EIP-AGRI Focus Group

IPM practices for soil-borne diseases

FINAL REPORT
OCTOBER 2015

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Summary: EIP-AGRI Focus Group IPM practices for soil-borne diseases

Soil-borne diseases, caused by fungi and nematodes, are major yield-limiting factors and they are difficult to control. Plant parasitic nematodes alone, have been calculated to take away approximately 10% of the World's global agricultural output, causing economic losses valued at over $125 billion each year (Chitwood, 2003). Applied knowledge on suppression techniques seems to be limited. Methyl bromide was one of the most widely used pesticides to control soil-borne diseases, but due to its ozone depleting characteristics, The United Nations (Montreal protocol) made the decision to phase out its use in 2010 in developed countries and in 2015 all over the world *(Anonymous, 2009)*. Other soil disinfectants such as dichloropropene and methylisothiocyanate are also being banned in more and more European countries. This increases the need for sustainable and economic alternatives.

From November 2014 until September 2015, the EIP-AGRI Focus Group IPM practices for soil-borne diseases evaluated the current state of the art on soil-borne diseases and brought together existing knowledge on innovative techniques to control soil-borne diseases caused by fungi and nematodes.

Based on literature and a questionnaire among Focus Group experts, a list of the most important soil-borne diseases in terms of impact was produced. Amongst this list, *Fusarium spp*, *Verticillium dahliae*, *Rhizoctonia solani*, *Meloidogyne spp* and *Globodera spp* were considered to be the most common fungi and nematodes causing several wide-spread soil-borne diseases. It is striking that in most European member states, statistics on infested areas, information on crop damage and economic impact are not available or are treated confidentially.

It is often thought that high cropping frequency is the main cause of problems. For some highly specialised organisms this is true. But many soil-borne pathogens, like *Rhizoctonia* and *Meloidogyne* have a broad host range, so it is not as much the frequency but the whole cropping sequence which is decisive.

The absence of an integrated approach to soil health and soil quality in general is the main cause of problems regarding soil-borne diseases. A lack of awareness and knowledge along the production chain, resulting in a lack of knowledge-based planning, monitoring and a lack of preventive measures leads to a reactive approach. The Focus Group members noted that they usually see a 'management per incident' approach.

The physical, chemical and biological characteristics of a soil determine its quality. These characteristics are strongly interrelated. Soil is not just a stacking of mineral parts mixed with organic matter. A soil is full of life, it is a complete ecosystem. Species that cause soil-borne diseases are mostly just a minority in the whole ecosystem, which includes many different fungi, bacteria, insects, protozoa and nematodes. These species interact so it is important to develop a soil health strategy instead of just concentrating on one species which causes a single disease. Soil health determines potential yield. It is more than the absence of disease, it is about equilibrium in the soil: the ability of the soil to cope with new incoming diseases and to keep pest and disease population levels sufficiently low that plants do not suffer damage. Developing and implementing a soil health strategy is urgent. Good soil care is a long-term investment and necessity.

The Focus Group considered the following research needs from practice as top priorities:

- Identifying the best protocols for applying biocontrol agents. Biological control agents (BCA) are one of the most promising innovations because they are relatively easy to use;
- Developing science-based sampling strategies and high throughput diagnostics;
- Finding indicators to predict the suppressing quality of compost and other organic amendments based on knowledge of the underlying mechanisms.

Operational Groups on monitoring, organic amendments and introduction of biological control agents will have the highest impact in the short–term regarding soil-borne diseases.

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For all measures taken to control soil-borne diseases, not only their short term efficacy is important but also their overall performance within the whole rotation period and beyond. As a consequence, long-term experiments are essential to be able to judge the validity of measures taken.

IPM of soil-borne diseases is knowledge intensive so effective knowledge exchange is crucial. It is important to communicate about 'permanent success stories'. Communication should be interactive and traditional methods such as on-farm demonstrations and training should be supplemented with websites, blogs and webinars. Data visualisation tools and easy to use Decision Support Systems such as smartphone apps help to transfer validated information and discover information gaps or misunderstandings. The use of Geographic Information Systems to visualise the available information on a farm map improves the farmer's understanding of the situation. By presenting the right data and combining it with relevant knowledge, a farmer can make an informed decision.

Existing long-term demonstration sites with soil health measures should be explored and new demonstration sites should be organised to show how a soil health strategy can bring future economic benefits. These benefits are a convincing argument to implement these measures by farmers. Economic analysis of different measures in different cropping systems will help to judge if a given measure fits in the economic goals of the farm. Communicating with farmers without a realistic outlook on cost/benefits is a waste of time.

Soil-borne diseases are very complex problems. Their control requires steady persistence, motivation and solid collaboration between actors in the food production chain and also between fundamental and applied research, so as to completely understand the underlying mechanisms.

Here is a short answer to the questions put to the Focus Group:
How to suppress soil-borne diseases (fungi and nematodes) in vegetable and arable crops and how to enhance cross-fertilisation between different crops and agricultural systems?

Develop a soil health strategy on farm level which is inseparable and integral part within a total soil quality strategy that combines soil biology, soil physics (structure) and soil chemistry (fertilisation). This needs integrated knowledge in the whole chain: consumer, farm, extension, trade, universities. Instead of incident management whenever a soil-disease develops, enhancing soil health constantly is the guiding principle. An interactive approach both on national and EU level by using this concept in research and in extension programmes (e.g. Operational Groups) will stimulate the interdisciplinary cooperation and therefore the successful implementation of science-based measures to support the sustainable status of our precious soils.

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Structure of this report

This report starts with the motivation, tasks and the process the Focus Group. Then an inventory of the most important soil-borne diseases – crop combinations is given. The results of the Focus Group work starts with the importance of an integral approach on soil health to tackle soil-borne diseases. From this soil health perspective this report looks subsequently at:

1. What is already generally applied at farm level?
2. What is in development, including the hurdles that hamper their implementation?
3. What kind of 'out of the box' possibilities could be explored?
4. What has to be done to improve the implementation of innovation in relation to:
    a. research;
    b. the setting-up of Operational Groups;
    c. knowledge exchange;
    d. improving of the benefits and reducing the costs;
    e. the follow-up actions of the Focus Group members

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Introduction on the Focus Group IPM practices for soil-borne diseases

This Focus Group was established to answer two main questions:

- **How to suppress soil-borne diseases (fungi and nematodes) in vegetable and arable crops?**
- **How to enhance cross-fertilisation between different crops and agricultural systems?**

Motivation

Maintenance of food security is important for the European Union (EU), and worldwide. Improving crop production for an increasing domestic production of protein, vegetable oil and energy is a challenge within the EU: intensification should be sustainable and pesticide application must be reduced (91/414/EEC; 128/2009/CE) while dealing with a changing climate. The United Nations has expressed their concern by proclaiming 2015 as the year of soils (**http://www.fao.org/soils-2015/en/)**. Soil-borne diseases, most of them caused by fungi and nematodes, are major yield-limiting factors and they are difficult to control. Plant parasitic nematodes alone, have been calculated to take away approximately 10% of the World's global agricultural output, causing economic losses valued at over $125 billion each year (Chitwood, 2003). Applied knowledge on suppression techniques seems to be limited. Methyl bromide was one of the most widely used pesticides to control soil-borne diseases, but due to its ozone depleting characteristics, The United Nations (Montreal protocol) made the decision to phase out its use in 2010 in the developed countries and in 2015 all over the world *(Anonymous, 2009)*. Other soil disinfectants such as dichloropropene and methylisothiocyanate are also being banned in more and more European countries. This increases the need for sustainable and economic alternatives.

Tasks

To fulfil its assignment, the Focus Group carried out the following tasks:

- identify the main soil-borne diseases relevant in the EU;
- identify the key elements that cause such soil-borne diseases and examine how they interact;
- identify, assess and compare different IPM systems and techniques (physical, chemical, biological and other) that suppress soil-borne diseases taking into account the cost-effectiveness in the different systems and crops and explore cross-fertilisation between different crops and agricultural systems
- explore strategies for a targeted breeding of cultivars that are more resistant to soil-borne diseases;
- identify and compare alternative techniques for soil fumigation that are ready to apply or easily applicable in short term by the farmers, in the framework of the prohibition of the use of methyl bromide;
- identify and compare according to the respective arable crop alternative soil-borne disease suppression techniques that are ready to apply or easily applicable in short-term by farmers;
- identify farm practices that reduce the pressure of soil-borne diseases;
- identify fail factors that limit the use of the identified techniques/systems by farmers and summarise how to address these factors and explore the role of innovation and knowledge exchange in addressing these fail factors.

Brief description of the process

This EIP-AGRI Focus Group consisted of a team of 20 experts from practice, extension and research, working in different EU regions (**Annex 1**). Leendert Molendijk was appointed as coordinating expert to write a **starting paper**, and to facilitate the technical discussions in the group and assist in the reporting. The starting paper included the state of the art based on a first literature search and personal experience. Additionally, a questionnaire was circulated amongst the Focus Group's members. Through this questionnaire, the coordinating expert was able to identify the Focus Group experts' opinions on the main soil-borne diseases, key elements that cause soil-borne diseases, and measures generally applied at farm level. This allowed him to provide data based on both literature and this expert opinion for the first Focus Group meeting.

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At this first meeting on 2 - 3 December 2014, the discussions were guided by the starting paper and the results of the questionnaire. As a result, the overview of the current soil-borne disease situation within the EU was completed and a first list of priority solutions and promising developments was identified. Based on this, ten mini-papers were written on a number of priority topics which needed further exploration (**Annex 2**). For each mini-paper, the Focus Group experts writing them were asked to analyse the given issue and to provide a list of existing solutions and propose innovative solutions and strategies that are needed to improve implementation. The mini-papers were circulated among the members of the Focus Group before the second meeting held on 22 - 23 April 2015. At the meeting, the mini-papers were discussed and this resulted in a complete evaluation of the current situation on soil-borne diseases, opportunities and fail factors, priorities for research and Operational Groups. Based on the highly motivated and tireless efforts of the Focus Group, the starting paper has been supplemented and extended to produce this final report which includes an overview of the state of art and recommendations on how to proceed.

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1. Inventory of the most important soil-borne diseases - crop combinations

According to the results of the questionnaire completed by the Focus Group experts, the following crops are most susceptible to soil-borne diseases: olive, tomato, potato, cucumber, carrots, lettuce, sugar beet and brassicas. In **Annex 3** crop acreage and yearly turnover are given (FAOSTAT). The list of the most susceptible crops to soil-borne diseases put together by the Focus Group corresponded to the crops of major importance in the FAOSTAT statistics.

Soil-borne diseases are caused by fungi, nematodes, bacteria and viruses. The latter are most commonly transmitted by nematodes or fungi. Fungi, nematodes and nematode-transmitted viruses seem to have the largest incidence and impact on agricultural crops. Priority therefore was given to fungi and nematodes.

Table 1 gives the inventory from the starting paper and this can be compared with the results of the questionnaire carried out before the first Focus Group meeting (Figure 1).

