SolACE

Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use

Proceedings of the Final SolACE Stakeholder Event

La Tricoterie, Brussels, Belgium

12 April, 2022

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These proceedings are available for download at https://zenodo.org/record/6463198.

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Cover pictures: Philippe Hinsinger, INRAE, 2022

For more information about SolACE visit the SolACE website at www.solace-eu.net and our Twitter account @SolACE_EU_NET

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The Final SolACE Stakeholder Event

Planning for the Final Stakeholder Event of SolACE - *Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use*[1] - began in April 2021 and it became clear early-on that to cover the full breadth of research and topics within the project, a series of specialised events with a more narrow scope would benefit any final discussions and activities. Based on this outlook, we planned for a series of virtual stakeholder workshops[2] covering topics across all work packages in the SolACE project to occur in early 2022, which fed into the final in-person event on April 12 2022 in Brussels, Belgium.[3] The event was organised by the University of Newcastle and the European Conservation Agriculture Federation (ECAF). It took place at *La Tricoterie* prior to the final SolACE project meeting in Louvain-la-Neuve, Belgium. The aim of the event was to elicit stakeholder feedback on policy implications of SolACE outcomes and discuss potential future research.

After an introduction by SolACE project coordinator Philippe Hinsinger, there were three main sessions:

- Key messages from SolACE: Improving water and nutrient use efficiency in agroecosystems – using a talk-show-style, the session participants highlighted and discussed the key messages coming from the series of stakeholder workshops, which parallel the key outcomes of the SolACE project.
- Feedback and experiences from multi-actor projects – a round table of experts discussed the pros and cons of the Multi-actor approach employed in many Horizon 2020 and Horizon Europe research project, as well as in other contexts.
- SolACE and beyond: what needs to be achieved from now on – in small groups, participants addressed key themes related to the SolACE project, discussing SolACE outcomes, where to go next and outstanding questions.

These proceedings include a summary of each session as well as the concrete feedback that came from it.

The Final SolACE Stakeholder Event was the fourth in a series. The first SolACE Stakeholder event took place in 2017 in Montpellier, France (Hinsinger & Willer 2018), the second in 2018 in Foggia, Italy (Pecchioni et al., 2018), and the third was held in 2019 in Dundee, Scotland (Kemper et al. 2020).

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[1] More information about SolACE is available on www.solace-eu.net.

[2] Information on the series of SolACE stakeholder workshops is available at https://conference.solace-eu.net/pre-conferences.html

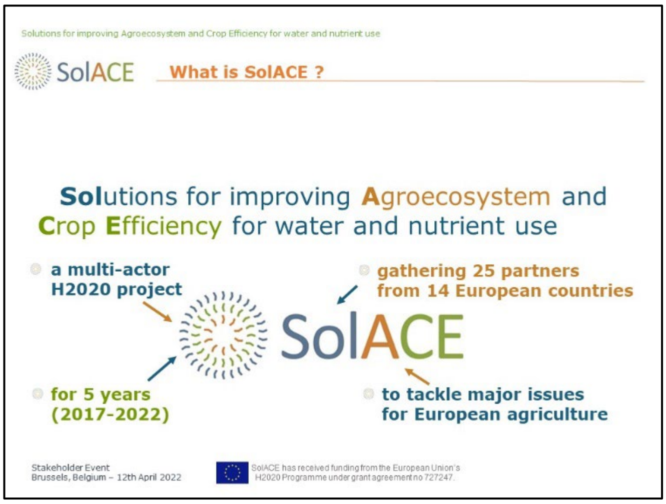
[3] Information on the SolACE stakeholder events is available at https://conference.solace-eu.net/

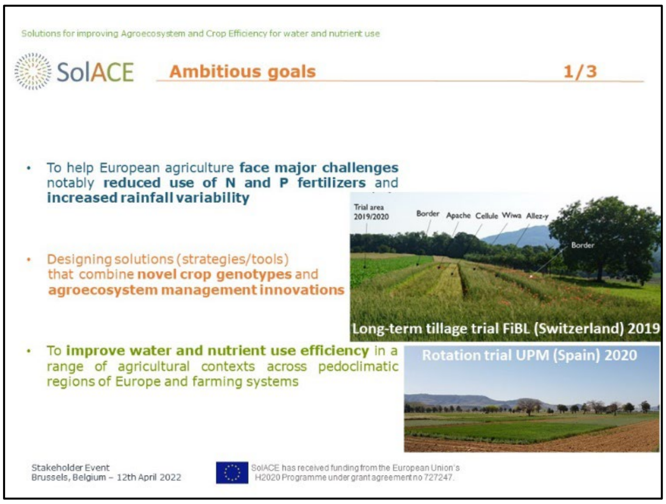
Programme

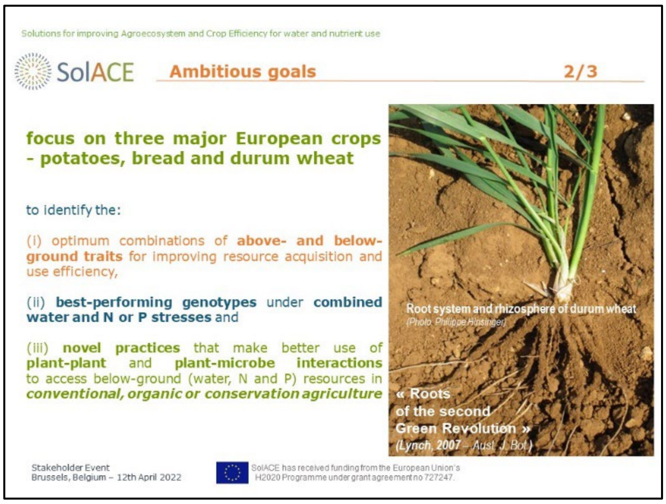
13:00	**Welcome and Refreshments**
13:20	**Introduction** *Philippe Hinsinger (INRAE), SolACE Project Coordinator*
13:30	**Key messages from SolACE: Improving water and nutrient use efficiency in agroecosystems** *Facilitator: Laura Kemper (Research Institute of Organic Agriculture, FiBL)* *Participants:* › *Kristian Thorup-Kristensen (University of Copenhagen, KU)* › *Xavier Draye (Université Catholique de Louvain, UCLouvain)* › *Christophe Salon (French National Research Institute for Agriculture, Food and Environment, INRAE)* › *Julia Cooper (Newcastle University, UNEW)* › *Tim George (James Hutton Institute, JHI)*
14:10	**Feedback and experiences from multi-actor projects** *Facilitator: Julia Cooper (Newcastle University, UNEW)* › *Sergui Didicescu (EIP-Agri Brussels) – EIP-Agri Focus Groups* › *Inès Verleden (INAGRO) – RENURE EIP-Agri Operational Group* › *Marleen Gysen (Borenbond) – LIAISON H2020 Project* › *Eddy Montignies (BRIOAA) – BRIOAA Living Lab* › *Geert-Jan van der Burgt (LBI) – LBI experience*
14:45	**Break**
15:00	**SolACE and beyond: what needs to be achieved from now on** *Facilitators:* › *Kristian Thorup-Kristensen (University of Copenhagen, KU)* › *Xavier Draye (Université Catholique de Louvain, UCLouvain)* › *Christophe Salon (French National Research Institute for Agriculture, Food and Environment, INRAE)* › *Julia Cooper (Newcastle University, UNEW)* › *Tim George (James Hutton Institute, JHI)*
16:15	**Refreshments**

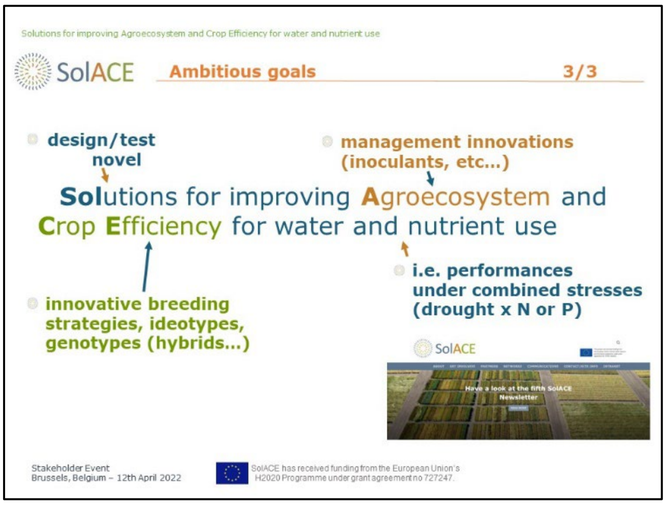
Introduction to the Stakeholder Event

SolACE project coordinator, Philippe Hinsinger (French National Research Institute for Agriculture, Food and Environment, INRAE), provided an overview of the SolACE project, its goals, novel approaches, partners, and major achievements as well as the programme for the event. He also explained the klaxoon board, which was used to collect questions from participants as well as feedback in session three. The slides are available below.








Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use
SolACE
Ambitious goals
3/3
design/test novel
management innovations (inoculants, etc...)
Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use
innovative breeding strategies, ideotypes, genotypes (hybrids...)
i.e. performances under combined stresses (drought x N or P)
SolACE
Stakeholder Event
Brussels, Belgium – 12th April 2022
SolACE has received funding from the European Union's H2020 Programme under grant agreement no 727247.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Novel Approaches
1/3
a double interactive innovation loop,
✓ based on agroecosystem management, via crop genotype mixtures, legume-based crop rotations or cover crops, microbial inoculants, as well as improved decision support systems
✓ and breeding strategies, including hybrids or products from genomic selection and participatory evolutionary breeding schemes
Potato inoculation trials by Agroscope in Switzerland (Photo: Brice Dupuis)
Durum wheat trials by CREA in Southern Italy (Photo: Philippe Hinsinger)
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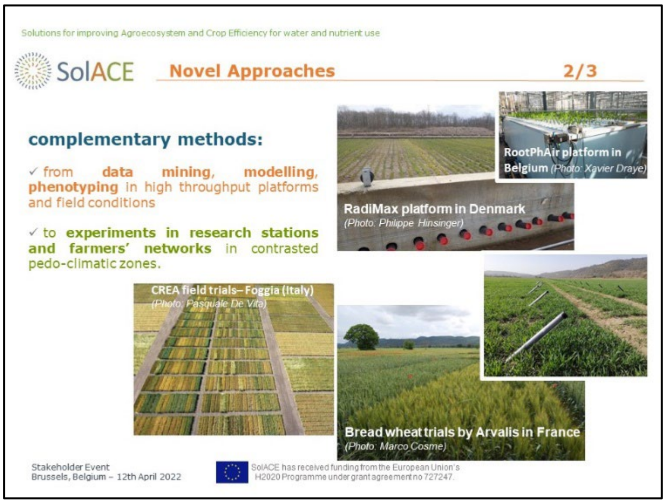
Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use
SolACE
Novel Approaches
2/3
complementary methods:
✓ from data mining, modelling, phenotyping in high throughput platforms and field conditions
✓ to experiments in research stations and farmers' networks in contrasted pedo-climatic zones.
RootPhAir platform in Belgium (Photo: Xavier Draye)
RadiMax platform in Denmark (Photo: Philippe Hinsinger)
CREA field trials– Foggia (Italy) (Photo: Pasquale De Vita)
Bread wheat trials by Arvalis in France (Photo: Marco Cosme)
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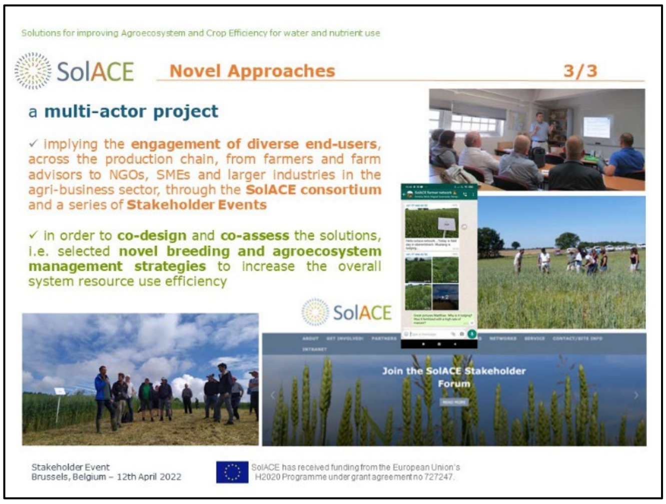
Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use
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Novel Approaches
3/3
a multi-actor project
✓ implying the engagement of diverse end-users, across the production chain, from farmers and farm advisors to NGOs, SMEs and larger industries in the agri-business sector, through the SolACE consortium and a series of Stakeholder Events
✓ in order to co-design and co-assess the solutions, i.e. selected novel breeding and agroecosystem management strategies to increase the overall system resource use efficiency
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Join the SolACE Stakeholder Forum
Stakeholder Event
Brussels, Belgium – 12th April 2022
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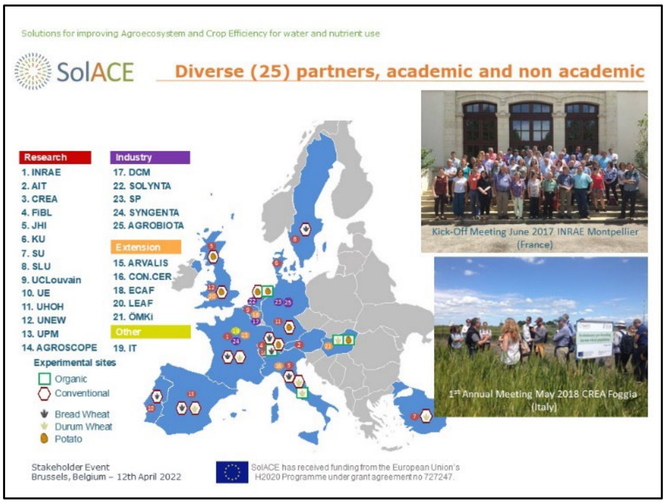
Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use
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Diverse (25) partners, academic and non academic
Research
1. INRAE
2. AIT
3. CREA
4. FIBL
5. JHI
6. KU
7. SU
8. SLU
9. UCLouvain
10. UE
11. UHOH
12. UNEW
13. UPM
14. AGROSCOPE
Industry
17. DCM
22. SOLYNTA
23. SP
24. SYNGENTA
25. AGROBIOTA
Extension
15. ARVALIS
16. CON.CER
18. ECAF
20. LEAF
21. ÖMKi
Other
19. IT
Experimental sites
Organic
Conventional
Bread Wheat
Durum Wheat
Potato
Kick-Off Meeting June 2017 INRAE Montpellier (France)
1st Annual Meeting May 2018 CREA Foggia (Italy)
Stakeholder Event
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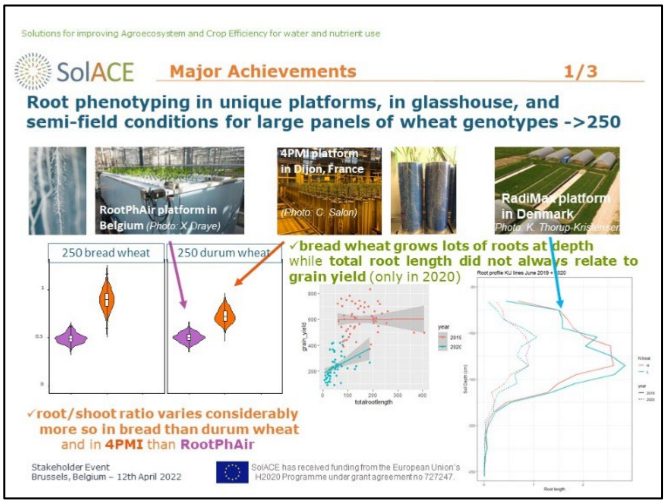
Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use
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Major Achievements
1/3
Root phenotyping in unique platforms, in glasshouse, and semi-field conditions for large panels of wheat genotypes ->250
RootPhAir platform in Belgium (Photo: X Draye)
4PMI platform in Dijon, France (Photo: C. Salon)
RadiMax platform in Denmark Photo: K. Thorup-Kristensen
250 bread wheat
250 durum wheat
✓bread wheat grows lots of roots at depth while total root length did not always relate to grain yield (only in 2020)
✓root/shoot ratio varies considerably more so in bread than durum wheat and in 4PMI than RootPhAir
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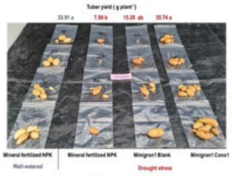
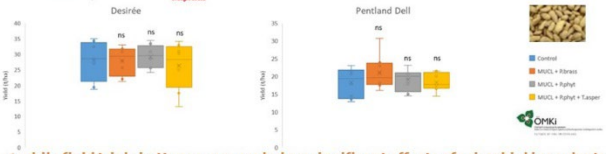
Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use

SolACE **Major Achievements** 2/3

On-farm testing microbial inoculants in potatoes



✓**pilot studies showed under drought stress, that the application of selected microbial consortia with Minigran had a significant effect on tuber yield**



✓ **while field trials in Hungary revealed no significant effects of microbial inoculants**

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SolACE **Major Achievements** 3/3

Participatory breeding for durum wheat with farmers groups / Con.Cer in Italy

✓ **farmers conducted their own selection based on their own criteria**

- Thousand Kernel Weight
- Grain Protein Content

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Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use

