EIP-AGRI Focus Group
Protecting agricultural soils from contamination

FINAL REPORT
MAY 2020

funded by European Commission

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1. Executive summary

This report presents the findings of the EIP-AGRI Focus Group on **"Protecting agricultural soils from contamination"**. Soil contamination is caused by various sources and remains a critical issue for many European countries, not only with regards to the large number of contaminated sites spread throughout the continent but also regarding the public health consequences that they could have (Brombal et al., 2015). Attention to soil, its functions and services (EC, 2019) is becoming increasingly important in Europe and this is reflected in the fact that one of the mission areas of the next EU research and innovation framework programme Horizon Europe is dedicated to "Soil Health and Food". We cannot produce healthy food from contaminated soils. The complex nature of soils however, which offers a great number of functions and services to humanity and biodiversity (Fig 1), requires a multi-functional and multi-stakeholder approach (Montanarella, 2015) with farmers and land-users at the centre. Quick, pragmatic and affordable solutions are needed to prevent soils from being contaminated in the first-place, and when this still happens to remediate and mitigate them. It is important to remember that it is cheaper to prevent contamination than to cure it. However, farmers alone, even when they are responsible for contamination, cannot afford the high costs of the process. The "polluter pays" principle cannot therefore always be implemented for farmers, especially without the support of public institutions. Based on these prerequisites, the main question for this Focus Group was: **How to prevent agricultural soil contamination and how to address the problem of contaminated soils?**

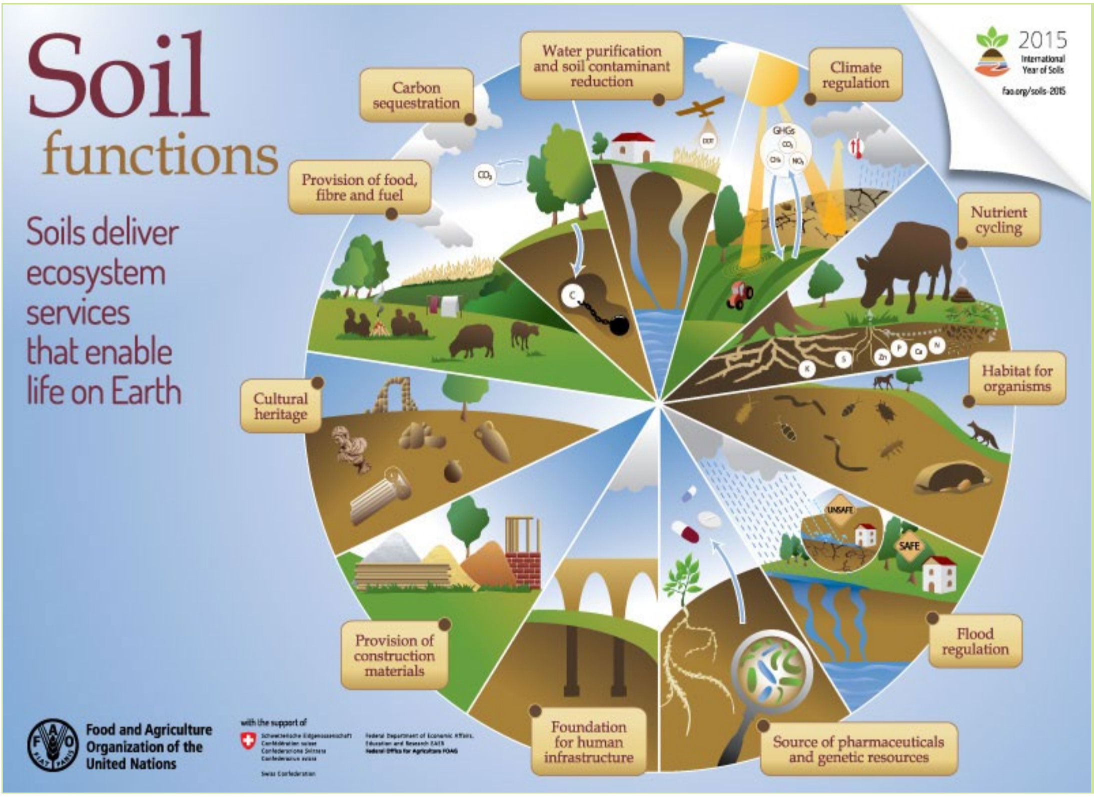

Fig. 1. Soil functions and services; soil contamination reduction is one of the main ecosystem services that soils provide. Source: FAO GSP, 2015 (www.fao.org/resources/infographics/infographics-details/en/c/284478/)

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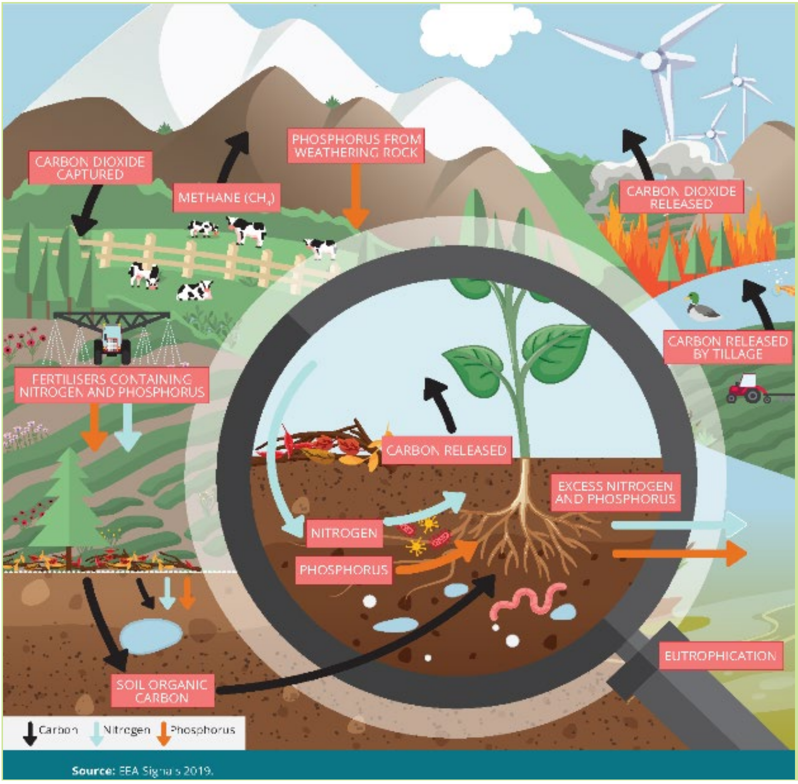

Fig. 2. The complex interactions of the nutrient cycle and the negative effects that the excess use of chemical fertilisers could have on soil/water quality. Source: EEA Signals 2019

To be able to respond to the main question, the Focus Group identified the following key objectives:

- Identify the main soil pollutants in different regions and the challenges each of them poses.
- Review existing knowledge about ways to measure soil contamination and share information.
- Identify innovative methods to prevent soil contamination in particular through improved farm management.
- Identify a set of good practices to prevent agricultural soil contamination from various sources and to remedy soils that are already contaminated.
- Identify remaining research needs from practice and propose possible directions for further research on soil contamination.
- Propose priorities for innovative actions by suggesting ideas for Operational Groups (OGs) to test solutions for the prevention of soil contamination or remediation of contaminated soils and other ways to exchange the practical knowledge gathered by the Focus Group.

This report summarizes the discussions and key findings of the focus group expert's work since the beginning of this FG in June 2019 including the research needs from practice and proposed ideas for OGs and other innovative projects in the area of soil contamination prevention, monitoring and remediation.