Fungi	Nematodes
Verticillium dahliae	Meloidogyne sp
Gaeumannomyces graminis	Pratylenchus penetrans
Rhizoctonia solani	Xiphinema index
Fusarium spp	Globodera sp.
Pythium spp.	Heterodera spp.
Phytophthora spp.	Ditylenchus dipsaci
Sclerotinia sclerotiorum	Trichodorids
Sclerotinia cepivorum	Paratrichodorids
Plasmodiaphora brassicae	
Synchytrium endobioticum Chalara elegans	

Table 1: List of the most common soil-borne pathogens based on literature

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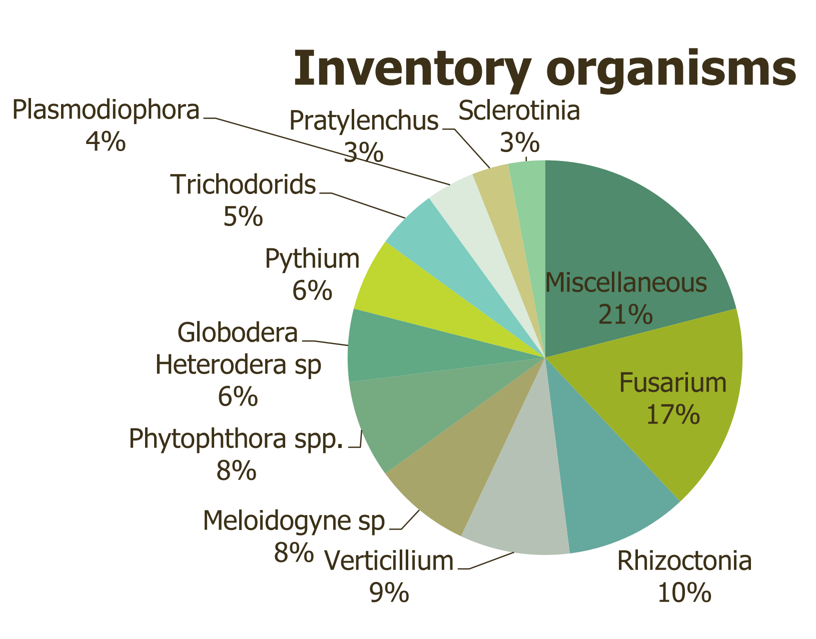

Figure 1: Main European soil-borne pathogens based on the questionnaire completed by the members of the Focus Group. 100% represents the total number of soil-disease crop combinations (128) listed by the experts

The experts concluded that for both horticulture and arable farming, there is a high level of consensus regarding which organisms are causing the main problems in Europe. However, except for Austria, Scotland and Spain, no objective figures are available on incidence, acreage and yield losses of the main crop disease combinations. For many authorities these impact figures are considered as sensitive information and are therefore treated confidentially. In some cases the figures are not available at all.

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2. An integral approach to soil health

Soil health is the biological condition of the soil which determines potential yield. Soil health is more than just the absence of disease. It is about equilibrium in the soil: the ability of the soil to cope with new incoming diseases and keep pest and disease population levels sufficiently low so that crops do not suffer damage. This depends on soil quality, which includes physical, chemical and biological characteristics of a soil. These characteristics are always strongly interrelated.

The Focus Group took their definition of Integrated Pest Management (IPM) from European directive 128/2009/CE (**Annex 4**). The main element of this definition is that chemical prophylactic (preventive) treatments should not be applied. Also, IPM treatments should always be based on the monitoring of a pest or disease, and control measures are only taken when the agreed damage threshold is reached, according to this definition. Therefore, the Focus Group found that their working title "IPM practices for soil-borne diseases" risked focusing only on single relations between a soil-borne disease and its control measures. They strongly emphasised the need to widen IPM in this context to the concept of soil health as an inseparable part of soil quality (Janvier et. al., 2007).

2a. Why develop a soil health strategy?

Soil is not just a stacking of mineral parts mixed with organic matter. A soil is full of life, it is a complete ecosystem. Species that cause soil-borne diseases are mostly just a minority in the whole ecosystem, which includes many different fungi, bacteria, insects, protozoa and nematodes. These species interact so it is important to develop a soil health strategy instead of just concentrating on one species which causes a single disease. The following three paragraphs elaborate on the interaction between the populations and the soil which make up the soil eco-system:

Disease potential is not only linked to inoculum density (= population levels of organisms which can cause diseases) but also to the capacity of this inoculum density to provoke the disease on a susceptible crop. The whole microbiota does not only control the inoculum density but also the inoculum capacity to infect the crop. Soil suppressiveness (the capacity of the soil to suppress the development of crop diseases) most often results from the antagonistic activity of the microbiota suppressing the activity of the inoculum, rather than from a low inoculum concentration. In other words, other organisms present in the soil can often prevent the organisms that cause crop diseases from actually doing so; these are called antagonists. It is not a question of whether a pathogen is present or not even its abundance, but what matters to farmers is its disease potential in a particular soil under certain circumstances.

Whether damage is caused depends on the amount of pathogens present, abiotic and biotic soil conditions (humidity, pH, oxygen, nutrients, the soil food web, antagonists etc.), the tolerance of the crop and climatic conditions. Everything that improves the vigour of the crop increases its tolerance to damage. Improving soil health starts with optimising soil conditions in terms of its physical, chemical and biological properties, to optimise growing conditions for crops. Very often however, there is very little knowledge available on the mechanisms of interaction between the different factors. It is especially important to know when a potentially neutral factor becomes a "risk factor", either on its own or when combined with others. When growing conditions are optimised, crops are much more tolerant to soil-borne diseases present in the soil, and as a result their impact on crop growth is minimised, but usually not sufficiently. It will be necessary to control soil-borne diseases according to the concept of a soil health strategy (see 2b. What could a soil health strategy look like?).

The amount of disease depends on cropping frequency and on the sequence of crops. This is especially the case for specialised organisms with small host ranges, for example Potato Cyst Nematodes only propagate on Solanaceae, so frequently planting crops of the Solanaceae family will increase their numbers. In the case of polyphagous organisms (organisms which infect many different crops) for example *Rhizoctonia solani* and *Verticillium dahliae*, the decisive element is the sequence of crops and the number of host crops within the rotation.

To develop a soil health strategy, thorough knowledge on biology and the epidemiology of the diseases is essential. The Focus Group discussed whether there are any techniques known which enhance the soil's overall capacity to suppress soil-borne diseases. They discussed the needs to identify farm practices that reduce the

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pressure of soil-borne diseases. The Focus Group concluded that a soil health strategy should be an inseparable element of a soil quality strategy. On many farms, soil-borne diseases are regarded as mostly invisible, isolated incidents and treated as such. At the moment, treatment of soil-borne diseases is rather limited to "reaction" instead of preventive "action".

2b. What could a soil health strategy look like?

Introduction

There was a strong opinion within the Focus Group that the main causes of soil-borne diseases are levels of infestation which are too high because of poor biodiversity and a poor soil structure. This means that general farm practices which improve soil biodiversity and soil structure should therefore be beneficial to the suppression of soil-borne diseases. The Focus Group mentioned the following general techniques for a better soil health: no or reduced tillage, smart crop rotations (to keep infestation levels low), using compost, seed treatments, using machinery that has a limited effect on the soil structure, the use of green manure (with or without Brassica spp.), increasing the organic matter content of the soil and good fertilisation practices. Both in practice and science, a lot of discussion is going on to distinguish between "facts and faith" with regards to all the efficiency of different measures.

The measures and techniques mentioned above will be most effective when they are used in the context of a comprehensive soil health strategy, as illustrated in Figure 2. A soil health strategy always combines the following different elements:

1. prevention
2. monitoring
3. crop rotation
4. additional measures.

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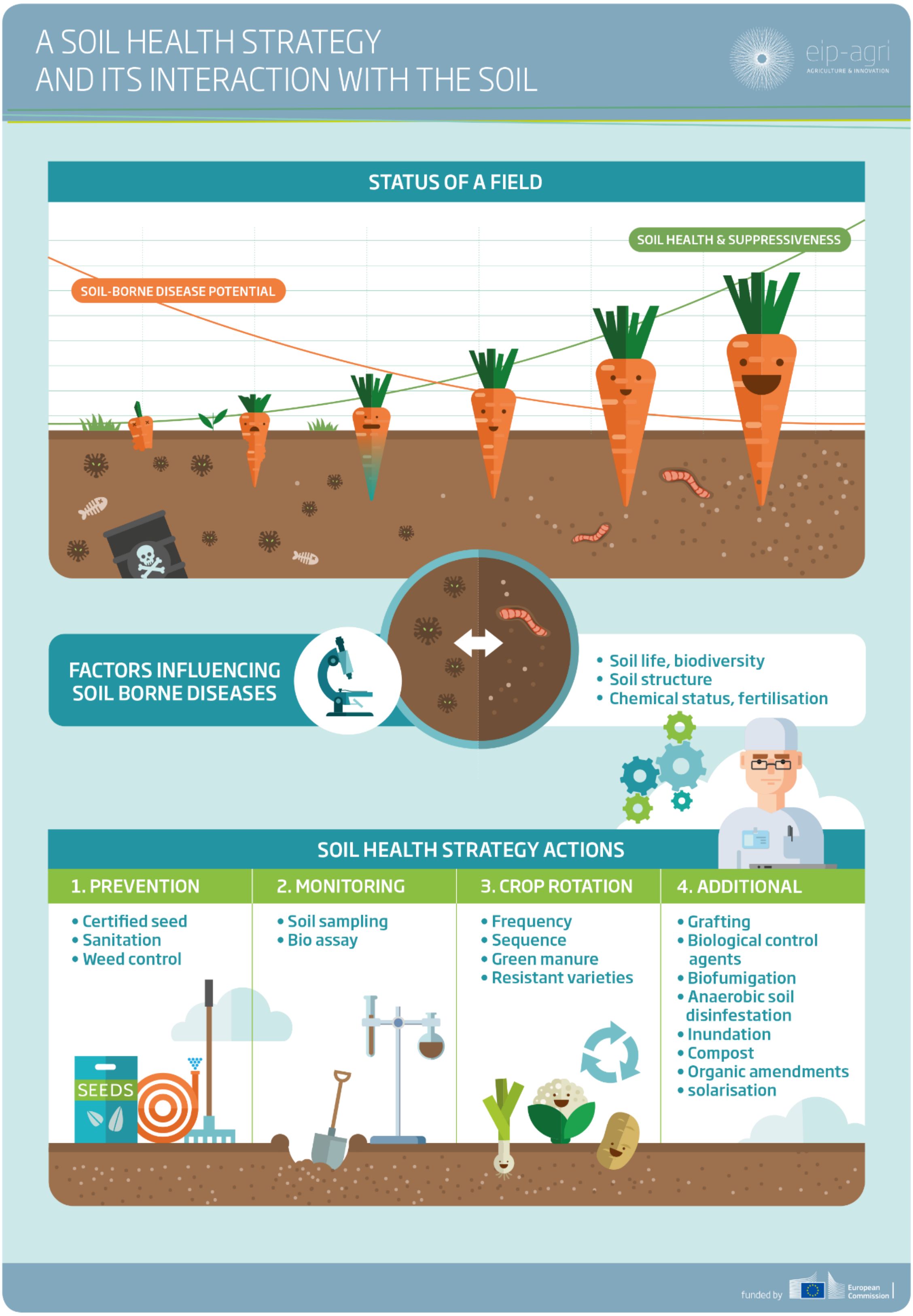
A SOIL HEALTH STRATEGY
AND ITS INTERACTION WITH THE SOIL
STATUS OF A FIELD
SOIL HEALTH & SUPPRESSIVENESS
SOIL-BORNE DISEASE POTENTIAL
FACTORS INFLUENCING SOIL BORNE DISEASES
• Soil life, biodiversity
• Soil structure
• Chemical status, fertilisation
SOIL HEALTH STRATEGY ACTIONS
1. PREVENTION
• Certified seed
• Sanitation
• Weed control
SEEDS
2. MONITORING
• Soil sampling
• Bio assay
3. CROP ROTATION
• Frequency
• Sequence
• Green manure
• Resistant varieties
4. ADDITIONAL
• Grafting
• Biological control agents
• Biofumigation
• Anaerobic soil disinfestation
• Inundation
• Compost
• Organic amendments
• solarisation
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Figure 2.

