This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727247 (SolACE)


# SolACE - Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use

# Deliverable D1.1
# SolACE Handbook of protocols and methodology

Planned delivery date (as in DoA): Month 6

Actual submission date: 10 December 2017

Work package: 1

Work package leader: Davide Cammarano, JHI

Deliverable leader: Dóra Drexler, ÖMKi

Author: Dóra Drexler and Davide Cammarano
Version: 1.0

| | |
|---|---|
| This Deliverable is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727247. | |
| Dissemination Level | |
| PU Public | PU |
| CI Classified, as referred to Commission Decision 2001/844/EC | |
| CO Confidential, only for members of the consortium (including the Commission Services) | |

Research and Innovation action: GA no. 727247

Start date of the project: May 1$^{st}$, 2017

Dissemination level: PU

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## Summary


**Objectives:**

The Deliverable D1.1 "SolACE Handbook of protocols and methodology" is intended for all SolACE project partners. It is intended to be a living handbook describing the standards to use for the data collection. This document generated at the beginning of the project will be constantly updated throughout the project

**Rationale:**

For more details about the rationale of the SolACE Handbook of protocols and methodology, see the introduction of the Handbook below.

It is intended to gather all the experimental designs for all the experiments conducted in platform, glasshouse and field (both on-station and on-farm) in SolACE, as well as the sampling strategies and protocols. The Handbook is also gathering all the protocols for modelling, statistical calculations, farmers interviews and stakeholder engagement. Finally, for all the measured and calculated parameters in SolACE, the Handbook is compiling their definitions and the protocols for their measurement and calcultation.

This Handbook is a practical reference guide to help all members of the project on the different aspects that they will have to deal with during the course of the project, in order to promote the use, whenever possible, of the same methodologies and protocols.

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SolACE

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

# Handbook of protocols and methodology

Call: H2020-SFS-2016-2

Topic: SFS -01-2016 Solutions to multiple and combined stresses in crop production

Type of Action: Research and Innovation action

Coordinator: Philippe Hinsinger, INRA Montpellier

Duration: May 2017 – April 2022 (60 months)

EC Grant Amount: 6 000 000 €

Lead Beneficiary: Dóra Drexler
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## 1. ADMINISTRATIVE DETAILS

**Project Name:** SolACE

**Principal Investigator / Researcher:** Philippe Hinsinger

**Description:** The overall goal of SolACE is to address the challenge of managing combined stresses in crop production. SolACE will (i) combine the expertise of a broad range of disciplines, from crop physiology and genetics to microbial ecology and agroecology, as well as social sciences, and (ii) promote strong interactions with a large panel of partners and stakeholders, across the whole production chain and across both conventional and organic agriculture sectors. The project will promote the interactions between actors of these two sectors, include conservation agriculture principles and involve a broad range of major pedo-climatic zones across Europe, from Mediterranean to boreal regions, as well as from Atlantic to continental regions. The choice of the crops of interest in SolACE (bread wheat, durum wheat, and potato) is based on their economic importance in Europe and for food security at a global level. These crops also represent different production systems, with contrasting biology (especially below-ground), agri-food targets (grain versus tuber crop) and responses to abiotic stresses. Wheat is more exposed to water and N deficits in the context of present-day European agriculture, and this is especially at stake for durum wheat in Mediterranean regions, while potato production is sensitive to reduced inputs of N and P fertilizers. Water limitation will affect nutrient availability and acquisition in general. This means that different strategies and tools will be developed in SolACE for breeding and managing these diverse crops in order to improve their water and nutrient use efficiency, in the context of conventional, organic and conservation agriculture systems. The novel solutions developed in SolACE will serve as models for developing similar approaches in other important crops.

**Institution:** INRA

## INFORMATION CONCERNING THE HANDBOOK

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## DATE OF CREATION OF HANDBOOK