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2. Introduction and brief description of activities

Soil contamination remains an alarming environmental problem in Europe (Ana Payá Pérez and Natalia Rodríguez Eugenio, 2018), not only in agricultural soils but also in many other contaminated sites spread across various countries (Panagos et al., 2013). Altogether, over 137,000 km^2 (6.24% of all agricultural soils in Europe) need remediation activities (Toth et al., 2016). Soil contamination comes from different sources, which could be natural or human-induced, but those caused by adverse human actions are of major concern, especially when agricultural practices are to be blamed. Very recent data from two EU-funded research projects (iSQAPER[1] and RECARE[2]) show for instance that pesticide residues were found in more than 80% of European soils tested (Silva et al., 2019). On the other side the overuse of N fertilisers throughout Europe is also problematic as shown in Figure 3.

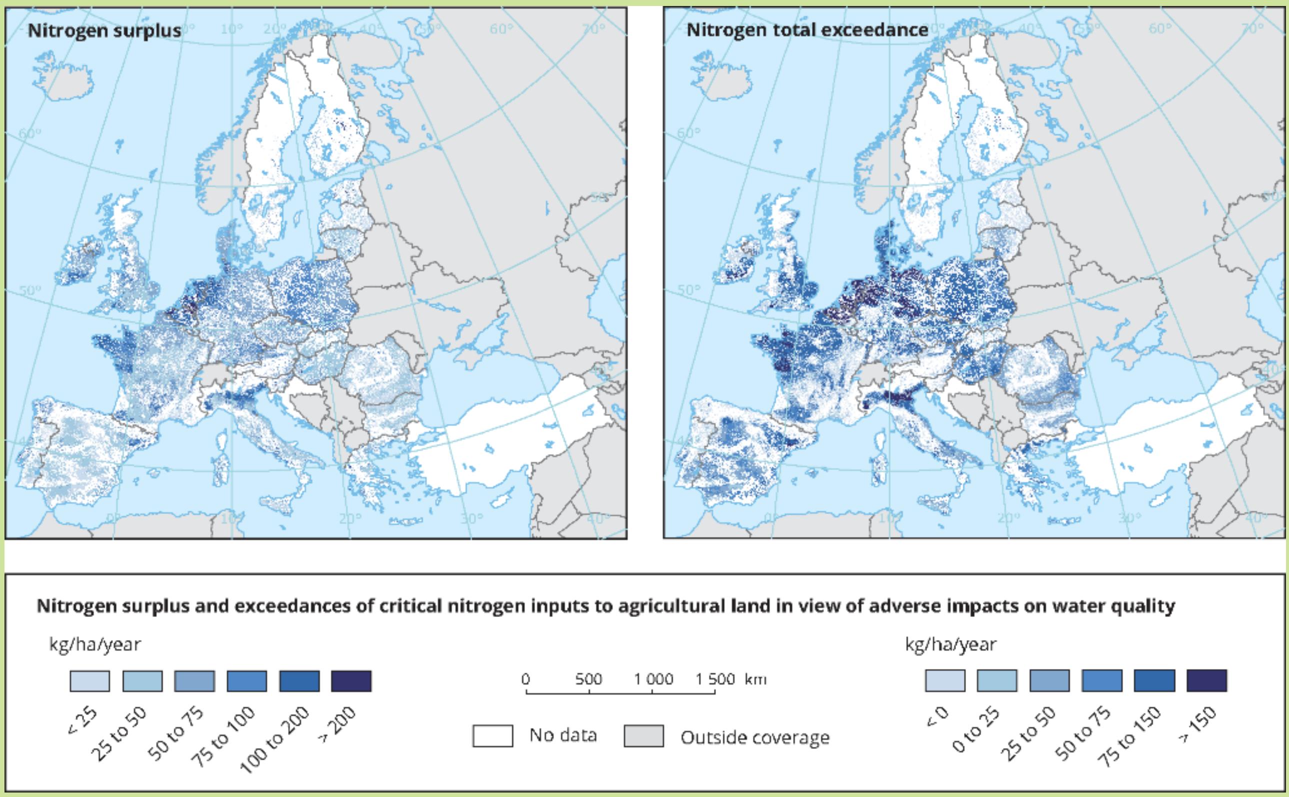

Fig 3. Maps on the calculated nitrogen surplus (inputs minus crop removal) and exceedance of critical nitrogen inputs (overuse) to agricultural land in 2010. Source: EEA, 2019.

The FG was composed of 16 experts from 12 EU countries with different professional backgrounds. The members actively participated in two meetings in Bari, Italy (11-12 June 2019) and Santarém, Portugal (19-20 November 2019).

Prior to attending the 1st meeting, FG members were asked to respond to a questionnaire that included a number of questions on the sources of contamination in agricultural soils, their intensity, and the types of actions taken, if any, to remediate contamination. Results showed that according to the FG experts, **pesticides and mineral fertilisers were the top polluters when used in excess,** followed by heavy metals, sewage sludge, industrial and urban waste, low quality irrigation water, plastic pollution and radiation. In terms of **remediation techniques,** the participants found **engineering and chemical techniques to be the most common** followed by bioremediation and excavation and removal of contaminated soils. Nevertheless, the experts pointed

[1] http://www.isqaper-project.eu/
[2] https://www.recare-project.eu/

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out that in many cases no action at all was taken, or they were not aware of such actions. The questionnaire findings were used to set the scene of the work of the FG and to define the framework for reaching outcomes, including drafting and finalising the mini papers (MPs) and identifying the ideas for OGs.

The FG placed particular importance on the public health consequences of soil contamination, noting that the process how contaminants actually enter the food system (Fig. 4) is highly complex and much research is still needed on this (Stankovics et al., 2018).

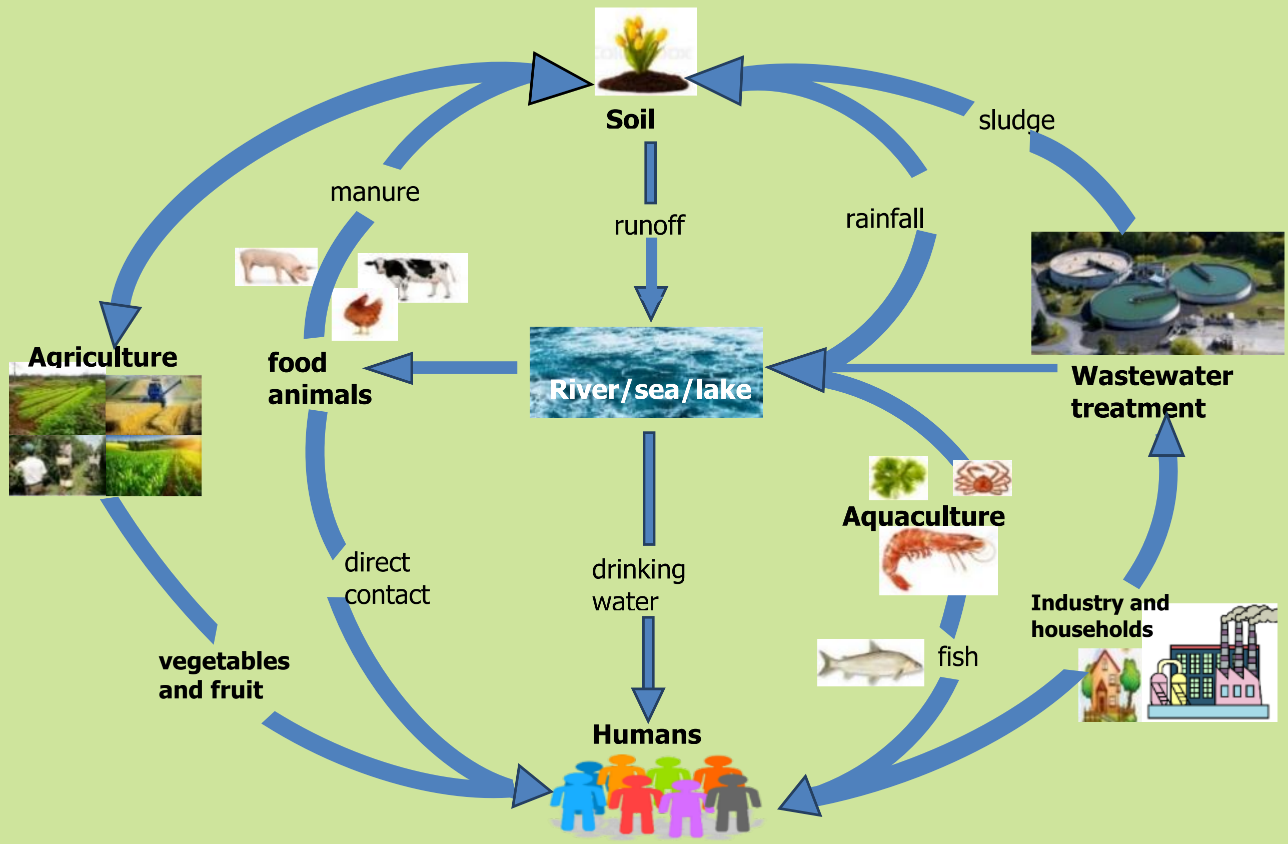

Fig. 4. The complex interactions of farming and industrial activities and their impacts on soil and food quality and public health
Source: Wanjaja et al., 2018