SolACE **Stakeholder Event** the **program for now**

- 13:30 – 14:10 Feedback / **SolACE Stakeholder Workshops** 2022
  – Chair : **Laura Kemper** (FiBL)
  - **Deep rooting** – Kristian Thorup-Kristensen (KU)
  - **Root phenotyping** – Xavier Draye (UCLouvain)
  - **Root microbiome interactions** – Christophe Salon (INRAE)
  - **Upscaling knowledge / microbial inoculants** – Julia Cooper (UNEW)
  - **Future proofing (modelling)** – Tim George (JHI)
- 14:10 – 14:50 Roundtable / **Multi-actor approach**
  – Chair : **Julia Cooper** (UNEW)
  - **EIP-Agri** – Sergui Didicescu (EIP-Agri Brussels)
  - **RENURE EIP-Agri Operational Group** – Inès Verleden (INAGRO)
  - **LIAISON H2020 Project** – Marleen Gysen (Borenbond)
  - **BRIOAA Living Lab** – Eddy Montignies (BRIOAA)
  - **LBI experience** – Geert-Jan van der Burgt (LBI)
- 15:00 – 16:00 Klaxoon Break-Out Session – **SolACE impact Road Map :**
  What to do next to face water and nutrient scarcity in European agriculture ?
- 16:00 – 16:15 Wrap-Up – **Review Road Map Conclusions**
  – Chair : **Philippe Hinsinger (INRAE)** and **Amelia Magistrali (UNEW)**
- 16:15 – 17:00 Refreshments

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Session 1: Key messages from SolACE: Improving water and nutrient use efficiency in agroecosystems

The opening session highlighted the key messages coming from a series of virtual stakeholder workshops held between January and March 2022[4] using a talk-show style approach. These highlighted major optics studied in the project, represented by key partners who facilitated and/or hosted each workshop:

- **The Roots of Agriculture: A series of Stakeholder Events on below-ground research from the SolACE project**
    - **Too Deep or Not Too Deep: Deep-rooting** – Kristian Thorup-Kristensen (University of Copenhagen, KU)
        - This event took place on January 20, 2022 and focused on root systems, both deep and shallow, as well as a virtual tour of the Radimax KU facility employed in SolACE.
    - **To Dig or Not To Dig: Root phenotyping for breeding** – Xavier Draye (Université Catholique de Louvain, UCLouvain)
        - Occurring on February 10, 2022, this event focused on root phenotyping strategies and tools, in particular values and limitations of root phenotyping in field and controlled conditions, with a virtual look at the RootPhAir facilities used in SolACE.
    - **To deal or Not to deal: Root and plant Microbiome interactions** – Christophe Salon (French National Research Institute for Agriculture, Food and Environment, INRAE)
        - This event took place on March 3, 2022 and followed the previous two by focusing on the characterisation of structural and functional traits associated with plant-microbiome-soil interactions, including a virtual tour of the 4PMI platform utilised by SolACE.
- **Upscaling Knowledge from Experiments to the Farm: How are bio-stimulants employed in controlled and un-controlled environments** – Julia Cooper (Newcastle University, UNEW)
    - This event took place on February 7, 2022 focusing on examples of evaluating microbial inoculants and biostimulants in controlled (lab, greenhouse, field trials) and un-controlled environments (commercial farms) from SolACE, other European projects and commercial experience.
- **Future Proofing in a Changing Climate: Modelling Farming Scenarios in Europe to Aid Decision-Making** – Tim George (James Hutton Institute, JHI)
    - Occurring on March 29, 2022, this event used and evaluated decision-making outputs from life cycle assessment (LCA) and Decision Support System for Agrotechnology Transfer (DSSAT), as well as crop modelling from the SolACE project to consider how these tools can aid policy-making in Europe.

The session, which was facilitated by Laura Kemper (Research Institute of Organic Agriculture, FiBL) aimed to inform the audience of the work done in the project to provide a baseline for discussions in sessions two and three. The questions and answers are included below. Please note that some answers were very thoroughly prepared in advance and others include 'notes' or 'suggestions' for how the panellists might respond, which allowed for some improvisation and flexibility.

[4] More information about the workshops, as well as a recording of each, can be found here: https://conference.solace-eu.net/pre-conferences.html

Questions and answers

Clearly, the SolACE project spent a lot of time investigating roots. Why roots?

Xavier Draye: Plants grow with resources they acquire from the environment, and the main ones they rely on are: light and CO_2, which are obtained from the atmosphere using leaves, and on the other side, water and nutrients, which are acquired using roots. The acquisition of each resource is a completely different story. Light always comes from above and is strongest at noon, so plants have learned to unfold their leaves high in the canopy when they need more light and breeders have learned to rely on these simple rules to optimise plant access to light. With soil resources, they are not always available in the same layers of the soil, in the same amount and at the same time. Plants need to find ways to adjust continuously to soil resource availability. Breeders are struggling to make varieties that are good at doing this, so we're left with applying large amounts of water and nutrients to the soil. If we believe that a resilient agriculture relies on reducing such inputs, then all actors (farmers, scientists, industry, policy makers, funding agencies) need to pay as much attention to the roots as they have been to the shoots.

Is it valuable for crops to have deeper roots? And why?

Kristian Thorup-Kristensen: The value of deep roots is in principle very simple: Roots to 1 m can use resources from the top 1 m of the soil, roots growing to 1.5 m can use resources from an extra half meter of soil volume. Especially water and N tend to move deep into the soil and can be available there. Deep roots are especially needed in dry situations.

How do we achieve deeper root systems? What are the traits that can be selected for?

Kristian Thorup-Kristensen: We can achieve deep rooting by breeding, but also by crop management, crop rotation and sometimes through crop choice. We can select for deep rooting directly in breeding, but that is very demanding to do. Then we can select for deep resource use in various ways, e.g. using tracers. We look for proxy traits which are more easily measured, but which we believe are related to deep and efficient root systems. Many other traits can be of value, such as uptake efficiency (uptake kinetics), root system architecture, root hair formation, root angles and others.

Could you explain what root phenotyping is? How is this different from looking at roots in the field?

Xavier Draye: I like to describe root phenotyping as an art. The art of observing, describing and quantifying plants. So for root phenotyping we observe cells, tissues, roots, root systems, plants and sometimes field plots. We describe and quantify the shape, the architecture, the properties (are they conductive or not), the processes (do they acquire nutrients efficiently or not), the performance, the interactions (between plants, between plants and their environments and their adaptability). So ideally we would prefer to observe roots in their natural environment, as we do for stems and for leaves, as we do for flowers and fruits, but it is far from easy because we just can't remove the soil around the roots to see them. So scientists are forced to use artificial cultivation systems (in pots and hydroponics and so on) to make the observations possible. However, in artificial systems we get artificial plants so we need to be wise and cautious when we conduct root phenotyping. Fortunately the modern techniques that we have in artificial conditions give us such nice descriptions that we learn a lot, even on artificial systems. So even if acquired in artificial conditions, this new knowledge can be used to develop new varieties or innovative management, which was the topic of the SolACE project.

What are we looking for when we use these types of platforms? Are all root systems equal?

Xavier Draye: Well, phenotyping comes, as I say, it's not a scientific discipline, phenotyping comes in support of scientists and the industry. For scientists, the aim is to uncover features or behaviours that will make plants more able to grow and produce under low input conditions. Probably the objective is different for industry, where the aim may be to quickly identify plants that possess these features or to test products that support the plant in doing that. Phenotyping is able to link quickly with technology, it's more and more connected to big data and so novel and smarter ways to use it appear every day in the literature. What we learn from root phenotyping is that root systems are not similar and they are not equal. They are extremely variable in their constitution and in their performance. This diversity is an opportunity, because we learned a lot when we see big differences, but what we also learned, is that the genetics of root features are complex, that there are different ways to get to the same level of performance, as Kristian was saying, and that what is efficient to acquire water, in some circumstances, can make them at the same time inefficient to acquire other resources.

What is the benefit of having roots that communicate with microbes?

Christophe Salon: Plants interact with or host microbes to fight pathogens and to cope with nutrient limitations. Previous studies pointed out that modern plant breeding neglected an efficient use of beneficial plant-microbe interactions and also indicated the presence of genetic and physiological variation that can be exploited to enhance beneficial plant-microbiome interactions.

Crop resource efficiency examples:

- Most plants establish symbiosis with mycorrhizal fungi (to improve phosphorus and water use efficiency).
- Others like legumes also establish symbiosis with rhizobia which help, through dinitrogen fixation, to reduce fertilizers needs and participate in mitigation of climate change and environmental impacts.
- Beside symbiosis, it has been shown during the meeting that other than symbiotic partners can benefit plants during stress (work of Marion Prudent on drought stress in legumes).
- IPM can also improve the geochemical cycles for other elements than C or N. As an example, plant microbiota contribute to plant iron nutrition and are involved in the sensitivity to iron deficiency. Pyoverdine siderophores synthesized by pseudomonads have been shown to promote iron nutrition in various plant species (Arabidopsis, clover and grasses) for instance.

