 4: For a rational transport and distribution of compost, heavy equipment is needed.

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COMPOST QUALITY TEST

This factsheet contains complementary information to the Best4Soil video on Compost quality tests.

INTRODUCTION

Compost is a natural product, and therefore the final composition and characteristics of each compost is different. Depending on the preliminary feedstock, composting process and the maturity / stability of a compost, its characteristics and therefore quality can vary greatly . For the correct and optimal application of a compost, it is therefore most important to determine the quality of the compost before its application. In the Best4Soil video on compost quality, a series of simple chemical and biological tests to measure this quality are presented.

QUALITY TESTS AND THEIR INTERPRETATION

Three chemical tests (the determination of the pH, the salinity and three forms of mineral nitrogen) and two biological tests (the open and the closed cress tests) (fig. 1) are presented in the video. You will find the values needed for the interpretation of these tests in the table below (according to the Swiss directive 2010 for the compost and digestate quality).

PARAMETER	COMPOST GENERAL USE	COMPOST HORTICULTURAL USE OPEN FIELD	COMPOST HORTICULTURAL USE GREEN HOUSE
pH-value *		< 7.8	< 7.5
Salt content [g KCl_{eq}/kg DM]**		<20	<10
Ammonium ($N\text{-}NH_4$) *	< 600 mg/kg DM	< 200 mg/kg DM	< 40 mg/kg DM
Nitrate ($N\text{-}NO_3$) *		> 80 mg/kg DM	> 160 mg/kg DM
Nitrite ($N\text{-}NO_2$) *		< 20 mg/kg DM	< 10 mg/kg DM
N_{min} (mineral nitrogen) *	> 60 mg/kg DM	> 100 mg/kg DM	> 160 mg/kg DM
Ratio $N\text{-}NO_3/N_{min}$		> 0.4	> 0.8
Open cress test (7 days after sowing)		> 50% of reference substrate	> 75% of reference substrate
Closed cress test (7 days after sowing)		> 25% of reference substrate	> 50% of reference substrate
Dry matter (DM)		> 50%	> 55%

* Extract of 50 g compost in 500 ml 0.1 m CaCl solution, shaking for 1 h. $N\text{-}NH_4$ = (NH_4 in extract (in mg/liter) / DM (in % FM)* 776.5); $N\text{-}NO_2$ = (NO_2 in extract (in mg/liter) / DM (in % FM)* 304.4); $N\text{-}NO_3$ = (NO_3 in extract (in mg/liter) / DM (in % FM)* 225.9)
** Extract of 50 g compost in 500 ml H_2O, shaking for 1 h. Salt content [g KCleq/kg DM] = EC value from extract (in mS) * 583.41 / DM (in % FM)

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For the determination of the dry matter (DM) of the compost, dry a sample at 105°C for one day.

Other important quality parameters are the content of other mineral nutrients such as P_2O_5, K_2O, Mg and Ca, and the carbon content of the compost. Analysis of these parameters are more complicated and therefore a sample has to be analyzed by a specialized laboratory. In general, laboratories which analyze soil can also analyze compost. For the interpretation of these results, national guidelines have to be consulted. Often, but not always, the interpretation is integrated in the analysis report of the laboratory.

COMPOST MOISTURE

A compost has to be humid to allow the microorganisms to be active. If the compost is too dry, no microbial activity is possible and the transformation (composting) process of the compost is stopped. If the compost is too wet, undesired microbial processes under anaerobic (= absence of oxygen) conditions will occur and the compost will possibly have a bad smell and contain phytotoxic acids.
A simple test to control the moisture content of a compost is the 'fist test'. You take a handful of compost, squeeze it firmly and then open the fist. If the compost is too dry, the compost will then fall apart (fig. 2). If the moisture content is normal, then compost stays together (fig. 3). In case the compost is too wet, then water will run out of your fist when you squeeze the compost (fig. 4). Depending on the situation, you can take the needed measures, such as adding water to the compost or cover the compost.

Fig. 1: Closed and open cress test, 7 days after sowing, ready for evaluation.

Fig. 2: Fist test: Compost is too dry.

Fig. 3: Fist test: Compost has the right moisture content.

Fig. 4: Fist test: Compost is too wet.

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GREEN MANURES & COVER CROPS: PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on Green manures & cover crops: Practical information.

INTRODUCTION

The use of cover crops and green manures has some potential to control soil-borne diseases of field and horticultural crops. But as their immediate efficacy is lower compared to more radical methods, such as chemical soil disinfestation or heat treatments, they have to be used in a more preventive and strategic manner.

Cover crops and green manures are grown with no intention of harvesting their biomass, either partly or completely, at the end of the cropping season. The difference between these two types of crops is their final use. The above-ground part of green manures is incorporated into the soil at the end of the growing period with the aim of returning accumulated nutrients (e.g., nitrogen) or useful secondary metabolites (e.g., glucosinolates) to the soil. Cover crops are grown for different reasons, such as to reduce leaching of nutrients (e.g., nitrate, then also designated as catch crops), avoid erosion, improve soil structure or suppress weeds. A combined use is also possible, a crop can serve first as cover crop (e.g., for weed control) and then be incorporated as green manure (e.g., for nutrient input) (Campiglia et al., 2009).

CONTROL OF NEMATODES

For the control of certain nematode species, nematode-resistant cover crops can be used. An important group for cooler regions are Brassica species such as oil radish (*Raphanus sativus*) (fig. 1) and white mustard (*Sinapis alba*). Special selected varieties are able to reduce beet cyst nematodes (*Heterodera schachtii*) by interruption of the gender differentiation in the nematodes life cycle. Also different marigold species (*Tagetes* spp.) are known to have a suppressive effect on some nematode species such as Pratylenchus penetrans (fig. 2) (Marahatta et al., 2012). Some radish varieties are able to disturb the transmission of tobacco rattle virus, which cause the corky ringspot in potato and is transmitted by *Trichodorus* nematodes. This negative effect on the nematode is also observed with pea early browning virus which is also transmitted by *Trichodorus* spp. Increasingly the ability of radish varieties to reduce *Meloidogyne* ssp. is becoming an important approach. As radish itself is only a very poor host plant for this important nematode, selected resistant varieties inhibit the life cycle of *Meloidogyne* and thus reduce the population. A third group of common cover crop plants which are resistant to different nematodes are sorghum (*Sorghum bicolor*) and sorghum-sudangrass (*S. bicolor x S. sudanense*) (fig. 3) (Dover et al., 2012). This group is more adapted to warmer regions. For all groups, important differences in the resistance level to the targeted nematodes exist between species and even between cultivars. Therefore, the final choice should be based on information from the seed provider and information from reputable internet sources. On a local level, the creation of a community of practice i.e., a group of people and practitioners who share knowledge on a specific topic, can help to find the best choice of cover crops or green manures to control specific nematodes. The setup of such a community of practice is supported by the Best4Soil network by organizing a workshop dealing with the concerned topic. If you are interested, then contact Best4Soil (contact form is on www.best4soil.eu).

Fig. 1: Oil radish (*Raphanus sativus*) cover crop

Fig. 2: Marigold (*Tagetes* sp.) cover crops

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FAST GROWING SPECIES

Fast growing species are valued as cover crops, as they suppress the growth of weeds by rapidly covering the soil surface. An alternative to the fast growing Brassica species is buckwheat (Fagopyrum esculentum) which germinates and grows very fast as long as temperatures are not too low. It is also an interesting crop as it belongs to the Polygonaceae family as the only other cultivated species of this family is rhubarb (Rheum rhabarbarum). Another fast growing plant is phacelia (Phacelia tanacetifolia), which has the advantage of belonging to the Boraginaceae family. As no cultivated species belong to this family and phacelia is an excellent plant for honey bees, it is an interesting cover crop. Both of these plants, buckwheat and phacelia, should be grown in summer – early autumn, as they need warm temperatures for good growth and are not winter hardy.

A REAL CROP

Sometimes, green manures or cover crops are not considered as a valuable crop, as they do not generate a direct profit and theireffect is not immediately visible. But to generate a positive effect on soil health, the establishment and growth of the crop has to be successful. Therefore, the use of healthy seed with a high germination rate, good seedbed preparation, sowing in favourable conditions, with sufficient nutrients, and if needed irrigation, have to be applied. Attempting to saving money by reducing inputs on a such a crop is wasting money.

Fig. 3: Sorghum sudangrass (*S. bicolor x S. sudanense*) green manure (image from C. Wohler, LZ Liebegg, Switzerland)

Additional information on green manures and cover crops are published as a EIP-AGRI minipaper:

https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/6_eip_sbd_mp_green_manure_final_0.pdf

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GREEN MANURES & COVER CROPS: ADVANTAGES & DISADVANTAGES

This factsheet contains complementary information to the Best4Soil video on Green manures & cover crops: Advantages & disadvantages.

INTRODUCTION

In general, cover crops have positive effects on soil structure, soil erosion, reducing nutrient leaching, weed suppression and feeding the soil microbiome. Some species used as cover crops can also fix nutrients (nitrogen by legumes) or make nutrient more available (phosphorus by buckwheat). Used as green manures, they also help to sequester carbon. As cover crops belong to different plant groups (families) their impact as promotors or inhibitors for soilborne diseases and nematodes has to be specifically chosen. Water availability and climatic conditions are also criteria that determine the use of specific plants.

WHICH GOALS?

Critical for the choice of the correct cover crop for the specific location is the cultivation target you want to improve with cover crop growing.
For nematode control and interruption of disease cycles the old concept of changing (rotating) plant families is a good general concept, such as, Brassica and legume cover crops before cereals, grass and legumes before Brassicas and so on. Special bred varieties may help to intensify this effect.
For additional biomass production to improve soil fertility,increase soil organic matter content and for the cultivation in less favorable areas, species mixtures offer better security for good establishment of the cover crops and for achieving a high biomass.

SPECIES MIXTURES

The concept of a multi-service cover crop (MSCC) describes very well the different possible positive functions of a cover crop (Justes & Richard, 2017). One possibility to achieve the most positive effects of a MSCC is the use of plant mixtures. An interesting combination seems to be mixtures of cruciferous species with leguminous species (Couëdel et al., 2019). This would combine the disease suppressive effect of crucifers with the nutrient service of legumes. However, such mixtures are relatively new and knowledge on all the potential advantages and disadvantages still has to be acquired through field studies. For example, most legume species are host plants of *Pratylenchus* spp., so how far this can be counterbalanced by the cruciferous species in the mixture needs to be demonstrated.