During the first meeting, four presentations were made to provide the perspectives of farmers and researchers when dealing with soil contamination. The first presentations emphasised the fact that farmers prioritise good yields and profitability without neglecting the need for good farming practices that enhance soil quality. A number of **good agricultural practices such as crop rotations, integrated soil fertility management and crop nutrition systems** were mentioned that ultimately reduce the use of chemical fertilisers, which cause contamination of soil and water when applied in excess. Researchers provided some of the results to remediate soil contamination through the use of organic amendments (i.e. compost, biochar) to immobilise and break down soil pollutants. There are different immobilisation solutions, to be used depending on the type of pollutant. For example, when contamination derives from polycyclic aromatic hydrocarbons (PAH), by adding organic amendments that are rich in soil microorganisms it couldl be possible to accelerate the process of organic pollutants immobilization .

Fig. 5. Group photo from the first meeting in Bari, Italy, June 2019

In the future, different sorbents used in decontamination need to be studied more thoroughly, as there is no "one size fits all" solution and the processes need to be fine-tuned according to the contaminants in question. It is also necessary to develop methods associated with new risks such as emerging pollutants as drug residues or endocrine disruptors and microplastics in soils. Other common contamination sources like manure pollution in areas with high concentration of swine, cattle and dairy farms require immediate attention. For example in the Po river valley in Italy and Catalonia in Spain, the Nitrate Directive has so far failed to reduce or keep under control soil and water contamination.

During the first meeting the experts also agreed on some key topics to be further explored through the mini-papers (MPs). These are short documents that aim to collect further information on the key topics discussed during the FG meetings while focusing on the practical solutions and information relevant for the practitioners. The following five MPs were suggested: **MP1** Agricultural sources of contamination, **MP2** Developing a soil quality toolbox for agricultural soil monitoring and assessment, **MP3** Biological remediation of contaminated agricultural soils, **MP4** Precision Agriculture as a tool to reduce and prevent soil contamination, and **MP5** Sustainable farm management for the preservation of soil quality.

The main conclusions from both meetings highlight that there are **various contamination sources**; both old and emerging. For instance, excessive use of chemical fertilisers and pesticides, and animal manures, slurries and sewage sludge pose contamination risks. Furthermore, irrigation with wastewater containing emerging pollutants such as pharmaceuticals, veterinary and personal care products (PCPs) are a high-risk contamination source (for further information see MP 1). Remediation of contaminated agricultural soils could be done in various ways and methods that may be applied *in situ*, *on site* and *off site* are different. Some of them are based on physical, chemical and thermal processes that could degrade soil functions, but could also drastically modify the soil physical, chemical and biological properties, and they could be too disruptive to be used in agricultural soils (see MP3), therefore must be selected carefully.

The experts identified tools that farmers need to use to assess and deal with contamination, and highlighted the need for a monitoring systems to keep contamination under control. They emphasised the need for innovative technologies such as precision agriculture, agro-ecology and/or organic farming that improve or maintain soil quality, while also providing sustainable yields for farmers.

The second meeting focused on finalising the MPs, drafting conclusions based on the initial FG topics to reach a common understanding on innovation and research needs from practice and to propose ideas for further research, OGs and other innovative initiatives.

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In conclusion of the two meetings, the Focus Group members proposed implementation of a follow-up approach finalised with the selection of research ideas and Operational Groups. It included i) examples of practical solutions for agricultural soil contamination, ii) gap analyses to identify the shortcomings in soil decontamination, iii) identification of priority research needs, iv) possible topics for OGs and innovative solutions to contamination, and v) suggestions for dissemination and training programmes.

The gap analyses and practical solutions to tackle agriculture soil contamination were also thoroughly discussed. The focus was on i) why contamination in European soils continues, ii) who should be responsible for soil remediation, iii) what method is more appropriate for each specific case, iv) who should pay for it, and v) what innovative state-of-the-art technologies are available to remediate contamination.

3. State of play

a. Framing key issues

Framing key issues was based on intensive discussions among the experts during the first meeting and further developed in the preparation of the MPs. The FG members adopted a logical framework approach divided into five steps.

Step 1: Challenges

Step 1 was mostly addressed in the context of **Minipaper 1** dealing with sources of contamination.

Aim: Identify problems related to soil contamination as follows:

- the main areas of concern on a regional and farm level
- the most relevant contaminant classes regarding farm level contamination

At the first meeting, experts focused the discussion based on the following question:

What is the impact of soil contamination on soil health?

Results:

During the discussions, the experts found some common challenges concerning different contaminants but also reported some regional peculiarities.

Collectively, the main concerns were **pesticides** and their residues, which are harmful especially for the biological part in the soil as well as to pollinators and other beneficial insects. Other chemical substances e.g. antibiotics, chemicals leaching from plastics, poor nutrient management, plastics in the soil and heavy metals were also listed as concerns. Pesticides remain problematic everywhere but they are addressed differently in different countries. The European Union for instance recently banned chlorpyrifos, because it is linked to health problems in children, but the U.S. has allowed its use because the USA Environment Protection Agency (EPA) did not agree with the assessment in Europe (Topping et al., 2020).

The FG members also emphasised that the effects of contamination on soil health are simultaneously physical, chemical and biological. Biological effects are very critical and not equally considered and studied compared to the others (Dieguez-Alonso et al., 2019).

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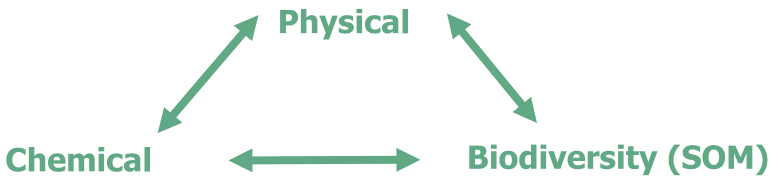

In fact, effects on **soil organisms and biodiversity** are not always apparent and sometimes even not measurable (Weil and Brady, 2017). Therefore, further research is needed on analytical methods and indicators for the effects on microorganisms. Also, when dealing with contamination, it is important to differentiate between contamination due to a polluting substance and the result of an unsustainable agricultural practice or activity (e.g. excess amendment of sewage sludge, which is not, it itself, a pollutant). The impact of agricultural practices on soil quality is extremely significant. These risks are further exacerbated by the contamination of surface and groundwater with severe consequences for public and animal health (see also Fig. 12).

In addition, **nutrient management** affects all the three components of the soil (physical chemical and biological), although most importantly the chemical part. Farmers are generally aware of some contaminants e.g. possible contamination with excess nitrates but sometimes they are unaware of others that might be present on their land. For example, the level of antibiotics in the soil could be quite high but the effects of this type of contamination on soil microbiota remains largely understudied.