What kinds of root traits and other plant traits encourage this type of interaction?

Christophe Salon: Both the structures involved in these interactions, root system architecture, nodules for grain legumes, hyphae for other plants, and possibly root exudates are key for characterizing the extent of “possible” root microbiome interactions and inform yield improvement or tolerance to various stresses.

- Root morphological traits modulate access to soil zones with contrasted nutrient availabilities and we can also consider the nodules of legumes or hyphae which host the interaction.
- Among functional traits, roots are producing exudates which have a crucial role for microbial recruitment.
- Rhizodeposition and the microbial necromass can lead to long-term soil carbon storage.

How do we evaluate the benefits of root-microbiome interactions?

Christophe Salon: Challenges are to identify best predictors of awaited targets in selection. Example of structural traits and functional traits to be measured for these benefits. Difficulties in field vs controlled conditions, going back and forth. Benefit can come from yield improvement in quantity and quality (as for an example N content of seeds) and tolerance to abiotic or biotic stresses. Improving yield and protein content of legumes in cropping systems and nutritional and industrial quality of the other crops.

For that we can have proxys with measurement of aerial structural traits (seed or fruit, leaf area and plant biomass, elemental content). We can also measure the amount and biophysical characteristics of root structures, correlated with the extent of plant-microbe interactions such as nodule characterization (number, biomass, colour, specific activity): these are key for assessing performance of nitrogen nutrition for grain legumes.

For exudates it is trickier as we need to harvest them in the rhizosphere zones, analyse with metabolomics methods (without a priori) their nature and quantity and then validate them as signalling or trophic links between plants and microbiome. All of this can be done in controlled conditions but in the field it is obviously much more difficult. As an example, it is tedious to extract architectural traits other than root surface and biovolume on the longer term in both controlled conditions and field. However, once identified in controlled conditions (which is much easier), then they can be validated in field conditions and valorised through either selection of the best partners (e.g. which rhizobium for which legume and in which conditions) or the best interacting molecules (for biological inoculants or biostimulants for example).

More broadly, benefits of root-microbiome interactions will come in the longer term: from reduction of pesticides, fertilizers and associated impacts on the environment (decrease of greenhouse gas emissions, of water and soil pollution, etc.) resulting from fertilizers, increase in soil fertility, biodiversity through root-microbiome based traits.

What were some of the discussion about how to address the difficulties of evaluating microbial products in controlled conditions vs. on farm?

Julia Cooper: We talked quite a bit about the challenges with assessing microbial inoculants in the field (whether a farmer's field, or an experimental field). There was a general agreement that results from field trials are very difficult to predict because we do not really know yet what factors, especially those relating to the soil chemistry and biology, determine the efficacy of an inoculant.

How do you define biostimulants? And what was evaluated in SolACE that falls under this category?

Julia Cooper: The EU defines biostimulants as: "substances and micro-organisms which can stimulate natural processes to improve nutrient uptake, nutrient efficiency and crop quality." That's a pretty broad definition. In fact, in SolACE, and at the workshop, we were really dealing with the microorganisms part of that definition. All the participants worked with microbial inoculants which are groups of organisms selected for their ability to promote growth of a plant when added to the soil.

What about SolACE's focus on trialling microbial products. Do they work? Under what kinds of conditions did they work in SolACE?

Julia Cooper: Well … like most questions in science, the answer is "it depends…". We had some mixed results in SolACE. There were some small benefits observed in field trials, in some places. One outcome was that the soil conditions can really determine the effect/success of the inoculants. So Günter Neumann explained how they have found that soil organic carbon makes a difference – soils with lower organic carbon levels are more likely to respond positively to inoculants. Jean-Pierre Cohan showed in the ARVALIS work that when nutrient supply to the crop was limited, there were more benefits from inoculants…

When we think about modelling as a decision-making tool, what do policy stakeholders see as the key benefits and limitations?

Tim George: The main feedback from the decision makers was that modelling is used as one of a range of sources of information, but is useful because it has a forward/predictive capacity and because of its clear often visual results. With particular respect to the focus of the SolACE project, modelling highlights the need to take account of the trade-offs between farmer income and environmental stewardship. Many outputs of the modelling demonstrate interventions being beneficial to one or the other but not both. However, many of our stakeholders agreed that modelling should come with a "health warning" in that the information should be provided with a clear assessment of probability associated with the output and a list of the assumptions made and the caveats of the data. Importantly the aspects that are not considered (e.g. impact on pest and pathogens in our models) should be made very clear. This will help improve trust and avoid overemphasis on exaggerated claims.

What kind of modelling are we talking about? Can you briefly describe what was included in this event and how SolACE has been using modelling?

Tim George**:** We have taken two distinct approaches to the modelling in SolACE and we presented the output of both of these to stakeholders. These included Life-Cycle Analysis and DSSAT crop modelling, using inputs that are specific scenarios from SolACE trials, which provides information for predictions/assessment but also allows for some validation. For the LCA, data were taken from the specific field trials and used to generate information on the productivity, economic and environmental impacts of different interventions including agronomic and genotypic interventions. In contrast, DSSAT crop modelling is predictive and has applicability for modelling longer time spans (e.g. 30 years) into the future. It thus used climate predictions to model future scenarios for crop and treatment interactions.

What about trade-offs between farmer income and environmental stewardship? How do we evaluate the impact of agronomic interventions when it comes to policy, especially if some of the scenarios modelled in SolACE indicate we may need to rely on one particular intervention more in the future?

Tim George**:** One of the key findings of our workshop was that it is clear that modelling highlights the need to take account of the trade-offs between farmer income and environmental stewardship. So to an extent we are already doing it. However, it was highlighted that we need to make sure we are assessing the benefits, detriments and potential policy drivers for a range of interventions not explicitly covered in SolACE including rotations, cover crops, reduced tillage, organic production, precision agriculture and irrigation. We also have the opportunity to design specific options for particular crops, such as understanding how potato fits in with regenerative farming for instance. Overall, how these trade-off with biodiversity and greenhouse gas emissions is critical.

We have a range of scale represented here, from roots and root-microbiome interactions to in-field assessment and evaluation to modelling that considers impacts over 30 year periods. How do we combine these different disciplines and scales in how we approach crop improvement and preparing to address climate change?

Kristian Thorup-Kristensen: Yes, we need models to try to integrate across disciplines, and to cover the very large complexity caused by different soils, crops, management factors, climate and weather conditions etc.. In order to extrapolate quantitative estimates to situations not measured, or to upscale to regions or national levels. However, we need to remember that no model is better than the research going into building it. We need to continue to perform experiments, both to develop specific aspects of the models and to validate model performance under different conditions.

How do we include roots in this—especially because they are 'less visible' to farmers and breeders, how does this information get incorporated?

Kristian Thorup-Kristensen: To some extent we need to use the "tough methods" of measuring root growth or root function directly. In breeding we may then make use of genetic markers, to allow us to select on a lot of material where we do not directly measure roots. We can also further develop easier, but less precise methods for estimating root growth and function, where we can e.g. select directly on larger numbers of genotypes. One example is 13C isotope measurements, indicating drought stress in plants. I expect that we will have to work both with the demanding methods in some cases and with easier more indirect methods allowing higher numbers of measurements in others.

What does 'high throughput' mean and how do you do it?

Xavier Draye**:** High Throughput means hundreds to thousands of plants, in addition to assessment of dynamics. This can mostly be achieved with automation, imaging or dedicated sensors. But it leads to massive numbers of images and data that requires a lot of data science.

Christophe Salon: High throughput phenotyping provides the opportunity to gain automatic characterizations of various traits (structural and functional?) for large numbers of genotypes (1000s individuals with replicates) for a range of species (not only model plants or genotypes, in pure or in mixtures, at (high) resolution, dynamically and non-destructively. In controlled conditions it allows to mimic a variety of environmental scenarios (e.g. climate change).

This allows high throughput phenotyping to feed models with data for understanding, simulating plant functioning according to climatic conditions. In the end, this contributes to speed up selection of plant varieties that are more tolerant to stresses.

What is the relationship between high throughput phenotyping and modelling? What is the role of root modelling?

Xavier Draye**:** Modelling can be used in high throughput phenotyping to enrich the process through modelling.

How do we improve trust in modelled data?

Xavier Draye: Different use of models – understand, analyse and predict – but a model must be kept simple. If it is not, then it is likely that we end up with a tool with so many buttons that we can always find settings (we call them parameters) that will lead to a correct prediction (analog to overfitting in statistics) – the risk is that very few of these buttons are interpretable. A model must be useful. I, personally, use models to put together different monolithic ideas and see what they tell us if the system was following them. It is different from what Tim will talk about.