A well-studied group of species mixtures are the grass-legume mixtures (fig. 1). Such mixtures result in an excellent root distribution in the soil (fig. 2). Furthermore, mixtures with a proportion of 40-60% legumes can increase the nitrogen fixation by legumes compared to pure legume stands (Nyfeler et al. 2011). Another advantage of grass-legume mixtures is that they can also be used for grazing, which makes them interesting for regions with mixed farming systems, such as field crops and dairy farming. Especially during years with more extreme weather conditions, such "reserve" grassland has a high value.


Fig. 1: Grass-legume mixture, can also be used for grazing


Fig. 2: Root colonization of the soil below a grass-legume mixture.

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Mixtures for cover crops and green manures are commercially available; often they are adapted to specific purposes. Making mixtures on-farm is complicated, the proportion of the seeds does not reflect the proportion of the plants once the crop is fully developed. The size of the seeds of the different species used for a mixture should also not vary too much, otherwise the depth of the seeding will not be adapted to all species of the mixture. For places where no commercial mixtures are available, developing mixtures could be the topic for a community of practice i.e., a group of persons who share knowledge on a specific topic. The setup of such a community of practice is supported by the Best4Soil network by organizing a workshop dealing with the concerned topic. If you are interested, then contact Best4Soil (contact form is on www.best4soil.eu).

TIMING IS IMPORTANT

Timing for sowing is most important, especially in Northern Europe, where the temperatures drop in the autumn season. When cover crops and green manures are sown too late, they will not fulfill the functions they are meant to, especially covering the soil rapidly to suppress weeds and reduce erosion.
As a cover crop is not properly harvested, the termination can also be a problem as there is no "need" to harvest the crop. When terminated too late, problems such as a C/N ratio which is too high, which indicates slow decomposition and nitrogen immobilization in the soil, and viable seeds, which can become a weed in the following crop, can occur.

SPECIAL BENEFITS

As mentioned above, some cover crops can be used to feed livestock. Another important group of animals that can be fed with cover crops are honey bees and pollinators in general (fig. 3). Most agricultural crops are flowering in spring – early summer. Cover crops are an excellent way to provide bees with pollen and nectar during the summer and fall season. Legumes, cruciferous species, buckwheat and phacelia are excellent plants to feed bees, particularly phacelia (fig. 4) is often grown with the special goal to nourish bees.

Fig. 3: White clover is an excellent fodder plant for honey bees.

Fig. 4: Phacelia is a melliferous cover crop, most attractive for honey bees.

Additional information on green manures and cover crops are published as an EIP-AGRI minipaper:

https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/6_eip_sbd_mp_green_manure_final_0.pdf

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BIOFUMIGATION: PRACTICAL INFORMATION, ADVANTAGES AND DISADVANTAGES

This factsheet contains complementary information to the Best4Soil video on Biofumigation: Practical information, advantages and disadvantages

INTRODUCTION

Biofumigation is the use of green manures crops which release biocidal molecules into the soil after their incorporation. This best practice was developed in several countries to cope with the withdrawal of methyl bromide, a most effective but controversial chemical soil fumigant. The effect of biofumigation is partly based on the release of natural toxic substances but also on their effect as a green manure plant. The effect of green manures and cover crops are explained in two Best4Soil videos and factsheets.

The nature of the soil is also an important factor when biofumigation is used as a control method. Lighter-textured soils with low organic matter content are better suited to this approach (Kirkegaard, 2009). Isothiocyanates get fixed to organic matter (sorption) and are therefore less active against soilborne pathogens and nematodes. Therefore, the lower the organic matter content, the less sorption of the isothiocyanates occurs in a soil. Lighter soils i.e., soils with a higher part of sand, allow a better diffusion of the toxic gases in the soil.

PULVERISATION IS IMPORTANT

For *Brassicas*, the transformation of glucosinolates into toxic and volatile isothiocyanates happens during the breakdown of the plant cells. The more cells which are broken and release glucosinolates, the higher the peak of isothiocyanates will be (Morra & Kirkegaard, 2002). This is critical for the efficacy of biofumigation. Therefore, the biofumigation crop should be shredded as finely as possible before soil incorporation (fig. 1), with the best method to use are mulching devices equipped with hammers rather than blades (Matthiessen et al., 2004).

NATURAL LIMITATION OF THE BIOFUMIGATION

The amount (concentration) of isothiocyanates needed for successful control depends on the targeted soilborne pathogens, nematodes and weed seeds (Klose et al., 2008). For the more resistant microsclerotia of the soilborne pathogen *Verticillium dahliae*, *Brassica* plants will not liberate sufficient isothiocyanates for a successful control in the field (Neubauer et al., 2014).

PLANT DERIVED BIOFUMIGATION PRODUCTS

An alternative to increasing the amount of isothiocyanates in the soil is the use of defatted seedmeals from *Brassica* cultivars with high content of glucosinolates (Patalano, 2004). Such products are commercially available, and in most cases sold as organic fertilizers (fig. 2). Therefore, their efficacy is not known as such products do not undergo efficacy evaluation, as is the case when products are registered as pesticides. However, the amount of seedmeal added to the soil is limited by its nutrient content, usually nitrogen in the first instan-

Fig. 1: The finer the mulching degree of the plants, the faster and more isothiocyanates will be released.

Fig. 2: Example of an organic fertilizer based on defatted mustard seedmeal.

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ce. The addition of too much seedmeal can result in an over-fertilization and potentially in the leaching of different nutrient elements (such as nitrate).

Seedmeal products are mostly applied by broadcast in form of pellets or powder (fig. 3) and incorporated into the soil before the planting of the crop. Once in contact with water in the soil, the transformation of the glucosinolates into isothiocyanates takes place. Irrigation after the incorporation of these products accelerates this transformation and also favors the diffusion and dispersal of the isothiocyanates in the soil.
Another way to apply isothiocyanates to the soil is the use of liquid *Brassica* seedmeal products (fig. 4). In this case, the seedmeal is manipulated before application. Through this manipulation, the glucosinolates are transformed into isothiocyanates and then dissolved in liquid which is applied to the soil through a drip irrigation system.

Fig. 3: Pellets of defatted mustard seedmeal before incorporation in the soil.

Fig. 4: Defatted mustard seedmeal can be applied to the soil in liquid form, even after planting the crop.

NOT ONLY BRASSICAS

The term 'biofumigation' was originally defined as the process of growing, macerating / incorporating certain Brassica or related species into the soil, leading to the release of isothiocyanates through the hydrolysis of glucosinolates contained in the plant tissues (Kirkegaard et al., 1993). But sorghum (*Sorghum bicolor*) and sorghum-sudangrass (*S. bicolor* x *S. sudanense*) cultivars with high content of dhurrin, a substance which is transformed in toxic hydrogen cyanide (also called prussic acid) are also plants that can be used for biofumigation (de Nicola et al., 2011). Both species are well adapted for growth under high temperature conditions, such as those which occur under protection in summer (fig. 5). Therefore, they are well suited to the southern regions of Europe (fig. 6). Another advantage is that they are grass species, which makes them especially suitable to be part of crop rotations in vegetable production systems.

Fig. 5: Sorghum-sudangrass 8 weeks after sowing under tunnel.

Fig. 6: Sudangrass in summer (> 35°C) in Southern Spain.

Additional information on biofumigation are published as an EIP-AGRI minipaper:

https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/9_eip_sbd_mp_biofumigation_final_0.pdf

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CROP ROTATION: PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on Crop rotation: practical information

INTRODUCTION

If the same crop is grown in the same field for a long time, the yield level declines. Important causes are diseases and nematodes, soil borne pests that need a susceptible host plant to survive and multiply. Since the roots of one crop always explore the same soil layers and demand the same proportion of different nutrients, the soil gets exhausted while pests such as nematodes can survive and multiply on the host plant. Although pest and disease management requires a multi-action approach, the basis for a healthy soil is a good crop rotation: a planned order of growing specific crops on the same field (fig. 1) in order to prevent diseases and pests, while also increasing and maintaining soil health.

WHY CROP ROTATION?

Crop rotation is one of the oldest and most effective strategies to control soil borne diseases and pests. The final result however – higher economic benefit – depends very much on the choice, frequency and order of the crops in the design, adjustment to local conditions and integration of other management practices., crop rotation forms the basis for pest and disease control. In a good crop rotation soil health is maintained for the long run and disease and pest pressure is maintained low, resulting in sufficient yield of high-quality crops. Additional reasons to apply a good crop rotation are to maintain a good soil fertility and structure.

Each year it is a challenge to grow the type of crops in the quantity needed to ensure the farm profitability while the soil quality is maintained for a long-term productivity. Another challenge is to prevent specific pests and diseases while also not promoting other pests or diseases when planning the sequence of host- and non-host plants. In the following paragraphs you learn how to do that, with examples of good crop rotations.

Fig. 1: Scheme of crop rotation. Crops of the different botanical families are grown alternately.

Table 1 shows the importance of applying a good crop rotation with enough time between the first and second time that the same crop is grown on the field (advised minimum frequency in years).

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Table 1. The balance between soil health and main crop groups, their minimum frequency and possible consequences if the minimum requirement is ignored (A minimum frequency of 1:5 means one crop is grown once in the 5 years at the same field.)

