EIP-AGRI Focus Group

Soil salinisation

FINAL REPORT
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1. Executive summary

This report summarises the main outcomes of the EIP-AGRI Focus Group (FG) on Soil salinisation, which was launched under the European Innovation Partnership, Agricultural Productivity and Sustainability (EIP-AGRI), for exploring possibilities on how to maintain agricultural productivity by preventing, reducing or adapting to soil salinity. The FG brought together 20 experts from different backgrounds to establish the state of play and draft recommendations on transferable innovative solutions.

The FG made an inventory of European areas affected by soil salinisation. Twenty-five case studies were collected as examples of saline land located in coastal and inland areas, in irrigated and rainfed conditions. The experts described current agricultural practices in the case studies and suggested specific good and innovative farming practices that could be introduced.

While preparing the state of play, a first key issue was the extent of saline soils, which appears to be underestimated by current public datasets. The main causes of salinisation relate to improper soil or water management (drainage and irrigation), but engineering mistakes, such as excessive earth movement and leakage of irrigation canals contribute as well. Some key issues still to be further studied are the methods of monitoring and mapping soil salinisation, modelling its effects on plants and evaluating the effects of soil salinity on ecosystem services. The FG then discussed the sustainability of farming practices to prevent and control the negative effects of soil salinisation. Besides the practices adopted in the case studies, the FG listed a further set of farming practices that can prevent, minimise or mitigate soil salinisation and alkalinisation in the various European environments. Since managing salt-affected irrigated land requires an understanding of complex interactions between soil, crop, irrigation water and climate, the FG considered the potential of modelling cropping systems and developing Decision Support Systems as tools to assist farmers to simulate interactions between these factors.

One main activity of the FG was exploring opportunities to add market value to locally adapted varieties which are tolerant to salt stress, so as to compensate for yield reduction. They also looked at the potential of minor crops with increased tolerance to salt stress. Eight case studies on market opportunities for crops adapted to saline conditions were identified and the potential of some species were described in two **mini-papers**. Crops of particular interest, due to their adaptive response to salt stress, are tomato, prickly pear, rice, maize, potato, table- and wine-grape, chard, erbastella or minutina, ice plant, and *Salicornia* species. *Salicornia* has already been used for oil production, biofuel and food production, but many other halophytes have not yet been identified for a specific industry. The edible salt tolerant species have a potential to develop a market niche. Also, some specific case of halophytes have been identified as salt accumulators, with potential utilisation for bioremediation.
The collaboration among multidisciplinary experts led to a deeper analysis of specific issues, which resulted in **7 mini-papers** dealing with the following subjects:

1. Measuring, mapping and monitoring of soil salinity
2. Crop productivity under saline conditions
3. Ecosystem services and salinisation
4. Prevention, mitigation and adaptation strategies for soil salinisation at farm level
5. Decision Support Systems for efficient irrigation on high salinity fields
6. Quality aspects of plant varieties in response to soil/water salinity under specific climate conditions
7. Examples of salt tolerant crops as an alternative for farmers

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Looking for main questions that could be developed through innovation, the FG proposed a set of ideas for innovative projects or potential Operational Groups (OG).The outlines of 14 ideas for innovative projects were elaborated, described and clustered according to 5 themes:

1. Monitoring and mapping soil salinity,
2. Prevention, mitigation and adaptation strategies to cope with soil salinisation,
3. Management of ecosystem services in lands at risk of salinisation,
4. Decision Support Systems to support farmers in managing irrigation in areas at risk of soil salinisation,
5. Opportunities for salt tolerant crops.

Based on the analysis of knowledge gaps, the Focus Group identified several needs from practice concerning soil salinisation, which may be solved by further research. The rationales of 23 possible research activities were described and presented under 4 thematic clusters: i) water management strategies, ii) crop and soil management strategies, iii) monitoring, modelling and mapping, and iv) local and new varieties.

Finally, the Focus Group made the following list of recommendations stemming from expertise and practice:

- Create soil salinity measuring standards and data sharing schemes to map the problem.
- Develop decision support systems and models to assess the effects of agriculture management practices on soil salinisation and provide advice to farmers.
- Consider possible off-site effects of salinisation prevention agricultural practices and their impact in ecosystem services.
- Explore marketing opportunities for halophytes or for crops with special properties when grown under saline conditions that can increase their market value.

Soil salinisation Focus Group Experts

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2. Introduction

Salinisation is one of the major threats to soils at global scale. In Europe, several million ha of agricultural land are deemed to be affected by salinisation (Daliakopoulos et al., 2016). The accumulation of salt can affect soils in coastal areas, because of sea water intrusion, as well as internal and continental lands, especially on salt rich parent materials where saline layers can occur in the soil profile. Besides the lands which are naturally affected by salinisation (primary salinisation), there are many more where soil salinisation is due to human activities (secondary salinisation). The adoption of improper agricultural practices, especially irrigation with poor quality waters, overpumping and consequent drawing of salt water and poor drainage conditions have induced or exacerbated soil salinisation, and their frequency appears to be increasing (Stolte et al., 2016). The rise of the mean temperature observed in the last decades and the consequent increase in evapotranspiration have also boosted the risk of soil salinisation in many parts of Europe. The projections for future climatic conditions and their consequences on soils are alarming. Thus, soil salinisation is expected to further increase in the future as a consequence of current climate, land use and management changes (Trnka et al., 2003).

The term soil salinisation often refers to two different processes:

- Salinisation, which is the accumulation of water-soluble salts in the soil profile, mainly chloride, sulphate, carbonate and bicarbonate of sodium, magnesium, calcium, and potassium.
- Sodification or Alkalinisation, which is the progressive saturation of the exchange complex with sodium , with a concurrent increase in pH in the soil solution to over 8.5.

Salinity increases the osmotic potential of the soil water solution, which limits the plant capacity to absorb water. It can cause nutritional imbalances or toxicity due to the presence of specific ions and has a direct negative effect on soil biology. An example for specific ion toxicity is an excess of Na+, which can negatively alter cell morphology, plant photosynthesis and chlorophyll production. Sodification and alkalinisation lead to the destruction of soil structure through the swelling and dispersion of clay particles and the formation of low permeability layers that restrict root growth. Clay dispersion also reduces water infiltration throughout the soil profile, causes waterlogging, clogs drainage pipes, reduces the bearing capacity of the soil (restricting the use of machinery to work the soil), and enhances surface and subsurface soil erosion (Stolte et al., 2016).

The impaired soil functionality caused by excessive soil salinity reduces the yield of crops, most of which are sensitive or have low levels of tolerance to elevated salt content in soils. However, the threshold value above which damaging effects occur can vary depending on several factors including plant species and varieties, soil water regime and climatic condition (Daliakopoulos et al., 2016). In early stages, soil salinity affects the germination of crops and reduces their productivity, but in advanced stages it kills all vegetation and consequently transforms fertile and productive land to barren land. Among the most important row crops barley, rye, rice, sunflower, potato and sugar beet are considered tolerant, whereas maize is sensitive in the early development stages of the crop. Vegetables are more sensitive to soil salinisation than grains and forages, with the notable exception of asparagus, artichoke, red beet, some varieties of carrot and cauliflower, and zucchini squash. Soil salinity limits tree growth and fruit yield in most fruit trees, such as stone fruits and citrus, but cultivars of olive tree and grapes can be moderately tolerant. Crops may demonstrate different salt tolerance depending on meteorological conditions (mainly rain and evapotranspiration demand), soil biotic properties and, growth stage, and agronomic practices including salt-resistant rootstocks.

As a whole, soil salinity has a significant negative effect on farmers' income, and for this reason, affected lands have been included by the EU in the delineation of the agricultural areas with natural handicaps (Reg. EC 1698/05). As well as its effect on food production, salinisation has an effect on several other soil ecosystem services: provision of freshwater for livestock, wild animals and plants, regulation of groundwater quantity and quality, soil water and wind erosion, supporting habitats and also on recreational areas and the aesthetic value of the landscape (Stolte et al., 2016).

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The aim of the Focus Group was to provide answers and recommendations with regard to the following general question: how to maintain agricultural productivity by preventing, reducing or adapting to soil salinity?

The Focus Group carried out the following main tasks:

1. Carry out a survey of European areas affected by soil salinisation and the current agricultural practices in these areas.
2. Identify and assess the sustainability of good and innovative farming practices from various pedoclimatic environments within the EU that can prevent or reduce the threat of soil salinisation or control its negative effects.
3. Explore opportunities to add market value to locally adapted varieties which are (more) tolerant to salt stress so as to compensate for yield reduction.
4. Discuss the potential of minor crops with increased tolerance to salt stress.
5. Propose potential innovative actions and ideas for Operational Groups.
6. Identify needs from practice and possible gaps in knowledge concerning soil salinisation that may be solved by further research.

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3. Brief description of the process

The Focus Group involved 20 experts from 9 countries, namely, Spain, Italy, Portugal, The Netherlands, United Kingdom, Bulgaria, Germany, Greece and Hungary. A starting paper was circulated to all the experts prior to the first meeting of the EIP-AGRI Focus Group, to outline the topic and identify points for discussions. Prior to the first meeting, the experts were asked to contribute to a mapping questionnaire linked to task 1 about areas affected by soil salinisation and the current agricultural practices in these areas. Experts were also asked to prepare **case studies** to their knowledge about i) existing innovative strategies and ii) market opportunities for crops adapted to saline conditions.

The first meeting of the Focus Group was held in Budapest (Hungary) on 15 and 16 May 2019. After the presentation and discussion of the starting paper, FG members introduced a selection of case studies. In the afternoon, the experts visited two farms in the Danube alluvial plain, which is where, alongside with Hortobágy area, most of the soil salinisation and sodification in Hungary can be found. The second day was devoted to the presentation of other selected case studies and working sessions in small groups. At the end of the first meeting, the FG developed a short list of specific topics to be elaborated in 'mini-papers', to be produced between and after the two EIP-AGRI Focus Group meetings.