Tim George: There were 3 main messages from the workshop:

1. Need to promote model output user confidence. This could be done in a couple of ways, co-creation of models with decision makers will give them confidence in the outputs. But also by giving stakeholders examples of how the model is able to predict actual events (e.g. impacts of recent oil price spike) or through providing models with user friendly (plug and play) interfaces so users can play with the outcomes.
2. Modelling should provide a range of intervention options to allow policy to move more towards a set of advice with options to meet an aspiration rather than a prescriptive policy which leads to practitioners doing the bear minimum.
3. Ultimately models should be used to create proactive rather than reactive policy to issues such as climate change.

What role do you think modelled data has for policy decision-making? And can data be modelled with policy decisions in mind to be more effective?

Tim George: Modelling clearly has a role to play in policy maker decisions and they value it. But I will reiterate that it is only one of many sources of information, and it needs to be provided with information on caveats and accuracy. It should be performed in consultation with stakeholders and most importantly it needs to provide the information that is required on the scenarios of interest to the decision makers.

How do we build trust in experimental results and maybe separately, how do we encourage farmers to participate in on-farm experimentation?

Julia Cooper: I am not sure we want to build trust in experimental results among farmers. I hope we can encourage farmers to think critically about products and innovations and assess if they will work on their own farms. One way they can do this is to learn how to conduct very simple on-farm assessments of novel practices. So even understanding the importance of having a "control" on their farm to compare against the new practice can be really valuable. This is the type of on-farm experimentation that can benefit the farmer directly. But we have to keep in mind that scientists might have different reasons for wanting to conduct experiments on farms – they may be interested in seeing if what they are developing works across a range of environments and management scenarios. They are more interested in drawing general conclusions, while farmers will want a conclusion that is very specific to their farm. I think we sometimes are not clear on the goal of the on-farm research and do not end up satisfying either type of "experimenter"! So a lesson from SolACE I think is to be really clear at the start on why the on-farm experiments are being done, and then design them to meet those needs. Where it is primarily for the advancement of science – farmers should be compensated financially. We did this in some of our SolACE networks, but not all.

Additional questions and answers were also prepared but due to time limitations, they were not discussed at the event. They are detailed below.

Can you explain what the 'biostimulant paradox' is?

Julia Cooper: The need to have an organism that is persistent enough in the soil to make an impact on the crop, i.e. outcompete the local populations) but not SO persistent that it becomes an invasive organism that disrupts local communities.

How do we address this paradox when it comes to research?

Julia Cooper: I think this is where we need more fundamental research to understand how the products we are developing interact with local microbial populations – more long-term studies on persistence of introduced organisms and looking at not only the microbial population (species present) but also its function, to ensure that function is not affected negatively. From a practical perspective, we can study management practices that improve persistence of introduced organisms. One of our commercial contributors at our workshop suggested adding AM fungi to the previous crop in the rotation (like a cover crop) so that it gets established in the year before the commercial crop is grown. This sounds like a good idea, but I am not sure there is experimental evidence to show that this works.

Is some form of symbiosis the goal in these interactions?

Julia Cooper: The goal is to have the plant benefit from the association with the microorganism – this usually means that the microorganism benefits as well (true symbiosis) but I suppose that is not necessarily the goal! The worry is that in many cases the interaction, if it is well established, can sometimes be parasitic. This is not something that the industry really wants to acknowledge, but it is an association where the plant is giving resources (carbohydrates) to the microorganism, and sometimes that organisms can be too greedy!

Christophe Salon: For microbial inoculants, the goal is to identify the structural and functional attributes of root microbiomes that provide protective effects against the investigated abiotic and biotic stressors. This knowledge can be used towards advanced bio-inoculation products, either universal or crop-specific. I am not a specialist but I know it is a challenge for example to get seed coating with both magic microbes and molecules that trigger efficient plant-microbe interactions. This supposedly will also work on the competitivity and persistence of microbes in inoculants in the case of perfect plant-microbe interactions.

The overall aim of the SolACE project was to look at combined stresses (specifically nitrogen, phosphorus and water limitations) rather than single stresses. How is this different in research approach?

Xavier Draye: How plants perform under stress and how they react to stresses are difficult questions. Soil-related stresses are among the most complex ones because the soil is heterogeneous, is influencing root development and is influenced by root development. In addition, and unlike the atmosphere, the soil compartment works like a memory, from one day to the next one. This explains why soil and crop science is evolving slowly and rarely comes up with clear-cut outcomes. When it comes to combine different stresses, we have the additional problem that the features that provide a plant with good performances under one stress may be those that provide the same plant with smaller performances under another stress. We are faced with antagonisms and optimisation under constraints.

Are combined stresses (like low N and dry conditions) especially challenging to crops?

Kristian Thorup-Kristensen: I agree with Xavier, but would like to add, that combined stresses are often not "additive", e.g. under dry conditions less N is needed, and under low N less water is used. However more complex *interactions also occur, if some stress limit early root growth, it can make the effect of other stresses more damaging later.*

What are the roles of biostimulants in addressing these combined stresses? Is this something we've seen in the SolACE project?

Julia Cooper: We did see that in poor soils (with low organic matter) the crop benefited from added inoculants, but ONLY when there was sufficient moisture present (through irrigation). So this is a reminder that conditions need to be optimum for the microorganisms to properly function and provide resources to the crop. I suppose the current fertiliser crisis will encourage more farmers to consider using biostimulants as a substitute for commercial fertilisers; I just hope that they understand that these are very different products. Inoculants are living organisms that need the right conditions to fulfil their promise.

What about the interaction of plants and microbes—how are we seeing these interactions affect crop performance under combined stress?

Christophe Salon: Global warming, climate change and associated stresses cause a significant decline in the complexity and composition of the soil microbiome, which is dynamic, and changes depending on the surrounding environmental conditions.

Plants actively seek cooperation with specific types of microorganisms, particularly during conditions of environmental stress through synthesis and excretion of chemicals that attract different populations of bacteria or fungi. The resulting interactions are then thought to increase plant tolerance to different abiotic stresses. To date, very little is known about the role of plant–microbiome interactions in plant responses to abiotic stress combinations, particularly under the predicted increase in CO_2 levels. The use of specialized inocula targeted for different stress combinations and specific crops should be explored in more detail to increase our chances of producing climate-resilient crops.

Because stress combinations can negatively affect soil microbiomes, care should be taken to match the bacterial/fungal inoculum with the harsh conditions that the plant is facing, and feasibility studies should be conducted under field conditions in multiple locations.

What about roots and carbon? Can we make efficient root system to deposit more carbon in the soil, and in deep layers?

Kristian Thorup-Kristensen: We can certainly make root systems deposit more carbon in the soil, there is a big variation in this among species and genotypes. However, we should remember that increasing carbon deposition is to some extent contrary to working towards efficient root systems.

What about traits that involve soil carbon storage? What do we already know and what would be useful to learn?

Christophe Salon: The sequestration of carbon in soils used for agriculture and forestry has been recognized as a promising option to mitigate climate change. In this way, maximization of root biomass to the soil has been reported as a straightforward means to increase soil organic carbon stocks.

Rhizodepositions and the microbial necromass (resulting from increased microbial biomass) can lead to long-term soil carbon storage. Recent findings also suggest a prevalence of microbial biomass over diversity to control soil carbon dynamics.

What do you think about this interest in securing carbon in soil? Should that be the focus?

Julia Cooper: Storing carbon in soils is really important for many reasons. In some cases it can be sequestered for hundreds of years and actually play a role in the drawdown of carbon dioxide from the atmosphere. But the focus should not only be on the potential to mitigate climate change. Building soil carbon is really important for climate change adaptation too. Building soils that are healthy and resilient to the impacts of climate change, particularly *weather extremes, is a benefit we will realise in the future through improved water holding capacities and the ability to withstand drought. So securing carbon in soils should be a focus – for both climate change mitigation and adaptation.*

What about beyond deep rooting, what other root traits are important?

Kristian: Deep rooting is the most obvious, deeper roots = more soil volume exploited, but many others will be important. Various aspects of root architecture may be related to improved root performance. Increased root hair length and density, and branching plasticity under nutrient deficiency have both been shown to be related to phosphorus efficiency. Uptake characteristics may be important, as it has been shown e.g. for phosphorus in rice. Important to try to understand limiting factors in the root system, and address them in studies, not just select for more roots or similar traits.

What do the models say about some of the specific solutions for improving water and nutrient use in agroecosystems?

Tim George: From the SolACE modelling we have demonstrated a number of key findings. These include understanding of the impact of climate change combined with a range of fertiliser options assessing the potential combinations of water and nutrient stresses that are of major concern in various regions across Europe.

Specific to the potato modelling and LCA we have assessed a number of genotypes with known differences in above- and below-ground plant traits which demonstrated the role of genotype to improve the efficiency of water and nutrient (N and P) use and its impact on yield, income and environmental impact.