CROP FAMILY	ADVISED MINIMUM FREQUENCY	HIGH RISKS IF CROP IS GROWN MORE TIMES THAN THE MINIMUM FREQUENCY
Solanaceae (e.g. potato, tomato)	1:5	Potato cyst nematodes *Verticillium dahliae* *Sclerotinia* *Alternaria* *Phytophthora* (oospores) *Rhizoctonia*
Alliaceae (e.g. onion, garlic)	1:6	White rot *(Sclerotium cepivorum)* *Fusarium* *Ditylenchus dipsaci* Onion fly *(Delia antiqua)* *Pratylenchus penetrans*
Apiaceae (e.g. carrot, parsley)	1:8	Soil borne fungal diseases (e.g. black spot disease, *Sclerotinia)* Carrot fly *(Chamaepsila rosae)* *Pratylenchus penetrans*
Beta vulgaris (e.g. sugar beet, red beet)	1:5	Beet cyste nematode *(Heterodera)* *Cercospora* *Rhizoctonia solani* *Verticillium*
Hordeum vulgare (barley)	1:2	*Rhynchosporium secalis* Net blotch *(Pyrenophora teres f. teres)* *Heterodera avanae* *Meloidogyne naasi* *Wheat balb fly (Delia coarctata)*
Triticum (e.g. winter wheat, summer wheat)	1:2	*Gaeumannomyces graminis f. sp. tritici* *Meloidogyne naasi* *Pyrenophora tritici-repentis* *Wheat balb fly (Delia coarctata)* *Pseudocercosporella herpotrichoides* *Saddle gall midge (Haplodiplosis marginata)*
Leguminosae (e.g. pea, broad bean, field bean)	1:6	Soil borne fungal diseases (e.g. foot rot diseases, *Sclerotinia)* *Pratylenchus penetrans* *Ditylenchus dipsaci*
Cruciferae/ Brassicaceae (e.g. rapeseed, cabbage)	1:4	*Sclerotinia sclerotiorum* *Verticillium dahliae* *Phoma lingam* *Plasmodiophora brassicae*
Zea mays subsp. mays (maize)	1:3	Soil borne fungal diseases *(e.g. Fusarium, Pythium)*

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STEPS TOWARDS A GOOD CROP ROTATION

The design of a crop rotation is determined by local conditions but general steps apply, as explained in the Best4Soil video (LINK to video 12, crop rotation). Planning the rotation is balanced by management decisions at farm and field level on an annual and multi-year basis. Normally, a crop rotation is made for each field based on the biology (e.g. nematode infestation levels) and then adjusted at farm level:

- to the amount of products you want to harvest from each crop in a year;
- to spread the risk evenly (income depending on multiple crops);
- to meet the market demand.

The following general steps apply:

- Determine whether you have problems with nematodes. Consider to apply soil analysis to determine the **infestation level of plant parasitic nematodes.**
- Consider the **fungal pathogens** you expect, since only a few can be analysed.
- **Decide which cash crops** you want to focus on and which varieties. Some **varieties** of the same crop can be less susceptible or even resistant for certain pests and diseases while others even multiply a nematode species.
- Make **a first design** in which you grow each crop preferably above the minimum frequency (table 1). Include the rotation of the past years.
- Use the Best4Soil online tool (LINK to Best4soil tool database) to see which nematodes and soil borne fungi are related to your crops and adjust your scheme:
    - **Alternate a host-plant by a non-host-plant** for at least 1 crop cycle. Growing a crop which is sensitive to an expected or already present nematode after a non-host plant, lowers the risk that the concerned nematode prevails.
    - If you have a **high infestation level** of a certain nematode, consider how to reduce this. For some nematodes you can grow specific crops which eliminate the species
    - Be aware that certain species can be good prevention against one nematode or disease, but at the same time be susceptible to another.
- **Consider crop characteristics.** Crops with specific characteristics can benefit from each other if planned wisely, such as a legume crop which fixes nitrogen in the soil, which is later consumed by a high nitrogen demanding crop.
- **Integrate** other best practices in your management to maintain and improve soil health, such as cover crops.

When considering the risks from table 1, depending on your region a good crop rotation can be designed like the examples given in table 2 and 3 for farms in The Netherlands and Spain. Here you also see how local factors influence your rotation, such as economic reasons. In table 2 for example, there was decided to grow the main crop potato with a frequency of 1:4 instead of the advised minimum of 1:5 because of its relatively high profit and a low risk was expected based on nematode analysis result. In table 3 the rotation was mainly based on the nutrient requirements.

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Table 2. Example of a good crop rotation for a farm on a light silty loam soil in The Netherlands, with potato, carrot, sugar beet, winter wheat and onion as main cash crops (GM = green manure). From a nematode analysis from this field follows there is a high risk for Trichodorus. Some fields have more light soils (sandy) and others heavier soils (more clay), resulting in a slightly different rotation.

<table>
<tr><th>SOIL PROPERTIES</th><th>FIELD</th><th colspan="2">YEAR 1</th><th colspan="2">YEAR 2</th><th colspan="2">YEAR 3</th><th colspan="2">YEAR 4</th><th colspan="2">YEAR 5</th><th colspan="2">YEAR 6</th><th colspan="2">YEAR 7</th><th colspan="2">YEAR 8</th></tr>
<tr><td>Clay</td><td>A1</td><td rowspan="2">Potato</td><td rowspan="2"></td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM grass</td><td>Onion</td><td>GM Mustard</td><td rowspan="2">Potato</td><td rowspan="2"></td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM grass</td><td>Onion</td><td>GM Mustard</td></tr>
<tr><td>Clay</td><td>A2</td><td>Carrot</td><td></td><td>Carrot</td><td></td></tr>
<tr><td>Clay</td><td>B1</td><td>Onion</td><td rowspan="2">GM Mustard</td><td rowspan="2">Potato</td><td rowspan="2"></td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM grass</td><td>Onion</td><td rowspan="2">GM Mustard</td><td rowspan="2">Potato</td><td rowspan="2"></td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM grass</td></tr>
<tr><td>Clay</td><td>B2</td><td>Carrot</td><td>Carrot</td></tr>
<tr><td>Sandy</td><td>C1</td><td rowspan="2">Wheat</td><td rowspan="2">GM Radish</td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM grass</td><td>Onion</td><td>GM Mustard</td><td rowspan="2">Wheat</td><td rowspan="2">GM Radish</td><td>Carrot</td><td></td><td rowspan="2">Potato</td><td rowspan="2">GM mix</td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td></tr>
<tr><td>Sandy</td><td>C2</td><td>Carrot</td><td></td><td>Onion</td><td>GM mix</td></tr>
<tr><td>Sandy</td><td>D1</td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM Radish</td><td>Onion</td><td>GM Mix</td><td rowspan="2">Potato</td><td rowspan="2">GM mix</td><td rowspan="2">Sugar beet</td><td rowspan="2">Wheat</td><td rowspan="2">Wheat</td><td rowspan="2">GM Radish</td><td>Carrot</td><td></td><td rowspan="2">Potato</td><td rowspan="2">GM mix</td></tr>
<tr><td>Sandy</td><td>D2</td><td>Carrot</td><td></td><td>Onion</td><td>GM Mix</td></tr>
</table>

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Table 3. Example of a good crop rotation for one year of a farm on a sandy soil in South of Spain. In red = main crops (high nutrients requirements). In green = secondary crops (low nutrient requirements). In black = Green manure.

YEAR 1		YEAR 2		YEAR 3		YEAR 4	
Cauliflower	Green manure	Pepper	Onion	Melon	Cabbage	Tomato	Carrot
Corn	Lettuce	Potato	Carrot	Green bean	Green manure	Eggplant	Onion
Peanut	Chard	Corn	Lettuce	Potato	Watermelon	Lettuce	Green bean
Pumpkin	Broad bean	Green manure	Cabbage	Pepper	Onion	Corn	Lettuce

MANAGING DISEASES AND PESTS WITH CROP ROTATION

Important pests to manage with a rotation are nematodes, tiny worms living in water (either in rivers, seas, soil or animals). There are thousands of soil borne nematodes, which are fortunately not all harmful. Whether nematodes become a problem depends on:

- Host range: Nematodes need specific host plants to survive and multiply. The range of host plants vary from very wide to narrow
- Mobility: Nematodes can be introduced and spread through the soil, water bodies, machinery, human or animals entering the field
- Persistence: Different species can be very sensitive to very persistent to survive
- Damage: Nematodes harm crops by feeding on them but also by spreading diseases

Managing diseases and pests successfully requires information on:

- How long a pathogen survives in the soil
- How the pathogen can survive: on which crops and how they survive between susceptible crops
- How it spreads or can be introduced
- Which other plant species can be affected by the disease or pest

If you recognize the damage (figure 2) of pests and diseases you have a better starting position to:

- Take samples to check for nematodes or diseases
- Cure the spot in the parcel where the damage is observed. For the current season it is mostly too late to solve the issue, but for the next season this is important information.

Figure 2. Damage to crops by pests and diseases: a) Fusarium in onion (middle onion plant), b) Verticillium in strawberry, c) Rhizoctonia solani solani in lettuce, d) Sclerotium cepivorum in onion.

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MANAGEMENT PRACTICES WITHIN THE ROTATION

You can utilize your crop rotation also for other reasons, e.g. to enhance soil fertility. By choosing certain crops, especially green manures and cover crops, you can focus on the following to enhance soil fertility:

- Use of perennials
- Cover crops and green manure
- Deep-rooting crops that bring back nutrients from deeper soil layers
- Permanent soil cover to prevent leaching and erosion
- Legumes to fix nitrogen
- Cash crops with additional benefits (e.g. wheat)

Furthermore, a rotation design can include weed management. For example soil cover between the main crops can prevent weeds to germinate. Also the weed species should be considered in the rotation since they can be host plants for nematodes.

A GOOD ROTATION: A COMBINATION OF PRACTICES, INSIGHT AND FLEXIBILITY

Planning a crop rotation can be very simple but planning a good one in which high economic profit is reached along with maintaining a healthy soil is a challenge. Integration with best practices, knowledge on the site-specific situation and smart use of tools like the Best4soil databases however form a good basis for a healthy crop rotation, ensuring productive soils on the long run.