The second meeting was held on 15 and 16 October 2019 in Tarragona (Spain). The meeting focused on presenting the work done in the mini-papers, further discussing the sustainability of farming practices to prevent and control soil salinisation and its negative effects, looking for ideas/main questions for innovative projects such as Operational Groups, and identifying needs for research from practice. The participants also went on a field trip to visit the Comunitat de Regants – Sindicat Agrícola de l'Ebre, the irrigators community in Deltebre. The experts saw the different salinisation problems of the area, and the current measures to counteract them. They also had the opportunity to exchange experiences with local farmers and researchers on the projects developed there to improve the management of the Ebro River delta.

After the second meeting, the experts finalised 7 mini-papers, dealing with the following subjects:

1. Measuring, mapping and monitoring of soil salinity
2. Crop productivity under saline conditions
3. Ecosystem services and salinisation
4. Prevention, mitigation and adaptation strategies for soil salinisation at farm level
5. Decision Support Systems for efficient irrigation on high salinity fields
6. Quality aspects of plant varieties in response to soil/water salinity under specific climate conditions
7. Examples of salt tolerant crops as an alternative for farmers

Some extracts from case studies and mini-papers are described in this report, but the complete documentation of the case studies is available **online** and the full mini-papers can be found **here**.

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4. State of play

The **starting paper** of the Focus Group provided background information to contextualise the problem presented in the introduction of this report. This information served as a basis for the debate of the Focus Group, aimed at addressing the **main questions and tasks**. In line with this, the starting paper exposed key issues that were debated by the Focus Group experts and can be summarised in the following questions:

- How to correctly delineate the geographical extent of the problem in order to identify the areas where measures need to be taken?
- Which are the available tools to monitor soil salinity and take the correct decisions on the best strategies to adopt at farm level?
- Which are the available tools to analyse the effects of soil salinisation on plant growing cycles, in order to better fine-tune crop management practices and minimise impacts on crop yield?
- Which may be the off-site consequences on ecosystems of adopting certain strategies at farm level?
- Which are the available strategies and good practices to prevent, adapt to, mitigate or remediate soil salinisation problems and what are the success and fail factors for their adoption at farm level?
- Which are the opportunities for compensating yield losses by growing salt-tolerant crop varieties or capitalising on the added value of special characteristics conferred to the crops grown under saline conditions?

The following sections will present the outcomes of the Focus Group experts' discussions on these topics. The outcomes will be illustrated with examples extracted from the **case studies** presented by the experts and references will be made to the **mini-papers** drafted by the experts in order to arrive at a deeper analysis on these questions.

a. Key topics discussed by the Focus Group

Spatial extension of soil salinisation

The location, extent and severity of the areas affected by soil salinisation in Europe, as reported by available maps, is still controversial. Different authors provide rather dissimilar spatial estimations, based on thresholds for identification of soil salinisation problems, which may vary from about 30 to more than 70 million hectares (read the **Starting Paper** for more information). As reported in the mini-paper on "**Measuring, mapping and monitoring of soil salinity**", EU member states do not possess publicly-available, detailed soil salinity maps of their salt-affected areas, although soil institutes in some countries have data on soil salinisation. However, also in these cases there are issues about the level of detail, the updating and monitoring process and the digitalisation of the data, which do not allow comparing or integrating data from different sources. As a whole, the extent of soils affected by incipient salinisation in Europe appears to be underestimated.

The 25 locations with salinisation problems identified in a survey carried out amongst the FG experts show examples of lands prone to soil salinisation in both coastal and inland areas (Fig. 1).Most of them are irrigated, but 6 are rainfed. 18 cases are in a Mediterranean climate, 5 Temperate and 2 Continental. Saline soils predominate, followed by saline-sodic and sodic, with 13, 9 and 3 cases respectively.

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Figure 1 – Locations affected by soil salinisation covered in an explorative survey carried out amongst the experts of the Focus Group

Most causes of the salinisation in the surveyed locations are related to improper soil or water management (drainage and irrigation, see figure 2). Engineering mistakes, such as excessive and inappropriate earth movement and leakage of irrigation canals are also relevant (see example from Bulgaria in text box below).

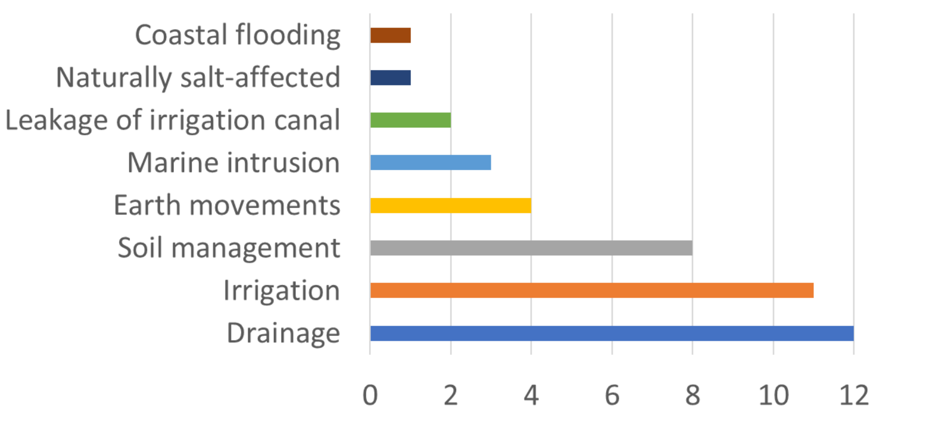

Figure 2 – Causes of salinisation problems identified in the locations covered in a survey carried out amongst the FG experts.

Improper management of soil and water are the main drivers of soil salinisation

From a case study in Bulgaria: most saline soils in Bulgaria are associated with irrigation. Leaking of irrigation channels and wells, and raising the saline water table through excessive irrigation are increasing the salinity of soils. Water management is the most important issue to control soil salinity. The degree to which water movements can be managed determines the feasibility of facing the salinity problem. Currently, crop selection is the main practice that farmers use to cope with soil salinity problems in the affected area.
In the picture: irrigated meadows on Haplic Phaeozems (Endocalcaric, Sodic, Clayic) near Sofia.

Many crops, mainly row crops and vegetables, have been affected by salinisation (Fig. 3).

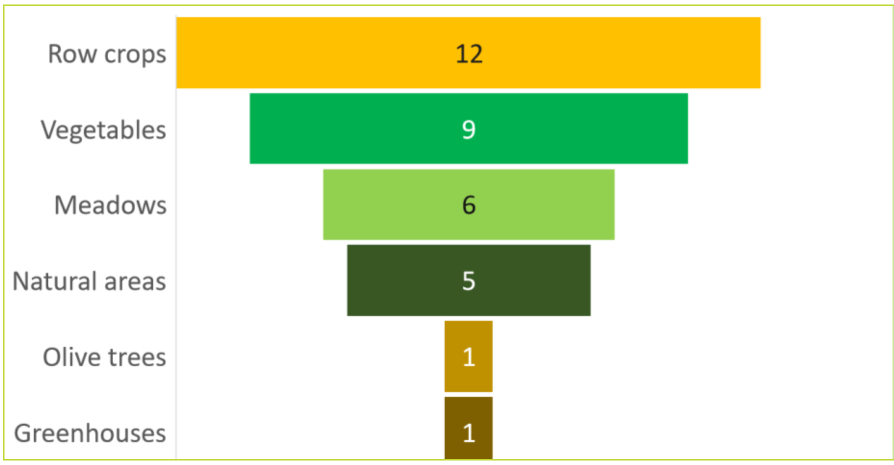

Figure 3 - Main crops in the locations with salinisation problems identified in a survey carried out amongst Focus Group experts.

According to the mini-paper on "Measuring, mapping and monitoring of soil salinity", a major knowledge gap to tackling soil salinity problems remains the lack of an **updated assessment of the extent, magnitude, and development of soil salinisation** at different scales. We lack experience on how to get the most out of the new proximal and remote sensors, as well as ICT tools, which have now become available in Europe. Ideas to generate the knowledge needed to address this issue are provided in section 5.

Monitoring and mapping soil salinisation

The extent of soil salinisation on the surface or underground is still uncertain. This is because the efforts and tools for monitoring and mapping soil salinisation are still insufficient, work is very time-consuming and the economic resources are limited. Nevertheless, there is a general consensus about an observed increasing trend of soil salinisation in recent decades, as a consequence of current changes in climate, land use, and management. Although monitoring and mapping soil salinity has been practiced for a number of years, a number of issues remain, especially in terms of the operational deployment of measurements, and lack of standardised methods and equipment. Additionally, one of the problems in monitoring of saline soils is because of variability in time and space: due to the dependency of salinity values on soil humidity (a specific

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salt content may show different salinity values in wet and dry periods); local soil variability; groundwater oscillations; land subsidence (see case study "**Reclaimed agricultural lands**"); as well as the variable quality and quantity of irrigation water (see case study "**Strategies to counter salinisation problems in Wadden region**"). A typical short-term change is the appearance and disappearance of salt efflorescence caused by upward seepage of saline water in dry periods. This may cause farmers to underestimate the effects of soil salinisation in the short run, especially in cases of incipient, seasonal, or periodic salinity (De Pascale et al., 2012).

Soil salinity can be detected in the laboratory and in the field with different methodologies (see the mini-paper "**Measuring, mapping and monitoring of soil salinity**". Measurement of the electrical conductivity[1]of saturated paste is the standard international laboratory method for interpreting soil salinity. However, the preparation of the saturated extract is labour-intensive and time-consuming and is poorly suited to processing a large number of samples. To make the analysis easier, there are many empirical relationships assumed to relate the value of saturated paste to that in different suspensions of soil and water. There are also several field methods for measurement of soil salinity. Ceramic cup suction samplers installed directly in the field enable samples of soil solution to be obtained from different soil depths and locations during crop growth. The electrical conductivity of the soil solution can also be measured with a hand-held electrometer.