Finally, we have been able to assess the impact of rotation with legumes in wheat and the use of microbial inocula in potatoes to help demonstrate the potential of agroecosystem management innovations to improve the efficiency of water, N and P use on farm and their impact on yield, income and environmental impact.

Session 2: Feedback and experiences from multi-actor projects

The multi-actor approach “means that projects must focus on real problems or opportunities that farmers, foresters or others who need a solution (‘end-users’) are facing. It also means that partners with complementary types of knowledge – scientific, practical and other – must join forces in the project activities from beginning to end” (European Commission, 2017). The approach, which has been employed in many Horizon 2020 and Horizon Europe research projects, was depicted using Figure 1 to facilitate discussion during this second session.

The Multi- Actor Approach: Roundtable

Actor: a partner taking part in project activities, contributing to project outcomes vs Stakeholder: simply person expressing a view/sharing knowledge during the project

A successful multi-actor project includes…	
Diversity of actors serving project objectives	✓
Participating in project planning/cocreation of the research	✓
Participation in project experiments	✓
Participation in dissemination	✓
Demonstrating results	✓
Use their practical and local knowledge and/or entrepreneurial skills to develop solutions and create ’coownership‘ of results	✓

Figure 1: Description of the multi-actor approach, used in Session 2. Source: Julia Cooper

In this session, a round table of experts discussed the approach based on their respective, diverse experience in multi-actor projects and provided feedback. The round table was facilitated by Julia Cooper (UNEW) and included the following participants:

- Sergui Didicescu, the agricultural European Innovation Partnership (EIP-Agri), Brussels
  Mult-actor project: EIP-Agri Focus Groups
- Inès Verleden, INAGRO, Belgium
  Mult-actor project: RENURE EIP-Agri Operational Group
- Marleen Gysen, Borenbond, Belgium
  Multi-actor project: LIAISON H2020 Project
- Eddy Montignies, Belgian Research Institute of Organic Agriculture and Agroecology (BRIOAA), Belgium
  Multi-actor project: BRIOAA Living Lab
- Geert-Jan van der Burgt, Louis Bolk Institute (LBI), the Netherlands
  Multi-actor project: Green Manure Gronningen

The discussion was open but framed based on Figure 1 and discussion topics centred on how the panellists utilised and experienced multi-actor approaches, especially the challenges and opportunities that are presented from this approach. Based on this framework, key points from the discussion are summarised below:

- Marleen Gysen spoke about engaging non-research actors in projects. There are many barriers for some non-research actors to enter a consortium (e.g. administrative barriers). It is not always needed to have all actors as formal partners in the project. But it is smart to include some activities in the project that engage other actors; you can use their voice instead of just disseminating *to* them. If you do not plan it in your project, it does not happen.
- A key challenge is getting everyone on the same page in terms of knowledge and understanding in order to collaborate. Geert-Jan van der Burgt gave an example of having to explain many times why nitrogen is depleted in the soil, even to a scientific groups; he was glad the group did not include more types of actors.
- Farmers are key stakeholders often involved in these projects and Inès Verleden spoke about the need to have farmers that want to work with you, i.e. the idea/topic already needs to be "living" amongst the farmers. Building on existing projects can help to attract people who are already interested in the topic. Having farmers involved is extremely valuable for project with applied questions. You can see what works and what does not in practical conditions and learn from their experiences.
- A final question posed by Julia Cooper was for the participants to suggest their 'Top Tips' for beginning multi-actor projects, particularly the most important things to consider in starting a project using this approach.
    - Sergui Didicescu speaking from the experience of EIP-Agri emphasised the need for support, especially a facilitator that helps the interactions between partners in a multi-actor project. Even if this facilitation is not required, it will help and enhance cooperation. A facilitator can help at project initiation, to get partners to meet each other (even at the stage of writing up the project) and to further support and arrange cooperation during a project.
    - Marleen Geysen emphasised 'trust, trust, trust' and echoed Sergui's suggestion about facilitators helping to create trust by ensuring everyone's voice can be heard. Everyone should feel as equal partners and valued. Even small actions, like organising your activity on-farm so at least the farmers feel more comfortable and are willing to speak up.
    - Eddy Montignies spoke about the need to speak the same technical language across the project. Marleen agreed that technical language is important but also literal communication across different languages, giving an example from an INAGRO protocol with farmers which included facilitation of a 'wrap-up' session every 30 minutes to ensure everyone could understand across French, Dutch and English content.
    - Geert-Jan suggested that initially it is important to invite as many people as possible to broaden ideas in a project, but at the same time, if you want a project to be truly innovative, it should have a clear focus that is maintained throughout.
    - Inès Verleden reiterated the importance of involving actors who are interested in engaging, both by being interested in the theme and having a willingness to commit to the project. If you ask for input, ensure that they are willing to give it, to ensure input from a range of different experiences from different participants.

Session 3: SolACE and beyond – what needs to be achieved from now on?

The SolACE project and outcomes can contribute significantly to help European agriculture face increased rainfall variability and reduced use of fertilizers. But how can these outcomes be used? Where can we go next? And what is still missing? Using the collaborative platform *Klaxoon*, the final session took the first steps to produce a roadmap forward. The in-person attendees were divided into five groups, each focusing on a key theme from SolACE and facilitated by a SolACE partner:

- Plant-Root-Microbiome Interactions: Christophe Salon (INRAE)
- Evaluating Microbial Inoculants and Biostimulants: Julia Cooper (UNEW)
- Breeding for Root Traits: Kristian Thorup-Kristensen (KU)
- Root Phenotyping: Xavier Draye (UCL)
- Applications of Modelling Analysis: Tim George (JHI)

Three online groups also looked at broader themes:

- The Microbiome
- Breeding and Phenotyping
- Participatory Experimentation

Each group added input to the Klaxoon board (see Figure 2 for overview and Table 1 for detailed feedback in the Annex). The feedback was then summarized by Amelia Magistrali (Newcastle University, UNEW) and Philippe Hinsinger (French National Research Institute for Agriculture, Food and Environment, INRAE). A summary of key insights from the session is included below.

Summary of key insights of the Final SolACE Stakeholder Event

Amelia Magistrali noted over-arching similarities across all of the themes, from both in-person and online participants, which included:

- A focus on farms, in particular bringing some of the technology, experiments and research developed and/or implemented through the project to farms (going beyond what took place in the SolACE project). Examples from the Klaxoon included:
    - Bringing phenotyping to farmers' fields—how do we translate messages from phenotyping platforms to farmers
    - Living Labs to network participation with farmers and engage in participatory experiments
    - Accumulate data on farms to consolidate solutions and feedback directly into modelling protocol.
- Applicability was referenced regularly across all of the themes, in particular how to make tools and technology relevant and functional for end-users:
    - How to make diagnostic tools that are useable and easy to employ, particular in the context of microbial products?
    - How do we make participatory research valuable commercially for farmers?
- Soil was a prevalent topic (to the point that it could have been its own discussion theme), particularly having a deeper understanding of soil and soil-microbial communities to help in designing and evaluating projects.
    - Importance of understanding soil conditions and factors in evaluating/employing microbial inoculants.

    - Working with 'real' soil—conflict of controlled vs. un-controlled environments. How do we establish 'real' soil environments for evaluation?
    - How do we talk about soil and microbial communities in a way that is accessible to farmers and other end-users to allow for understanding, applicability and engagement? What about communicating the importance and functioning of soil and microbial communities to consumers and other non-agricultural stakeholders?
- Communication—how is information disseminated and shared?
    - Importance of producing material that can be shared as technical guidance or as products (e.g. microbial formulations)
    - Linking to EIP Frameworks to communicate and disseminate information
    - How to employ social media to engage with audiences?
    - Communication between farmers and researchers is very important—how is this communication facilitated on-farm and across other platforms?
    - Overlap with multi-actor approach discussion earlier in the event—terminology and language is important in overall communication plans.

Philippe Hinsinger provided some additional summarising reflections, specifically looking to acknowledge some of the conflicting goals produced by discussions.

- Do not be over-ambitious, e.g. do not focus on multiple stressors vs. the reality that multiple stressors are always in play.
    - Focus was a key word across discussions—getting into more focused questions or experiments vs. the reality of a range of factors affecting scenarios in 'real-life' where we cannot stick to single stressors or single factors.
- At some point we need more multi-disciplinary/trans-multi-disciplinary approaches, across different domains of science and across actors, which is difficult but an exciting opportunity for multi-actor approaches.
    - Focus of farmers as end-users in SolACE but not much consideration of other end-users (a large omission being consumers)
        - Example of some crops (e.g. legumes) included solely for the purposes of representing a rotational benefit in SolACE without considering their uses and applicability (are these crops functional foods for animals and humans?), which are unfortunately still frequent barriers for including more legumes in European agriculture.
        - Living Lab approaches that have become popular recently emphasise going beyond interactions between farmers and scientists but also include the whole value-chain, including consumers in the end to develop co-innovation along the production chain.
- Language is a key word mentioned by panellists of the multi-actor discussion and the final discussions, which is always a difficult component of projects even among scientists but especially across different countries working on a European-scale project.
- Commitment and trust are additional key words, as emphasised by the multi-actor discussion, and even though they did not come up as much during the final discussion, they are worth mentioning as key components for successful projects.