Furthermore, **other chemical substances** in the soil such as herbicide residues, chemicals originating from plastics (phthalates, Bisphenol A or BPA, endocrine disruptors) can affect the soil negatively, but once again, the exact effects are not very well known. In case of herbicides, there is a strong pressure to decrease their use (Silva et al., 2019) but equally effective alternative methods to reduce weeds on the fields are not yet readily available. In addition, heavy metals affect soil healt both on farm and at regional level (Toth et al., 2016). Another problem, which is now more widely recognised, is the presence of **plastics in soils** (Corradini et al., 2019). This affects soil biota because of the leaching of chemicals, but it can also cause runoff of microplastics to aquatic environments or lead to soil porosity being impaired by larger plastic fragments. More studies are needed to understand the real impact of plastics on agricultural soils (De Souza et al., 2019). Concerning plastics and other emerging pollutants, there are big knowledge gaps to overcome e.g. mapping of sites, isolating the effects on human health, defining thresholds for environmental safety and human health.

One of the main issues is that farmers are not always aligned with priorities of the public (e.g. yields vs product quality) and this could have an influence on soil management and contamination. The conflict could originate from the higher cost of the soil-friendly management practices or remediation techniques, which in turn increases the price of the agricultural products and some consumers may not be able or willing to pay for this extra cost.

Step 2: Opportunities

Aim: Identify sources of innovation for addressing soil contamination

How to prevent agricultural soil contamination and how to address the problem of contaminated soils?

This question lead to discussions on the possible sources of innovation in soil contamination prevention/remediation/monitoring. Good farming practices described in detail in **MP5** should be adopted to reduce the risk of polluting the ground and surface waters through excess use of mineral fertilisers and manure applications. Factors, such as soil characteristics, should be taken into consideration, because they are relevant to nutrient availability/solubility. Moreover, the chemical form of the nutrient also affects its mobility, for instance: organic N is quite immobile in soil, slowly released according to the mineralisation rate, whereas nitrate has greater mobility and is more easily lost through leaching than ammonium, which can be adsorbed onto soil minerals or organic matter.

Precision agriculture (PA), see **MP 4,** is also an innovative form of farming that may prove cost-effective for farmers and environment-friendly by providing optimised chemical input applications, thus minimising the load on the environment. With the correct use of PA technologies, the inputs such as pesticides, fertilisers and other chemicals are only used when and where there is a need for application. Some technologies enable this via machine and hardware-based solutions (such as section control to avoid multiple applications on the same spot), some via the use of data and data processing methods, such as machine learning and artificial intelligence, but they all aim to optimise profitability.

MP 2 looked into soil monitoring and soil quality measurements at farm level which are needed more than ever. Technology for this is developing at a fast pace and the private sector is heavily involved in the development of new devices that are quick, cheap and easy to use also for the average farmer. Using artificial intelligence and machine-learning techniques and robotics, nowadays it is possible to perform high accuracy crop modelling, resource-based management and weather forecasting for sustainable farming. Through these technologies, farmers are empowered to check and control the life cycle of their crops in terms of soil moisture stress and pest and disease indicators. They are all managed by a single device that can retrieve and disseminate data anywhere and anytime via the Internet. Furthermore, numerous apps are becoming available for the farmers making modern farming easier and challenging in the same time[3].

Step 3: Prevention

There are several well-known techniques and management practices to prevent soil contamination as described in detail by **MP 5**. They include, but are not limited to, cover crops and rotations, organic farming, diversification of land uses, etc. The problem is that these practices are far from being widely used. To boost their wider adoption, education and dissemination need to be improved. Key aspects for this are to reinforce farmer-to-farmer learning ("influencers" from the farming community), train the advisers to communicate with farmers and foster the interaction amongst farmers, advisers and researchers to speed up innovation. Training of trainers is also important.

Precision agriculture as described in **MP4** and/or smart farming practices also have an important role in preventing soil contamination, offering different solutions e.g. reducing the input of herbicides or helping to avoid excessive fertilisation. Robots can remove weeds, and other types of precision farming machinery can help to apply fertilisers and irrigation only when and where it is needed. Satellite and drone images may be used to map the crop water and nutrient needs[4].

Concerning new contaminants such as plastics, farmers may not be aware of their presence or of their impact on soil functions. Sometimes the use of plastics is unavoidable, but for certain applications it is possible to use biodegradable plastics. The use of biodegradable alternatives is still scarce; in some cases this is due to their higher cost but often the underlying reason is the lack of awareness of the consequences plastics have on the soil functions in the long run. On top of that, there are still knowledge gaps concerning the actual degradation of these types of plastics or their potential to be re-used for compost production. The concerns of plastics accumulating in the soil are addressed in more detail in **MP1**.

[3] https://www.arable.com/

[4] https://smart-akis.com/SFCPPortal/#/app-h/technologies

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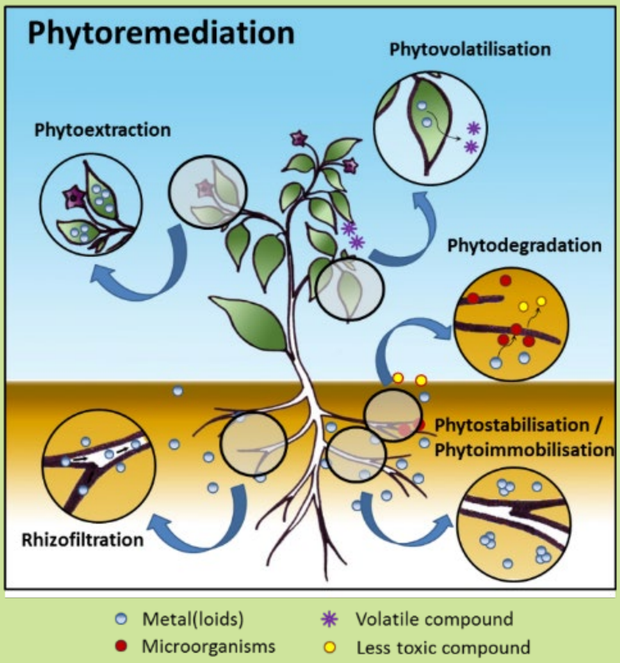
Step 4: Remediation

On the occasions where soil contamination has already occurred due to previous improper management or other reasons such as industrial contamination originating from factories situated near farming areas, it is important to apply the correct remediation techniques to clean the soil and restore its functions as much as possible. Several remediation techniques are described in **MP3** (see also Fig 6 and boxes below). Examples include phytoremediation or application of amendments to reduce the availability of the pollutant (liming, compost, biochar, metal oxides, clay or silicate minerals, combination of products, etc.). When it comes to remediation of soils, treatments should be decided depending on the exact source of the contamination, type of pollutant compound, its availability and also target threshold. For example, in phytoremediation the selection of the plants used depends not only on the pollutant but also should consider soil type and climate conditions.



Box 1. Phytoremediation technologies for contaminated soils.

Phytostabilisation or phytoimmobilisation: Reduction of the availability (fixation) of the contaminants in the soil (rhizosphere) and retention in the roots.

Phytoextraction: Extraction of the toxic elements from the soil by accumulation in harvestable parts of the plants.

Phytovolatilisation: Absorption of soil contaminants, transformation into volatile species and volatilisation into the atmosphere

Phytodegradation: Biodegradation of organic toxic compounds in the rhizosphere by plant root associated microorganisms.

Fig. 6. Phytoremediation processes for inorganic contaminants (heavy metals and metalloids) and organic contaminants (adapted from Pardo, 2013).