05. October 2017 (V0.1)

**Current version:** V0.3 13 October 2017

## INFORMATION ON THE RESEARCH PROJECT

**Identifier of the call for proposal**

H2020-SFS-2016 - Resilient and resource-efficient value chains

**Project funder(s)**

European Commission - SERI for Swiss partners

**Name of research programme**

SFS-01-2016: Solutions to multiple and combined stresses in crop production

**Reference of funding agreement**

grant agreement N°727247

**Project acronym**

SolACE

**Name of research project**

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

**Project leader institution, coordinator & beneficiary (name, country)**

INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE, France

**Other partners (name, country, role of each partner other than the project leader institution)**

| Nº | Participant organisation name | Type | Country |
|---|---|---|---|
| 1 | Institut National de la Recherche Agronomique (INRA) | Re | France |
| 2 | AIT Austrian Institute of Technology (AIT) | Re | Austria |
| 3 | Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA) | Re | Italy |
| 4 | Forschungsinstitut für biologischen Landbau (Stiftung) (FiBL) | Re | Switzerland |
| 5 | James Hutton Institute (JHI) | Re | United Kingdom |
| 6 | Kobenhavns Universitet (KU) | Re | Denmark |
| 7 | Sabanci Üniversitesi (SU) | Re | Turkey |
| 8 | Sveriges lantbruksuniversitet (SLU) | Re | Sweden |
| 9 | Université Catholique de Louvain (UCL) | Re | Belgium |
| 10 | Universidade de Évora (UE) | Re | Portugal |
| 11 | Universität Hohenheim (UHO) | Re | Germany |
| 12 | University of Newcastle (UNEW) | Re | United Kingdom |
| 13 | Technical University of Madrid (UPM) | Re | Spain |
| 14 | Eidgenoessisches departement fuer wirtschaft, bildung und forschung (AGROSCOPE) | Re | Switzerland |
| 15 | ARVALIS Institut du Végétal (ARVALIS) | SME | France |
| 16 | CON.CER Societa Cooperativa Agriccola (CONCER) | Oth | Italy |
| 17 | De Ceuster Meststoffen NV (DCM) | Ind | Belgium |
| 18 | European Conservation Agriculture Federation (ECAF) | Oth | Belgium |
| 19 | INRA Transfert (IT) | Oth | France |
| 20 | Linking Environment And Farming (LEAF) | Oth | United Kingdom |
| 21 | Ökológiai Mezőgazdasági Kutatóintézet (ÖMKi) | SME | Hungary |
| 22 | Ontwikkelingsmaatschappij Het Idee (SOLYNTA) | SME | Netherlands |
| 23 | Sourcon Padena (SP) | SME | Germany |
| 24 | SYNGENTA (SYNGENTA) | Ind | France |

He: Higher education organisation; Re: Research organisation; Ind: Industrial company; SME: Small-medium enterprise; Oth: Other

<u>**Contribution per work package**</u> (WPL: WP leader, WPC: WP co-leader, T: Task leader, C: contributor)

| | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | WP7 |
|---|---|---|---|---|---|---|---|
| **INRA** | WPC / C | T | C | T | | C | WPL / T |
| **AIT** | C | C | WPL / T | | | C | |
| **CREA** | T | C | C | WPL / T | | C | |
| **FiBL** | C | C | C | | T | WPL / T | |
| **JHI** | WPL / T | T | | C | | C | |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **KU** | C | T | | | | C | |
| **SU** | | | | C | | C | |
| **SLU** | | | T | | T | C | |
| **UCL** | C | WPL / T | C | | | C | |
| **UE** | C | | C | | | C | |
| **UHO** | | | C | | | C | |
| **UNEW** | C | | C | | WPL / T | T | |
| **UPM** | C | | C | | C | C | |
| **AGROSCOPE** | C | | WPC / C | | | C | |
| **ARVALIS** | C | WPC / C | T | C | C | C | |
| **CONCER** | C | | | C | C | C | |
| **DCM** | | | C | | C | C | |
| **ECAF** | C | | | | | C | |
| **IT** | | | | | | T | WPC / C |
| **LEAF** | C | | | | C | WPC / T | |
| **ÖMKi** | T | | C | C | WPC / C | C | |
| **SOLYNTA** | | C | | WPC / C | | C | |
| **SP** | | | C | | C | C | |
| **SYNGENTA** | | T | | T | | C | |

**Unit to which project leader belongs**

INRA, UMR Eco&Sols, Place Viala, 34060 Montpellier (France)

**Project dates and duration**

From 2017-05-01 to 2022-04-30

## 2. INTRODUCTION

The *Handbook of protocols and methodology* describes the **parameters** that are measured and/or calculated in the SolACE project (Solutions for improving Agroecosystem and Crop Efficiency for water and nutrient use), and indicates according to which **protocols** the measurements or calculations were conducted. Moreover, the Handbook includes the **definitions** of central concepts that are of key importance to the project, and shall be interpreted the same way throughout SolACE. The Handbook focuses primarily on those parameters and definitions that are used **by more than one partner of the project**, and sets – wherever possible – common guidelines for conducting measurements and calculations. The purpose of the Handbook is to guarantee a **methodological consistency within the project**, and where possible the comparability of results – let it be greenhouse, field, or laboratory investigations. Because of the above mentioned reasons, the Handbook is a "**living document**", ready for development throughout the project. Its content evolves together with the project, taking into account the possible changes and adaptations that are an organic part of scientific work.