Annex: Session 3 Outcomes

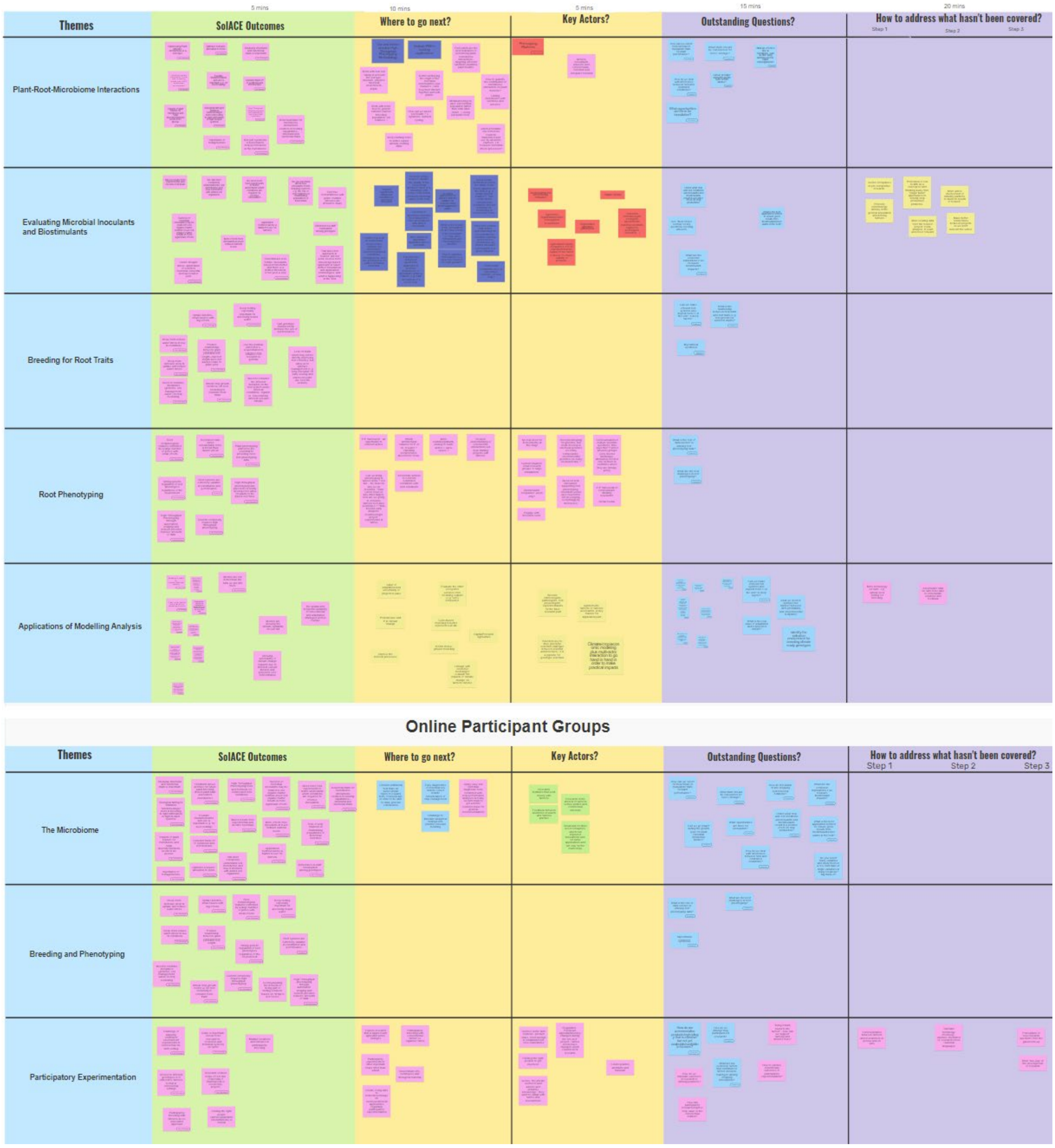

Figure 2: Klaxoon board overview (for full transcript see Table 1). Please note that the online participants were divided into two groups during the event (Microbiome and Participatory Experimentation) based on the number of participants.

Table 1. Detailed Klaxoon board outcomes from the interactive discussion session during the Final SolACE stakeholder event. The comments from online participants in the Microbiome theme have been incorporated into the Evaluating Microbial Inoculants and Biostimulants theme in this table.

Theme	Key Messages	Key Actors	Questions	Next Steps
Plant-Root-Microbiome Interactions	Beneficial traits for microbiome interactions centred on hosting capabilities--structural and functional traits High Throughput Phenotyping tools and methods for control and field conditions Exudate characterization and use is important (e.g. for seed coating) Biological Nitrification Inhibition functions/larger roots in breeding to fight nitrification (and nitrate leaching) in high N-input systems Consider trade-off of symbiosis and root biomass Harnessing plant-microbe interactions is a hot topic Holobiont shows promise for future plant breeding (breed plant and associate microbiome) Impacts of plant mixture on microbiome (bacteria and fungi) diversity/functions needs to be precise Importance of metagenomics Not just symbiosis is beneficial to crop performance in the microbiome Optimize resource allocation to roots Studying structural and functional traits is important	Phenotyping Platforms "farmers, consultants, advisers (non-commercials), scientist and computer scientists"	Can we go longer during the growth cycle for plant microbial interaction studies? How can we select for beneficials or mutualistic traits for plant performance? How do we deal with differences between field and controlled conditions? What are effects of Biological Nitrification Inhibition on microbiome, such as dinitrogen fixing bacteria (on non-target microorganisms? How can we asses soil health? C dynamics, nutrient cycling. What opportunities are there for inoculation? Which affordable low tech tools could be transmitted and use by all actors (farmers...) to measure microbial driven processes? What traits should be considered for soil carbon storage?	Deep learning tools to better exploit already existing data! "How to quantify the contribution of microbiome interaction on plant benefits? Linking microbiome with functions and services!" Include plant-microbial interactions in funding applications Metabarcoding on alive soil microbial population rather than total DNA (dead...): using adequate tools. Use and further develop High Throughput Phenotyping Methodology Work with real soil. Taking in account the soil type, structure, physico-chemical environment, depth Work with more diverse genetic material (farmer breeding population, old relatives...) Find which are the best indicators of performing plant-microbiome interactions - targeting different functions (nutrition, plant health). Better identifying the origin of the microbial communities (soil, manures...) and how their interact together and with plants.

Theme	Key Messages	Key Actors	Questions	Next Steps
Evaluating Microbial Inoculants and Biostimulants	Application method can be a barrier to use for farmers Differences in Arbuscular Mycorrhizal Fungi (AMF) colonisation among genotypes Mixed results from experimental and on-farm field trials More effects from inoculants at lower fertiliser nutrient levels Need more field experiments to better understand which conditions are required for effective inoculation Soils that are less fertile, inoculants may perform better (but there is a bottom threshold of too poor a soil) Still don't completely understand soil microbiome and how it interacts with added soil organisms Success of microbial inoculants may be related to soil organic matter content--lower soil organic matter results in more significant effects Under drought stress, application of selected microbial consortia increases tuber yield Trial and error approach in SolACE did not work; need a more knowledge-based approach in future; better formulations and application technologies; and what is happening in the field Don't be overambitious with goals; multiple stresses are difficult to study. We need to think about how inoculants fit into cropping systems,	Biostimulant/inoculant producing companies Organic farmers Regenerative agriculture practitioners Scientists (microbiologist, ecologists, agronomists, material scientists, engineers, pedologists, modellers...) Agronomy organisations/advisors/applied researchers Agricultural supply companies; it is so important that the supply to the farms is timely, to ensure viability of products. Research institutes that work closely with farmers Research in the interest of farmers versus politics and commercial interests Feedback between academic research and farmers practice Small and medium sized companies, which can implement innovations also for niche applications and not only for the main crops	How do inoculants fit into cropping systems/crop rotations? Under what crop and soil conditions will inoculants and biostimulants result in a positive effect on crop production? What is the impact of the formulation on the final effects of the inoculant? i.e. how does formulation and microorganism interact? How to optimise formulation? is a new one required for each product? Conduct additional field trials on same/similar topics to expand body of knowledge in order to be able to draw general conclusions What are the economic implications if we measure biostimulant impacts? Do you select many variables and study them in a few field trials or single variables in many locations? Big trade-off Under what conditions does a consortium colonise, for how long? Challenge to translate analytical findings into practice relevant meaning	Involve companies in pre-competitive research. Promotion of soil health as a concept to shift thinking away from "magic bullet" approaches to solving crop production problems. Make better connections between projects so we don't reinvent the wheel. Breeding approaches for varieties that are suitable for systems using biostimulants/inoculants More studies on appropriate application rates of inoculants Targeted experiments linking soil conditions to success of inoculants Start from scratch with better understanding the soil microbiome; machine learning processes to predict how an added inoculant will respond in a given situation. Develop simple tests to validate the quality of the commercial product? there is a challenge with some commercial products not being viable in the field Need simple methods to follow the strain of the microorganism in the field (e.g. a strain-specific marker?). This works under experimental conditions; but not practical for monitoring in commercial fields.