1. Prevention

The introduction of new invasive species of soil-borne pathogens is always a risk to the farmer. In this context, the issue of imported and/or shared (contaminated) **seeds**, propagation material, fruits, food, technical equipment as well as the effects of tourism (e.g. parts of soil is carried on shoes from one territory to the other) were identified as important elements to be aware of and to take care of.

An important factor with regards to prevention is the awareness of all actors within the production chain. All players within the chain around a crop/field can help prevent diseases spreading within fields, between farms and between regions/countries. Many soil-borne pathogens are spread with **seed and planting material**. **Sanitation** and control of propagating material is a first step: machinery hygiene, cleaning of casks and storage can take away initial contamination. Weeds are hosts of several kinds of organisms, therefore **weed control** is another preventive measure.

2. Monitoring

Once a field is infested with a pathogen it is impossible to eradicate the pathogen and to reach a zero infestation level again. Management can only force infestation levels below damage or detection thresholds by taking the necessary control measures. Monitoring is the cornerstone and one of the key principles of effective integrated pest management (IPM). Effective implementation of IPM requires accurate estimates of target fungal and nematode abundance, assessment of presence/absence of natural control e.g. fungal control of cereal cyst nematodes (*Heterodera avenae*), and reliable assessments of crop damage and its effects on yield. Appropriate sampling for target pathogens is key in terms of monitoring (Nielsen et al., 2010, Wallenhammar et al., 2012), so the choice of sampling technique for field testing is vital and it can be pathogen specific.

Based on the epidemiology and biology, a disease risk assessment can be made to determine whether a field is susceptible (soil type, pH, climatic conditions to survive adverse periods). At harvest, products can be checked for symptoms (full field **bioassay**). **Soil sampling** can be done to detect pests and diseases in an early stage or to measure the infestation level to estimate crop damage and the economic feasibility of control measures. **Bioassays** can be used to assess the soil suppressiveness potential, we can see examples of this in practice in Sweden and Austria for pea crops which are susceptible to *Aphanomyces*.

More information can be found in the **mini-paper - Monitoring of soil-borne pathogens (fungi, protists and nematodes) and soil tests**.

3. Crop rotation

Rotation is very important but again, it needs to be combined with other measures to be effective. In the case of polyphagous organisms, the **sequence** is far more important than the cropping **frequency**. Also the timing of sowing and planting a crop is part of the rotation planning. Much attention is needed for the period that the cash crops are not on the field: weed control in the fallow period or the choice of a convenient **green manure** crop are important elements within the strategy. In some cases **resistant or tolerant varieties** are available or varieties with resistant rootstock (grafting). In many cases, these resistant varieties are partially resistant, which means that pest and diseases have less opportunity to spread, but they are still present. These partially resistant varieties can be very useful provided that the level of resistance is known, but if they are not known they could be a risk for farmers because diseases can still occur.

4. Additional measures (control measures)

Additional measures are necessary when there are no feasible options with regards to the rotation, prevention or improving soil health. Two of the more general measures are the use of organic matter and fertiliser & manure management (see below). For other more specific measures, please see the chapter "New developments both in research and practice".

Organic matter and organic matter amendments

The suppressive capacity of compost against soil-borne pathogens has been demonstrated in several studies; the use of disease suppressive compost can reduce crop losses caused by soil-borne diseases and therefore benefit growers (Hoitink and Fahy, 1986; Hoitink and Boehm, 1999; Noble and Coventry, 2005; Hadar, 2011).

In fact, compared to other amendments, such as crop residues and peat, compost has been shown to be the most suppressive material with more than 50% of cases showing effective soil-borne disease control (Bonanomi et al., 2007). However, the success or failure of compost for disease control depends on the nature of the raw materials from which the compost was prepared, on the composting process used and on the maturity and quality of the compost (Termorshuizen et al., 2006). Fortifying compost with beneficial microorganisms is one possibility which can help in the success of compost use, increasing the efficacy and reliability of disease control (De Clercq et al., 2004).

Organic matter amendments, compost as one of the best, are suggested as a promising tool for the management of plant-parasitic nematodes, although some reports point to an increase of these nematodes after the use of organic matter. Thoden et al 2011 suggest that proliferation of non-pathogenic free-living nematodes may help reduce the population of plant-parasitic nematodes.

More information can be found in the **mini-paper Organic Matter, Compost**.

Fertiliser and manure management

Effects on fungi and nematodes depend on the types of fertilisers used. Liquid manure contains more salt than other fertilisers and it is presumed this has negative effects on the microbial life. The right dose of fertilisers is important: too many or too few nutrients can weaken crops and soil-borne diseases have more chance to occur. The Focus Group highlighted that the interaction between nutrients (e.g. magnesium) and diseases is an important aspect as there is a risk of "overfeeding" the soil. In this context, the Focus Group also discussed the pH-level of the soil, its organic matter content and an excessive use of nitrogen which we are seeing today in some parts of Europe despite clear regulatory requirements.

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3. Measures generally applied at farm level

This chapter presents the main measures that are in place in many parts of Europe. The next chapter, chapter 4, will present measures which are currently applied in very specific areas or are not widely applied, but that have potential for larger implementation.

3a. Prevention

The use of certified seed and planting material is obligatory for a number of crops within the European Union. These certified seeds and planting materials should therefore be free of diseases and pests. Using farm saved seed, or using seeds and planting material without disease control methods may lead to the spread of pests and diseases.

3b. Crop rotation

In most cropping systems, growers are aware of the importance of crop rotation. Still, the lack of knowledge on host status, epidemiology and damage thresholds for many soil-borne diseases hamper the possibilities to design crop rotations which are appropriate for a given situation. The small array of profitable crops is another reason that crops are grown in too frequently or in a sequence that is not ideal to reduce the incidence of pests and diseases.

3c. Resistant varieties

Resistant varieties of crops are an important tool to solve problems within the rotation. The Focus Group experts would recommend that breeders would interact more with farmers and plant pathologists. They also recommend not just focussing on the crops showing the problem. The solution can often be found by introducing resistance in the other crops within the rotation which precede the sensitive crop: the resistant crop will bring down the infestation level before planting/sowing the sensitive crop and thus improve its yield. The large acreage of maize for example, means it is an ideal crop to introduce resistance against soil-borne diseases from which the next crop will benefit. Much resistance is found within tomato, cucumber and other greenhouse crops, often via grafting. In arable crops, breeding resistance against potato, beet and wheat cyst nematodes and club root on oilseed brassicas and cabbage crops is already widespread. In green manure there is some investment in breeding against nematodes.

3d. Chemical control of soil-borne diseases

With the exception of Scandinavian countries and Germany, most countries use (or used in the past) fumigants and granular fungicides/nematicides to control soil-borne diseases. In many cases, the use is preventive and not based on the result of monitoring. In **Annex 5** you can find a list of active ingredients used in the recent past or still used at the moment which is based on the questionnaire completed by the Focus Group experts. The phasing-out of methyl bromide has raised the interest of crop protection industries to find new molecules and to develop new products, and the first results are starting to enter the market. The first new products have now been approved for use in the USA, and the registration process to allow these products to enter the European market is ongoing.

4. New developments both in research and practice

The Focus Group discussed developments both in research and practice and based on their perspectives they prioritised the most important ones which need to be implemented on farm level. The hurdles and fail factors hampering implementation and development are also presented in this chapter.

None of these developments are used on a comparable scale to chemical methods. The efficacy of these techniques depends a lot on the target organisms, climatic circumstances and the economic possibilities of the crops. Some of them have been developed to broader applications but it has not been possible to develop any of the alternatives into to a general control method.

4a. Grafting

Grafting horticultural crops on rootstocks is a relatively old technique that combines a productive variety which is sensitive to a specific disease with a rootstock that is resistant to this disease. A famous example is grafting the European grape vine on the rootstocks of American grape vine species to protect them from the threat of Phylloxera (Boley et al., 1979). Grafting fruit trees is also a long established technique, in this case not to control soil-borne diseases or pests but mainly to modify their growth vigour, and more recently, to increase their resistance to fire blight. Grafting vegetable crops on rootstocks was first done in Asia (Japan, Korea) and is now also widely done in Europe and North America (Lee et al., 2010). On a relatively small scale, breeders are working on resistant varieties or resistant rootstock (Giannakou Karpouzas, 2003). The Focus Group made an inventory of these projects and the expected developments. See for detailed information **the mini-paper - Success and failures of grafting against soil-borne pathogens**.

Grafting is considered one of the most important alternatives to chemical fumigants for controlling soil-borne pathogens in vegetable crops that can (easily) be grafted. In tomato, cucumber and melon crops, grafting with resistant rootstocks is common practice, at least in countries which banned methyl bromide before the official phasing-out starting in 2005, such as the Netherlands or Switzerland. In Southern European countries grafting has become an important method to control soil-borne pathogens, in particular for tomato and melon crops. We are seeing the establishment of specialised grafting companies following the increasing market demand.

One of the most important hurdles is the high cost. The grafting process is very labour intensive, it requires skilled technicians as it is not yet fully possible only using machines or grafting equipment. Because of this, grafting is particularly used in solanaceous and cucurbitaceous crops in horticulture. To make grafting feasible for more crops, automatic grafting systems or on-farm grafting could be a solution but this would require further development.

Another hurdle is the lack of independent information about the resistance and vigour of rootstocks. The testing within the breeding companies is carried out on a limited number of strains. These strains may be different from those present on the farms using the rootstock. On-farm testing is necessary to confirm the efficacy of the chosen rootstocks.

Last but not least is the concentration of seed and plant production within a limited number of companies, meaning that farmers are dependent on the rootstock and varieties provided by these companies. In the Netherlands for instance, organic tomato growers lost a good rootstock with the phasing out of the rootstock 'Big Power' when the seed company Rijk Zwaan considered the organic market too small to keep Big Power in production.

Despite these difficulties grafting has the potential to broaden to more crops and soil-borne diseases.

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4b. Biological control agents

The value of the global bio pesticide market is expected to reach $4,556.37 Million by 2019, at a compound annual growth rate of 15.3% from 2014 to 2019 (source: Marketsandmarkets.com, 2014; last access 31/03/2015). The EU Directive on the Sustainable Use of Pesticides (2009/128/EC) is expected to stimulate the bio pesticide market.

Some active ingredients have been included in **Annex 1** to Regulation EC 1107/2009 so they can be used to develop products. Presumably, several others are under development by multinational agrochemical companies. Microbial biocontrol agents should be targeted at reducing the inoculum in the soil rather than as a substitute to chemicals and most of their failures in controlling the pathogens is linked to their misuse (i.e. dipping roots at transplanting, late application, concentration in soil below the threshold of activity, etc.). For some biocontrol agents (i.e. *C. minitants* on sclerotia of *Sclerotinia* species) the application on the previous crops in a rotation results in a reduction of the inoculum which can benefit the following crops if they are hosts of the same pathogen.

The mode of action of microbial biocontrol agents against plant pathogens include direct antibiosis (caused by secondary metabolites which are toxic for pathogens), hyper parasitism (BCA parasitizes target organism), induction of resistance and competition for space and nutrients. Some microbial agents also act as a bio fertiliser and/or a plant growth promoter by fixing N, solubilising P, chelating Fe, producing hormone-like substances, degrading organic matter and releasing nutrients into the soil.

In the **mini-paper - The use of microbial biocontrol agents against soil-borne diseases**, an update is given on the approved bio control agents and those which are under development. For each organism, you can find their characteristic, mechanism of action, use, advantages, limitations and ways to improve efficacy.