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The Handbook does not wish to repeat detailed protocols that can be cited from available literature, but aims to document which protocols were chosen as common understanding and approach of SolACE partners in specific tasks. In case it is not possible to harmonize methodologies and protocols for a topic, the Handbook will indicate all applied methods, and will include the reasoning behind this decision. This way, we aim to keep track of the logical development of the project, and make sure that methods and protocols are discussed and thought through within the consortium, in order to achieve as much coherence and transparency as possible.

Further aim of the Handbook is to **design a system for collecting and managing the data** generated from the literature review, data mining, and new investigations during SolACE. For this purpose, **guidelines for the collection, storage, and quality control of data** are included in the Handbook. **The Handbook** describes the standards to use for the data collection, and **is used by all WPs**.

## 3. EXPERIMENTAL DESIGNS AND SAMPLING STRATEGIES

# WP2

## T2.1. Platform experiments on wheat panels

### Platform 4PMI (INRA-Dijon):

250 Durum Wheat, 250 Bread Wheat.

1 experiment, 4 plants per line, 1 condition (combined water deficit and low N), greenhouse, 3-week long.

Root and shoot architecture over time. Daily imaging. Precise list of variables will depend on the status of image processing pipelines.

### Platform Aeroponics (UCL):

250 Durum Wheat, 250 Bread Wheat, 400 Durum Wheat (EPO panel).

3-4 experiments, 4 plants per line, greenhouse, 3-week long.

Root growth and development over time. Imaging every 2 hours. Precise list of variables will depend on the status of image processing pipelines.

## T2.2. Field experiments on wheat panels

Bread wheat: 250 lines, 2 sites (ARVALIS – Gréoux, SYNGENTA - )

Durum wheat: 250 lines, 2 sites (CREA – Foggia, INRA – Maugio)

2 conditions: control – Water deficit and low N

Phenology, yield components. The precise list is under construction and depend on each partner possibility.

AMF sampling on one site for each species. The choice of site is under discussion, based on determinations of the AMF communities in the soils (UCL).

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### T2.3. Potato ecophysiology

Panel of 24 potato lines grown in field experiment under polytunnels (9.2 m width x 100 m length; c.f. Wishart et al. 2014, *Plant Soil* 378, 351-363)

2 conditions: control (conventional fertiliser applications (Defra RB209) with supplemental irrigation (two to three 30 min. applications per week as required)) – Water deficit and low P (conventional fertiliser applications but without P fertilizer, with no irrigation)

Canopy closure and final yield will be measured, as well as mineral concentrations in shoots and tubers at harvest to assess nutrient use efficiencies. Five access tubes will be inserted randomly into each block and soil moisture readings will be taken weekly at depths of 100 mm, 200 mm, 300 mm and 400 mm using a Delta T PR2 Profile Probe (Delta T Devices, Cambridge, UK) throughout the experiment. Soils will be sampled before the application of fertilisers.

For each treatment: Each genotype will be grown in rows of five plants, of which the middle three will be harvested. One row of each genotype will be grown in each of three blocks (i.e. three replicates). Planting rows will be arranged across the tunnel as: Guard, Test, Test, Guard, Sprayway, Guard, Test, Test, Guard

### T2.4. Wheat ecophysiology

Panels of 40 lines. Factorial Water deficit x low N experiments.

4 platforms involved: PhenoArch (Montpellier, Greenhouse, plant architecture, monitored transpiration), RadiMax (KU, field with rhizotubes), ARVALIS (highly equipped field, durum wheat), INRA-GDEC (highly equipped field, bread wheat). In addition, 10 genotypes in rhizotrons (UCL) and field rhizotubes (ARVALIS).

On the three field experiments: microbiome diversity (10 genotypes) and metagenome sequencing (2 genotypes).

## WP3

### T3.1 Pilot studies to select microbial combinations

- **AIT:** Randomized greenhouse study testing 2 Bread Wheat varieties (Ludwig, Mulan), non-sterile soil (1:1 mixed with sand), 10 microbial combinations (*Pseudomonas protegens* 3BS, P. jessenii 17BS & *Strenotrophomonas maltophila* AS14SGY2; *Kosakonia* sp. & *Herbaspirillum* sp., *Kosakonia* sp. & *Herbaspirillum* sp., *Rhizophagus irregularis* MUCL 41833, *P. brassicacearum* 3Re2-7 & *Rhizophagus irregularis* MUCL 41833; *Paraburkholderia phytofirmans* PsJN & Rhizophagus irregularis MUCL 41833; *Paraburkholderia phytofirmans* PsJN & *Trichoderma asperelloides* A; Pseudomonas sp. KCZ4-3 & *Rhizophagus irregularis* MUCL 41833; *Pseudomonas brassicacearum* 3Re2-7 & *Trichoderma asperelloides* A; *Rhizophagus irregularis* MUCL 41833, Trichoderma asperelloides A; *Paraburkholderia phytofirmans* PsJN, *Rhizophagus irregularis* MUCL 41833& *Trichoderma asperelloides* A), 9 controls (*Paraburkholderia phytofirmans* PsJN; *Pseudomonas* sp. KCZ4-3; *Rhizophagus irregularis* MUCL 41833; *Trichoderma asperelloides* A; *P. brassicacearum* 3Re2-7; *B. amyloliquefaciens*

FZB42 (Rhizovital); *B. amyloliquefaciens* FZB42 (Rhizovital) sterilized; *Trichoderma asperelloides* A sterilized).