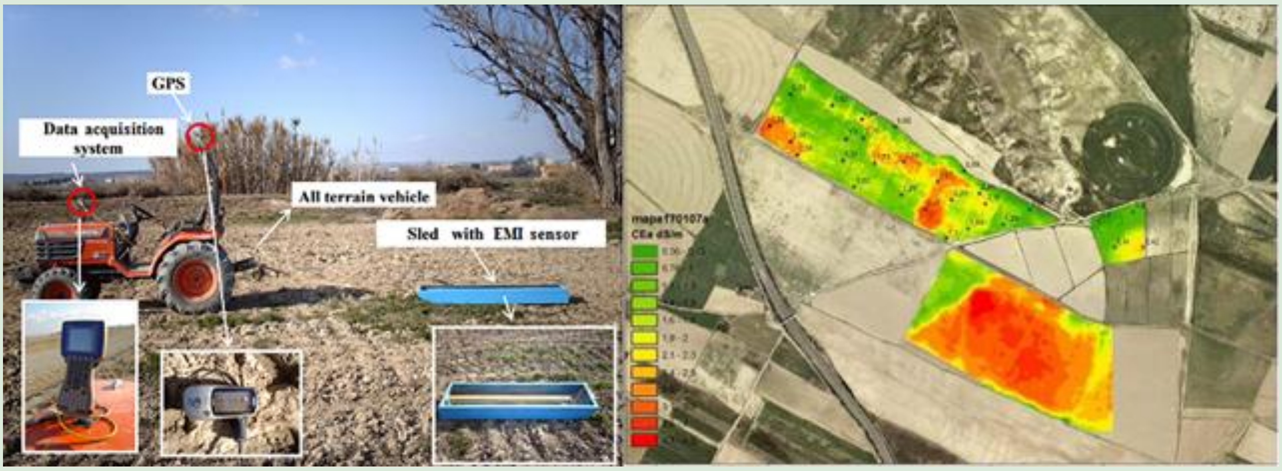
Mapping and monitoring are required to follow ongoing salinisation or desalinisation over time, to ensure up-to-date delineation of crop management zones (see text box below), and to establish the most appropriate soil and water management practices. There are promising methods of analysing and monitoring soil salinity at the farm level, beyond traditional laboratory methods, namely proximal sensors. These obtain data from the soil when they are in contact with the soil or close to it (within 2 m). Three types are currently used for crop and land management applications: electrical resistivity sensors, dielectric sensors, and electromagnetic induction (EMI) sensors (see case study "**Salinisation risks in irrigated alluvial and marine origin soils**").

Soil salinisation can also be monitored by remote sensors (see the mini-paper "**Measuring, mapping and monitoring of soil salinity**". Air-borne sensors (in helicopters, light aircraft, drones) and satellite-borne sensors can facilitate soil salinity mapping by reducing time-consuming and costly field surveys. Soil salinity can be assessed directly or indirectly by using aerial or satellite images obtained with sensors that measure different wavelengths of the light reflected by crops and earth surface, through the ratios of reflectance values at different wavelengths. However, these spectral data only provide direct information on the soil or crop surface, not from the soil profile. Nevertheless, indirect methods, such as multi-year crop stress evaluations, or using multiyear, multiresolution, and multisensor datasets, may be used to estimate the presence and severity of salinity in the root zone.

[1]The standard method is the electrical conductivity measurement of the extract obtained from a saturated soil paste (EC_e at 25°C, dS m^{-1}).

Innovation in monitoring soil salinisation: proximal on-the-go sensors and digital mapping

For more efficient mapping of soil salinity, portable electromagnetic induction (EMI) sensors are combined with Global Positioning Systems (GPS) and data-loggers, which are all incorporated with vehicles such as small tractors. These automated salinity mapping systems are known as Mobile and Georeferenced Electromagnetic induction Sensors (MGES). The resulting map displays the spatial patterns of soil salinity and can be used to identify and rank salinity in the affected areas (e.g. slightly, moderately and severely affected).
Detailed field-scale surveys are useful for identifying causes of salt-loading and establishing proper management (including crop selection and irrigation schemes) and rehabilitation strategies.



(Left image taken from Urdanoz et al., 2008; right image with the permission of E. Amezketa)

Mapping and monitoring soil salinity are key for overcoming the awareness issues among farmers of the effects of soil salinisation in the short run, especially in cases of incipient, seasonal or periodic salinity, and also in order to optimise the crop, soil and water management. However, there is a lack of easy, reliable and harmonised methods, and of affordable tools, to set up early-warning systems at the farm scale, and to monitor the soil salinisation process and the outcomes of the implemented strategies. Research and innovation are needed in this area to develop the technology and methodologies able to meet these needs. Needs for research and ideas to cover this knowledge gap are discussed in section 5.

Modelling soil salinisation effects on plants

The Focus Group agreed that management of crops on saline soils to maintain agricultural productivity is a complex issue, which requires an understanding of the interactions among the soil, plant, microbes, and water. The understanding of the effects of salinity on plant growth, yield and evapotranspiration rate (the loss of water from the crop and the soil surface)can be facilitated by the use of models.

A range of models can be used to estimate crop productivity from the determination of evapotranspiration. Such models assume that yield and evapotranspiration decrease as soil salinity increases. As discussed in the mini-paper "Crop productivity under saline conditions", salinity can alter the development and growth cycles of some plant species: the higher the salinity of the soil, the lower the leaf surface (leaf area index - LAI). Lower leaf area reduces the plant's capacity to intercept solar radiation, therefore, the gross primary productivity is reduced. The time evolution of LAI is used in several models to estimate productivity since this variable is related with crop development. Actual soil salinity can be also used to model productivity.

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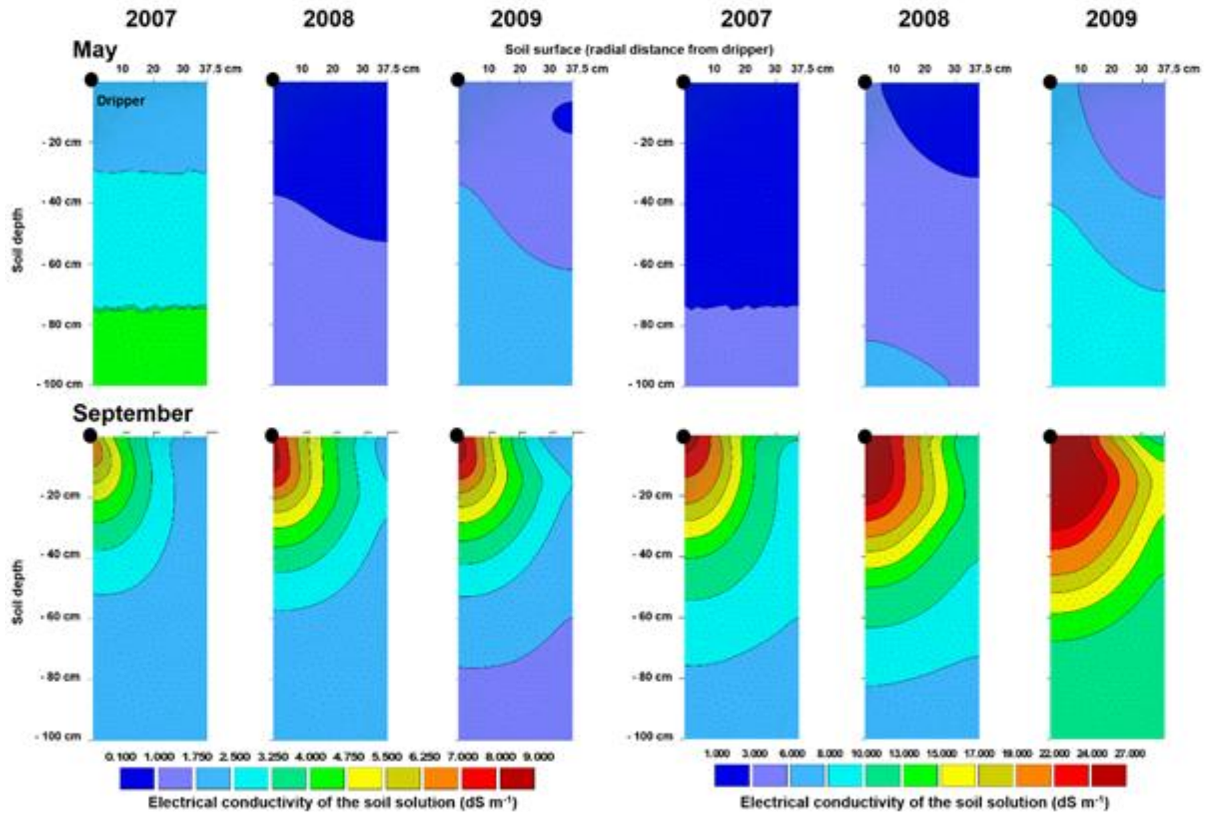
Alternatively, transient-state models can be used to simulate the salinisation processes induced by irrigation: the upward movement of salts from saline groundwater table and the sodification process.
A common drawback that prevents most models from being directly used in practice, by farmers or agricultural
extension services, is that they require a series of data that are not sufficiently known, or that may not exist. In other words, models use site-specific inputs that are either difficult to obtain or suggested or tabulated parameters from the literature that are hardly extensible to actual field conditions.

Modelling the long and short-term effects of irrigation water quality on soil properties, crop yield, groundwater and the environment

Salinisation control has to be based on knowledge of water and solutes dynamics in the soil.
Modelling is a processes integration tool enabling comparison of different scenarios, which can help to understand the complex interplay among crop, soil, climate and agrotechniques in saline conditions. However, a real challenge and a knowledge gap to be filled is spatial variability of soil properties, particularly soil hydraulic properties, and upscaling from plot or laboratory scale (where they usually are measured) to larger areas.

The image shows the simulated distribution of electrical conductivity of the soil solution in plot irrigated with fresh (left) and saline (right) waters during sowing (top) and harvest (bottom), in three crop seasons.