Biological control agents (BCAs) are often very sensitive to environmental conditions. Good protocols of use are necessary to increase the success of their application. Preservation of the product until application (ie. shelf life), transport to customers and application techniques are considered to be hurdles in this process.

There are several commercial products that are sold as fertilisers or bio stimulants which contain biocontrol agents. These products usually do not claim to act as a direct fungicide, however they suggest that they may improve plant health and that they contain the most common species used in biocontrol. This creates confusion not only for farmers, but also for some experts. These products do not have to declare the amount of active propagules (CFUs), nor do they guarantee the viability of the microorganisms. Most of the time they are unsuccessful and they therefore give a bad image to microbial biocontrol agents. A more strict regulation is needed to guarantee the quality of microorganisms contained in bio fertilisers and to avoid their misuse (as plant protection products).

The registration process is one of the biggest hurdles for the introduction of biological control agents on the market. In many cases this registration has to be done for many disease crop combinations in different countries or regions. It is a very long and expensive process. In order to improve microbiological control, it would be useful to combine several strains of the same genus-species, or several genus-species and it would also be useful also to combine biological control agents with different modes of action. However, this would demand registration of every single strain.

The high cost of registration also prevents a large number of potential biocontrol agents from reaching the market. Each registered use must be supported by specific efficacy trials, and so companies tend to register the products against those pathogens with the largest potential market. This results in products which are potentially active against a large number of soil-borne pathogens, but authorised only on the specific one on which the registration trials have been carried out.

Due to these constraints, biological control of soil-borne plant diseases in Europe is still very limited.

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4c. Green manure and cover crops

Both 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. They are grown for different purposes. The above-ground part of green manures is incorporated into the soil at the end of the growing period so that the accumulated nutrients (e.g., nitrogen) or useful secondary metabolites (e.g., glucosinolates for biofumigation) are returned to the soil. Cover crops are grown for other reasons, such as the reduction of leaching of nutrients (e.g., nitrate), avoiding erosion, improving soil structure and suppressing weeds. A crop can even serve as both, first as a cover crop (e.g., for weed control) and then be incorporated as green manure (for nutrient input) (Campiglia et al., 2009). The cultivation of these crops varies widely within Europe. In Germany, Austria, the Netherlands and Belgium, more than 50% of growers use cover crops and/or green manure. In Lithuania, in contrast, green manures are rarely grown.

Cover crops affect soil-borne organisms in several ways. The roots can liberate a range of molecules (e.g. sugars, amino acids) during the growing period (Börner, 1960) and although the amount of these substances is too small to directly affect plant health, they can directly influence the type and biomass of soil microorganisms (Ladygina & Hedlund, 2010). In a tomato cropping system, cover crops have been shown to influence the soil microbial biomass and composition more than soil temperature, moisture, pH, and texture (Buyer et al., 2010).

Green manures can potentially have the same effect on soil-borne diseases as cover crops as described above, until harvest. Then through the incorporation of the above-ground biomass of green manure crops, important amounts of carbon, nutrients, microorganisms (i.e. endophytes) and secondary metabolites are added to the soil. The important amounts of readily useable carbon in the form of organic amendments (fresh or dried plant material) added to the soil, stimulates the general soil microbial activity (Stark et al., 2008; Michel & Lazzeri, 2011). Such increases in soil microbial activity can be correlated to a decrease of the number of soil-borne pathogens e.g., *Verticillium dahliae* (Michel & Lazzeri, 2011). However, the incorporation of fresh organic matter can also lead to a temporary increase of certain soil-borne diseases (Hoitink & Boehm, 1999). An indirect effect of the nutrients released after the incorporation of green manure plants on the following crop may also increase plant health and yield. For example *Tagetes patula* is used to control root lesion nematodes.

The most significant fail factor is the preventative nature of green manures/cover crops. Their cultivation uses resources (time, money, space, water) with no immediate visible return. The second fail factor is the limited efficacy of this method, which is insufficient in cases of strong disease pressure.

The possibility of green manures or cover crops to be a host plant of a soil-borne pathogen is the third fail factor. For example, *Brassica* species are not accepted as green manures by Swiss vegetable growers because the percentage of cruciferous species in their rotation is high. The relatively high price and low availability of seeds of specific green manure varieties e.g., brown mustard with high content of glucosinolates, is another fail factor. Limited availability of water is in some regions is also a hurdle. The lack of knowhow and equipment to grow green manures (grown as a field crop) by farmers and horticulturists also hinders the adaptation of green manure crops within growing systems. Green manures and cover crops cannot be grown in an easy-to-apply way, like the application of methyl bromide. Their use has to fit in the specific situation of each individual grower or even field and it has to be adapted to the agricultural, ecological, political and economic environment. The way of controlling soil-borne diseases once they have become an important production constraint has to be changed when green manures and cover crops are used as control method. Green manures and cover crops have to become part of an integrated control concept and be applied preventively.

Green manures and cover crops have much potential to play a more prominent role in a soil health strategy to prevent soil-borne diseases whilst contributing to many other aspects of soil quality.

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4d. Biofumigation

The term 'biofumigation' was originally coined by J.A. Kirkegaard to describe the process of growing, and subsequently macerating and incorporating certain *Brassica* or related species into the soil. This leads to the release of isothiocyanate compounds (ITCs) through the hydrolysis of glucosinolate (GSL) compounds contained in the plant tissues (Kirkegaard et al., 1993). This can result in a suppressive effect on a range of soil-borne pests and diseases. Since then, the term 'biofumigation' has been used rather loosely and incorrectly in some contexts, to describe any beneficial effects derived from the use of green manures, organic amendments and composts. In this Focus Group, biofumigation is considered in its strictest sense as referring to the use of plant material containing glucosinolate for the purpose of enabling ITC-mediated pest and disease suppression. Biofumigation could be considered as a 'natural' alternative to chemical fumigation and there is a similarity with the use of metam sodium which releases methyl-ITC to control a variety of soil-borne diseases. Biofumigation showed promising results in basic research (Kirkegaard Sarwar, 1998), (Lazzeri Manici, 2000). However, in practice, positive results have been reported but it could be based on general positive effects of green manure crops and not on the efficacy of disease control as such (Vervoort et al., 2014).

Historically, social and cultural barriers have impeded the uptake of biofumigation with the dual concerns that adoption would accelerate the removal of synthetic pesticides and the lack of trust regarding the equivalent efficacy of biofumigant crops. However, there now appears to be an increasing interest by farmers and growers in biofumigation but the variability in levels of disease control or the lack of any evidence for the benefits of this approach for particular crop-pathogen combinations are still major barriers to widespread adoption. This urgently needs to be addressed, ideally through collaborative approaches and projects between researchers and industry. There is also still a lack of consistent advice and information on how to grow biofumigants for maximum GSL production. Biofumigant seed producers could provide more detail on aspects such as such as seed rate, fertiliser applications, sowing dates and biofumigant crop selection. In addition, appropriate machinery optimised for maceration and incorporation is not universally accessible to growers and farmers.

However, despite these barriers to implementation, there are some innovative growers for instance in the Netherlands, Belgium and Germany, who have already adopted biofumigation and integrated this technique into their farming practices. This might be in response to specific problems and it seems to be more often the case that plant parasitic nematodes are targeted rather than soil-borne fungal diseases, perhaps due to the fact that there is more research evidence and experience in using biofumigation for nematode control.

Overall, research concerning biofumigation for control of soil-borne pathogens does not constitute a major area of work and there has been a lack of a consistent experimental approach. Hence, levels of control have varied considerably between different target organisms and a number of studies have highlighted this as one of the major problems associated with adopting biofumigation. It is clear however from *in vitro* studies that pathogens vary in their sensitivity to different ITCs (e.g. Brown and Morra, 1997; Smith and Kirkegaard, 2002) as do the susceptibility of different life cycle stages and structures of soil-borne pathogens such as spores, mycelium and sclerotia. It is clear therefore that different pathogens will require different biofumigants for effective control and further work is required to clarify the best biofumigant(s) for specific disease problems. Also, the negative effects on beneficiary organisms (e.g. earth worms) should be addressed.

Researchers have been trying to understand, demonstrate and optimise the biofumigation process, and more studies have now found a way to quantify GSLs or ITCs. It has become increasingly apparent that the beneficial effects observed may not always be related to the activity of GSL-based hydrolysis compounds, and that other mechanisms may play a complementary or more dominant role in disease suppression. This is probably as a result of incorporating large amounts of organic matter into the soil potentially resulting in improved soil structure, increased nutrient availability, increased water holding capacity and stimulation of beneficial/pathogen-suppressive microbial communities. These effects could be independent of GSLs or ITCs and be achieved with other green manure or cover crops as well.

It is most likely that biofumigation will be promoted on the basis of its multiple benefits to farmers in addition to potential disease control. It will form just one part of an integrated strategy that could include additional approaches such as biological control for the more intractable soil-borne diseases (see **mini-paper - The use of microbial biocontrol agents against soil-borne diseases**). The ins and outs of the technique are highlighted in the **mini-paper - Biofumigation for the control of soil-borne diseases**.

4e. Enhancement of soil suppressiveness

Compost and other organic amendments

The biggest hurdle for putting in place a successful control measure of compost and other organic amendments is to identify the criteria that make the compost and other organic amendments effective at suppressing soil-borne diseases in specific soil types and conditions (input material + composting process + storage). Compost should therefore be considered as a source of organic matter which improves soil quality in general and can be promoted as a 'no regret' application.

However, another hurdle is a lack of quality control and certification methods to give reassurance that the composting process was of the highest standards and that no weed seeds, contaminations etc. are going to be introduced. Because of the lack of sanitation (which only happens if there are long periods of high temperatures during composting), the absence of soil-borne pathogens and other plant pathogens in compost cannot always be guaranteed.

Because of the costs for the process, technical equipment and application, composts of good quality can be rather expensive, especially in regions with a high demand for organic waste e.g. competing with energy production. There are more and more competitors taking organic material out of farming systems. In the EU over 10 million tons of plant residues are produced every year, but this amount is not sufficient for the total cropping area, see **EIP-AGRI Focus Group on soil organic matter**.

Seed treatment to improve the rhizosphere

Two types of existing seed treatment were discussed by the Focus Group: adding microorganisms to the seed and heat treatment. The idea is to try to affect only the rhizosphere instead of the whole 'bulk' soil. The mechanisms and different steps to achieve results are not yet known. Basic research is needed to develop this potential solution.

4f. Anaerobic soil disinfestation and other techniques of non-chemical disinfestation

In the Netherlands, steaming (Runia, 2000) and inundation (Muller, 1989) are traditional methods which have been modernised and implemented on a large scale. Anaerobic soil disinfestation is moving from the level of research to implementation in practice encountering all the hurdles that have to be taken (Butler *et al.*, 2014). In Mediterranean countries, solarisation is being developed more and more and is proving to be an effective and an easily applicable tool for farmers. There are many similarities between the techniques and 'modes of action' of soil solarisation, anaerobic soil disinfestation and inundation/flooding. The basic concept of all three is that organic material is incorporated into the soil, which is then broken down anaerobically by sealing the soil with water (inundation) or virtually impermeable film. In these anaerobic circumstances, many different organic compounds controlling soil-borne diseases are formed. These methods are explored in detail in the **mini-paper - Anaerobic Soil Disinfestation and other techniques of 'non-chemical' soil disinfestation techniques**. Another **mini paper is dedicated to inundation in the cultivation of flower bulbs**.