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Introduction on the use of the Best4Soil databases

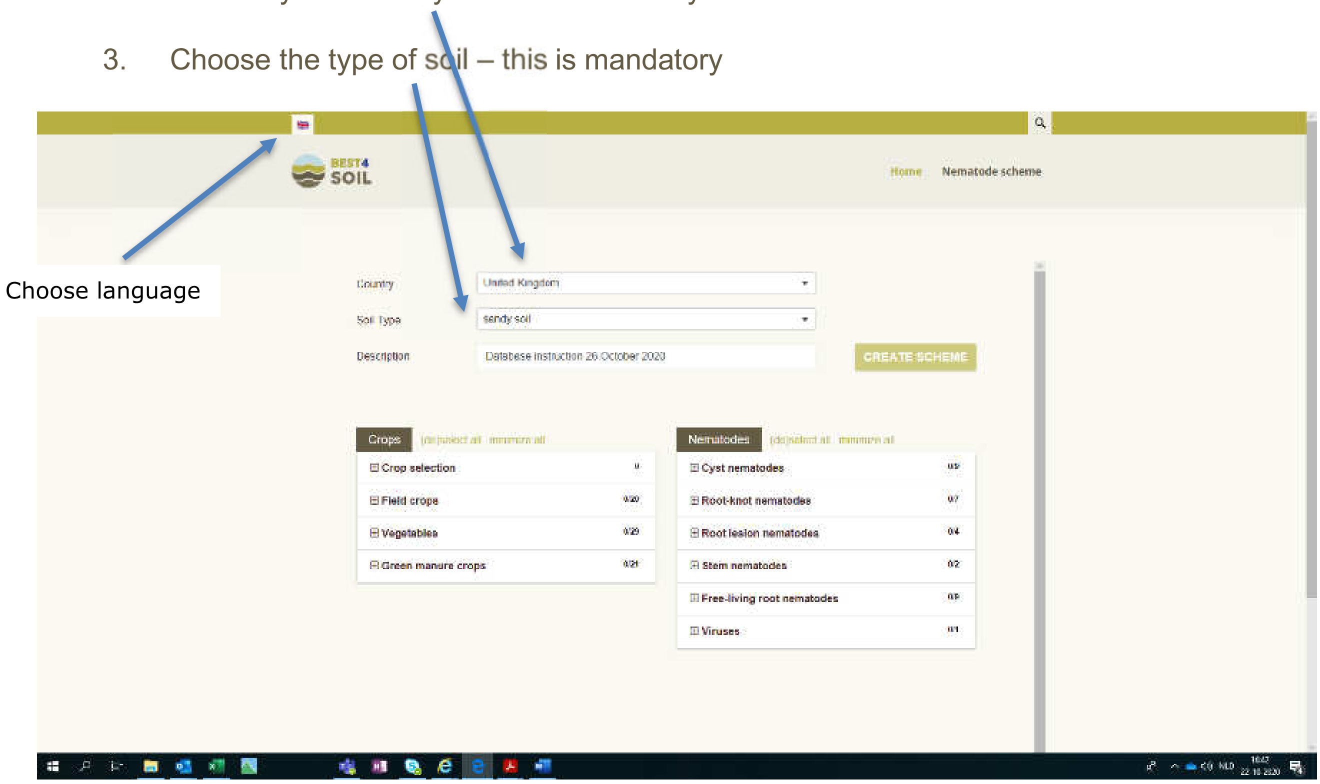
Best4Soil provides information on the host status and damage sensitivity of crops for a large number of nematode species and soilborne pathogens.
The approach is based on the concept of Wageningen UR | Field Crops – www.aaltjesschema.nl
Based on this information you can determine the optimal order to grow the different crops. The trick is to grow a poor host plant preceding a crop that is damage-sensitive to this pest or pathogen. In this way the contamination levels in the year of cultivation of the damage-sensitive crop are low and no damage occurs.
The other way round, of course it is not a problem if the infection levels are high at the moment a crop is grown that is not affected by it.
The tool is currently available in 22 languages. The tool contains 70 crops, 32 nematode species and 138 soilborne pathogen species. Each nematode-crop combination will get a background page (WIKI) with additional information, photos and do's and don'ts. Also, each pathogen will be provided with such a WIKI page.

The working method for the nematode scheme and the pathogen scheme is the same. Click on the DATABASE (PATHOGENS) > or DATABASE (NEMATODES) > button on the bottom of this page and the tool of your choice appears:

1. Choose your language – by choosing a flag, above the Best4Soil logo

2. Choose your Country – this is mandatory.

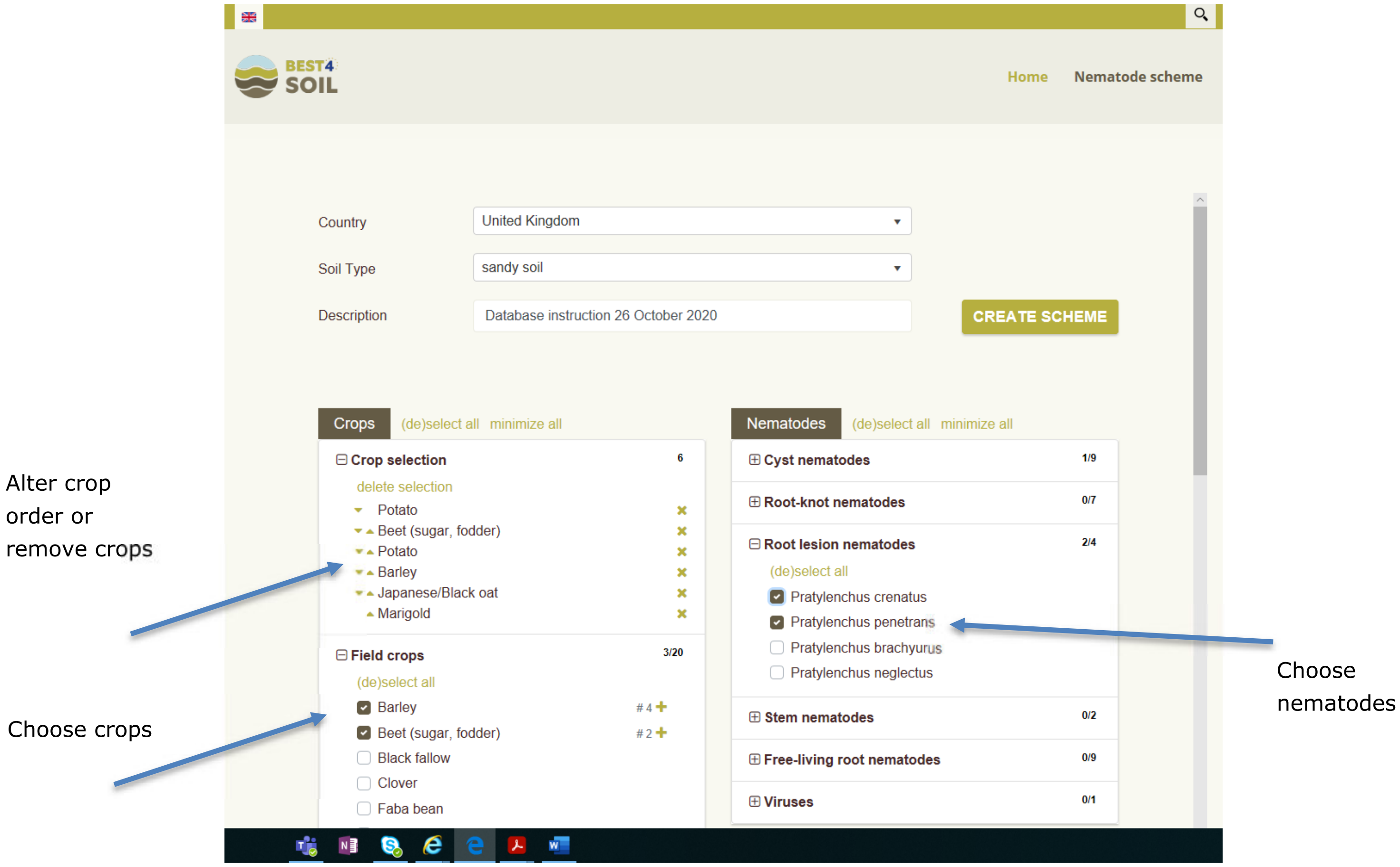
3. Choose the type of soil – this is mandatory



4. Choose the crops you are growing now or would like to grow. You can choose the same crop several times by clicking on the plus sign.

5. Now you can open the Crop selection above the selected crops. You can change the crop order with the arrows or remove a crop with the cross.

6. Choose the nematodes or soil pathogens that are present in the field. **Do not pick more than 30 soil pathogens at a time.** This could adversely affect the readability of the document. In that case, create a second scheme.



7. Press the CREATE SCHEME button

8. Open the pdf to view the result.

BEST4 SOIL

Nematode scheme 2020

Date : Thursday, October 22, 2020
Country : United Kingdom
Description : Database instruction 26 October 2020
Soil Type : sandy soil

Click on a cell for background information about the crop / nematode combination

	Cyst nematodes				Root-knot nematodes							Root lesion nematodes				Stem nematodes		Free-living root nematodes		
	Globodera rostochiensis / G. pallida Potato cyst nematode	*Heterodera avenae* Cereal cyst nematode	*Heterodera betae* Yellow beet cyst nematode	*Heterodera schachtii* Beet cyst nematode	*Meloidogyne arenaria* Peanut root-knot nematode	*Meloidogyne chitwoodi* Columbia root-knot nematode	*Meloidogyne fallax* False columbia root-knot nematode	*Meloidogyne hapla* Northern root-knot nematode	*Meloidogyne incognita* Cotton root-knot nematode	*Meloidogyne javanica* Sugarcane root-knot nematode	*Meloidogyne naasi* Barley root-knot nematode	*Pratylenchus brachyurus* Pratylenchus brachyurus	*Pratylenchus crenatus* Cerial rootlesion nematode	*Pratylenchus neglectus* Sugarbeet lesion nematode	*Pratylenchus penetrans* Northern root lesion nematode	*Ditylenchus destructor* Potato rot nematode	*Ditylenchus dipsaci* Stem nematode	*Trichodorus primitivus* Stubby-root nematode	*Trichodorus similis* Stubby-root nematode	
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	
Potato	●●●	-	-	-	?	●●●	●●●	●●●	?	?	-	?	●	?	●●●	●●● R	●●●	●●	●●●	Potato
Beet (sugar, fodder)	-	-	●●● R	●●● R	●●	●	●●●	●●●	●● R	●● R	●	?	●	?	●	-	●●●	●●	●●●	Beet (sugar, fodder)
Potato	●●●	-	-	-	?	●●●	●●●	●●●	?	?	-	?	●	?	●●●	●●● R	●●●	●●	●●●	Potato
Barley	-	●●●	-	-	?	●●	●	-	?	?	●●●	?	●●●	?	●●	-	-	●●	?	Barley
Japanese/Black oat	-	?	?	?	?	●●●	?	?	?	?	●	?	?	?	-	?	?	?	?	Japanese/Black oat
Marigold	-	-	-	-	?	-	-	-	●● R	●● R	-	●● R	?	?	-	?	?	?	?	Marigold

Legend damage	
	unknown
(green)	none
(yellow)	little (0-15%)
(orange)	medium (16-35%)
(magenta)	serious (36-100%)

Legend propagation	
--	active decline of population
?	host plant suitability unknown
-	non host
●	poor host
●●	moderate host
●●●	good host
R	variety dependent
S	serotype dependent
i	some information

Legend soil type	
1	sandy soil
2	reclamed peat soil
3	sandy clay loam
4	clay soil
5	silty soil (loess)

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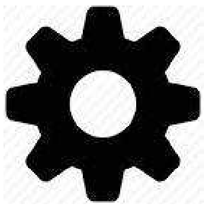
9. **Troubleshooting:**
If you press the CREATE SCHEME button and nothing happens:

- Make sure you choose a country and a soil type, these are mandatory
- Check for an ad blocker or pop-up blocker and turn it off (usually found under the gear icon)



- Don't use Internet Explorer but choose another browser like Google Chrome, Mozilla Firefox or Microsoft Edge.