Among the biological solutions for soil remediation, it is possible to consider certain **bioremediation** methods, which are more appropriate for organic contaminants and include **biostimulation**, **bioaugmentation,** and **bioventing. Biostimulation** uses indigenous (naturally occurring) microorganisms to degrade (metabolise) organic contaminants found in soil, converting them to harmless end-products. **Bioaugmentation** is recommended for sites where the number of autochthonous (native) microorganisms is not high enough to degrade the contaminant load present, or when the native consortia do not have the catabolic pathways necessary to metabolise the molecules (Cycoń et al., 2017). **Bioventing** involves supplying air and nutrients through wells to contaminated soil to stimulate the indigenous bacteria. Bioventing employs low air flow rates and provides only the amount of oxygen necessary for the biodegradation, while minimising volatilisation and release of contaminants to the atmosphere (Vidali, 2001). Although several biological methods based on plants and microorganisms and their interactions have been developed for soil remediation, the practical application of some of them needs to be tested under real conditions. There is no single method that could be applied to all soils, climatic and pollution situations, but there is an optimum method for each particular case.

Case 1. Energy crops grown in arable soils contaminated with heavy metals

Site 1: Agricultural land is located in the Upper Silesian Metropolitan Association (Poland), in the vicinity of a former lead (Pb) and zinc (Zn) factory, which has been operating for over 100 years. In the last 30 years, the area had been used for the cultivation of cereal crops, especially wheat. The total content of Pb and cadmium (Cd) exceeded 4 to 6 times the limits for agricultural soils, while those of Zn were exceeded by 4 to 7 times (Journal of Laws of 2016, item 1395). The bioavailable forms of Cd and Zn were approx. 5% and 2.5% of the total content, and that of Pb was below the limit of quantification.

Site 2: located in Germany in the vicinity of Leipzig, in a place where 650,000 tonnes of municipal sewage sludge were deposited between 1952 and 1990. The total content of Pb, Cd and Zn in soil was similar to the level found in the site 1, with very low bioavailability of metals.

Energy crops – *Miscanthus x giganteus*, *Sida hermaphrodita*, *Spartina pectinata* and *Panicum virgatum* - were grown in both sites during three seasons. Phytoextraction of heavy metals was very limited in site 2 due to their low bioavailability linked to the high soil organic matter content. *Miscanthus x giganteus* was able to extract the highest amount of Cd and Zn among all the tested species. The species *S. pectinata* proved to be useful for soil amelioration despite low metal uptake in the aboveground biomass; *S. hermaphrodita* accumulated Cd and Zn while *P. virgatum* had high concentration of Zn in shoots with low concentration of Pb and Cd.

Case 2. Miscanthus biomass options for contaminated and marginal land: quality, quantity and soil interactions

Several novel *Miscanthus* seed-based hybrids were tested on marginal and contaminated lands at three locations in Europe (Poland, Germany, United Kingdom). *Miscanthus* is an alternative non-food crop, used for energy. The slightly increased heavy metal concentrations in the biomass cultivated from heavy metal contaminated soil had no negative effects on the ash melting behavior. Harvesting before winter seems to be favorable for anaerobic digestion, with a slightly higher substrate specific methane yield. Increased heavy metal content in biomass did not affect negatively the anaerobic digestion. *Miscanthus* was confirmed as a safe and profitable crop for marginal and contaminated soils.

Miscanthus in a heavy metal contaminated soil

Case 3. Restoration programme of an agricultural soil polluted by a mining spill

The agricultural land was affected by a toxic pyritic spill of acid water and sludge in 1998. After the removal of the sludge and the first top layer of the affected soil by heavy machinery, the soil (loam texture, carbonates<0.5 %, pH range 2-7) remained contaminated by Zn, Pb, arsenic (As), Cd and copper (Cu), with a range of concentrations and solubility. The remediation programme was based on the following sequence: 1. Active phytoremediation (2 years) with two successive crops of *Brassica juncea* and the addition of organic amendments (compost and cow manure) and lime (in the acid patches) for extraction of the soluble metal fraction; 2. Natural attenuation without external intervention (5 years) and the colonisation with wild species; and 3. The restoration of the site (5 years) by re-vegetation with selected native shrubs (*Retama sphaerocarpa*, *Tamarix gallica*, *Rosmarinus officinalis* and *Myrtus communis*), for the re-establishment of the soil ecological services with a permanent vegetation (Clemente et al., 2006; de la Fuente et al., 2014).

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Fig. 7. Phytoremediation programme: left - soil before restoration; right - soil after restoration.

Other remediation technologies include:

- The combination of indigenous willows and fungi to decrease petroleum hydrocarbons in contaminated soils by 65-75 %, even in cold climates (Robichaud et al., 2019)
- A combination of phytoremediation with alfalfa and biochar (Zhang et al., 2019)

Further research is being conducted for the bioremediation of soils contaminated with pesticides. This is done by using a biosurfactant-producing bacterial consortium (*Bordetella petrii I* GV 34, *B. petrii* II GV 36 and *Achromobacter xyloxidans* GV 37) to degrade endosulfan (ubiquitous organochlorine insecticide, POP), and its metabolites in a contaminated surface and subsurface agricultural soil. The complete removal of alpha and beta endosulfan was observed in 25 days in a simulated soil profile reactor (Odukkathil and Vasudevan, 2016). Use of a microbial consortia (*Brevibacterium frigoritolerans, Bacillus aerophilus, and Pseudomonas fulva*), isolated from soil contaminated with phorate (organophosphorous insecticide, banned in EU but limited use in the US) showed that in a sandy loam soil the highest phorate removal was between 97.65 and 98.31%, reached in only 42 days (Jariyal et al., 2018).

Step 5: Monitoring

Soil monitoring is essential for farmers to make well-informed decisions about their land management. However, the soil monitoring that farmers need and the soil analyses that scientists perform are not always in line with each other. Monitoring was addressed in further detail by **MP 2** that emphasised the need to monitor soil quality from two stakeholder perspectives: farmers and researchers. The farming approach needs to consider profitability and the scientific approach includes ecological, physiological, toxicological and chemical assessments. The practical implications of these assessments needs to be clearly communicated to farmers.

At farm level, monitoring should include:

- Periodic control of soil macro nutrient levels (NPK), especially when associated with crop rotation.
- Analysis of chemical micro components (Mg, S, Si, Na…), the ratio of them and presence of residual pesticides
- Data coming from classical soil surveys and pedological investigations through complete study of soil profiles
- Biochemical assessment of topsoil samples

All these aspects can be evaluated through in-depth analyses and/or other techniques, in close collaboration with farmers who have a good understanding of the situation on the ground. For instance, specific appearances of chlorotic or necrotic leaf spots or pests are indicators of disturbances and sometimes can help to diagnose the problem quickly. Furthermore, it is recommended to observe the historical data of all interventions on the soil and the different diagnosis made (from precise assessments to simple farmer observations) in order to improve the performance of the agricultural management system and enhance soil quality.

Fig. 8. Discussions during the second meeting in Santarém

The second meeting focused on finalising the MPs, drafting conclusions on the initial FG topics to reach a common understanding on innovation and research needs from practice and to propose ideas for further research, OGs and other innovative initiatives.

b. Good practices

During the two face to face meetings FG members explored two good examples of soil and crop management.

The Focus Group experts discovered a unique practice of grape cultivation in **Bari, Italy** where they met farmers of the OROFRUIT table grapes cooperative. The farming practice is based on the grinding of the surface rocks and mixing them with the remaining soil. Extensive rocky content that could reach as high as 80% reduces the soil water holding capacity and necessitates the application of efficient fertigation systems that provide the right amount of water and fertilisers in the right time and place.

Fig. 9. New table grape plantation on stony soils inside the OROFRUIT cooperative, FG members interact with local farmers

Following advice from an agronomist, Pasquale Parente, farmers are using all possible sources of organic materials, compost and green manuring through legume crops, to increase the soil organic matter that is inherently low in these types of soils. Legumes are also used for N fixation. On the other hand, table grapes are highly demanding on soil nutrients and the intention is to provide these as much as possible from organic sources while limiting chemical fertilisers that may result in soil contamination[5].

The second good practices example that the FG visited was a farm located at Quinta da Cholda[6] in the fertile alluvial soils of Tejo river valley near **Santarém in Portugal**. This farm is the biggest in the area and among other crops, 200 ha of corn has been grown using no till direct seeding for the past 20 consecutive years without rotations. Winter cover crops are used to increase soil fertility and a very balanced plant nutrition system based on soil analyses is implemented.