There are quite a number of fail factors: In horticulture, plant residues can carry plastic materials (e.g. for guiding the plants) that need to be removed. An abundance of water is required to initiate microbial activity. Sometimes the time required for the application of these techniques (3-8 weeks) before planting is too long. A temperature higher or at least similar to growing is required, and this implies often one season without crop. Plastic tarp is required to achieve the best results, but wind, birds, deer etc. can easily damage the tarp allowing the entrance of oxygen with diminished efficacy as a result. Inconsistent results have been found for different organisms. The effect on beneficiary organisms is not known. There is a fear that these methods could spoil soil

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resilience and make soils more receptive for the introduction of new diseases. At present there are no indications or research results that confirm this fear but it cannot be excluded. In Spain and the Netherlands these techniques are embraced with enthusiasm. Experts from other countries are far more reluctant, although in many situations very efficient, the long-term effects on soil health have not been explored yet. Also for these methods the negative effects on beneficiary organisms (e.g. earth worms) should be addressed.

4g. Monitoring and Decision Support Systems

In the classical approach, monitoring is about estimating the incidence and abundance of pests and diseases. Growers are now asking for a total overview of soil health to be informed whether the incidence and abundance of all good and bad organisms is such that crops can be grown without any risk on damage by soil-borne diseases. Knowing the inoculum level is often not good enough, farmers want to know about disease potential within a crop. For some crops, a number of monitoring tools and decision support systems already exist.

Tailor-made solutions for making the right decisions on managing soil health on field level need a lot of specific data and knowledge. On many farms, a lot of this data is gathered but not used for decision-making. Long-term baseline data should be available to act as a direct comparison to field collected data. This is especially important for slowly changing environmental conditions like climate change. Initial implementation of IPM strategies by inexperienced farmers may result in crop damage so it is important to have sufficient underpinning baseline data available to support decisions.

For nematodes, a systematic approach was developed based on the first nematode crop schedules and the strategies from the pre-chemical era (Hijink Oostenbrink, 1968). In the nineties, these ideas were further developed in the Netherlands (Molendijk Mulder, 1996) and used to make a qualitative on line tool which helps farmers to choose the best crop sequence within the rotation, see www.aaltjesschema.nl (Dutch). A quantitative system specifically for potatoes is available which is used by advisers (Been *et al*., 2007) (www.nemadecide.com) in the Netherlands. Based on population dynamical models combined with yield damage models, the efficacy of control measures can be calculated and scenario comparisons help the farmer/advisor to make the most economically profitable decisions. Also to control Sclerotinia in vegetables, an initiative to use a DSS has been taken (Jörg *et al*., 2006).

A lot of work is being done at the moment on the indicators of soil health. As nematodes are present in all trophic levels, they are considered as potential indicators for this purpose. In the United Kingdom, a prototype soil qualification system will be introduced in 2015. In the Netherlands, a similar system is in the lab phase. In Belgium, phospholipid fatty acids measurement (PFLA) of mycorrhiza, fungi and bacteria is used to qualify the soil quality of orchards. Meta genomics (identifying genes for soil functions) is considered worldwide to have the potential to deliver indicators for soil health and soil quality (idea phase).

Emerging technologies in monitoring will be at the forefront of IPM for soil-borne pathogens. Unmanned aerial vehicles with hyperspectral imaging platforms are being tested in Germany and the United Kingdom as potential tools to detect crop disease prior to the onset of visual symptoms. Linked to precision agriculture this would be a powerful tool for reducing inputs (pesticides) and maintaining crop yields. The possible use of remote sensing techniques similar to the Copernicus satellite system which has land use and soil moisture detection capabilities has also been suggested. In this context, the question of data security and privacy needs to be addressed.

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As technologies improve, the movement of diagnostics from non-specialists in the laboratory to so-called "point-of-care" diagnostics in the field operated by farmers is a legitimate prospect. Prototype technology development is under consideration in the United Kingdom and would empower landowners and growers to make immediate decisions on pathogen control. In the **mini-paper - Monitoring of soil-borne pathogens (fungi, protists and nematodes)** the state of the art is described and examples of monitoring and decision support systems can be found.

Monitoring and DSS demand a high standard of knowledge and education in farming, extension services and research. Many countries/regions cannot meet these requirements. When switching from chemicals to knowledge driven and complex IPM solutions, education and extension are the most important parts of the challenge. Baseline information, data sharing and converting data into management tools was considered a big hurdle by the experts in the Focus Group. Like in all areas, big data without proper tools will end in a digital traffic jam. An important issue is how to create confidence in the data and tools. The potential of IPM based on data and knowledge makes it very worthwhile to show ambition and to take action in this field.

Next to monitoring of soil-borne diseases there is a demand for monitoring soil quality in all its aspects. In the UK and the Netherlands, a number of research projects are running which aim to define the minimal dataset which is needed to qualify a soil and to give indications and guidance to take the right measures to improve and reach a sustainable use of soils.

4h. Estimated impact of priority techniques on soil health in general

New techniques and management strategies should have a positive or neutral impact on general soil health. The Focus Group experts expressed their opinion about the impact of the prioritised techniques. Compost and green manure are considered to be 'no regret' actions although even these measures bring along risks when used without a proper strategy, but in general, the pros are far bigger than the cons. The Focus Group considered Biofumigation and Anaerobic Soil Disinfestation to be rather drastic measures with a potentially significant impact on soil life with a risk of diminished soil resilience. However, there is no proof of this presumption and it was argued that it could actually have a positive impact, therefore long-term experiments and experience are needed to clarify this. Biological control agents are very targeted products with negligible side effects. Besides introducing resistant rootstocks, grafting could be used to improve general soil health by selecting rootstocks which promote beneficial soil life. This is not taken up by companies active in the selection in the actual rootstock development.

4i. General fail factors and hurdles

Next to the specific fail factors and hurdles mentioned above, a number of general fail factors and hurdles were identified:

- Too high frequency of profitable crops for economic reasons. Farms and farmers are more and more specialised on one or a small array of crops. This development is market driven and difficult to tackle. Low price levels force farmers to survive on short notice and distracts from long-term sustainability. However it is a misunderstanding that low cropping frequencies would prevent soil-borne diseases because many of the diseases and pests causing the diseases can feed and thrive on different crops.
- Lack of awareness. Many soil-borne diseases do not show very specific, striking symptoms. They are therefore often detected at a late stage when the area of infestation has already grown out of hand. Early detection (before symptoms appear) is often expensive. Farmers and extension officers do not recognise the symptoms and interpret them as problems with nutrition or soil structure.
- Lack of knowledge and infrastructure. In many countries there are no routine laboratories or advisory services where growers can send their soil samples to check them on soil-borne diseases nor are there skilled intermediaries.

- Lack of knowledge of indicators that predict the efficacy of preventive (soil health) measurements and no guarantee for effectiveness of the cure, in contrast to chemicals where effectiveness is more predictable.
- In agricultural education, soil-borne diseases are not sufficiently highlighted.
- Up-scaling of agriculture. Because of economy and mechanisation, the acreage operated by one grower is increasing rapidly. The challenge is to scale up and to intensify attention per m^2 at the same time. Technical tools like Geographic Information Systems (GIS) and data exchange via web services could be of help but are not yet developed into applicable tools.
- Brain drain of knowledge. In many countries there is a lack of education in phytopathology. Fewer and fewer people have the skills to work on the topic in extension or science. A lot of resources are spent for example on high-tech genetic/molecular solutions which could certainly be of help and are promising in the long-term but should not replace long-term field research.
- Free trade of planting material and farm saved seed are accelerating the spread of diseases within and between countries. Certified seed is of help but not good enough from a technical point of view. For example, statutory sampling methods are prescribed that only detect high levels of infestation. In such cases, certified seed is no guarantee that it is really free from diseases/pests.
- Withdrawal of pesticides. Pesticides with a broad working spectrum against soil diseases, are more and more restricted. Instead of a quite easy general solution (e.g. for nematodes- applying a nematicide) a whole range of detailed and tailor-made solutions need to be made. This is far more complicated and more knowledge intensive.
- The Focus Group mentioned the ownership situation of soil. As the owner of the field is often not the user, there might be a lack of responsibility/acknowledgement for how well it is functioning. The temporary soil user might refrain from investing in long-term quality control of the field as they may not believe it brings them any benefits. Also the price of land might have an influence on the development of soil-borne diseases and the land that a farmer can afford might not of the best possible quality. Finally, increasing farm sizes could also be a factor for the emergence of soil-borne diseases, as larger acreages could make them more difficult to control.

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5. Thinking outside the box

The Focus Group was challenged to think out the box to come up with innovative (if a little crazy) ideas. To facilitate this activity, a subgroup wrote a mini-paper on this topic. The approach is described in the **mini-paper - Less boxes and more horizons**. **Annex 6** presents the results of the out of the box approach; they have been summarised below.

While thinking about innovative ideas, it should be noted that what is considered 'innovative' depends on the context. Many techniques which are now considered "old-fashioned" (e.g. chemical fumigation with methyl bromide) or "common sense" (e.g. use of clean seed and plant material) were once very innovative. Also old-fashioned techniques can become innovative when small changes are made (e.g. green manures vs. agro-ecological service crops which have multiple benefits). Some currently innovative techniques are so new that it is not yet possible to estimate their potential impact (e.g. Anaerobic Soil Disinfestation-ASD).

Back to the future
Search for old techniques used for example in monasteries and royal gardens centuries ago. Use these to develop modern equivalents.

New sources
Search for new sources of active ingredients. Possibility of using nanotechnology to apply biocontrol agents and pesticides. Find new environments to grow crops.

Work on total plant health
Integrate all possible knowledge to strengthen plants.

Breeding other varieties
"Speaking plants" as an indicator for biotic and abiotic stress. These plants give a signal before damage thresholds are reached. Breed highly competitive strains of soil-borne diseases with low virulence which can control the original strains.

Plant communication
Find the mechanisms how plants communicate with each other, with soil-borne diseases and their antagonists.

Quick and easy indicators
Introduce a network of indicator plants in a region for early detection of soil-borne diseases in that region. This concept is used in vineyards were they plant susceptible rose varieties as an early detection of mildew. The concept of "speaking plants" as mentioned before also fits in this idea.

New or improved non-chemical solutions
Use banker plants to introduce biocontrol agents. These are plants carrying a large amount of the biocontrol agents which are planted within the crop they should protect. Solar heating and heat pumps for soil sterilisation. Mobile dykes to be used in inundation.

Search and destroy
Use modern techniques like drones, satellite images, robots, sensors on farm equipment to search for early infestations. Use them to identify the exact spot which needs treatment and only apply treatment there.

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6. Feasibility of an integrated approach

The question has to be raised whether an integral approach can be implemented successfully in most disease crop combinations. Important differences can be expected between arable and vegetable crops in open field systems compared to greenhouses. The level of specialisation of farms with only one or just a small number of crops is a complicating factor. Solutions found in these highly specialised and capital intensive systems will be very helpful for outdoor or less intensive systems. Exchange of knowledge and experience between sectors, countries and cropping systems is very valuable and requires attention. The **mini-paper - Transfer IPM Systems** is about getting IPM strategies up and running.

To facilitate transfer of IPM systems against soil-borne diseases, community-based approaches can be considered more successful than individual farm activities. Individual farm activities are presumably more successful when they form part of an overall IPM scheme that reduce costs or efforts on short notice.

Farmer acceptance is crucial for the adoption of IPM systems against soil-borne diseases. IPM systems can affect the most important, almost unchangeable production factor of a (soil-based) farm: its crop land. IPM leads to long-term, not immediately foreseeable, ecological and economic consequences which sometimes entail risks. These risks together with the positive prospects need to be addressed transparently to gain confidence with the farmer to establish an IPM system.

In the EIP-AGRI Focus Group on Fertiliser efficiency in Horticulture, a **mini-paper** was written about the need for a systems approach to increase nutrient use efficiency in horticulture. The prototyping method as developed by Vereijken (1999) is used as a starting point. This systematic approach could be very useful to develop and implement soil health strategies.