For more help, questions or feedback: Paulien van Asperen, paulien.vanasperen@wur.nl

An instruction video on how to use the tool is available here

Authors: Miguel de Cara García (IFAPA, Spain), Vincent Michel (Agroscope, Switzerland)

(BIO)SOLARISATION: PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on (Bio)Solarisation: Practical information.

INTRODUCTION

Solarisation is a soil disinfection method consisting of covering a moistened soil with a thin transparent plastic film, for 4-6 weeks during the part of the year with the highest sun radiation and temperatures. Solarisation increases soil temperature and produces changes in the microbial soil community as well as the chemical and physical properties of the soil. It is a method commonly used in the greenhouses of Southern European countries in summer, with the aim of 'enhancing' the health of the soil for the next crop, at the same time reducing the level of harmful soilborne pests.

WHEN SHOULD A SOIL BE SOLARISED?

Solarisation is applied when the presence of pests in the soil can potentially limit the profitability of the subsequent crop. These pests include fungi, nematodes, bacteria, insects and weeds. Moreover, mono-cropping practice can lead a soil to become fatigued, so solarisation can help to re-establish the health of the soil, and recover the fertility of the soil. The cost of this technique is comparatively high, so economically it is usually only appropriate for intensive crop systems.

STEPS TOWARDS A GOOD SOLARISATION

The efficacy of soil solarisation is determined by local conditions, but in general steps to achieve a good solarisation, as explained in the Best4Soil video (LINK to videos 14 and 15, solarisation) are consistent to all locations. The longer the solarisation is in place, the better the expected results. It is recommended to leave soil solarising for **at least 4 weeks, however 6 weeks are better**. The preferred period for carrying out a solarisation ranges between 15th June and 1st September at Mediterranean latitudes.

Sufficient moistening of the soil is required. Irrigating the soil close to water saturation before and/or after the film deployment will assure good heat transmission to all the parts of the soil. Soil water saturation can be assured with tensiometers measuring between 0-10 cb (fig. 1). Additionally, tensiometers at different depths can help to avoid uneven moisture throughout the soil and leaching of nutrients (fig. 2).

Fig. 1: Tensiometers to measure the soil humidity during solarisation. The left one is placed at 15 cm-depth, and the right one at 35 cm-depth.

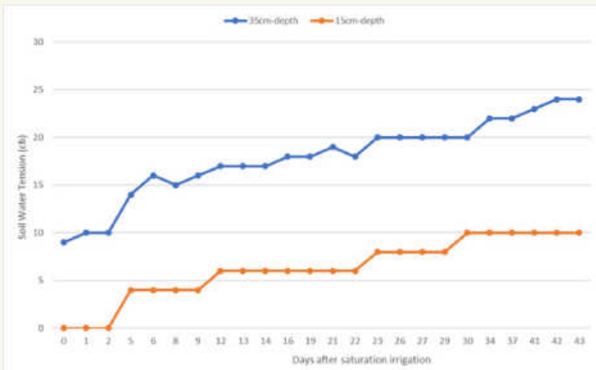


Fig. 2: Evolution of soil water tension at two depths during solarisation.

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A **transparent film** is used to allow the sun radiation to penetrate into the soil, heating the water in the saturated soil. Polyethylene is the most common material used for the films, with a thicknesses between 0.25-0.325 microns recommended. Some films for solarisation include layers with specific products to increase the impermeability or to reduce condensation, thus improving the efficacy of the solarisation treatment.

A high air tightness is required to avoid losses of heated air from the soil. To achieve this, the edges of the films are covered with soil once they are deployed (fig. 3). If possible, the films can be overlapped but firmly joined. The use of staples after rolling two films is a good and simple technique to do it (fig. 4). In greenhouses with posts, sealer tape can help to fix the film edge to the post.

Fig. 3: After deploying the film, edges are covered with soil or other material, to avoid losses of heated air.

Fig. 4: Sealing of film layers can be carried on by stapling.

Shades in greenhouses reduce the light interception by the soil, so they have to be rolled back or removed. Also, if white paint was added to shade the greenhouse, it has to be washed off before solarisation.

The majority of soilborne pathogens are thermally inactivated when exposed for 30 minutes to temperatures ranging between 45-55 °C (table 1). These temperatures are easily reached at 15 cm-depth in well solarised soils.

TABLE 1: THERMAL INACTIVATION OF SEVERAL SOILBORNE PATHOGENS.

Adapted from Jarvis R. J. (1997). Managing Diseases in Greenhouse Crops, APS press, USA.

Pathogen	Temperature (°C)	Exposition time (min)
Botrytis cinerea	55	15
Cylindrocarpon destructans	50	30
Fusarium oxysporum	57	30
Phialophora cinerescens	50	30
Phytophthora cryptogea	50	30
Pythium sp.	53	30
Rhizoctonia solani	53	30
Sclerotinia sclerotiurum	50	5
Verticillium dahliae	58	30
Heterodera marioni	48	15
Meloidogyne incognita	48	10
Pratylenchus penetrans	49	10

The addition of fresh organic matter into the soil before solarisation is called biosolarisation. This practice can increase the efficacy of solarisation as the incorporation of organic matter improves the health of the soil and the amount and diversity of non-pathogenic microorganisms in the soil. The incorporation of the organic matter (C/N ratio of 8 – 20) in combination with the excess water supplied starts a fast decomposition that produces biocidal/biostatic products (ammonium, polyphenolics, fatty acids,…) for 2-3 days. At the same time aerobic microorganisms that consume available oxygen are highly stimulated and this induces the soil microbial community to shift to facultative and obligate anaerobes. As the soil is covered and there is abundant water, oxygen cannot be supplied, so there are three factors, added to the high temperature, affecting plant pathogens in this first stage: (1) the lack of oxygen, (2) the abundance of competitors and (3) the presence of toxic compounds. Once these immediate effects dissipate, there is a longer second stage in which the microbial population decreases, but the balance between saprophytic and pathogenic microorganisms moves in favour of saprophytic. As time

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goes by the soil moisture level decreases and the oxygen content increases. Other biocidal molecules are released once the moisture levels decrease. After this, saprophytic microorganism populations increase and establish as there is organic matter available. Additionally, a soil colonization by the surrounding environmental microbiota is possible. Niche and resource limitations for soil microbiology appear; competition and fungistasis* phenomenons are observed.

* Fungistasis: restriction of fungal propagules to a certain extent in their ability to grow or germinate.

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(BIO)SOLARISATION: ADVANTAGES AND DISADVANTAGES

This factsheet contains complementary information to the Best4Soil video on (Bio)Solarisation: Advantages and disadvantages.

Biosolarisation has been evaluated in the last years, showing great results in several crops to manage soil borne diseases.

For **strawberry** crops, several materials have been tested in different countries, showing promising results when applying biosolarisation with available fresh poultry manure (FPM) to control fungi and nematodes (López-Aranda et al., 2012; Zavata et al.,2014) (fig.1).

Fig. 1: Strawberry field trial during biosolarisation and subsequent (healthy) crop.

For more than ten years, biosolarisation has been tested and improved, to a stage where it is now implemented by greenhouse **flower** growers in the province of Cádiz (South of Spain). Initial trials showed a complete control of *Fusarium oxysporum* f. sp. *dianthi* when a mix of FPM and fresh flower plant residues were incorporated into the soil, deep irrigated and solarised with polyethylene film (García-Ruíz et al., 2012). Follow on trials repeated the successful control Fusarium wilt of carnation and *Meloidogyne incognita*, using only 5 kg/m2 of FPM (Melero-Vara et al., 2012).

For more than 20 years, bell **pepper** has been subject of investigation to identify alternatives to methyl bromide, with many different methods and products being tested.

Results of this long period of trials show that biosolarisation is the best alternative to control *Phytophthora capsici* and P. *parasitica* as well as *Meloidogyne incognita* (Martínez et al., 2006; Ros et al., 2008). Also soil fatigue was reduced when biosolarisation was conducted. The biosolarisation was performed in these trials using the following approach. Easily available fresh sheep manure (FSM) was mixed with fresh pepper residues and/or FPM. The dosage of organic matter was reduced as the treatment is repeated year after year: FSM+FPM: 5+2.5 kg/m2 (1st year), 4+2 (2nd year), 3+1.5 (3rd year), 2+0.5 (4th and later years) (Martínez et al., 2011). In these studies, the biosolarisation is highly effective when applied in Summer (fig.2).

Fig. 3: Healthy pepper crop after biosolarisation of soil with Meloidogyne spp.

Recent trials in greenhouses cultivated with **tomatoes** or **cucumbers**, have shown comparable results to those exposed above. Soil fatigue, knot-root nematodes, *Phytophthora parasitica, Fusarium solani* f. sp. *cucurbitae* and *Fusarium oxysporum* f. sp. *radicis-cucumerinum* are

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some diseases that have been controlled by means of incorporating fresh organic matter (mostly a mix of plant-crop residues and fresh manure) followed by a deep irrigation and tarping with transparent polyethylene or Virtually impermeable film (VIF). Some growers sow mustard and other Brassicas on their own farms to mix with fresh manure and/or crop residues, and in many cases the biosolarisation is performed only on the plantation rows (cropping areas), which reduces the consumption of plastic and organic matter (LINK to Videos Biofumigation) (Martín-Expósito et al., 2013; García-Raya et al., 2019; Gómez-Tenorio et al., 2018) (fig. 3).

Fig. 3: Tomato field trial during biosolarisation and subsequent (healthy) crop.

LIMITATION TO SOUTH EUROPE?