Fig. 10. The innovative farmer: Mr Coimbra explaining the results of no till in increasing soil fertility and corn production as well as a set aside green corridor with ponds for protection of biodiversity. Pivot irrigation systems are fuelled by solar panels.

[5] https://ec.europa.eu/eip/agriculture/en/news/inspirational-ideas-italian-table-grape-farmers
https://www.youtube.com/watch?v=NMz1ALs83XY
[6] https://www.quintadacholda.pt

Apart from consolidated corn yields well above 10 ton per ha, soil organic matter has increased from 0.5 to 3 % after the 20 years of no till cultivation, an exceptional achievement. The farmer Mr Coimbra, has invested heavily in precision agriculture and is one of the pioneer farmers in the area to implement Common Agriculture Policy (CAP) principles of ecological corridors and green areas for protection of biodiversity. Irrigation is a must in the area and the groundwater is pumped using the energy captured by solar panels on the field margins (resulting in a more environmentally friendly irrigation system). It is common that nearby farmers come and visit and talk to him about these innovations. It should be noted also that Mr. Coimbra is a large-scale farmer compared to the other farmers in the area. He also collaborates closely with several universities such as the University of Lisbon and Wageningen in the Netherlands.

Another good example comes from **Ireland** where the IOA (Irish Organic Association[7]) has developed an eco-scheme that follows the principles of agroecology and organic farming. Data from the farm of **Mr Fergal Byrne**, member of the FG show that for a period of only five years of conversion from conventional to organic farming the yields are even higher. In fact, much of the yield increase is the result of better soil health and fertility. Mr Byrne uses organic compost to fertilise his soils and he grows red and white clover to feed lambs, cattle, and sheep. Red clover is especially high in protein and very nutritious for the animals.

Figure 11. The red and white clover growing in the farm of Mr Byrne

Soil quality is increasing at an unprecedented rate. A test made in late summer of 2019 on a site cultivated with red clover showed an amazing number of earthworms and beetles that are typical indicators of soil fertility and biodiversity. Moreover, a large number of nitrogen-fixing nodules and mycorrhizal fungi were vigorously thriving on red clover roots fixing nitrogen from the atmosphere into the soil. Mr Byrne also grows cereal crops, such as organic oats, which are used to make organic porridge for human consumption. He also grows oats in a mixture with barley and peas. This crop is harvested and then rolled to feed cattle, sheep, and turkeys.

Mr Byrne uses cover crops to protect his soils, meaning that until sowing the next crop, the soil is always covered with vegetation. By doing so, the lands benefit from reduced soil erosion and increased soil fertility. A rape field is grazed by lambs in January/February; composts or farmyard manure (FYM) is then applied and ploughed, after which seeds are sown four to five days later. Later on, when the crop has sprouted, he applies compost of tea extract and plant extract. Following such an approach, no chemical fertilisers or chemical pesticides,

[7] http://www.irishorganicassociation.ie/

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herbicides or fungicides are needed on his farm. The organic oat yield in 2019 was a record high of 6.5 tons per hectare.

Fig. 11. Combi-crop from a mixture of barley and pea (right) and organic oats (left)

Literature is full of many other best management practices that are gradually spreading throughout Europe and around the world (WOCAT, 2007; Liniger et al., 2008; Schwilch et al., 2012; WOCAT, 2016) and they are more thoroughly described in **MP5**. For instance, **Regenerative Agriculture** a term that is often used synonymously with "carbon farming," includes a set of practices — from cover crops and no-till to compost application and managed grazing — that builds organic matter in the soil. This effectively stores more water and draws more carbon out of the atmosphere making this also climate smart agriculture. Other practices include **introducing fungi to wheat roots** (e.g. mycorrhiza) to boost the uptake of key nutrients that could lead to new, 'climate smart' varieties of crops, which are less reliant on fertilisers. It was shown that fungi in symbiosis with the wheat rooting system provides significant amounts of phosphorous and nitrogen (Tom J. Thirkell et al, 2019). Across the globe, wheat is a staple crop for billions, and wheat farming uses more land than any other food crop (218 million ha in 2017). Despite increasing the application of nitrogen and phosphorous fertilisers to boost yields, the amount of wheat that can be produced from a given area has reached a plateau in recent years, hence new innovations are needed to keep up with increased production.

Other science frontiers are the use of **agricultural stimulants or inhibitors** based on microorganisms that increase the availability of mineral elements in the soil, improve soil physics, and stimulate vegetative and root growth. The benefits of these technologies include partial or total replacement of fertilisers (minimum 50% reduction), stimulating plant growth and protection against pathogens, increasing the productive potential of soils by reducing depletion, detoxifying soil contaminated by heavy metals, and recovering degraded pastures. The use of inhibitors enables the plant to have more time to absorb nitrogen from the soil and assimilate it in the form of amino acids and proteins, thus reducing its loss in the form of nitrates or nitrogen gases (Corrochano-Moslave, 2019).

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Summary of good practices for farmers:

- Keep the soil constantly covered with crops and vegetation
- Implement efficient irrigation systems that save water and increase yields
- Use renewable energy sources to fuel irrigation
- Use legume crops to increase soil fertility, especially with nitrogen and organic matter
- Implement no till farming to increase soil quality
- Establish ecological corridors and green areas for protection of biodiversity
- Convert from conventional to organic farming
- Use organic compost to fertilise soils and biochar to increase stress resilience
- Implement crop rotations whenever possible and combine legumes with other crops
- Be open-minded, receptive to innovations and cooperation with researchers

c. Success and fail factors

Success and failure factors in soil contamination are associated with a variety of issues often acting simultaneously and contradicting each other. For instance, farmers need to earn a decent income, and they are generally interested in improving yields. This could be achieved either by intensifying production (Garnett et al., 2013) through intense use of chemical inputs, or through a long-term soil conservation process that pays back after a certain number of years (see the example of no-till management in Mr Coimbra's farm in Santarém, Portugal). When adding other benefits such as the increase in soil fertility, biodiversity, and higher amounts of carbon sequestration in the soil that could be claimed by farmers under carbon farming process, the results are even better. However, the successful implementation of agri-environmental schemes depends strongly upon trust between actors involved, as well as trust in institutions that govern these schemes (Jasper et al., 2019). Moreover, not all farmers are either aware or willing to change their farming practices and this could impede the implementation of soil conservation technologies. Fig 12 from **MP1** demonstrates very clearly the sources of contamination that could derive from agricultural practices. They were used as the starting point for drafting the ideas for innovative technologies, research needs and OGs.