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7. What needs to be done?

Developing and implementing a soil health strategy is an urgent issue. It is essential to raise awareness with farmers, consumers and policy makers about the fact that good soil care is a long-term investment and a necessity. The Focus Group also identified the following specific research needs, ideas for Operational Groups, and other recommendations. Addressing these can contribute to the development and implementation of soil health strategies.

7a. Research needs from practice

In Annex 7 a list of research needs from practice is presented. This list includes all the topics that are listed in the mini-papers and those that were discussed during the meetings.

Monitoring is the essential starting point in IPM. **The development of science-based sampling strategies** and **high throughput diagnostic tests** should allow farmers to get information with a good cost/benefit ratio. Processing of data and presenting results in an applicable format is a critical success factor. The Focus Group agreed on the opportunities presented by **integrated decision support systems** but there was some scepticism about the feasibility of the approach. In the UK and the Netherlands this approach is implemented and supported but less so in other countries.

Improving general soil health (prevention) is the goal, rather than incident management. Indicators that give information on the health status of a soil would also be a step forward. Organic matter is considered the brain of the soil; it steers soil processes and determines its properties. In order to use organic matter in an effective way (compost, digestate, biochar, manure, green manure), we have to understand the **mechanisms and functions of the different types of organic matter** in different soils and conditions. Farmers need **indicators on the soil-borne disease suppressing quality of compost/organic matter**. A shortage of organic matter is reality in many European regions so instead of the application of big volumes, **micro application of compost, seed coating with compost extracts** could lead to solutions.

Green manure crops should be promoted as they are a valuable source of organic matter and can diminish depletion of nitrogen and prevent water and wind erosion. To convince farmers, the **host status of the available green manure crops** needs to be clarified. Depending on the soil-borne disease present, a farmer has to choose the appropriate green manure crop and variety, but in order to make the optimal decision, the farmer needs to know the effects of the chosen crop on other soil quality parameters like nitrogen, organic matter. However, there is a lack of **information on the effect of growing season, growing period** on these parameters. There is a need of **more/new green manure crops** also taking into account the role of such a crop in improving the biodiversity of the soil.

Biofumigation can be considered as a green manure crop with special benefits. So the questions raised for green manure crops are also relevant for biofumigation crops. Understanding the mechanism and defining recommendations about how to apply to get the fumigation effects would help to get realistic advice on which green manure crop and how to tackle certain soil-borne diseases. **An agreement on research protocols** would avoid wrong conclusions and confusing information for farmers.

Anaerobic soil disinfestation, solarisation and flooding could be considered as very specific types of organic amendments to the soil. **Alternatives for covering soil with impermeable film** are needed to allow these measures to be used on large acreages. **Defining the region-specific criteria** (such as type of local organic matter, temperature, time) for effective implementation will increase the success rate and motivate farmers to use one of these techniques. Little is known about the **effect of these drastic techniques on soil life and soil quality in the long term** and so these techniques must be considered as an important research topic before introducing it on large scale.

Grafting of resistant rootstocks has the potential to be developed further especially in intensive cropping systems. There is a need to **widen the scope of grafted crops and resistance against more soil-borne diseases and more crops**. Grafting olives, strawberry and Phaseolus would solve a lot of problems. **The development of grafting machinery** would bring down the costs and enlarge the market for grafted plantlets. **Standardised testing protocols** and the choice of relevant disease strains to be used when testing the level of resistance should be agreed on.

Biological control agents (BCA) can replace chemicals in certain crop disease combinations. The use of BCAs is easily adapted because in many cases the spraying of a chemical is replaced by spraying spore suspensions. For a farmer this is not too big a change. But **application protocols** are needed to describe the best ways to apply BCAs against soil-borne diseases. What are the possibilities of **combining BCAs with other measures** such as ASD or compost? It would be useful to increase knowledge on the efficacy of the BCAs against **other pathogens** than those which are mentioned in the label. Which **carriers** for the BCAs can increase survival in soil?

While all of these research needs were considered important by the Focus Group, most of the experts considered BCAs to be the most promising because of their relatively easy-to-use aspect. They therefore considered identifying protocols for applying biocontrol agents a top priority. The development of science-based sampling strategies and high throughput diagnostics was identified as another top priority. The third was the need for indicators to predict the suppressing quality of compost and other organic amendments.

For all measures taken to control soil-borne diseases, short-term efficacy is important, but the overall performance within the whole rotation period and longer must also be considered. As a consequence, **long-term multidisciplinary experiments** (LTEs) are needed to judge the validity of measures taken. In many European countries, budget cuts in agronomic research have meant that many LTEs have stopped and have made it quite impossible to start new ones.

7b. Priorities for Operational Groups

In **Annex 8** a list of priorities for Operational Groups is presented. This list is a selection of all the topics that are listed in the mini-papers and those that were discussed during the meetings in order of priority.

Implementing a soil health strategy interacts with nearly all aspects of farming. This makes it quite a challenge to confine the subject of an Operational Group in such a way that participants can deal with the topic on its own. Individual themes which could be appropriate are **on-farm production of compost** combined with the **development of indicators predicting the qualities (e.g. disease suppressiveness) of compost**.

Another possibility is **on-farm implementation of green manure**. This would cover topics such as optimal choice of the crop based on starting situation and targets, sowing and growing techniques, effects on N depletion etc. The same approach could be chosen for **biofumigation crops and farmer networks applying solarisation, anaerobic soil disinfestation or inundation.**

Operational Groups on grafting could develop **on-farm grafting techniques**, completed by **testing of resistances against local strains** of soil-borne diseases present on their farm.

Operational Groups working with specific **biological control agents** could optimise the introduction and use of BCAs by exchanging experience and knowledge. BCAs combined with other techniques could be part of it.

Monitoring is a subject which could be developed within Operational Groups. Part of this could include the recognition of symptoms, developing and **testing diagnostic tools** together with farmers. Developing **tools on soil quality management**.

Ultimately, the challenge is to get people motivated to start the needed holistic approach and lead to a soil health strategy. As described in **the mini-paper on transfer IPM systems,** organising **communities of practice** on integrated management of soil-borne diseases could be a starting point to reach the ultimate goal.

A community of practice fits in the concept of Operational Groups. In fact, it would be even more interesting to start Operational Groups within **the concept of prototyping to develop farming systems**.

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The Focus Group concluded that Operational Groups on monitoring, organic amendments and introduction of BCAs would have the highest impact in the short-term.

7c. Knowledge exchange

In Operational Groups, knowledge exchange will be an important element. IPM of soil-borne diseases is knowledge intensive, so effective knowledge exchange is crucial. It is important to communicate on **"permanent success stories"**. This will help increase interest in maintaining soil health to control soil borne-diseases now and in the future. Communication should be interactive, using tools such as a Wikipedia page on soil health as part of soil quality. Traditional methods like demonstration on farms, training for farmers, extension officers, traders and consumers should be supplemented with websites, blogs and webinars. **Visualisation tools offered as apps** on smartphones could trigger people to implement solutions. **Easy to use Decision Support Systems (apps)** help to share validated information and discover information gaps or misunderstandings along the production chain.

The use of **Geographic Information Systems** to visualise the available information on the farm map improves the farmer's understanding of the situation. By presenting the right data, combined with relevant knowledge a farmer can make an informed decision. When farmers experience financial benefits because of this approach, they will be motivated to look for more data and knowledge.

The Focus Group considered that organising Communities of Practice on soil health strategies and the introduction of sampling strategies within cropping systems were the most important subjects to be tackled through knowledge exchange. This is in line with the points discussed on Operational Groups.

7d. Cost benefit

Sustainable food production based on the sustainable use of soils is a long-term goal. Farmers have to survive market changes at short notice. Therefore each step towards improving the sustainability of our food production should also show short-term cost benefits. If not, efforts for sustainability will not be made voluntarily and regulation by law is the only way to enforce it. Economic analysis of measures to improve soil health in different cropping systems will help to evaluate whether these measure would fit in the economic goals of the farm.

The Focus Group discussed opportunities to improve the cost/benefit ratio of IPM methods. For organic matter and compost, new sources can be found from industry, cities, algae etc. Also, modifying organic matter to make it more fit for agriculture could improve cost/benefit ratios. For example by adjusting stable systems of dairy farming and convincing dairy farmers that sludge/manure is not a waste product but a valuable basic input. For green manure and biofumigation crops it would be helpful to reduce the costs involved in growing and incorporating them into the soil, for instance through using fewer seeds per hectare, cheaper seeds or cost effective weed control.

For anaerobic soil disinfestation, cheaper covering methods and a shorter application period need to be identified. To enhance the use of BCAs, speeding up the registration process for low risk products would reduce costs. Optimising and reducing the costs of production will be a matter of scale. For monitoring, the development of combined and EU-wide sampling strategies and multipurpose high throughput diagnostic tests will improve the cost/benefit ratio.

Long-term experience with measures can help demonstrate how a soil health strategy can bring future profits. This can provide a convincing argument to implement measures now.

Farmers need information on the costs and benefits of any new measures before they can decide on whether or not to test them on their farm. Communicating with farmers without a realistic outlook on cost/benefits is a waste of time.

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7e. Follow up

From the beginning, the Focus Group was very motivated to actively disseminate of the outcomes in their home countries and to cooperate in new initiatives both in research and Operational Groups.

We must urgently raise awareness in national farmer organisations and authorities. The lack of objective information on the occurrence, severity and overall impact of soil-borne diseases hampers the substantial coordinated attention and action which is needed. That is why the Focus Group members are going to contact their national ministries of agriculture to promote the outcomes of the EIP-AGRI Focus Group. They have decided to present results in seminars and short reports to their local authorities.

Most of the members expressed the intention to write about the results of the Focus Groups in farmer magazines and internet fora.

In some of the countries, the members are already planning workshops and demonstrations on soil quality in the context of the United Nations Year of soil. They will use these opportunities to present the outcomes of this Focus Group. For example in Belgium there are events on soil management for farmers and policymakers in October 2015. In Italy in December 2015 there will be a workshop with advisors from neighbouring countries where anaerobic soil disinfestation and biological control agents could be discussed.

Some of the members expressed their wish to initiate thematic networks and Horizon 2020 research projects on the topics mentioned in **Annex 7**.

Initiatives on Operational Groups on soil quality are already in progress in different countries. Initiatives are taken to realise the topics for Operational Groups as mentioned in **Annex 8**.

As the Focus Group concluded that there is a lack of information on the long-term effects of all kind of measures, the members will try to prevent long-term experiments being cancelled because of funding cuts. Moreover, they expressed the need to look for opportunities and financial support to develop a network of coordinated long-term experiments and to agree on a common protocol to facilitate the exchange of information and integral analysis of data.

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8. Closing remarks

The Focus Group was a highly motivated and dynamic team bringing together a lot of information and ideas both from practice and research on short notice. As a result, next to the **starting paper** and this final report, **10 mini papers** have been published which are very informative. The Focus Group considers the final report and mini papers not as an end result but as a starting point to raise awareness and initiate European cooperation on the preservation and improvement of one of our most important food-producing factors: **soil**.

To complete this final report, **Annex 10** reviews the answers on the objectives and tasks given to the Focus Group which were described in the starting paper.

Objective given to the Focus Group

How to suppress soil-borne diseases (fungi and nematodes) in vegetable and arable crops and how to enhance cross-fertilisation between different crops and agricultural systems?