Solarisation is traditionally used in Southern Europe, where long periods of sunshine are sufficiently present. At the beginning of the solarisation process, it is especially important that several days continuous sunshine occurs. It is at this point that the temperature in the first soil layer has to be raised as fast as possible to kill weed seeds. Otherwise, weeds will grow and push the plastic film upwards, thereby strongly reducing the warming effect of solar radiation on the soil. Therefore, solarisation is a technique not fully suited to northern countries of Europe. However, with the increasing temperatures during the last years (fig. 4), and especially very warm and sunny summers, the solarisation method might become achievable for certain regions in the central part of Europe. The efficacy of the process can furthermore be increased by applying the biosolarisation method i.e., adding easily degradable organic matter to the soil before covering with the plastic film. In regions where solarisation is not used, the potential of this best practice could be a topic for a community of practice i.e., a group of persons who share knowledge on a specific topic. The creation of such a community of practice is supported by the Best4Soil network by organizing a workshop dealing with the concerned topic. If you are interested, then contact Best4Soil (contact form is on www.best4soil.eu).

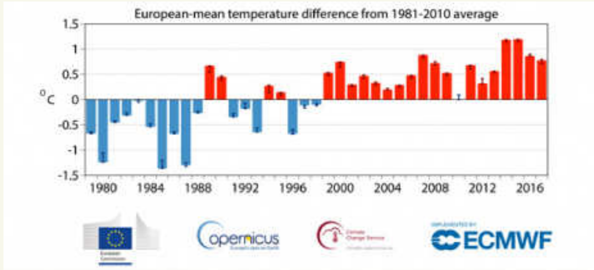

Fig. 4: Evolution of the mean air temperature in Europe (Source: https://climate.copernicus.eu/climate-2017-european-temperature).

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PRACTICAL INFORMATION FOR SOIL HEALTH

This factsheet contains practical information for soil health

MAINTAIN AND STIMULATE SOIL HEALTH

Soil health is of major importance to grow high yielding crops and to harvest high quality products. Different factors promote a healthy soil which is more resilient to constraints such as pests and diseases (figure 1). A resilient soil means that the soil is capable to resist or recover its healthy condition in a response to these constraints.

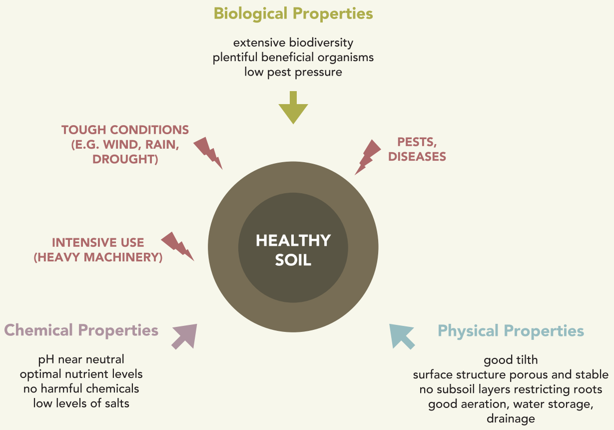

Fig.1: A healthy soil is promoted by both physical, biological and chemical properties. (Content from Building Soils for Better Crops, 3rd Edition, SARE, 2009)

Farmers have influence on soil health by management practices:

- Healthy crop rotation (link to factsheet / video crop rotation)
- Management of soil flora and fauna to increase the soil biodiversity.

The Best4soil Video on Soil Health (link to video 16) shows what soil health is and gives an overview of measures you can take to build or maintain a healthy soil. Here we describe further how the soil food web and management practices lead to a healthy soil with a good productivity.

SOIL BIODIVERSITY FOR SOIL HEALTH

Healthy soil ecosystems contain a high soil biodiversity. Sufficient soil organic matter (SOM) content is the basic factor for this because it is the first level of the soil food web (figure 2). To create or maintain a rich soil biodiversity it is important to feed all organisms active in the soil food web.

Organisms from the soil food web:

- Render plant nutrients by decomposing organic matter (bacteria and fungi);
- Contribute to a good soil aggregate stability and soil structure;
- Contribute to the water holding capacity;
- Contribute to disease suppressiveness (fungi, nematodes, bacteria, protozoa).

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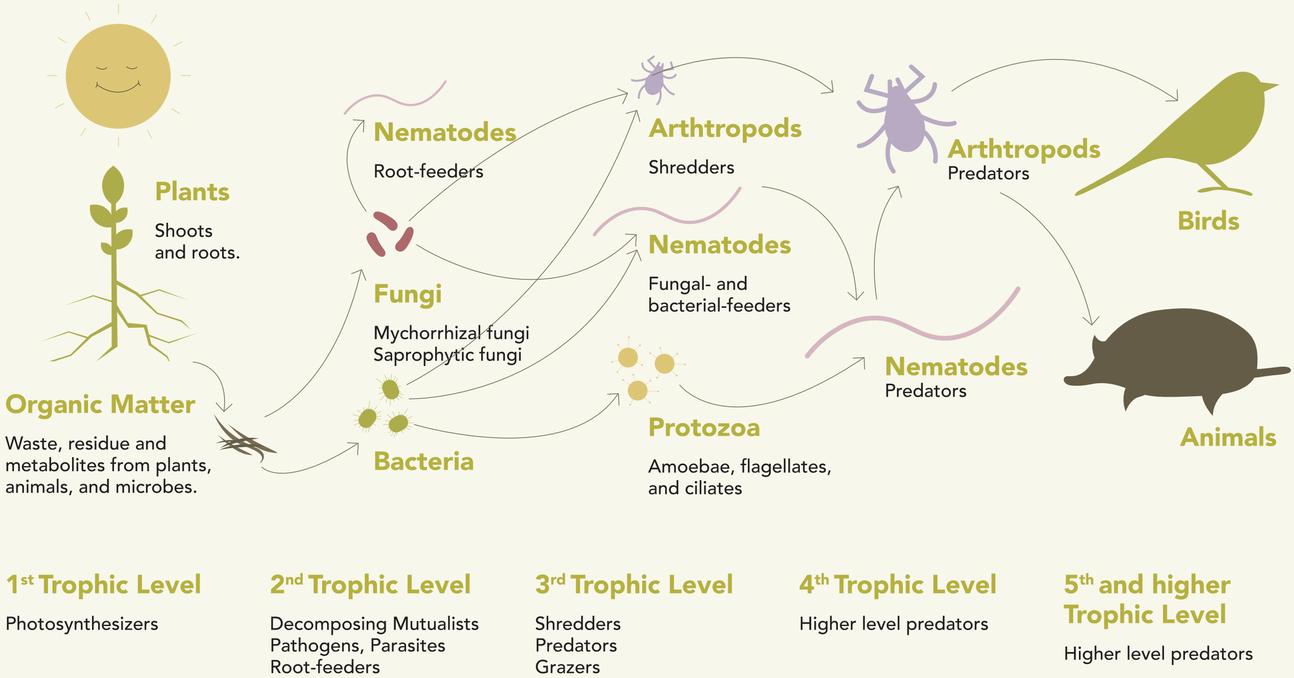

Fig. 2: The soil food web (Modified from: USDA Natural Resources Conservation Service)

For a rich soil biodiversity a yearly and sufficiently high input of organic matter (OM) is necessary to compensate for the yearly breakdown of SOM (figure 3). The type of input differs in OM content and influences the development of the various types of soil life. Therefore, a balanced input of different sources of organic matter is required.

The most important sources of OM are:

- Crop residues
- Animal manure
- Green manure
- Cover crops
- Compost
- Vermicompost

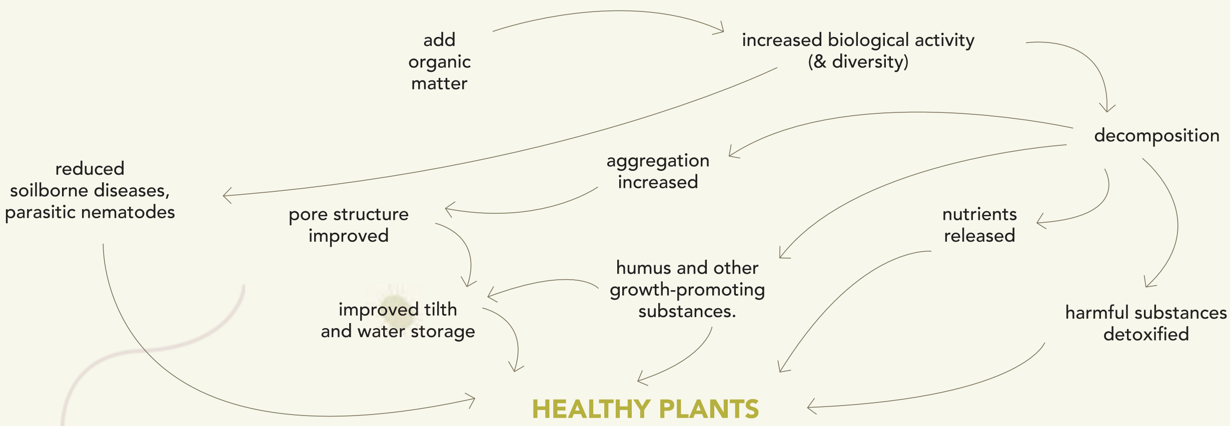

Fig. 3: Modified by SARE (https://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition) from Oshins and Drinkwater (1999)

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CONTRIBUTION OF SOM TO SOIL HEALTH

Also the degradation rate of SOM (the speed at which soil organisms break down SOM) depends on the type of material. An important characteristic of the material is the balance between carbon (C) and nitrogen (N) expressed in the C/N ratio.

It indicates the ease of decomposition and the balance between two fractions in SOM: (fig. 4)

- Active organic matter (including microorganisms)
- Resistant or stable organic matter (humus).

Both fractions have specific functions for a healthy soil:

- The active fraction which is easily decomposed contributes to the biological and chemical soil fertility while;
- The resistant or stable fraction mainly contributes to the physical soil fertility, by improving the nutrient and water holding capacity.