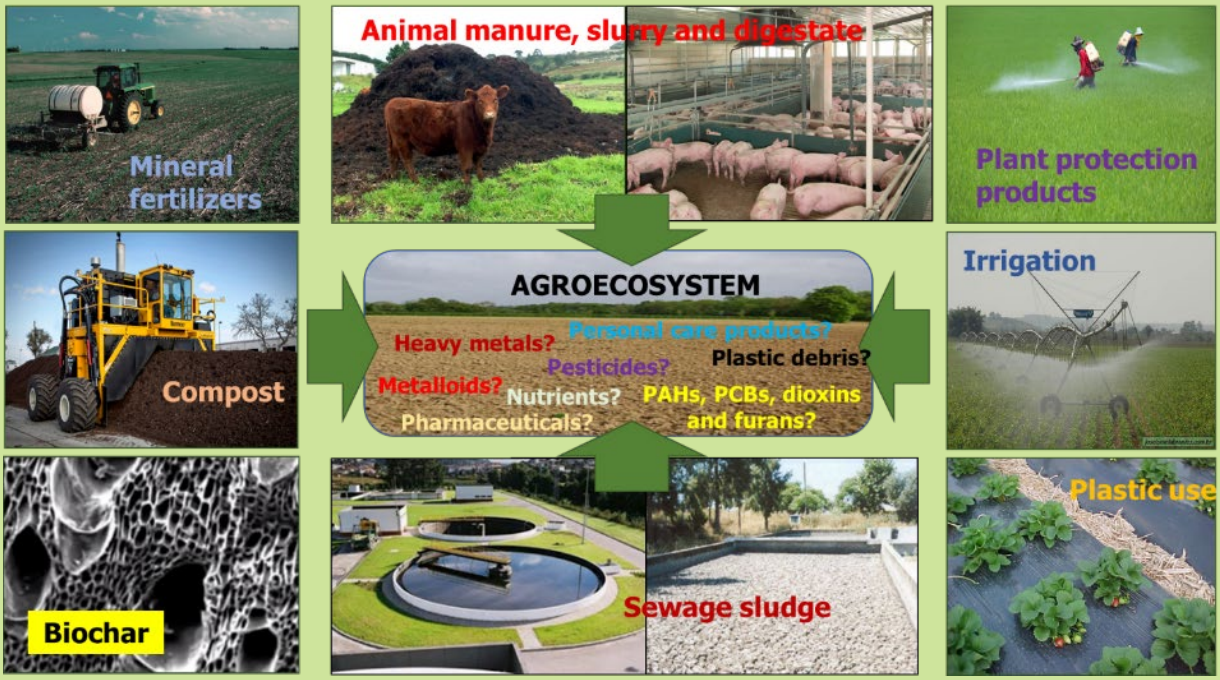

Fig. 12. Contaminants that can potentially enter agroecosystems from different agricultural practices (Some Photos are courtesy of StockFreeImages.com https://www.stockfreeimages.com/).

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It is interesting to point out that many farmers still consider the herbicide glyphosate indispensable for weed control especially in no-till farming, despite recognised risks. It is widely used also in Europe and associated with contradicting results regarding public health and most probably also soil health. A survey conducted in 2019 in the USA revealed that in the light of missing legal constraints only 2% will shift from glyphosate and only 7% of glyphosate users will decline to use it, while 36% will continue to do so and another 53% is waiting for an alternative product, but still interested to use another similar form that may still be harmful. Whether this is a failure to endorse environmentally friendly farming systems is still to be seen, but again, this is fact that the large majority of farmers are most probably forced in the first place to secure economic survival with profitable yields and only in second place to preserve healthy soils.

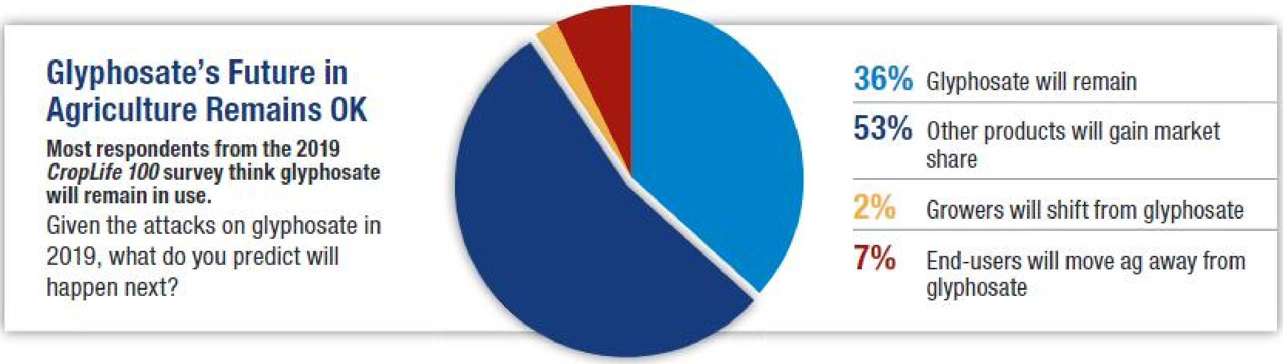

Fig. 13. The future of glyphosate in the USA - Source: CropLife® magazine, 2019

4. Ways forward

The FG identified areas and issues where research, development and innovation through EIP-AGRI Operational Groups would support the protection of the agricultural soils from contamination. These ideas are discussed thoroughly in the MPs, while the following sub-sections provide the summary of recommendations and findings. During the second meeting, FG members proposed and ranked a priority list of the most important research needs and intervention issues to to better protect agricultural soils from contamination (Table 1).

a. Research needs from practice

First, the Focus Group experts identified **needs for research to protect agricultural soils from contamination.** Understanding the complex interaction between soil characteristics and contaminants is a complicated process that requires further research and implementation of new technologies. However, the most important aspect is prevention of soils from contamination followed by remediation, mitigation and monitoring. Annex D compiles ideas for research and development, connected to the major issues identified by the FG, to promote innovative farm technologies, such as precision agriculture as well as development of remediation technologies that should be cheap and affordable for all farmers, big and small. For more information, please read the respective MPs.

The FG also highlighted the importance of **organising existing and future knowledge** in an easy to use way, showing a practice-oriented step-by-step procedure. They ask for "mini-manuals or mini-protocols" on, for instance, how to use pesticides and fertilisers or how to identify local plant species that fit for remediation of specific contaminated soils, and so on.

Table 1. Priority ranking of research needs

Ranking	Research needs and actions
1	Links between soil laboratory data and their applicability at the farm level to prevent and monitor contamination. This would require e**stablishment and setting** up of a **soil quality monitoring protocol**, which enables the farmers to assess the respective soil status at farm level.
2	Plant behaviour and the uptake of contaminants: identify alternative crops to be cultivated in contaminated soils (e.g. energy crops, fibre, biomass, etc.)
3	Establish long-term experimental sites to deliver scientific criteria for the long-term efficacy of soil remediation. This would help to assess cost-effectiveness of different remediation methods.
4/5	Establish the fate of emerging contaminants such as pharmaceuticals, veterinary and personal care products (PCPs) and define threshold values.
4/5	Standardisation/validation of different precision agriculture methods (roadmap for farmers) that would help to make precision agriculture methods usable and affordable for small-scale farmers.

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b. Ideas for Operational Groups

Ideas for Operational Groups are reported based on the outcomes of the second FG meeting as they are also included in the MP.

Table 2. Ideas for Operational Groups

MP and Key issues	Ideas for Operational Groups
MP1 Sources of contamination to agricultural soil	**1. Evaluation of emerging contaminants (pharmaceuticals, veterinary products and PCPs) in agricultural soils:** inputs, concentrations, bioavailability, behaviour, (eco)toxic effects, and the possibility of proposing threshold values.
	2. Plastics in agricultural soils: potential sources, transport, content and behaviour in soil, additives leaked after plastic decomposition and their (eco)toxicity, short and long-term effects of the plastic debris on soil microbiota and plants, biodegradation of different polymers in soil, and the possibility of proposing policy measures regarding threshold values and use.
	3. Uptake of contaminants by crops, their entrance into the human food chain, and the consequences for human health
	4. Technological transformation of biowaste-based amendments (e.g. manure, slurry, sewage sludge, compost, biochar), to allow nutrient and organic matter valorisation, avoiding the input of their contaminants load to soils.
	5. Linking the crop, and soil amendments with the soil health status
	6. Evaluation of bioavailability, bioaccessibility and solubility of **contaminants in agricultural soils** to protect crops and water
MP2 Soil monitoring on farm level	**1. Establish common soil sampling procedures to evaluate and monitor soil quality based on farmer's needs:** intensity of sampling, laboratory analyses and establishing a GIS-based open source information system available at cadastral land register level. Draft procedures on soil management inside the EU in line with the wide range of regulations on nutrient levels that are influenced by the different micro-climate, soil types, and topography.
	2. Link foliar nutrient levels with fertilisations needs Foliar analyses to define crop nutrient needs have been used for several decades. However, they still remain underutilised mostly due to the lack of laboratory equipment and qualified staff. Therefore, it is needed to increase these facilities that are cost effective and quick to advice farmers when and how to use fertilisers based on a crop's eco-physiological needs.
MP3 Biological remediation	**1. Define alternative plant crops for low quality agricultural or marginal land:** advantages, disadvantages, and benefits for farmers and for the environment.
	2. Non-food crops as alternatives for soil remediation in Mediterranean and other European climate regions
	3. Evaluation of bioavailability, bioaccessibility and solubility of contaminants in agricultural soils to protect crops and water quality
	4. Buffer strips near surface waters as biodiversity areas and contaminant sinks
MP4 Precision agriculture	**1. Standardisation** and validation of precision agriculture methods: developing a roadmap for farmers.
	2. Establish **evaluation tools for environmental impacts** and benefits of precision agriculture
	3. Increase applications of available technologies for **small scale farmers** using drones for weeding or spraying of chemical inputs.
MP5 Sustainable farm management	**1.** Implement sustainable farming systems to **apply the right amounts of fertilisers** based on plant eco-physiological needs