The Focus Group concluded

Develop a soil health strategy on farm level which is inseparable and integral part within a total soil quality strategy that combines soil biology, soil physics (structure) and soil chemistry (fertilisation). This needs integrated knowledge in the whole chain: consumer, farm, extension, trade, universities. Instead of incident management whenever a soil-disease develops, enhancing soil health constantly is the guiding principle. An interactive approach both on national and EU level by using this concept in research and in extension programmes (e.g. Operational Groups) will stimulate the interdisciplinary cooperation and therefore the successful implementation of science-based measures to support the sustainable status of our precious soils.

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Annex 1: Members of the Focus Group

Familiy Name	First name	Country	Profession
Alabouvette	Claude	France	Senior scientist, phytopathology
Clarkson	John	United Kingdom	Research leader, plant pathology
de Cara	F. Miguel	Spain	Scientist, phytopathology
de Carvalho França	Soraya	Brazil	Senior Scientist, bio control
Debode	Jane	Belgium	Senior scientist, soil management
Elorrieta	Mª Antonia	Spain	Research leader, phytopathology
Furlan	Lorenzo	Italy	Research leader, entomology
Grand	Alfred	Austria	Organic farmer
Hinarejos Esteve	Estefanía	Spain	Agronomic engineer, bio control
Kos	Johan	Netherlands	Director applied research station
Michel	Vincent	Switzerland	Senior scientist, phytopathology
Neilson	Roy	United Kingdom	Senior scientist, nematology
Pertot	Ilaria	Italy	Senior scientist, sustainable agro-ecosystems
Pugliese	Massimo	Italy	Senior scientist, biological and integrated disease management
Urba	Karolis	Lithuania	Extension officer
Van der Lugt	Teun	Netherlands	Grower of chrysanthemum
Verbeek	Fons	Netherlands	Grower biological vegetables (greenhouses)
Vilich	Vivian	Germany	Scientific officer/programme manager
Wallenhammar	Ann-Charlotte	Sweden	Research leader, molecular detection, decision support systems
Zahrl	Johann	Austria	Consultant for Crop Production

Facilitation team

Molendijk	Leendert	The Netherlands	Senior scientist, nematology coordinating expert
Desimpelaere	Koen	Belgium	Policy officer for the European Innovation Partnership "Agricultural Productivity and Sustainability
Karasinski	Céline	France	Policy officer for the European Innovation Partnership "Agricultural Productivity and Sustainability
Boot	Iman	The Netherlands	Policy officer at the European Commission, DG for Agriculture and Rural Development

You can contact Focus Group members through the online EIP-AGRI Network.
Only registered users can access this area. If you already have an account, you can log in here
If you want to become part of the EIP-AGRI Network, please register to the website through this link

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Annex 2: Mini-Papers on prioritised topics

Title mini-paper	Authors	hyperlink
Monitoring of soil-borne pathogens (fungi, protists and nematodes)	Roy Neilson, John Clarkson, Jane Debode, Lorenzo Furlan, , Ann-Charlotte Wallenhammar, Johann Zahrl	link
Organic Matter, Compost	Jane Debode, Maria Antonia Elorrieta, Alfred Grand and Massimo Pugliese	link
Green Manures and cover crops to reduce the pressure of soil-borne diseases in annual crops	Vincent V. Michel, Karolis Urba and John Clarkson	link
Biofumigation for the control of soil-borne diseases	John Clarkson, Vincent Michel, Roy Neilson	link
Anaerobic Soil Disinfestation and other techniques of 'non chemical' soil disinfestation	Miguel de Cara	link
Inundation in the cultivation of flower bulbs	Johan Kos	link
The use of microbial biocontrol agents against soil-borne diseases	Ilaria Pertot, Claude Alabouvette, Estefanía Hinarejos Esteve, Soraya Franca	link
Success and failures of grafting against soil-borne pathogens	Massimo Pugliese, Vincent Michel, Fons Verbeek	link
Transfer IPM Systems	Vivian Vilich	link
Less boxes and more horizons	Soraya França, Jane Debode, Ilaria Pertot	link

All mini-papers can be found here:

http://ec.europa.eu/eip/agriculture/en/content/ipm-practices-soil-borne-diseases-suppression-vegetables-and-arable-crops

Annex 3: Acreage and yearly turnover of crops in the regions of the European Union (FAOSTAT)

	Crop	Turnover 2004-2006 k$	Crop	Area (hectare)
1	Wheat	17,447,790	Wheat	54,246,541
2	Grapes	13,504,519	Oil crops Primary	33,929,940
3	Potatoes	12,406,435	Pumpkins for Fodder	29,181,000
4	Tomatoes	7,592,171	Barley	24,379,286
5	Olives	7,476,558	Maize	18,335,325
6	Sugar beet	7,407,782	Sunflower seed	16,027,859
7	Sunflower seed	6,098,928	Rapeseed	8,236,721
8	Apples	6,031,003	Fruit excl, Melons, Total	7,360,310
9	Rapeseed	5,285,341	Oats	6,092,694
10	Maize	3,613,275	Potatoes	5,981,823
11	Barley	2,765,309	Olives	4,925,495
12	Vegetables, fresh	2,065,673	Rye	4,543,967
13	Onions, dry	2,053,254	Vegetables & Melons	4,117,619
14	Carrots and turnips	1,937,718	Pulses, Total	3,744,163
15	Peaches and nectarines	1,848,093	Grapes	3,570,708
16	Strawberries	1,787,469	Soybeans	3,446,955
17	Chillies and peppers, green	1,332,067	Sugar beet	3,426,188
18	Plums and sloes	1,298,463	Triticale	3,199,360
19	Lettuce and chicory	1,292,500	Peas, dry	1,968,290
20	Rice, paddy	1,157,917	Apples	1,050,495
21	Cabbages and other brassicas	1,157,691	Treenuts, Total	984,583
22	Oranges	1,101,420	Rice, paddy	688,660
23	Cucumbers and gherkins	1,090,025	Pulses, nes	688,436
24	Pears	1,045,284	Citrus Fruit, Total	541,817
25	Cherries	937,990	Vegetables and roots fodder	512,640
26	Raspberries	878,084	Plums and sloes	511,467
27	Rye	861,377	Tomatoes	506,583
28	Soybeans	854,849	Linseed	485,912
29	Leeks, other alliaceous vegetables	771,615	Cabbages and other brassicas	413,175
30	Tangerines, mandarins, clementine's, satsumas	709,971	Onions, dry	384,653

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Annex 4: Directive on IPM 128/2009/CE

1) Before taking any decision on pest control, harmful organisms must be monitored by adequate methods and tools where available; tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems

2) Treatments may be carried out only where and when the assessment has found that levels are above pre-determined economic thresholds for crop protection

3) If economic thresholds are exceeded, agronomic solutions - mainly rotation - should be considered to avoid damage to crops including: interference of newly established pest populations through tillage timing and other modifications; choice and modification of sowing dates and alterations of rotation sequences

4) If economic thresholds are exceeded and no agronomic solutions are available, biological control, physical treatment or another non-chemical pest control method should be considered as a replacement for chemical treatment

5) If economic thresholds are exceeded and no agronomic solutions, biological control, physical treatments or other non-chemical pest control methods are available, chemical treatments should be selected among those that pose the lowest risk to the environment and human health and they should be used in a way that minimizes the risk of pest resistance by limiting their use over space and time.

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Annex 5: List of nematicides and fungicides used to control soil-borne diseases

Nematicides		
	Fumigants	**Non fumigants**
1	methyl bromide	aldicarb
2	methyl iodide	ethoprofos
3	1-3 dichloropropene	fosthiazate
4	chloropicrine	oxamyl
5	metam sodium	Abamectin
6	metam potassium	
7	dazomet	***fluensulfone***
8		***fluopyram***
9	***dimethyl disulfide***	
10	***Iodomethane***	
In ***bold italic*** recent developments are given		
Approved active ingredients of fungicides against soil-borne diseases		
		Azoxystrobin
		Boscalid (formerly nicobifen)
		Captan
		Chlorothalonil
		Cymoxanil
		Cyprodinil
		Etridiazole
		Fluazinam
		Fludioxonil
		Fluopyram
		Fluoxastrobin
		Folpet
		Fosetyl
		Fuberidazole
		Hymexazol
		Iprodione
		Metalaxyl
		Metalaxyl-M
		Metam (incl. –potassium and –sodium)
		Pencycuron
		Prochloraz
		Propamocarb
		Propiconazole
		Prothioconazole
		Pyraclostrobin
		Tebuconazole
		Thiophanate-methyl
		Thiram
		Tolclofos-methyl
		Trifloxystrobin

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Annex 6: "Crazy ideas"

Back to the future

Integrate (old) gardening techniques in agriculture.

New problems = more technology = new problems, look at past, we forget to look at the interactions, we detect these interactions, but what is their function? Look at the activities and interactions. Do not try to solve new problems with new technologies but think about old solutions.

Pick a SBD (i.e. club root) go back in time on methods/literature/knowledge when certain tools were not available and see how people managed this. Then apply modern methods and combine.

Webinars in different languages, on big farms (practice), "re-interpreting" lost knowledge

New sources

Root extracts (in a bottle) to stimulate germination of SB pathogens and then apply a BCA or biocide

Nanopesticides + nanorobots

Develop or introduce virulent mycoviruses and bacteriophage

Extract useful plant protection chemicals from plant waste

Change environment, growing crops away from diseases like inside the ocean (experiments going on in Italy)

Work with autochthon antagonists

Help farmers to develop their own antagonists' microorganisms

Innovation and agriculture: Study object in psychology

Electronic plant, biosensors, smart grass

Linked to low cost sensor which activates a mobile phone application

Work on total plant health

Combine catch crops with ASD/ biofumigation…

Water quality: macrophytes and allelopathy

Antagonists of pathogens and enhance antagonists trough. Changes in crop management "immune therapy" rather than chemotherapy

Breeding other varieties

Develop varieties that benefits

Genetic modification, genetic modify soil-borne pathogen, we see the damage but not the pathogen (spread) - change environment without soil-grow outside the soil in bubbles

Develop varieties that benefit from the presence of SBD

Breed "speaking" plants

Genetically modify SB pathogens to be more competitive against the "wild" SB but at the same time with low virulence/absence of virulence

Genetically modify BCA or crops

Interchange resistant markers in varieties

Develop plants that have an indicator of biotic stress

Plant communication
Talkative soil, innovation old study areas, how to stimulate people (What does this mean?)
Dogs smelling plants stress
Breed "speaking" plants
If mind power exists can we use this for better growing of the plant?
Can we find something than can "read" plants and can understand the communication of the plant?