(from Ramos et al., 2012, modified)

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The FG experts recognise that there is a need for specific field research in salinised environments to obtain the crop and soil data necessary to formalise the model parameters. Since these are not generally available, this currently prevents the greater use of models in agricultural practice. The real challenge is to **transfer the models from research laboratories to agricultural practice**, indeed it is essential to study them in tune with farmers who work every day in saline environments. A further advantage that derives from the proximity of the model developers to the farmers is the adaptation of the models, so that they become user-friendly tools, easily used to predict crop productivity in saline soils.

Evaluating soil ecosystem services modifications caused by salinity

Soil salinisation has long been considered a threat to soil fertility and crop productivity, but as highlighted in the text box below, several other soil ecosystem services are affected by salinisation as well (see mini-paper on "**Ecosystem services and soil salinisation**"). All services are constrained by increased salinisation: climate regulation, protection from erosion, water infiltration, biodiversity and pollination, the capacity to retain and degrade pollutants, amount and quality of usable raw material, fodder and timber.The progressive salinisation of soil leads to an increase of degradation due to a cascade effect. Salinisation leads to stunted growth and plant decline, as well as to biodiversity loss, including soil microbiota, and can result in land desertification. When plant canopies do not cover the ground and, roots are insufficiently developed, soil is unprotected from erosion. It is worth mentioning though, that in some primary salinised soils, where lowland grasslands/wetlands were mostly converted into arable fields by plowing and drainage, a portion of the most difficult areas remained intact. Such areas comprise very important fragments of non-saline areas as well as remnants of natural saline ecosystems. Many European flagship national parks, such as Camargue, Doñana, the Wadden Sea, Hortobágy and Margherita di Savoia protect rare and invaluable biodiversity and endemism.

Besides on-site effects, soil salinisation produces a set of mainly negative off-site effects affecting other croplands and natural ecosystems (see details in the mini-paper "**Ecosystem services and salinisation**". Salts leached out of the soil profile reach aquifers under the land. This highly saline water may be the source for a neighbour farmer or may be used to irrigate other plots of the same farmer. Salts can also arrive at non-saline wetlands and terrestrial ecosystems, leading to soil degradation and to a biodiversity change from sensitive species to salt-tolerant ones. Off-site negative effects may typically exceed those on-site; unfortunately, they are more complex to measure and are usually not assessed. A holistic, "life cycle thinking" perspective is therefore much needed. Looking at the whole picture allows identifying unintended trade-offs that occur when decision-making processes are guided by a partial view of a problem: in this case, addressing only on-site soil salinisation effects without taking into account effects elsewhere. These include mainly negative environmental, social and economic consequences, which are the three dimensions of sustainability. Recognising the need to develop knowledge on the effects of soil salinisation on other on-site and off-site ecosystem services from saline soils in cropped or natural areas, the Focus Group identified specific needs for research to cover this knowledge gap and Operational Group ideas. These are presented in **section 5**.

Good practices and strategies adopted at farm and territorial levels in salt affected areas: success and fail factors for their adoption

Salinisation of agricultural soils is mainly caused by high evapotranspiration rates, hydraulic characteristics that impede water drainage and cause salt accumulation in the topsoil layers, bad quality irrigation water and see water seepage into the groundwater. The problem may be created or aggravated by improper management and variations in rainfall and temperature patterns due to climate change. Therefore, the adoption of certain practices and strategies will depend highly on the soil salinisation risk as well as on the soil and climate conditions.

Soil salinisation may be a risk, or already a reality. In vulnerable environments it is necessary to take preventive measures. In areas where salinisation developed due to poor management or where the salts equilibrium may be maintained, remediation strategies could be put into place. Adaptation strategies can be used in lands where salinisation is recurrent or remediation is not possible, or as a complement to remediation (see the box below).

Coping with Water Scarcity and Brackish or Saline Water in Eastern England

In coastal zones in the East of England, much of the groundwater resource for irrigation is becoming increasingly saline. Drier summers like 2018 are exacerbating the problem. Also, one-off salinity events such as coastal flooding decimated farmland in 2013, 1978 and 1953. Under future climate predictions, this is expected to occur more frequently.

Farmers have adopted new cropping system strategies to ensure crop growth. These include modifying the water extraction process by digging 'seepage pits' to rapidly abstract freshwater lenses. Farmers are also testing the blending technique, consisting in mixing brackish and freshwater for irrigation. These strategies grant the availability of water for agriculture while saving on water for other uses. Yet, the effects on soil and plants of irrigating with brackish water are uncertain in the long term. More research on monitoring and modelling these effects is needed to fine-tune these practices to the local conditions and maintain sustainable productivity levels.

The case studies shown by the Focus Group give an overview of the current practices adopted in Europe to tackle the salinisation problem. A further analysis of these practices has been made in the minipaper on "Prevention, mitigation and adaptation strategies for soil salinisation at farm level". Most of them are related to water management at the farm level, while soil and crop management are still poorly implemented (Fig. 4).

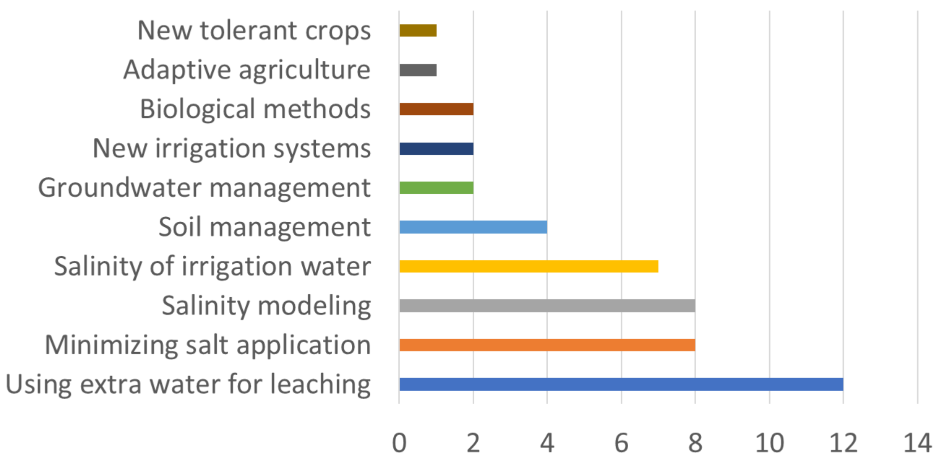

Figure 4–Number of case studies and current practices and strategies adopted to tackle the salinisation problem.

Examples of success and fail factors of water management are described in the case study "Salinisation risk in soils irrigated with saline waters". In the Netherlands, the main approach is to flush all the surface water system with fresh water from the rivers and lakes. In this way the salty water, collected in the surface water from the drainage system, is diluted or replaced by fresh water. However, every location is unique, so tailor-made adaptive farming systems should be developed. Also, new locations may be so unique that a new solution has to be developed, rather than a proven approach selected.

In Spain, the case study "Salinity management in Almería greenhouses - Blending and other solutions" shows examples of blending aquifer water with desalinated water, application of salt leaching irrigations in response to monitoring of soil solution, and on-farm desalination. The adopted strategy is currently successful, in that blending enables salinity-sensitive crops to be grown without adapting crop management. Yet, farmers do not adopt optimal irrigation practices; consequently there are negative off-site effects, such as saline wastewater and nitrate leaching.

The case study "**Soil crusting prevention – Chemical amendments**" reports an example of soil management in saline agricultural lands. The application of chemical amendments on the surface of sodic (and even non-sodic) soils is an effective practice to prevent or minimise soil crusting and maintain or improve water infiltration rates. Possible chemical amendments include sulfuric acid in calcareous soils and gypsum products. However, there are possible fail factors, such as management risks in the use of sulfuric acid, and the low dissolution rates of gypsum, which leads to excessive irrigation water volumes to dissolve the amendment.

As well as the practices adopted in the **case studies**, the Focus Group listed a set of farming practices which can be implemented to prevent, minimise or mitigate soil salinisation and sodification (Table 1). Most of these practices have been analysed in more detail in the mini-paper "**Prevention, mitigation and adaptation strategies for soil salinisation at farm level**".

	Prevention	Adaptation	Remediation
Water management practices			
Store good quality water in winter to use it in the most sensitive phenological stages of the crop. ("Freshmaker")		X	
Leaching, implementation of drainage systems (Salinisation problems in the Axios River wetlands)	X	X	X
Adaptive subsurface drainage (Adaptive subsurface drainage)		X	
Drain brackish water from deep soil layers to store fresh water from precipitation and increase the freshwater lens (Strategies to counter salinisation problems in Wadden region)		X	
Drip irrigation	X		
Mixing saline and fresh water (Salinity management in Almería greenhouses- Blending and other solutions)		X	
Alternate or cycling irrigation with saline and fresh water (Strategies to counter salinisation in rice fields)		X	X
Increase irrigation water every 3-4 watering events (Salinisation risks in irrigated, alluvial and deltaic soils)		X	X
Alternative water sources, e.g. reuse wastewater (Water Scarcity and Brackish/Saline Water in Eastern England)		X	
Change from irrigated to rainfed			X
Desalination of irrigation water (Salinisation risk in soils irrigated with saline waters)		X	X
Surface water flushing	X		
Control interval between irrigations	X		
Flood trenches with fresh water or infiltrate fresh water in the ground to avoid sea water intrusion.	X		
Crop management practices			
Plant salt-tolerant crops (Salinisation risk in soils irrigated with saline waters)		X	
Plant halophytes (Salinisation risk in soils irrigated with saline waters)			X
Green manuring		X	
Phytoremediation with crops (Salinisation risk in soils irrigated with saline waters)			X