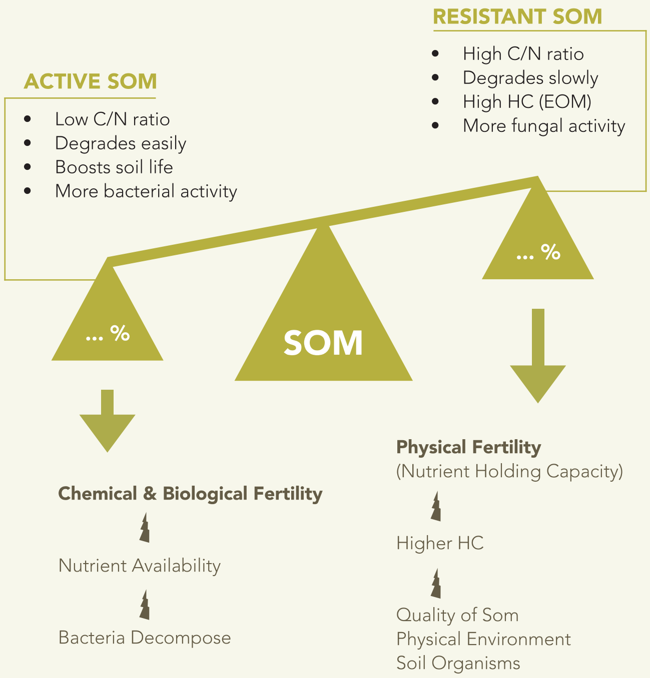

Fig. 4: Soil organic matter (SOM) characteristics and underlying processes. C = carbon, N = nitrogen, HC = humification coefficient, EOM = effective organic matter.

Therefore, a balanced input of different sources of organic matter is required.

Materials such as wood are more resistant and have a higher C/N ratio, which results in a slower degradation. The amount of SOM still present in the soil 1 year after application is called the effective organic matter (EOM). The factsheet about Soil organic matter (LINK TO FACTSHEET SOIL ORGANIC MATTER) shows the amount of EOM for different sources of OM.

HUMUS

A large proportion of the SOM is decomposed into inorganic minerals that plants absorb as nutrients (mineralisation). Another part (the very stable part) of the SOM does not mineralize and is transformed into humus through humification: The very stable part of the organic matter will be incorporated into the soil by soil life and becomes a permanent part of the soil structure. The mixture of compounds and biological chemicals in humus has many functions for soil health. An indication of the degradation rate of SOM is the humification coefficient (HC): the fraction of EOM to the total SOM.

The HC is mainly determined by:

- Soil organisms
- Physical environment and
- Quality of the SOM

The higher HC, the more stable is the SOM. Compost for example is very stable and has a high HC (0.9, table 1).

Table 1. Humification coefficient (HC) from a few organic amendments

Source	HC
Green plants	0.20
Plant roots	0.35
Straw	0.30
Slurry from dairy cows	0.70
Slurry from pigs	0.33
Stable manure cows	0.70
Plant material based compost	0.90

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RESILIENCE AGAINST SOIL BORNE DISEASES

Healthy soils can show suppressiveness against infestation with soil borne pathogens. Soil suppressiveness to pathogens is defined as the capacity of soil to regulate soil-borne pathogens. Soil suppressiveness relates to the activity, biomass and diversity of soil organisms. It is based on the capacity of non-pathogenic constituents of soil and rhizosphere microbiomes to compete with and be antagonistic to pathogens. Soil suppressiveness can be managed by agricultural practices, but the effects reported so far remain inconsistent (Bongiorno et al., 2019).

Soil suppressiveness across 10 long term experiments was linked mainly to microbial biomass and labile carbon in the soil, but not to total soil organic matter content (Bongiorno et al., 2019). The conclusion is that labile carbon is important for the maintenance of an abundant and active microbial community, which is essential for soil suppressiveness. However, soil suppressiveness could only partly (25%) be explained by the soil parameters measured, suggesting that other mechanisms contribute to soil suppressiveness such as the presence and activity of specific bacterial and fungal taxa with high bio control activity.

Low C/N ratio stimulates bacterial growth; higher C/N ratios more stimulate fungal growth.
Depending on this ratio, microbes will, on the short term, mineralise or immobilise soil N:

- C/N >25: microbes will take up soil-N (immobilisation)
- C/N <25: microbes will release soil-N (mineralisation).

Green manure is relatively easy to decompose and gives a boost to micro-organisms in the soil. Bacteria are active in decomposing green manures, with the result that nutrients become available for plants. Fungi are better equipped to break down more stable forms of organic matter such as lignin and cellulose. Depending on the C/N ratio N-immobilisation on the short term can be the case.

The fungi/bacteria ratio in the soil gives an indication of the status of SOM:

- Fields with input from manure, with many easily decomposable material show more bacterial activity while;
- Soils with input from more stable compost show more fungal activity (Leroy et al., 2009).

RESILIENCE AGAINST SOIL COMPACTION

A healthy soil is more resilient to intensive use such as heavy machinery, causing soil compaction. The soil particles are then packed closer together, especially under wet conditions. Prevention is better than treating it. A healthy soil is more resilient to the high pressure and has better water infiltration which also lowers the risk. Thus, preventive measures as proposed by Best4Soil help to build and maintain a healthy soil but also other measures such as prevention of soil compaction should be taken to get the most out of your soil.

SOIL HEALTH PROBLEMS

When soil borne diseases cause problems in practice there are a few measures that can help to solve the problem: anaerobic soil disinfestation (ASD) and bio-solarisation. See for more information Best4Soil video's and fact sheets on these topics. In any case, the combination of preventive practices that support the soil biodiversity and a backup of curative practices is a strong basis for a healthy thus productive soil (figure 5).

Fig. 5: Healthy plants in healthy soils (Source: WUR)

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SOIL BORNE DISEASES: PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on Soil borne diseases: practical information.

Soil borne diseases are caused by soil borne pathogens, a group of microorganisms that can cause the reduction or limitation of yield in intolerant crops. Soil borne pathogens include nematodes, fungi, bacteria and even viruses.

Once soil borne pathogens are present in a soil, they can be controlled by chemical soil fumigation. However, fumigation is expensive (it is not economically feasible for extensive or open field crops) and non-selective (the majority of the living organisms within the soil, including beneficial and saprophytic[1] microorganisms are also reduced after fumigation). Avoiding outbreaks of soil borne diseases can be achieved if a soil health strategy is adopted (LINK TO FACSHEETS EIP AGRI: https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_infographic_soil_health_2015.pdf). Soil health is maintained or increased by means of the 4 Best Practices of Best4Soil.

NEMATODES AND FUNGI

These two groups of organisms include the majority of the soil borne pathogens that are economically relevant. In Best4Soil database (LINK) you can find information on the nematodes and soil borne fungal pathogens of the main field crops, vegetables and green manure crops grown in Europe.

Nematodes are small worms, mostly microscopic in size, which are impacted by soil temperature and moisture content. Therefore, there are some species more adapted to the environmental conditions of Southern Europe and others to Northern Europe conditions. Nematodes prefer sandy soils but some species are also common in clay soils. It is crucial to understand their life cycle. Some species have specific root-infective motile stages, and adult females that are non-motile (fig. 1).

[1] Saprophytic organisms are involved in the degradation of dead organic matter in soil.

Fig. 1: Non motile females of a cyst nematode (*Heterodera schachtii*) breaking out of cabbage roots.

Fungal infections also depend on the soil temperature and moisture content. Oomycetes and Chitridia[2] are microorganisms that produce flagellate spores. These are spores able to swim in with water-filled pores of the soil, thus moving from diseased to no diseased roots, spreading the disease very efficiently. Moreover, most fungal pathogens produce quite resistant resting spores, which allow them to survive for longer periods in the soil. Such resting structures include chlamydospores, oospores, microsclerotia or sclerotia (fig. 2). There are reports of microsclerotia or cyst spores surviving in soils for more than 10 years.

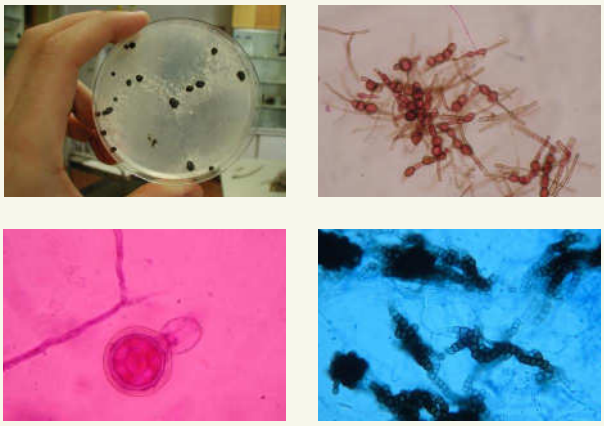

Fig. 2: Examples of resting structures of fungi (from top to bottom and left to right): Sclerotia; Chlamydospores; Oospores; Microsclerotia.

[2] Oomycetes and Chytridia were historically identified as fungi, however they are actually no more included in the Kingdom Fungi.

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Both nematodes and fungi can survive in soils by means of resting structures or bodies fixed to the detached roots after removal of an infested crop. This is a reason for planning precise crop rotations, to avoid the perpetuation of soil borne pathogens in a soil. You can learn about crop rotation in Best4Soil Video 12 (LINK). There are other practices that will help you to increase soil health, thus reducing the presence of soil borne pathogens and increasing the presence of beneficial organisms and increasing the fertility of your soil. These practices are covered by Best4Soil videos and factsheets. Visit our webpage for more information www.best4soil.eu

Fig. 4: Symptoms of root rot caused by *Colletorichum coccodes* Early stage (top) and late stage (bottom) on tomato root infection.

SYMPTOMS AND DIAGNOSIS

As soil borne pathogens are microscopic and inhabit the soil, their detection is difficult until symptomatic plants appear. Symptoms of soil borne diseases (also called telluric or edaphic diseases) may resemble other biotic or abiotic stresses, but the general appearance of affected plants is similar. They display symptoms such as wilt, chlorosis (yellowing of the leaves), dry leaves, epinasty, or plant decay. These visible symptoms of the above ground plant structures correspond to the damage caused by soil borne pathogens. They can be divided into 2 types: Damage of the roots and / or stem base and damage of the vascular system. Examples of the first type of damage are found for fungal pathogens such as *Pythium aphanidermatum* or *Colletotrichum coccodes* (fig. 3 and 4), but also for nematodes (fig. 5).

Fig. 5: Bad growing patches in onions caused by *Meloidogyne fallax*. Knots formed by the nematode visible on the roots.

Fig. 3: Symptoms of cucumber stem rot caused by *Pythium aphanidermatum.*

Damage such as this is caused by an infection of the roots by the pathogen, which destroys the roots and/or the crown of the plant so that it is unable to absorb or transport water and nutrients. Vascular diseases imply the colonization of the xylem of plants by a fungus, which clog the plant vessels, reduce the water pressure in the leaves and release toxins into the plant (fig. 6).