Quick and easy indicators
Visualisation (movies, drawing)
Spread indicators
European monitoring of soils with very susceptible varieties to main diseases and mapping the distribution of the disease and their importance, collecting information on main acting factors as the same time study well those without any symptom in risky area.
Monitoring- we don't have the overview, indicator plants, produce key soil indicators.
Soil indicator stick you put in the soil and predict 1 suppressiveness and 2 effectiveness of green manure, BCAs or soil fumigation
Develop plants that have an indicator of

Mechanical solutions (flooding, soil rotation
Catch crop, cover crop, root extract- bank of plants, inoculation of BCAs by using pre-colonized plants for rotation or intercropping
Silage of green manure plants inoculated with BCA
Cables in the soil
Pasteurise soil, heat pumps and solar panels and pipes in soil to influence soil health (greenhouse/tunnel)
Mobil dykes for flooding
Flooding agriculture in estuarial

Search and destroy
Attract and kill pathogen or nematodes: isolate compounds that attack zoospecies or nematode, coat with them micrograules of fungicide/nematocide
Farmers produce their antagonists and set back in the soil (law, legal aspects)
Insects that attacks aerial plants could stimulate beneficial in roots
Modify soil-borne pathogens with green fluorescent markers or similar to see them
Spray indicator on the plants or field

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Annex 7: List of research needs from practice

Nr.	Topic	Research need
1	Compost	COM extracts in relation to SBD
2	Compost	Micro application of COM and COM extract (e.g. seed coating)
3	Compost	Indicators of SBD suppressing quality of Compost (prediction)
4	Compost	Digestate biochar
5	Green manure	Host status of crops/cultivars to most important SBD
6	Green manure	Effect of available crops on other soil quality parameters like Nitrogen depletion, OM content, …
7	Green manure	Effect of growing period and growing season on this biological, physical and chemical aspects of soil quality
8	Green manure	Select new crops
9	Biofumigation	Understanding the mechanism; ITC production or general effects of improved fresh organic matter
10	Biofumigation	Agreement on research protocols to avoid artefacts
11	Biofumigation	Selection of biofumigation crops with resistance against SBDs
12	ASD	Define the region specific criteria for an effective ASD: soil temperature, minimum period, amount of organic matter, type of organic matter C/N, …
13	ASD	Alternatives for covering soil with VIF
14	ASD	Long term effects on soil health, resilience, …
15	BCA	Identification of the best protocols to apply biocontrol agent against soil-borne disease
16	BCA	Possibilities to combine BCAs with other measures like ASD or compost
17	BCA	Enlarge the knowledge on the efficacy of the microbial biocontrol agents against other SB pathogens than the targeted in the label and possible use with carriers which can increase survival in soil, in particular to prove environmental safety
18	BCA	New strains protoplast fusion
19	Grafting	Develop resistant root stocks for more SBDs
20	Grafting	Develop rootstocks for more crops (Olives?)
21	Grafting	Validated tests for resistance testing of rootstock
22	Monitoring	Development of science based sampling strategies for SBD
23	Monitoring	Development of high throughput diagnostic tests
24	Monitoring	Integrate nematode data into decision support systems (DSS)
25	Monitoring	Managing big data
26	Transfer	Raise awareness with policy makers, consumers and farmers that good soil care is a long term investment and necessity
27	Transfer	Organize Operational Groups on soil quality management (e.g. farmer field schools)
28	Transfer	Develop tools on soil quality management in which the control of SBDs are integrated (DSS)

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Annex 8: Suggestions for Operational Groups

Nr.	Topic	Operational Groups
1	Compost	On farm production of compost
2	Compost	On implementation of compost in cropping systems
3	Compost	Indicators of SBD suppressing quality of Compost (prediction)
4	Compost	Test to see which diseases are in the compost
5	Green manure	Implementation of cover/green manure crops in farming systems. Exchange of sowing systems, extension on growing practices…
6	Green manure	Effect of available crops on SBD and other soil quality parameters like Nitrogen depletion, OM content, …
7	Green manure	Effect of growing period and growing season on this biological, physical and chemical aspects of soil quality
8	Green manure	Define criteria for effective results
9	Biofumigation	On development of incorporating techniques
10	Biofumigation	Exchanging information and experiences on appropriate management of biofumigant crops
11	Biofumigation	Define criteria for effective biofumigation
12	ASD	Define the region specific criteria for an effective ASD: soil temperature, minimum period, amount of organic matter, type of organic matter C/N, …
13	ASD	Alternatives for covering soil with VIF
14	ASD	Implementation of ASD in different farming systems
15	BCA	Farmer groups working with specific BCAs, exchanging knowledge and experiences to optimize the introduction and use of BCAs
16	BCA	Combination with other techniques
17	BCA	The use in replanting perennial crops
18	BCA	To test a specific BCA on different cultivars
19	Grafting	On farm grafting on crops
20	Grafting	On farm testing of resistances against SBD
21	Grafting	Reduce costs of grafting techniques
22	Grafting	To test combination grafting and BCA?
23	Monitoring	Develop DSS based on farmer inputs on answers to be given and farmer inputs on interfaces to be delivered
24	Monitoring	Field schools training farmers, students and extension workers on recognizing SBDs on early symptoms and keeping track based on GPS systems
25	Monitoring	Testing and developing diagnostic tools together with farmers
26	Monitoring	To develop easy lab on the farm
27	Monitoring	To monitor the risk in advance, low/high
28	Transfer	Organize CoPs (Communities of practice) on Integrated Management of SBD
29	Transfer	Training and education networks on IPM of SBDs
30	Transfer	Develop tools on soil quality management in which the control of SBDs are integrated (DSS)

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Annex 9: List of topics for knowledge transfer

Nr.	Topic	Knowledge transfer
1	Compost	Quality control and certification
2	Compost	Soil practitioner training for different kind of farmers
3	Compost	Indicators of SBD suppressing quality of Compost (prediction)
4	Compost	Demonstration on farm
5	Green manure	DSS to make the right tailor made choices based on field specific circumstances
6	Green manure	Inform policy makers on all aspects of these crops not only the biodiversity issue!
7	Green manure	Effect of growing period and growing season on this biological, physical and chemical aspects of soil quality
8	Biofumigation	Tailor made advices on the biofumigation crops chosen based on the SBD present in a field
9	Biofumigation	Agreement on research protocols to avoid artefacts
10	ASD	Define the region specific criteria for an effective ASD: soil temperature, minimum period, amount of organic matter, type of organic matter C/N, …
11	ASD	Demonstration fields at experimental and commercial farms
12	BCA	Introduce BCA via CoPs and exchange experiences
13	BCA	Demonstration fields at experimental and commercial farms
14	Grafting	Independent information on claimed resistances of rootstock
15	Grafting	DSS to select the optimal rootstock in a given situation
16	Grafting	Produce grafted plant on farm
17	Grafting	Produce information on rootstock compatibility of the grafted varieties
18	Monitoring	Introduce sampling strategies within cropping systems
19	Monitoring	Training of extension officers and farmers in recognising crop symptoms in early stages
20	Monitoring	Integrate nematode data into decision support systems (DSS) and transfer this technic to farmers
21	Transfer	Raise awareness with policy makers, consumers and farmers that good soil care is a long term investment and necessity
22	Transfer	Organize CoPs Communities of practice on Integrated Management of SBD or even on soil quality management (e.g. farmer field schools)
23	Transfer	Develop tools on soil quality management in which the control of SBDs are integrated (DSS), don't forget to study tools at long term
24	Transfer	Use mutual funds in order to implement technics
25	General	Use visualization tools like smartphone
26	General	Be interactive, creating and using Wikipedia page concerning SBD
27	General	Website, blog, webinars in different languages

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Annex 10: Tasks carried out, answers given

To finish this final report the answers on the objectives and tasks given to the Focus Group, as described in the **starting paper**, are reviewed in this Annex.

To fulfil the assignment the following tasks were performed:

- **identify the main soil-borne diseases relevant in the EU:**
- Based on literature and a questionnaire among Focus Group participants, a list of the most importantse soil-borne diseases was produced. Fusarium spp, Verticillium dahliae, Rhizoctonia solani, Meloidogyne spp and Globodera spp are considered to be the most common fungi and nematodes that cause several wide-spread soil-borne diseases. It is striking that in most European member states statistics on infested areas, information on crop damage and economic impact are not available or treated confidentially.**identify the key elements that cause such soil-borne diseases and examine how they interact:**
- It is a prejudice that high cropping frequency is the main cause of problems. For some highly specialised organisms this is true. But many soil-borne pathogens, like *Rhizoctonia* and *Meloidogyne* have a broad host range, so it is not as much the frequency but the whole cropping sequence which is decisive. A lack of awareness, lack of knowledge by all who are involved in the production chain, a lack of knowledge-based planning, a lack of monitoring and a lack of preventive measures result in a reactive approach. The Focus Group members noted that they usually see a 'management per incident' approach. The absence of an integrated approach to soil health and soil quality in general is the main cause of problems regarding soil-borne diseases. Another key element is the reduction of general soil quality causing suboptimal growth of crops with less tolerance against diseases as a result. Examples are neglected care for organic matter, too heavy machinery, counter-productive manure practices and suboptimal growing periods.
- **identify, assess and compare different IPM systems and techniques (Physical, chemical, biological and other) that suppress soil-borne diseases taking into account the cost-effectiveness in the different systems and crops and explore cross-fertilisation between different crops and agricultural systems:**
  The basis is to optimise growing conditions for the crop. Organic matter management is crucial in this. Manure, compost, green manure crops and other organic amendments are all available products which should be used with sense and show opportunities to be developed further. The development of biological control agents (BCAs) is promising but faces administrative difficulties in registration resulting in a long and very expensive process. Non-synthetic chemical methods of soil disinfestation such as solarisation, inundation, anaerobic soil disinfestations (ASD) and biofumigation are being used, but particularly the last two methods need further development. There is a lack of long-term experiments to judge the cost/benefit and the impact on soil biodiversity. Monitoring is the starting point of any integrated pest management strategy. Modern sampling and diagnostic techniques combined with Geographic Information Systems and Decision Support Systems would give farmers the tools to cope with their data and come to valid decisions.
- **explore strategies for a targeted breeding of cultivars that are more resistant to soil-borne diseases:**
  For intensive cropping systems breeding for resistant rootstock and grafting it on the desired cultivar is an important existing tool for some crops like tomato, cucumber and melon. Grafting with more crops and against more diseases is feasible. Development of grafting machinery would bring down the costs and enlarge the market for grafted plantlets. For crops grown in rotations, breeders should also look for resistance against soil-borne diseases causing damage in the next crop. By growing the resistant crop as preceding crop, the sensitive crop starts at lower infestation levels. In this way, yield loss can be prevented.
- **identify and compare alternative techniques for soil fumigation that are ready to apply or easily applicable in short term by the farmers, in the framework of the prohibition of the use of methyl bromide:**
  Some new active ingredients are developed and listed in this report. Non-chemical techniques to be used are catch crops like Tagetes against rootlesion nematodes, solarisation, inundation or anaerobic soil disinfestation.

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- **identify and compare according to the respective arable crop alternative soil-borne disease suppression techniques that are ready to apply or easily applicable in short term by the farmers:**
  The use of farmyard manure and organic amendments are known for their enhancement of soil suppressiveness. Because of a lack of understanding which mechanisms are involved, it is impossible to give a recipe to enhance soil suppressiveness in specific situations.
- **identify farm practices that reduce the pressure of soil-borne diseases:**
  See above
- **identify fail factors that limit the use of the identified techniques/systems by farmers and summarise how to address these factors and explore the role of innovation and knowledge exchange in addressing these fail factors:**
  The main fail factors in general and for different techniques are listed in chapter 4: New developments both in research and in practice. The lack of integral knowledge and approach within all levels from farm to university hinder progress.
- New possibilities or directions for innovation were identified during an out of the box thinking. The results are presented in the chapter 5: Thinking outside the box. The Focus Group identified needs from practice and proposes directions for further research and suggests potential Operational Groups and ways to disseminate the practical knowledge gathered.

Here is a short answer to the questions put to the Focus Group:
How to suppress soil-borne diseases (fungi and nematodes) in vegetable and arable crops and how to enhance cross-fertilisation between different crops and agricultural systems?

Develop a soil health strategy on farm level which is inseparable and integral part within a total soil quality strategy that combines soil biology, soil physics (structure) and soil chemistry (fertilisation). This needs integrated knowledge in the whole chain: consumer, farm, extension, trade, universities. Instead of incident management whenever a soil-disease develops, enhancing soil health constantly is the guiding principle. An interactive approach both on national and EU level by using this concept in research and in extension programmes (e.g. Operational Groups) will stimulate the interdisciplinary cooperation and therefore the successful implementation of science-based measures to support the sustainable status of our precious soils.

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AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.
- ✓

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on: **http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf**

More information on EIP-AGRI Focus Groups

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