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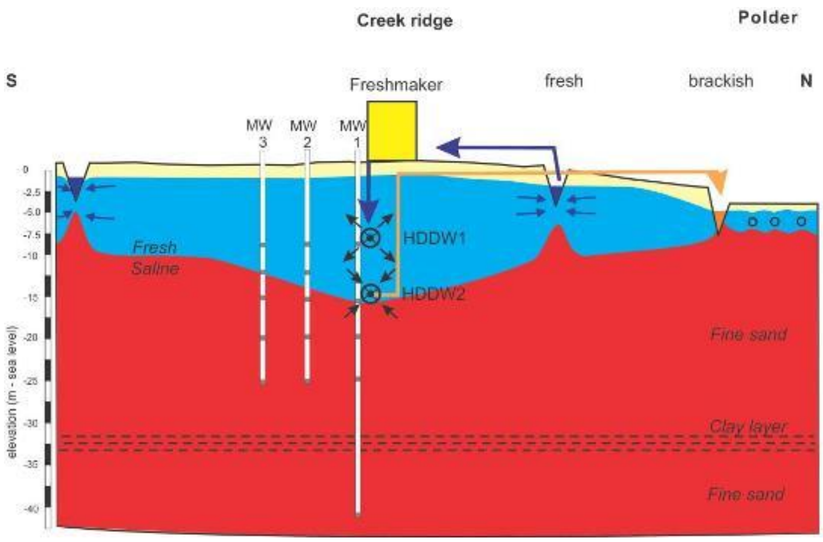
	Prevention	Adaptation	Remediation
Grafting on salt-tolerant rootstocks		X	
Inoculation with mycorrhizal associations		X	
Apply biological agents to increase crop resistance to salinity or plant growth under saline conditions		X	
Crop rotation with salt-tolerant crops.		X	
Use biostimulants to counter salinisation effects on the crop (Biostimulants to overcome salinisation problems)		X	
Convert to pastureland (Strategies to counter salinisation in pastures of the Tagus river margins) and (Water management and crop selection to counter salinisation in Bulgaria)		X	X
Soil management practices			
Mechanical removal of surface salt crust			X
Deep tillage to mix soil layers and reduce salinity of the top layer		X	X
Inorganic amendments (Sodic soil reclamation – Chemical amendments)			X
Organic amendments (Biotechnological potential of saline soil microorganisms)			X
Intervention in the nutrition of plants (e.g. fertilisers)		X	
Mulching		X	
Careful use of machinery to avoid soil compaction	X		
Application of conservation agriculture	X		
Adoption of precision farming	X		
Proper dimensioning of slope reshaping and earth movements before crop establishment	X		
Chiselling to remove hard pans and increase drainage			X
Creating 'seepage pits' to rapidly abstract freshwater lenses		X	

Table 1 – Overview of practices and strategies adopted at farm and territorial levels to tackle soil salinisation.

It is difficult to generalise strategies against soil salinisation that can be adopted at the farm level. There are success and fail factors that should be considered before adoption at the farm level. The analysis by the Focus Group of the success and fail factors of strategies presented in case studies can be found **here**. The key issues for adopting the strategies from table 1 can be summarised as follows: Possible practices of "saline agriculture" are constrained by local soil, climate and landscape conditions, as well as by the territorial setting and water infrastructures (reclamation and irrigation systems, see e.g. case study "**Salinisation problems in the Axios River wetlands**") and by competition between alternative use of water (for agriculture, civil needs and industrial activities, tourism, wildlife and natural preserves, see case study "**Considering the whole environment to truly reduce environmental impacts of irrigation-induced salinisation**").

Storing fresh water in winter to use it in the most sensitive phenological stages of the crop

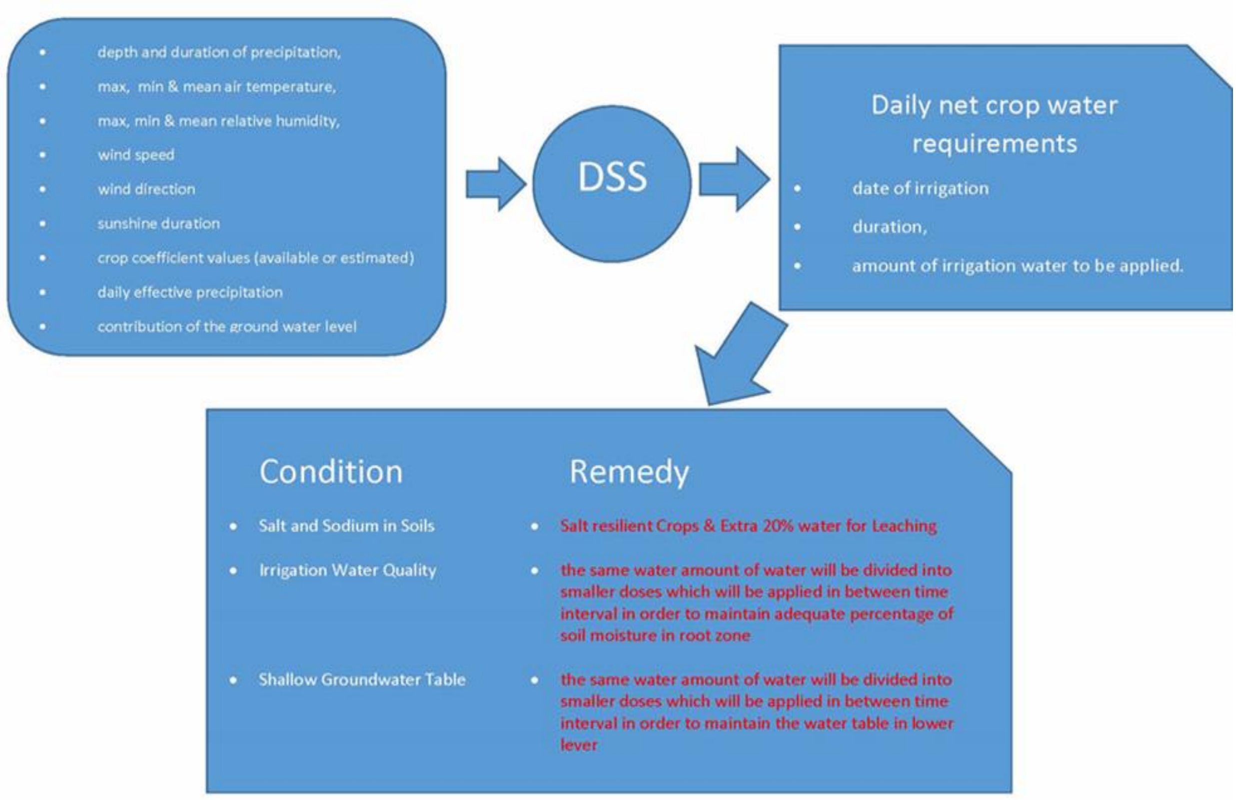
In areas of the Netherlands prone to salinisation, farmers install drains to evacuate water that passes through the soil and washes away salts. Yet, experts discovered that excessive drainage could cause problems during dry summers, since underground water containing salts may ascend through capillarity and bring up the salts again. Good monitoring of soil salinisation allows to better manage the drainage systems and control the problem, by storing fresh rainwater in the ground to prevent salts ascending by capillarity in dry periods. The technology is promising, but investment costs are still barriers for large-scale implementation.



According to the mini-paper "[Decision Support Systems for efficient irrigation on high salinity fields]", not adopting the correct strategies may lead to mismanagement and worsening of the problem. Managing salt-affected irrigated land and marginally saline irrigation water requires understanding of complex interactions between soil salinity, crop salt tolerance, soil physical properties, groundwater quality, irrigation water quality, irrigation management, water table depth, climate, and crop yield. This understanding can lead to estimates of the consequences of adopting agro-techniques or water management systems in specific soil conditions. However, this may be a challenge, particularly to farmers who cannot count on the means to retrieve or assess all the factors involved in taking the correct decision. Decision Support Systems (DSS) can assist farmers with interactive computer programmes to simulate interactions between all these factors. Using DSS, irrigation advisory services can considerably assist farmers with the adoption of new technologies and techniques to increase water use efficiency, while minimising environmental risks, thereby contributing to sustainable agriculture.

Decision Support Systems (DSS) for Efficient Irrigation on High salinity Fields

A Decision Support System (DSS) is a logical arrangement of information that includes engineering models, field data, Geographical Information System (GIS), and graphical user interfaces, and which is used by managers to make informed decisions. A DSS that assists with managing salt-affected irrigated lands and marginally saline irrigation water is an interactive computer program that simulates interactions between these factors. This type ofDSS shows the effects of changing one factor in input on the outputs of the cropping system (e.g. crop yield) during one or more growing seasons. The user selects climate, crop, agronomic techniques and soil characteristics from menu lists, then sets the water table depth, groundwater quality, irrigation water quality, and the DSS then develops an irrigation schedule.
Although DSS are useful and popular tools, their adoption is often constrained by the lack of proper calibration and validation suited to the very local conditions where they are applied.



However, the economic costs of farming in saline soils cannot be ignored. Adopting additional practices can be rather expensive for farmers. In marginal lands and extensive cropping systems, where crop profitability is already low even in non-saline conditions, the public economic support to farmers can be insufficient to compensate the extra costs given by the adoption of measures to counteract soil salinisation (see e.g. case study "**Water Scarcity and Brackish/Saline Water in Eastern England**"). This makes farming less attractive in such areas and has sometimes led to land abandonment (Lasanta et al., 2017).

In conclusion, the experts of the Focus Group stressed that water and soil management in salt-affected lands are very sensitive to local conditions, so it is necessary to collect and systemise an array of possible solutions

about drainage and irrigation, including leaching requirements, using proper agricultural husbandry, tailored to a broad range of situations. The costs of the different practices must always be carefully considered.
Phyto- and bioremediation techniques of salt-affected soils are still in their infancy. Knowledge is needed on the potential of using selected plants(possibly including mycorrhization or microbial inoculation for enhanced growth)to remove salts and sodium in different soil and climatic regions. The Focus Group identified needs for research and Operational Group ideas to cover the aforementioned knowledge gaps, which are addressed in **section 5**.