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c. Final recommendations

Healthy soils are paramount to the future of agriculture by maintaining ecosystem functions and services and sustaining plant communities. Unfortunately, some management practices have led to soil degradation through contamination, erosion, declines in soil organic matter and other stress factors. It has been estimated that nearly 40% of the Earth's arable lands have been degraded at some level by human activities. On the contrary, sustainable agricultural systems, in addition to better soil health, also create critical ecological and natural resource impacts that benefit society, such as improved water quality and conservation, biodiversity, pollinators and wildlife habitat.

Recent approaches to soil pollution assessment, such as FAO GSP (2018), are oriented to site-specific risk assessment based on land use, proximity to urban areas and pollutant transfer to subsoil, groundwater and other environmental compartments. Integration of studies at field level assisted by remote sensing technology for soil mapping, laboratory (selective chemical extractions applied to define form, mobility and bioavailability of pollutants), and microscopic levels (identification of associations between pollutants and soil components enabling to understand the fate of contaminants) are crucial. These issues are useful for both scientists and farmers and advisers to improve the selective chemical extraction techniques for simulation of pollutant behaviour in soil and plants, for stakeholders and policy-makers involved in harmonising methodologies to allow comparisons of results between different countries.

This FG reached the conclusion that **prevention should lead farmers to protect their soils from contamination**. This could be done through the implementation of sustainable farm management and soil conservation technologies, and a few of them are also given as good management practices in this report. Soil is a non-renewable resource, fragile and vulnerable at the same time, but resilient when used in the right way. Farmers know this more than anybody else.

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Annex A. Members of the Focus Group

Name of the expert	Profession	Country
Paula Alvarenga	Researcher	Portugal
Nicolas Beriot	Researcher	Spain
Maria Pilar Bernal	Researcher	Spain
Fergal Byrne	Farmer	Ireland
Isabel Campos	Researcher	Portugal
Kate Carmody	Farmer	Ireland
Ove Gejl Christensen	Repr. of an NGO	Denmark
Mihály Lajos	Farmer	Hungary
Vince Lang	Researcher	Hungary
Chiara Manoli	Industry	Italy
Gregor Mlakar	Farmer	Slovenia
Carlos Ortiz-Gama	Civil servant	Spain
Marta Pogrzeba	Researcher	Poland
Aila Riikonen	Farmer	Finland
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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 B. List of mini-papers

Minipapers	FG members
MP1 Sources of contamination to agricultural soil	Paula Alvarenga coord. (PT), Isabel Campos (PT), Carlos Ortiz (ES), Nicolas Beriot (ES/NL), Maria Pilar Bernal (ES)
MP2 Soil monitoring on farm level	Fergal Byrne (IR), Isabel Campos (PT), Ove Christensen (DK), Vince Lang (HU), Gregor Mlakar (SL), Aila Riikonen coord. (FI)
MP3 Biological remediation	Maria Pilar Bernal coord. (ES), Paula Alvarenga (PT), Kate Carmody (IE), Marta Pogrzeba (PL), Gerhard Soja (AT)
MP4 Precision agriculture	Aila Riikonen (FI), Lulu Zhang (DE), Gregor Mlakar (SL), Vince Lang coord. (HU)
MP5 Sustainable farm management	Amalka Vukelic coord. (CR), Fergal Byrne (IR), Chiara Manoli (IT), Carlos Ortiz (ES), Nicolas Beriot (ES), Lulu Zhang (DE)

Annex C. Relevant research projects

iSQAPER – Interactive Soil Quality Assessment: good Agricultural Management Practices lead to better soil quality
http://www.isqaper-project.eu/

RECARE – Protecting and Remediating degradation of soils in Europe through land care
https://www.recare-project.eu/

LANDSUPPORT: Development of Integrated Web-Based Land Decision Support System Aiming Towards the Implementation of Policies for Agriculture and Environment
https://www.landsupport.eu/

OPERA: (OPerationalizing Ecosystem Research Applications
www.operas-project.eu

LUC4C: Land-use change: assessing the net climate forcing, and options for climate change mitigation and adaptation,
luc4c.eu

IMPRESSIONS: Impacts and risks from high-end scenarios: Strategies for innovative solutions, www.impressions-project.eu

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Annex D. Research needs from practice

Table 3. Proposed research needs and interventions

MP and Key issues	Research needs for protecting agricultural soils from contamination
MP1 Sources of contamination to agricultural soil	**1.** Define the long-term build-up of **persistent organic contaminants** in agricultural soils, accumulation, bioavailability, effects on soil biota, interactions with soil constituents, potential leaching and runoff. **2. More research on pesticides**: environmental risk assessment of their interaction, and the establishment of threshold values in soils for approved currently used pesticides; **3. Biochar and compost**: potential absorption and adsorption of contaminants, specific mechanisms in soils amended with biochar and compost on the (im)mobilisation of organic and inorganic contaminants, on the modification of their (eco)toxic effects, on the translocation of these contaminants from roots to shoots, and on the migration towards groundwater.
MP2 Soil monitoring on farm level	**1. Development** of smart sensors and/or affordable tools for fast determination methods and with improving resolution and accuracy to allow farmers to conduct in-situ field monitoring of the fundamental parameters' contents mainly the macronutrients concentrations (N, P and K) and organic carbon. Worth mentioning that these procedures should be tested under practical conditions regarding low-threshold applicability, compared with standardised laboratory methods and validated individually; **2. Establishment and setting** up of a **soil quality monitoring protocol**, which enables the farmers to assess the respective soil status at farm level. **3.** Research for the development of **alternative systems for soil scanning** and monitoring (besides the laboratory analysis) using state of the art technologies such as remote sensing and drones, which can foster quick assessment of soil contamination and decrease associated costs involved with it. **Development of kits** for the determination of soil enzymatic activities (low tech, easy-to-use and affordable) to monitor the soil microbial activity
MP3 Biological remediation	**1.** Develop strategies for **new pollutants**: microplastics, fluorinated compounds, endocrine disruptors, drug residues. **2.** Define strategies for **mixed combined contamination**: organic and inorganic pollutants, or heavy metals and metalloids. **3.** Define **local plant species** for different climatic conditions and **specific for each remediation method**. **4. Long-term experiments for validation of the remediation techniques**: efficiency versus time and cost. **5.** Establishment of **criteria for remediated soils**: pollutant bioavailability, risk assessment, soil health and biodiversity. **6. Assessment of the social costs** of delaying remediation of brownfields or in urban areas.
MP4 Precision agriculture	**1. Increase and optimise technology** for precise use of chemical inputs at the right spot and the right time to minimise the impact on the environment and soil quality. **2. Develop precision agriculture technology** affordable and usable also for **small scale farmers**
MP5 Sustainable farm management	**1.** Develop a **farm-centered approach** to incorporate wider **biophysical, socio-economic and business components** into the farming system **2.** Develop **multi-actor and interdisciplinary decision support tools** that are easy-to-use and help farmers and decision makers to implement sustainable soil management technologies that support increased and sustained yields without making harming soils and the environment.

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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

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