Fig. 6: Tomato xylem vessels showing necrosis caused by *Verticillium dahliae.*

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Wilting appears initially on the youngest leaves, and generally in the warmest hours of the day. As the development of the disease progresses, wilt is more evident throughout the day, sometimes even killing the plant completely (fig. 7). Chlorosis, necrosis or simply epinasties (green wilt with decay of plant organs) can appear before a general wilt symptom appears (fig. 8).

Fig. 7: Wilt prior to death of tomato plant.

Fig. 8: Epinasty in cucumber plant.

These symptoms can be easily confused with a lack of water, and can lead to more abundant and frequent irrigation, which itself can increase the rate and spread of infection in the case of a soil borne disease. Plants infected by soil borne pathogens appear in spots or within the crop rows, homogeneous and generalized affections covering an entire field are normally not observed at the beginning of disease development.

Diagnosis of the causal agent of the disease is essential, as different pathogens or other environmental reasons can produce similar symptoms. Some of the microscopical structures above mentioned can help to identify the pathogen, but specialised laboratories are required for a reliable diagnosis. The control of each pathogen will require a different solution, and the knowledge of the relationship hosts x pathogen is crucial for a successful control. Best4Soil provides knowledge on hostplant x pathogen or nematode relationship by the means of two databases (link to scheme).

BENEFICIAL AND SAPROPHYTIC ORGANISMS

It should be remembered that not only harmful microbes live in the soil, 99% of the microorganisms living in an agricultural soil are not pathogenic. The majority are saprophytic, which means that they are involved in the decomposition and mineralisation of dead organic matter, which is essential for maintaining soil fertility. Insects and mites initiate organic matter trituration, earthworms continue transforming the organic matter into humus, later nematodes refine the product, followed by fungi, which participate in the aggregation of organic matter, and finally bacteria proceed with the mineralisation and oxidation or reduction of minerals, making them available for the plant roots.

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SOIL ORGANIC MATTER

This factsheet contains complementary information to the Best4Soil video on Soil Organic Matter

INTRODUCTION

Soil consists of different materials. Even if the main fraction is mineral, the organic matter in soil plays a critical role in the functions of a healthy soil. The main functions (Schulte et al.,2014) in soil, such as primary productivity, water purification and regulation, carbon sequestration and regulation, biodiversity and nutrient cycling are all highly dependent on soil organic matter (SOM). The organic fraction in soil consists of approximately 58% carbon, which was mostly removed from the atmosphere through the photosynthetic activity of plants. Therefore, the level of SOM is not only critical for the soil and the farmer, but also for climate, environment and society as a whole. Depending on the type of soil, most organic matter levels in arable and vegetable production are between 1 to 6% of total soil mass. Even with such a small proportion, soil organic matter has a huge impact on most physical, chemical and biological characteristics of the soil.

SOM IMPACT ON PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERISTICS

Physical impact

If soil organic matter is raised in soil, the impact on physical characteristics is significant. Aggregate stability (fig. 1), and therefore water infiltration, water holding capacity as well as air and water distribution are all increased. A reduction in crusting and better pore spacing also result from increased SOM levels and can be monitored easily.

Chemical impact

Increased cation exchange capacity and therefore higher nutrient dynamics can be measured, if the organic matter in soil is increased. Plants and farmers benefit from higher total nutrient levels and faster nutrient mobilization for plant availability.

Fig. 1: Soil aggregate stability of two sandy loam soils with 7% SOM (left side) and 2% SOM (right side).

Biological impact:

Soil organic matter is not only a habitat for soil microorganisms and even larger organisms in soil, but it is also a food for them. The higher the level of SOM is, the more diverse and abundant life in the soil is. This not only results in more dynamic mobilization of nutrients for the plants, but also in better competition against soil borne diseases and therefore increases soil health.

In general, soil organic matter plays a critical role in making soils more resilient, that is the capacity of the soil to deal with negative effects from outside (e.g.: drought, harsh temperatures, compaction, pesticide pressure, ...).

HOW TO PROTECT EXISTING ORGANIC MATTER IN SOIL

Protecting soil organic matter is therefore critical for each farmer and grower. The main methods to maintain SOM levels is to reduce tillage, avoid the possibility of erosion and to reincorporate crop residues (fig. 2). Tillage particularly plays a critical role, because it opens the

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soil. Microbes react to the higher availability of oxygen and consume some of the soil organic matter, which results in carbon dioxide release. Soil carbon dioxide is the most important plant nutrient (photosynthesis!), but increased levels at this point do not help and are lost to the atmosphere.

Fig. 2: reduced tillage and crop residues help to fight the loss of soil organic matter.

METHODS TO INCREASE SOIL ORGANIC MATTER IN SOIL

Because some SOM is always lost through farming activity, increasing levels is not only possible, but also necessary. There are several methods to do the job:

Crop rotation

Growing a diverse range of crops with spring and autumn seeding dates provide all year coverage of soil and therefore balance SOM levels.

Cover crop and green manures

In between cash crops, cover crops and green manures are used not to deliver a crop for the farmer, but a benefit for the soil. These plants are not harvested but incorporated back into the soil and therefore raise SOM levels (fig. 3).

Fig. 3: Earthworms feed on crop residues therefore increase soil organic matter.

Perennial crops

Perennial crops are often used in crop rotations by organic and livestock farmers. Clover, lucerne (alfalfa) and clover-grass mixes are perfect crops for increasing soil organic matter for two reasons. They sequester a lot of carbon all year round and also, these fields are not tilled when the crops are present.

Composts, manures, organic fertilizers and soil amendments

Growing SOM on the field is one opportunity, applying carbon through compost and other organic resources is another opportunity to increase SOM.

Biochar

Biochar application, often in a mix with compost or manures is a rather new method to raise SOM in soil. Biochar is charcoal produced from organic residues through pyrolysis. It is rich in carbon and used in soils also, where it stays intact for centuries.

Livestock for mob grazing[2]

Another method, which is gaining more and more attraction again is mob grazing (fig. 4). Animals in high population densities are used to graze, trample and leave plants on the ground. This method mimics large buffalo and antelope herds, which helped to create fertile soil in the prairie.

Fig. 4: Cattle grazing on a grass-clover ley grassland.

[1] EIP-AGRI Focus Group Moving from source to sink in arable farming: Final report https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-focus-group-moving-source-sink-arable

[2] EIP-AGRI Focus Group Grazing for carbon: Final report https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-focus-group-grazing-carbon-final-report

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Additional information on organic matter are published as an EIP-AGRI minipaper:

https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/2_eip_sbd_mp_organic_matter_compost_final.pdf

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MICROBIAL ANTAGONISTS & BCA: PRACTICAL INFORMATION

This factsheet contains complementary information to the Best4Soil video on Microbial antagonists & BCA: Practical information

INTRODUCTION

Soil microorganisms are a major factor in the four best practices promoted by the Best4Soil network to reduce the pressure of soilborne diseases in arable and vegetable crops. The two preventive practices, compost/organic amendments and cover crops/green manures, increase the activity and number of microorganisms antagonistic to soilborne pathogens and nematodes, so-called microbial antagonists. The two curative practices, ASD and solarisation, also rely on the effect of microbial antagonists, which cause the physical and chemical effects making these methods effective. Another use of microbial antagonists is the application of biological control agents (BCA), commercially produced microorganisms with a high ability to control certain soilborne diseases.

DIRECT EFFECT ON PLANT GROWTH

Microbial antagonists have an indirect positive effect on plants because they reduce the pressure from soilborne pathogens on the crop plants. But there is also a great number of microorganisms in the soil, which have a direct positive effect on plant growth and health (Somers et al., 2004). One group of such microorganisms are bacteria which are located on or close to the roots, the so-called rhizobacteria. They stimulate plant growth by producing phytohormones or by making mineral nutrients more available to the plants. Therefore, they are designated plant growth-promoting rhizobacteria (PGPR).
A second group are microorganisms which induce the activation of a systemic defense mechanism (Pieterse et al., 2003). Both bacteria and fungi can stimulate such an induced systemic resistance (ISR). Induced systemic resistance does not provide complete protection, but it has the advantage that it protects the plant from several pathogens in the same time (Raaijmakers et al. 2009).

COMMERCIAL BCA PRODUCTS

With the increasing pressure from consumers, and also for environmental reasons, there is a need for alternative plant protection products to replace synthetic plant protection products. In the case of soilborne diseases, the phasing-out of the methyl bromide (Gullino et al., 2003) added additional pressure to find such solutions. Fungicides, bactericides and nematicides containing BCAs as active ingredients are available as commercial products. Their efficacy has been demonstrated as they are officially registered (fig. 1). As they can be costly in comparison to more traditional fungicides, their application should be aimed at the treatment of seeds or roots of the plantlets before planting. For the treatment of the whole field, their use is too expensive and the distribution of organic amendments rich in microorganisms, such as compost, are currently more appropriate for this purpose.
Because of the comparative high costs of the registration, many BCA-containing products are not registered as plant protection products. They are sold as plant strengtheners, plant stimulants, organic fertilizer and similar products, and their efficacy may be unknown or not yet demonstrated. A way to find out how much such a product is worth to control soilborne diseases could be setup of a community of practice i.e., a group of persons who share knowledge on a specific topic. The Best4Soil network supports the setup of communities of practice by organizing a workshop dealing with the concerned topic. If you are interested, then contact Best4Soil (contact form is on www.best4soil.eu).

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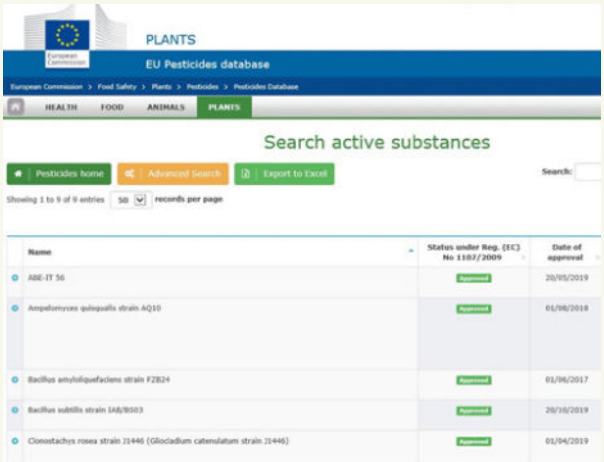

Fig. 1: Fungicides and other plant protection products containing microorganisms as active ingredient have to be registered.

Additional information on biofumigation are published as an EIP-AGRI minipaper:

https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/8_eip_sbd_mp_biocontrol_final.pdf

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