Opportunities for locally adapted varieties, potential for minor crops with increased tolerance to salt stress

The experts of the Focus Group summarised two groups of opportunities for development in salinised land in two mini-papers: "**Quality aspects of plant varieties in response to soil/water salinity under specific climate conditions**" and "**Examples of salt tolerant crops as an alternative for farmers**". In fact, crop and variety tolerance to soil salinity can range widely, so a proper choice of crop allows farmers to have many possibilities to adapt farming to the local soil salinity conditions. But moderate soil salinity can also be an opportunity to develop new agricultural strategies. In spite of the overall negative effect of excess salts on many crops, it has been shown that moderate salinity, or subsoil salinity, may increase the quality of certain crops (check the **starting paper** for more information). There is increasing evidence that soil salinity may improve quality parameters of field crops, but particularly of fruits and vegetables (see case study "**Tomatoes in Campania region**"). Moderate salt stress may positively impact physical properties of fruits, including firmness and texture. Additionally, the accumulation of certain substances induced by salinity can improve the overall flavour and may have health benefits (see case study "**Market opportunities of halophytes and salt resistant crops**"). The excellence of some local food is actually determined by the characteristics of climate, soil, and saline water, which interplay with management to produce a high-quality fruit.

Market opportunity for potato varieties adapted to saline conditions

This potato variety is exported for the market of north Africa and the Middle east. The seed potato is growing in a clay soil with no possibility to irrigate because of brown rot disease. In dry summers the roots are growing in relatively high salt concentrations without yield loss. This allows production under saline conditions, but more knowledge is needed on the potato variety, yield and performance under different salinity levels, in order to assess its viability in different growing conditions.

Some species have been identified as particularly interesting due to their adaptive response to salt stress conditions. Some examples can be found in the Mediterranean region where plants have developed different strategies to respond to drought, including morphological, physiological and phenological adaptation. These species have developed different strategies to adapt to extreme conditions of water stress and salinity. Crops of particular interest are tomato, prickly pear (*Opuntia ficus-indica*), rice, maize (resistant to salinity in late developmental stages and having a potential for creating tolerant varieties though breeding), potato, table and wine grape, salt–tolerant chard (*Beta vulgaris* subsp. *Vulgaris*), halophytes such as erba stella or minutina (*Plantagocoronopus*), Ice plant (*Mesembryanthemumcrystallinum* L.) and pickle weed or samphire (*Salicornia*)(see e.g. case studies "**Rice production in Central Macedonia**", and "**Market opportunities** of halophytes and salt resistant crops”). *Salicornia*, in particular, has already been used for oil, biofuel and food production, but many other halophytes have not yet been identified for a specific industry. Moreover, the edible ones have a very small market niche (see case study “Salicornia in Portugal”). Halophytes also have possible bioremediation potential as some of them are able to extract salts from the soil (case study “Desalinisation of greenhouse soils by halophytes”). Even though, presently, the proportion of salts extracted from soils is not sufficient to justify their inclusion in crop rotation, their extraction ability might be improved through breeding techniques.

Soil salinisation may be an opportunity where a functional link between salinisation and product quality is found, but the knowledge needed to relate the quality of specific crops and varieties to local environmental and management conditions is lacking in most cases. Suggested research and Operational Group ideas are presented in the following sections.

5. Main outcomes of the discussion

a. Ideas for innovative projects and EIP-AGRI Operational Groups

This section presents some ideas for Operational Groups and other innovative projects. Further ideas and details are in Annex C.

Improvement of salinity management

Description: Appropriate cultivation on soils affected by salinity needs the integration of water, crop, and soil management techniques. The detailed tuning of the different practices such as drainage and irrigation, crop selection and management, requires mapping and monitoring of soil salinity levels and crop productivity over time. There are now many novel techniques using proximal and remote sensors that could be tested and adapted in Operational Groups. Also, the available GMES[2] system might be able to monitor soil salinity, possibly complemented with proximal sensing, although its use at the farm and field levels still shows many technical and economic difficulties and challenges.
Objectives: Combining this information with the crop, irrigation and agricultural practices adopted by farmers and weather information will enable following the process of salinisation or desalinisation and identifying the impact of the different farming practices. This will help identifying best practices and lessons learnt and improving salinity management.
Stakeholders: Farmers, researchers, agronomists, local irrigation districts, local farmers’ associations and advisory services.

Leaching requirements for salinity prevention

Description: OGs in different European environments identify and test leaching requirements in irrigation practices. Leaching requirements are specific to soil types and climatic regions, cultivated species, and quality of the available water. The activity will develop and test leaching schemes for different soils, cropping systems, and water quality combinations, also considering the potential for use of saline waters.
Objectives: Successful schemes for specific soil, crop and water conditions. Development of water quality guidelines and leaching requirements for specific regions; guidelines for successful use of saline waters.
Stakeholders: Researchers, farmers, advisory services

[2] GMES: Global Monitoring for Environment and Security, now Copernicus https://www.copernicus.eu/en

Innovation needs to improve strategies to counter salinisation threatened by climate change

In the margins of Rio Sado (Portugal), soils are affected by salinity because of the sea tides. In these heavy clay soils there is no other crop that can grow and yield like rice.
The strategies followed to mitigate salinity include avoiding pumping water from the river during high tide and making trenches inside the paddy to irrigate with greater homogeneity. During crop development the farmers use only fresh and good quality water (from a dam) to avoid increase of salinity levels. However, the problem may increase due to climate change and these strategies may be not be enough in the long term. Innovation is needed to develop more salt-tolerant varieties and knowledge on soil microorganisms that can contribute to mitigate the negative effects of salinity on the crop, in order to enable long-term sustainable rice production in the area.

Agronomic profiling of salt tolerance and product quality traits in crops exposed to soil salinisation

Description: In a specific environment, encompassing a set of soil conditions within a same climate and social environment, a selection of species and cultivars suited to saline environments will be tested in small and short-time experiments, allowing a context-specific analysis of salinisation progression vs environmental indicators and quality parameters. The activity will also include screening for potential labelling and branding the produce. Training of farmers in adapted farming systems under salinisation conditions will also be considered, and demonstrations on different crop varieties (technical aspects and market opportunities).
Objectives: Increased farmers' returns through new market opportunities for different crop varieties.
Farmers trained in farming systems under salinisation processes. Rural cohesion in the territories. Increased knowledge on ecosystem services, aimed at agro-ecological landscape preservation.
Stakeholders: Farmers, researchers, advisors, agribusiness, NGO associations /consumers.

Using biofertilisers to help crops to cope with salinity

Description: The practice of using plant growth promoting bacteria (PGP) to reduce the effects of salt stress in plants is not yet widespread, although there are already some commercially available biofertilisers. Operational Groups will test the agronomic results and economic feasibility of the adoption of PGP in specific environmental and agronomic conditions.
Objectives: The use of biofertilisers is expected to increase crop yield through their ability to fix nitrogen; increase the availability of other nutrients (such as phosphorus and iron) through the production of phytohormones (namely auxins); and improve crop tolerance to biotic and abiotic stresses (including salt tolerance). Biofertilization also reduces the amount of chemical fertilisers needed for crop production, increase the biological activity of beneficial microorganisms in the soil, and improve several soil properties. In general, there is an improvement in soil health and quality.
Stakeholders: Farmers; agronomists; agri-business.

b. Research needs from practice

The FG focused on several research topics of practical interest, where gaps could be filled through launching or supporting research and technology projects. The proposals were grouped in four themes, related to i) water and ii) crop and soil management strategies, iii) modelling and mapping/monitoring, and iv) local and new varieties. Some of the most relevant research needs are highlighted below. Further needs identified in the FG and the details are reported in Annex D.

Water management strategies

1) **Need for research:** Water harvesting.
Rationale: Secondary soil salinisation is driven by improper use of irrigation and ignoring the extra water required for leaching salts. For centuries, water collection for irrigation and leaching has been common practice in arid lands, which allowed excellent agriculture even where annual rainfall was as low as 80 mm per year. However, because of the large amount of work needed the traditional water harvesting practices have almost been abandoned in recent years, and replaced by remote water resources or intensive exploitation of ground water, including non-renewable waters stored in geological layers. New affordable techniques are needed to collect, store and manage natural water resources such as rainfall and groundwater, avoiding loss and contamination with saline waters.

2) **Need for research:** Smart flushing – "leaching".
Rationale: The amount of water for leaching should be reduced and its effectiveness improved before, during, and after the crop season (irrigation timing). This is only possible by developing site-specific tools based on the integration of models with crop and soil sensors, using available weather forecasts. Besides guidelines, specific kits to decide how much and when to apply are needed as well. These instruments should include ICT tools and software applications running on farmers' computers.

Crop and soil management strategies

3) **Need for research:** Soil microbiology in salt-affected soils.
Rationale: Microbiology might be an important component for improving soil quality and the delivery of ecosystem services. It can also contribute to improve the tolerance of plants to salinity. None of these issues have been studied in depth so far, and it is not known which microorganisms may be important in one case or another. Studies need to be made on microbiota functions under different saline and environmental conditions and agronomic practices.

4) **Need for research:** Effect of soil salinisation and management practices on ecosystem services.
Rationale: When a healthy soil is affected by salinisation, its quality declines. This in turn may affect the delivery of the ecosystem services, but not much is known about the influence of salinisation on soil functions. Moreover, the decline may happen on-site, where the secondary salinisation is arising, and off-site, beyond that area, for instance, by soil leaching and deposition of salts on a downstream wetland. Therefore, indicators should be developed to measure how management practices adopted to counter salinisation may have negative effects on ecosystem services of soil, aquifer, wetlands, etc.

Modelling and mapping/monitoring

5) **Need for research:** Improving the use and integration of satellite data for soil salinity mapping.
Rationale: Detailed spatial data are needed to identify salt-affected soils. The available remote sensing technologies are not yet mature for soil salinity mapping. Satellite images of higher spatial and spectral resolution are needed to map soil salinity at farm level, as well as reference spectral data for calibration and validation. Other issues are: identification of the best spectral bands, band combinations and ratios, and spectral indices to map salinity; development of spectral libraries for soil salinity identification and calibration of remote sensing data; and development of methods for automatic processing and extracting information from multi-year satellite data, and validation/calibration of remote sensing data with ground truth soil salinity data (resolve the scale gap). For achieving new technologies in mapping soil salinisation should be integrated by using satellite images and data from drones, robotics, proximal sensors, and data upload systems.