	e.g. the role of crop rotations in maintaining populations of beneficials			
Theme	**Key Messages**	**Key Actors**	**Questions**	**Next Steps**
Evaluating Microbial Inoculants and Biostimulants			What is the best application method to ensure good results from biostimulants/inoculants in the field? Easy diagnostics of microbial key factors versus holistic consideration of crop management	Further research on relationship between the existing soil microbiome, environmental/soil conditions, management, and the persistence of added microbial consortia. Experiments looking at agronomic strategies to promote persistence of inoculants within a rotation; e.g. AMF inoculation of a cover crop. Selection of genotypes that are best adapted to form associations with added inoculants. Apply easy soil microbial diagnostic tools combined with crop performance analyses in many on-farm trials to get a better evidence base for general recommendations Promote microbiology literacy in the general population and among farmers Mine existing data from the SolACE project; meta-analysis; to learn and move forward. More active involvement of industry partners, so build on results of SolACE.

Theme	Key Messages	Key Actors	Questions	Next Steps
Breeding for Root Traits	Deep rooting especially important for accessing N and water Deep roots increase deep N uptake and reduce water stress Deep roots reduce water stress in low N conditions Need to combine disciplines (genetics, soil, management, water) in crop modelling Positive relationship between grain yield and root length--total root length not always relate to grain yield Uptake characteristics->"small causes with big effects" as shown for P Wheat crop growth model w/ 3D root modelling to consider more traits		Can we make efficient root systems also deposit more C in the soil? In deep layers? Mycorrhizal symbiosis What is the relationship between crop traits and root traits (e.g. leaf greenness and root depth)? Can genotype mixtures help increase the use of soil resources	Use the political interest in C sequestration to enhance root research in general Need to consider the different demands on the root system under different conditions, organic vs. conventional, different soil and climate Look for traits which may not be directly improving root efficiency, but allow us to optimize management (e.g. long coleoptile for early sowing and improved water use over the season)
Root Phenotyping	Genetic complexity requires high throughput phenotyping High throughput phenotyping has also more recently developed to allow for plants to be traced over time High Throughput phenotyping through automation, imaging and sensors provides massive amounts of data Plant phenotyping platforms are essential to providing more root phenotyping data Root morphological features controlled by a large number of genes with small effects Root systems are extremely variable in constitution and performance Root/shoot ratio varies considerably more in bread than durum wheat	Current situation: small research groups <> large installations. No real need for tech industry at this stage Biostimulant companies: users only? Engage with breeders soon Need for tech innovation, supporting root phenotyping. Scientists would save much time not developing everything by themselves "EIP framework to communicate. Monthly newsletter. Social media."	Communication of mature scientific questions. Who says this? Farmer advisory groups (very diverse landscape, absolutely needed, rely on them in countries where they are strong), policy. What are the next challenges in root phenotyping? What is the role of data science in utilising root phenotyping data?	EIP framework : an opportunity to connect actors Which architectural features for P, or N, or water? Handling compromises. Need more focus. More multidisciplinarity. Analog to multi-actors > same issues? Deepen understanding of soil-microbe interactions will help starting projects with farmers. "Can we bring phenotyping in farmer fields? Yes but... Be clear on why we do research. Think Green Deal (or any other target): how are we going to convince farmers to reduce pesticides? Think beyond early adopters. (SoilDiverAgro project, experiments in farms)"

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Root Phenotyping	Strong genetic regulation of root phenotypes regardless of the environment			Accelerate actions to confront controlled conditions with field conditions Root phenotyping for genetics, but could develop in chemical genetics (so many compounds), environmental genetics (so many environments)? Connect lab and fields: we have started learning how, we must go on. Don't think more complex than SolACE. More unifying themes? Support large-coverage field networks, but also support local networks, with facilitation mechanisms to make it viable, profitable and resilient. "Force" scientists to leave their comfort zone to reach field actors reality. Field actors do not have the resources for that.
Applications of Modelling Analysis	Clear visual results are a benefit of modelling outputs 'Health warning' including clear assessment of probability and limitations of factors is necessary in presenting modelling outcomes Impact of climate change with range of fertiliser options modelling to assess impacts of water and nutrient stress in Europe Impact of legumes in rotations with wheat and microbial inocula in potatoes model to demonstrate potential of agroecosystem management to improve efficient resource use	Breeders, entomologists, pathologists, root physiologists, experimentalists for the base research part agronomists, farmers or farmers' association, policy makers for application part Breeders key to drive genotype selection (dialogue between scientist and breeders). It is a pipeline for genotype selection	Assessing benefits, detriments and potential policy drivers for interventions not included in SolACE: rotations, cover crops, reduced tillage, organic production, precision agriculture, irrigation Assessment of increased circularity of the food system Can we design specific options for specific crops--how does potato fit in a regenerative farming system?	Value of adaptation and uncertainty of projected value Evaluate the other ecosystem services from modelling outputs (e.g. greenhouse gas emission)= Pest/disease and P in climate change Gene-based modelling to better represent Genetic x Environment x Management interactions Improve the root/soil processes Refine below-ground modelling Linkage with economic modelling to evaluate the impacts of climate change on farmers' income Digital/Precision Agriculture Impact of land use

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Applications of Modelling Analysis	Modelling can assess unintended consequences of policy and codified practice (e.g. organic certification) Modelling is useful for forward/predictive capacity Models are not better than the data we put into them Models should generate range of information on traits and characteristics implicit in policy (e.g. ghg, nutrient loss) Potato modelling and Life-Cycle Analysis demonstrated role of genotype to improve water and nutrient (N or P) use and impact on yield, income and environment Scale matters--data can be presented as impact per unit of food and impact per unit of land area Models are showing the climate variability on Genetic x Environment x Management interactions Showing uncertainty of climate change impacts due to different Climate Models and projected CO2 concentration the spatial and temporal variability of conventional and adaptation strategies across Europe	Climate/crop/economic modelling plus multi-actor interaction to go hand in hand in order to make practical impacts	Development of opportunities for grain legumes (we know from models that they're beneficial) Monitoring the impact of interventions on ecosystem services and the performance of monitor farms Trade-offs between biodiversity and food security--can we reduce yield to promote biodiversity? What is the real value of adaptation under projected climate? What we need to optimize the trade-off between farm profitability and environmental footprints? What is the role of genotype selection/use of diversity to make the system more resilient and robust? identify the selection environment for breeding climate ready genotypes	

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Participatory Experimentation	Access to different genotypes is of interest to farmers to trial in commercial settings Challenge of applying 'controlled' environment experiments to commercial on-farm setting Participatory breeding with farmers as co-innovation approach Research context helps off-set risk (especially if financial risk is covered by project) Scale is important--needs to be relevant for economic and technical systems on farms Finding the right people (farmers/practitioners/institutions) is crucial Multiple locations and climates in participatory breeding	Involve the private sector to add advise and industry knowledge - they want to adapt with farms and researchers Finding the right people to get involved	How do we arrange truly participant-led research? How do we commercialise products/technology that is effective but not yet scalable/available to farmers? How do we translate outcomes in research to farming practices? What are the economic factors that contribute to farmer decision-making in utilising cropping innovations? How can participatory research improve crop value in the commercial market? "Bring it back round to the farmer" - how can we support farming and farmers more? How to valorise scientifically outcomes of participatory experimentation?	Explore research that is aligned with agriculture policy changes Regulation: European agricultural policy changed during the SoLACE project - farmer needs have changed which could benefit research Participatory experiments in other important crops other than wheat Create Living labs to network/exchange on common/different approaches regarding participatory experimentation Participatory breeding with conventional vs. organic farms Communicating the benefits of being part of finding solutions. Based on "What is in it for me" Income in the farm context - product value, cost savings in establishment, less cultivations Disseminate info, techniques and biological material More technology on farm: e.g. optical seed sorting for breeding Communication between farmers and researchers in person and on farm Accumulate data on farm to be able to consolidate solutions and feedback Translate terminology effectively - practice orientated vs. research terms/national languages Create practice abstracts and translate Formulation of new research questions from the grassroots up More 'two-way' research development

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