6) **Need for research:** Determination of model parameters.

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Rationale: The determination of model parameters is a prerequisite for simulation tools to become operational innovations for soil, crop and water management in lands at risk of salinisation. It is essential that these parameters are determined in real cropping systems. There is a need for specific field research that collect data from environments subject to salinity. It is strongly advisable to create a series of long-term experiments representative of different European conditions from which to obtain the crop and soil data necessary to determine the modelling parameters. The general lack of these values represents the real obstacle to speeding up the use of models in practice. Only consistent determination of model parameters will allow reliable modelling of the salinisation risk under different climate change and agronomic options.

Local and new varieties

7) Need for research: Introducing tolerance traits in high-yielding lines.
Rationale: Genetics can help to make salt tolerant varieties and rootstocks available to farmers by introducing tolerance traits in high-yielding lines. The research programme has multiple aspects, such as getting tolerance traits from wild relatives or local varieties, using advanced genetic phenotyping techniques to understand the physiological and molecular basis of tolerance, and profiling quality traits of crops in salinity conditions. A long-term breeding programme should start matching the optimal growth conditions (agronomic and environmental conditions) with salt tolerant lines and cultivars.

8) Need for research: Crop quality and salinity.
Rationale: The scarce information on quality improvements of salt-affected foods highlights the need to define environmental and genetic factors that interact with salt stress response and might improve the nutritional profile of commercial products. The nutritional content of crops grown under saline conditions should be profiled better, with a view to define the commercial return for quality trait improvements that may compensate for yield loss in saline environments. Also there is a need to have more information on the accumulation of sodium in commercial products, which generates health concerns.

c. Other recommendations

Management of protected areas

- In European protected areas, the Focus Group suggests matching limitations of salt-affected soils with agronomic practices. Farmers would benefit from a list of banned/permitted/recommended operations during and outside the growing season for the possible range of crops that are grown in their areas, in order to improve and avoid harming the protected area.

Market opportunities and awareness raising

- It is advisable to promote awareness campaigns for the negative consequences of soil salinisation. This could raise awareness among farmers and stakeholders along the value chain of agricultural products, on the off-site effects of soil salinisation on ecosystems, and about the importance of ecosystem services to sustain agricultural production and human well-being. Rural associations, such as the French initiative centres to promote agriculture and rural systems (CIVAM in French), which connect farmers, rural population and civil society to encourage a more sustainable agriculture, are fit-for-purpose platforms.
- Consumers should be educated on quality aspects of products derived from crops grown in saline conditions; it might be envisaged to develop a salinity label that intrinsically defines a higher quality product (e.g. *SalQual*™). The lack of consumer awareness on the quality and benefits of these products impedes the exploitation of their quality added values related to salinity. Differentiation of these products in terms of higher nutritional quality associated with health benefits could also have market opportunities.

Civil science: enrolling farmers in monitoring

- The risk of a soil to become saline is masked in the early stages because salts gradually build up. During the very early stages there are no obvious salinity symptoms but only a gradually decreasing fertility. So, salinity deserves more attention from society, and climate scenarios should indicate the level of risks of soil salinisation.
- New policy instruments for encouraging soil salinity mapping and monitoring should be developed, such as policies/programmes on salinity surveillance based upon widespread use of salinity sensors and smart/wireless communication systems for salinity mapping at farm level (for farmers) or at regional level (for local/regional agricultural departments, irrigation districts, advisory services, etc.). A proposed soil mission under Horizon Europe should be used to advance the monitoring of salinity in soils.
- The Focus Group recommends the incorporation of soil salinity and irrigation water testing in routine (regular) agronomic soil testing in areas of emerging saline concern (e.g., coastal North Sea areas) where salinity testing has not been common before.

Improving advisory services

- Among the experts of the FG there is a general consensus that soil reclamation strategies should be implemented only through well trained advisory services, because of the complexity and variability of factors that cause salinity and sodicity problems. Each situation must be evaluated separately, because of differences in its economic, political, climatic, environmental and resource conditions.
- In order to let farmers become familiar with the available information on proper management of lands at risk of soil salinisation, specific indoor and outdoor training sessions about understanding salt and sodium in soils, irrigation water and shallow groundwater should be organised to explain soil salinity terms, effects, problems, and possible solutions in an easy-to-understand format.

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Annex B. List of mini-papers

Framing key issues led to seven overriding themes related to soil salinisation, which were developed in mini-papers:

1. Measuring, mapping and monitoring of soil salinity
2. Crop productivity under saline conditions
3. Ecosystem services and salinisation
4. Prevention, mitigation and adaptation strategies for soil salinisation at farm level
5. Decision Support Systems for efficient irrigation on high salinity fields
6. Quality aspects of plant varieties in response to soil/water salinity under specific climate conditions
7. Examples of salt tolerant crops as an alternative for farmers

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Annex C. Ideas for Operational Groups

Theme: monitoring and mapping soil salinity

TITLE	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/IMPACT
Pre- and post-irrigation mapping of soil salinity with MGES techniques and relationship with irrigation/farming practices performed by farmers (Improvement ofsalinity management)	- Surveillance of soil salinity from just pre-irrigation (t0- salinity maps) and X years (Xy) after irrigation started (repeat maps at tXy) and explain the changes with the field management performed by the farmers and with meteorological data. - The idea can be extrapolated to areas having pre- and post-irrigation salinity maps, or just post-irrigation salinity maps at 2 times separated by some years (tx-ty years)	Researchers, agronomists, farmers, irrigation districts, local farmers associations and advisory services.	Irrigation/farming practices responsible for salinisation and desalinisation; impact of management practices on soil salinity; identification of best practices and lessons learnt; improve salinity management; establishment of surveillance programs of soil salinity
Combined SMART irrigation and EC management at field scale	Combined use of both soil moisture and soil salinity proximal sensors to simultaneously manage root zone soil water and soil salinity optimally, testing different EC methods under smart agricultural solutions at field scale	Growers, researchers, advisors, developers of smart agriculture technologies	Development of combinations of technology and management to simultaneously optimally manage irrigation and salinity
Farmers monitor salinity	Monitoring of salinity levels in a network of farms. Setting a network of monitoring farms together with water authorities. A form of Citizens science - Farmer's science.	Farmers, researcher, advisor	Data gathered can be used as foundation for an action plan to address salinity issues punctually according to local characteristics.

Theme: prevention, mitigation and adaptation strategies to cope with soil salinisation

TITLE	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/IMPACT
Leaching requirements for salinity prevention	Test leaching schemes in different EU pedoclimatic regions	Researchers, farmers, advisory companies	Successful schemes for different pedoclimatic regions.
Phytoremediation of sodic soils	Testing different crops, eventually including microbial inoculation for enhanced respiration rate and different leaching schemes for sodium removal in different pedoclimatic regions.	Researchers, farmers, advisory companies	Successful schemes for phytoremediation in different pedoclimatic regions.

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Microbial use for plant tolerance in salt-affected soils	*In situ* test microbes or microbial resources already known to be helpful in improving plant tolerance to salinity	Researchers, farmers, Phyto-sanity companies	Microbial products that could be used to improve plants tolerance to salinisation.
Adaptation of crops and farming practices in a coastal area with salinity problems derived from sea water intrusion	Selection of plants adapted/resistant to salinity. The goal is to have a list of specific plants and practices for farmers in a specific area, to increase yield	Farmers; Water board; Advisory services; agronomists	Marketing results to promote the new product
Use biofertilizers to help crops to cope with salinity	Using PGP bacteria (plant growth products) to reduce the effects of salt stress in plants	Farmers; agronomists; companies that sell fertilizers	Increased yield, improvement of soil properties, N fixation, improvement of soil health and quality

Theme: management of ecosystem services in lands at risk of soil salinisation

TITLE	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/IMPACT
Optimal management for sustaining current salinity status	In protected natural areas the maintenance of biodiversity is the most important objective. There is a wide range of agronomy versus grazing possibilities in such areas. Several combinations of land uses should be tested for maintaining/enhancing biodiversity of protected animals/plants.	Farmers Nature conservationists Local, national, EU administration	Optimal location-specific land management can contribute to the long-term goals of agro-environmental objectives.
Environmental sustainability assessment of innovative agricultural practices to combat soil salinisation in nature protected areas	Innovative techniques to control soil salinity are many times promoted as being more environmentally friendly. This cannot be claimed if the ecological consequences of the salts leached down to the aquifer and/or to the surrounding natural area are not assessed.	Farmers, Management body of the natural park or local authority, Experts in agriculture, Experts in environment	Innovative techniques that truly aim at being more environmentally sustainable practices to fight soil salinisation
Marketing plan for agricultural products grown in salinised soils with sustainable on-	Consumers increasingly prioritise products respectful with the environment. This market configuration encourages business models that promote sustainable agri-	Farmers, Consumers, Local agribusinesses, Supermarkets Society, Socio-economists, Experts	Rising farmers' profit and boosting the economy of the producing area; It contributes to preserve the natural environment and nature-agriculture mosaics

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site and off-site practices	food products coming from unique areas (salinised soils) and communicate the innovation to society/consumers.	in marketing. Local, regional administrations	

Theme: Decision Support Systems to support farmers in managing irrigation in areas at risk of soil salinisation

TITLE	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/IMPACT
Innovative water management irrigation in high salinity soils with shallow water table	DSS for irrigated fields with high soil salinity with real time monitoring of crucial parameters and supporting farmers with advisory services	Researchers, Agronomists, Farmers, Irrigation Land Reclamation Organizations, Department of Agriculture/Soils (e.g. Directorate of Agriculture at Regional Level), …	Irrigation/farming practices responsible for higher crop yield in a sustainable way; identification of best practices for farmers; improve salinity management; establishment of surveillance programs of soil salinity in irrigated agriculture

Theme: opportunities for salt tolerant crops

TITLE	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/IMPACT
Agronomic profiling of salt tolerance and product quality traits in European crops exposed to soil salinisation. Show cases for the introduction of new tolerant crop varieties and/or varieties with better quality traits	- Selection of salt tolerant varieties. - Small- and short-time experiments. - Analysis quality of crops and environmental indicators. - Training of farmers to adapted farming systems. - Demonstration of different crop varieties (showing how well they behave/produce to farmers)	Farmers, researchers, Advisors, Agrobusiness, Local Institutions (municipalities, regional departments), NGO associations/consumers	New market opportunities. Screening for potentially labelling and branding foods. Skills and knowledge transfer to farmers. Rural cohesion in the territories. Increased yield. Increased knowledge on ecosystem services. Agroecological landscape preservation.
Diversifying and promoting cropping systems in territories where crop diversification should be increased	- Introducing new crops in areas with monoculture /crop rotation - Measuring ecosystem services - Promoting local/regional distribution of the new crops - Develop a label	Supermarkets, consumers, supply chain, farmers, society, participatory approach, advisors, researchers	Creating alternatives for a territory where agronomic issues due to soil salinity are overcome with monoculture and monosuccession, thus reducing the bulk of agro-ecosystem services

Annex D. Research needs from practice

Water management strategies

Need for research	Rationale
Water harvesting	Natural water resources, such as rainfall, should be better managed, collecting and storing them and avoiding any possible loss, starting from the "green water", which is the infiltrated rainfall stored into the soil profile. We need to minimise the use of other water resources (waters stored in geological layers) in times of shortage/higher needs
Smart flushing – "leaching"	There is the need to improve leaching guidelines before/after/during the crop and develop site specific tools based on models/sensors/weather forecast. More than guidelines, go to concrete tools to measure how much to apply. Need for developing specific tools based on models, sensors, weather forecasts, climate and soil data in models. Field specific methods, site specific (in that farm, what is happening)
Adaptive drainage	Taylor-made strategies for each site (smart drainage) means to develop machinery and models for setting the drainage system according to soil info. Tailoring the drainage theory to the specific farm, soil types, modelling could be useful (smart drainage). Find new machinery to allocate the drainage system into the soil Models to make the calculations. What would be the costs for the farmer → model this too (depends on the output of the models)
Mixing irrigation water, including closing water cycles, to make an efficient use of water and energy and improve management of fresh water.	Blending fresh water with water of low quality to have appropriate water increases water resource availability, permits farmers to use poor quality water and enables farmers to have the right EC of irrigation water for each phase of the crop. It enables the farmers to have the right EC for each stage of the crop (depending on the crop phenological stage), you can increase salinity without using extra fertilisers. Synchronize the salt concentration in soils to sensitivity of each phenological stage.
Smart irrigation, supplemental irrigation of extensive crops	The problem to find a new irrigation system is not for the horticultural crops but for the open field crops. We need new irrigation systems for field crops, major crops, extensive crops, such as micro-irrigation for field crops. The aim is providing the right amount of water and maintain the right amount of salinity in the field.

Crop and soil management strategies

Need for research	Rationale
Soil microbiology in salt affected soils	Microbiome or belowground biodiversity might be an important resource for improving soil quality and the delivery of ecosystem services. It can also contribute to improve plants' resistance to salinity. None of these issues are well studied, and thus, it is not known which microorganisms may be important in one case or another. Studies need to be made on microbiota functions under different naturally-salt affected soil as model system.
Effect of salinisationon weed management	Weeds that are not resistant to salinity may be controlled in the case of crops which are resistant to salinity. In order to know whether it is possible, it is needed to study whether saline conditions can prevent or promote weed invasion. Other research questions would be whether foliar application of salts can be used to suppress weeds or whether weeds can be controlled by varying soil salinity

	through water management practices.
Effect of soil salinisation and management practice to counter it on ecosystem services.	Study the relation/influence of salinisation on soil properties and functions. Develop indicators to measure how management practices may affect off-site soil and water salinity as well as ecosystem services at a large scale. Develop soil management strategies to counter these negative effects on ESs (soil, aquifer, wetlands…). Create approaches to assess soil salinisation impact off-site, environmental impact and ESs. Quantify off-site and on-site effects on salinisation management.
Tailor-made strategies for salt tolerant varieties.	Improve knowledge of the agronomic management of new salt tolerant varieties so as to optimize crop production.
Change the land use in extreme cases	Gain knowledge on the economic value of the loss of ecosystem services as a tool to raise awareness. Develop methodologies (sensors, remote sensing, GIS…) to identify sustainable and non-profit agriculture areas that should go through a land-use change. Define criteria for extreme cases so as to prioritize the plots that should go through a land-use change. Develop payment for ESs schemes to compensate for economic losses

Modelling and mapping/monitoring

Need for research	**Rationale**
Need of accurate inventory of salt-affected areas (extent, severity) at local, regional, national, and EU levels	Inventory is required for field management, crops and irrigation water planning, identifying recharge/discharge of saline areas, prioritising areas for changing land-use, providing information for development of policies. The detailed data collection procedures often result in hidden databases. These precious data, particularly when collected by community funding, should provide spatial information for better mapping.
Standardisation of analytical methods	In order to provide balanced decisions at regional, national and EU level it is necessary to use comparable methods. More in general, there is a need for a concerted approach at national and European level for providing guidelines on harmonised methods for measuring, mapping and monitoring soil salinity.
Define criteria to identify areas at risk of soil salinisation. Develop user friendly risk maps.	Due to the variability of cultivation practices in salt-affected areas, what can be considered as sustainable can vary. It is necessary to provide criteria for widespread practices such as: Secondary salinisation in irrigated horticulture, including orange and olive trees, etc., Rice cultivation, including in coastal areas, Dryland agriculture on sodic areas. The spatial assessment should be provided with reliable and easy-to-understand maps.
Developing new cheap and reliable proximal sensors	There is a need for more developments in local, data-based management of salt-affected soils. At present the sensors are expensive which is an obstacle for their use. EU should support the development of cheap but reliable sensors for salinity measurement.
Determination of model parameters	The determination of model parameters is a prerequisite for the simulating tools to become operational innovations in the agricultural sector. It is essential that these determinations are carried out in real cropping systems. There is a need for specific field research that collects data from environments subject to salinity. Even better would be to create a series of Long-Term Experiments (LTEs) in a double transept from North to South Europe and from East to West from which to obtain the crop and soil data necessary to formalize the modelling parameters. Since they are not generally available, these values represent the real limit that currently prevents the speeding up of the use of models.
EU network of salt-affected soils	There is the need of an EU network of salt-affected soils for sharing data and knowledge (e.g., development of monitoring grids and data transfer tools to inventory information available in the existing farmer networks) and for

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	monitoring soil salinity, particularly in irrigated areas.
Improving the use and integration of satellite data	To identify salt-affected soils we need detailed spatial data. The available technologies are not fully developed yet for soil salinity mapping. We need satellite images of higher spatial and spectral resolution to map soil salinity at farm level and overcome the lack of reference spectral data for soil salinity identification/mapping. Other issues are: identification of the best spectral single bands, band combination/ratios, and spectral indices to map salinity, development of spectral libraries for soil salinity identification and for calibration of remote sensing data, development of methods for automatic processing and extracting information from multi-year satellite data (through machine learning techniques, etc.), and for validation/calibration of remote sensing data with ground truth soil salinity data (resolve the scale gap). Integrating new technologies in mapping soil salinisation such as satellite images and data from drones, robotics, novel sensors and data upload systems.
Integration of models	New modelling approaches combining multiple sources data (RS, terrain attributes derived from DEM, geological maps, land use, meteorological data, irrigation water quality, groundwater level and quality, etc.) for mapping soil salinisation and assessing salinity risk at regional levels. Develop models to scale soil salinity data from local to regional levels. Modelling salinisation risk in critical areas considering different climate change scenarios.
Integration of models and indicators	Develop mathematical models and regionalised indicators that generalise the learnings drawn from: - potential innovation 1: models and indicators to assess impacts of soil salinity on soil quality aspects apart from yield decline such as synergetic effects on the soil microbiome and soil erosion - potential innovation 2: models and indicators to assess the transport of salts out of soils and the transference to aquifers and other water bodies - potential innovation 3: models and indicators to assess the consequences of high salt concentrations on natural environments and taxa.

Local and new varieties

Need for research	Rationale
Introducing tolerance traits in high yielding lines	Salinity is increasing in farmland. Farmers need salt tolerant varieties and rootstocks: How to introduce tolerance traits in high yielding lines? - Select the most tolerant commercial varieties and start from those to improve them. - Get tolerance traits from wild relatives and/or local varieties. - Advanced technologies: CIS genetics? - Understanding the physiological and molecular basis of tolerance - Profiling quality traits vs. salinity **Expected results:** - Find the optimal growth conditions (agronomic and environmental conditions) - Mapping salt tolerant lines vs. cultivars/conditions - The results of the two previous points can be the starting point for long term breeding programs. **Time frame:** - Short term (2-3 years): identification of most tolerant varieties among existing commercial/local lines. - Medium term (2-3 years): Getting more insights into the mechanisms of tolerance

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	- Long term (10-15 years): Specific breeding programmes and development of salt tolerant varieties.
Crop and salinity stress	There is a limited knowledge on the physiological and molecular basis of salinity tolerance and agronomic implications. We need elucidating the physiological and molecular basis of crop tolerance to salinity and functionalize this knowledge to optimize agronomic management of saline agricultural systems
Crop quality and salinity	The scarce information on quality improvements of salinised foods addresses the need to define environmental and genetic factors that may interact with salt stress response and affect the nutritional profile of commercial products. In particular: 1. Profiling the nutritional content of crops grown under saline conditions 2. Defining a threshold of commercial return for quality traits improvements vs. yield loss in saline environments 3. Profiling the biosynthesis of biofunctional molecules that may have beneficial health implications
Crop quality and salinity	There is ascarce information on the accumulation of sodium in commercial products, which generates health concern. Improving knowledge on dietary Na+ uptake in emerging agricultural systems under climate change can also develop market products that do not need seasoning.

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 practicecloser 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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