- All bacterial strains growing overnight in 10% TSA, except *Kosakonia* and *Herbaspirillum* were in glucose yeast media (15 g glucose, 2 g yeast extract for 1 l)
- For *Trichoderma* the strain was grown for 6 days on PDA and the mycelium was scraped from the plates and dissolved in 25 ml 1 x PBS, (every time one plate for 25 ml), 6 plates of *Trichoderma* were prepared to have enough inoculum
- For the sterilization of the *Trichoderma* strains (control C8), 75 ml (from three plates) were autoclaved at 121°C for 20 min each time
- From each strain of the overnight culture the OD was adjusted to 0.2 and inoculated for 1 hour at room temperature (25 ml).
- 15 seeds per pot were sown (after germination 10 seedlings per pot was left)
- The control C7 (FZB42) was sterilized by autoclaving 20 min at 121°C (we used the strain without formulation, because also the other strains were without formulation
- The *Rhizophagus* was added before sowing into the soil of the corresponding treatments - 12.5 g per pot, placed at 5 different spots in the pot.
- The pots were placed in foliar tunnels protected from water under natural temperature regime
- The germination per treatment was recorded.
- The treatments were as following: stress treatment: 4 weeks 70% WHC followed by 2 weeks of stress with 40% WHC and two weeks re-watering to 70% of WHC; no stress treatment: 70% WHC

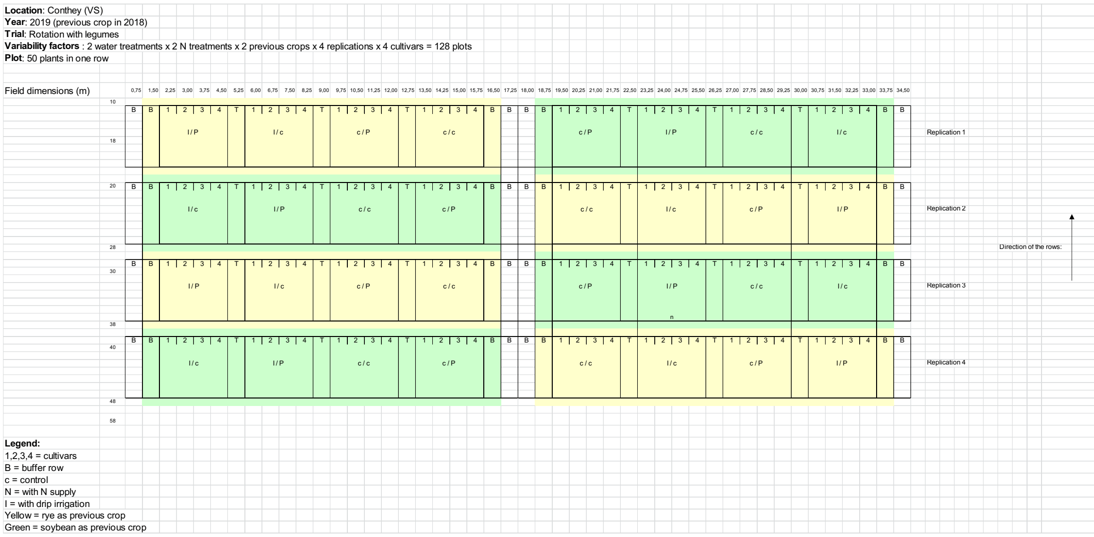
- Parameters to assess: dry and fresh root biomass, dry and fresh shoot biomass, root volume, root length, N and P concentration in shoots
    - Shoot fresh weight: above ground biomass all 10 plants weighted and later dried for dry mass and P and N measurement
    - Roots: washing roots from the soil (5 roots per pot); root fresh biomass
    - Scanning 1 root per pot in rootscanner ((Winrhizo)) for root length and volume (to be decided if it would be the same work load if we scan all three roots from all samples)
    - After scanning the roots, drying the roots for measurement of dry biomass
    - P and N in the shoots (P - mangan molybden method; N - CHN analyser)

## T3.2 Potato on-station trials

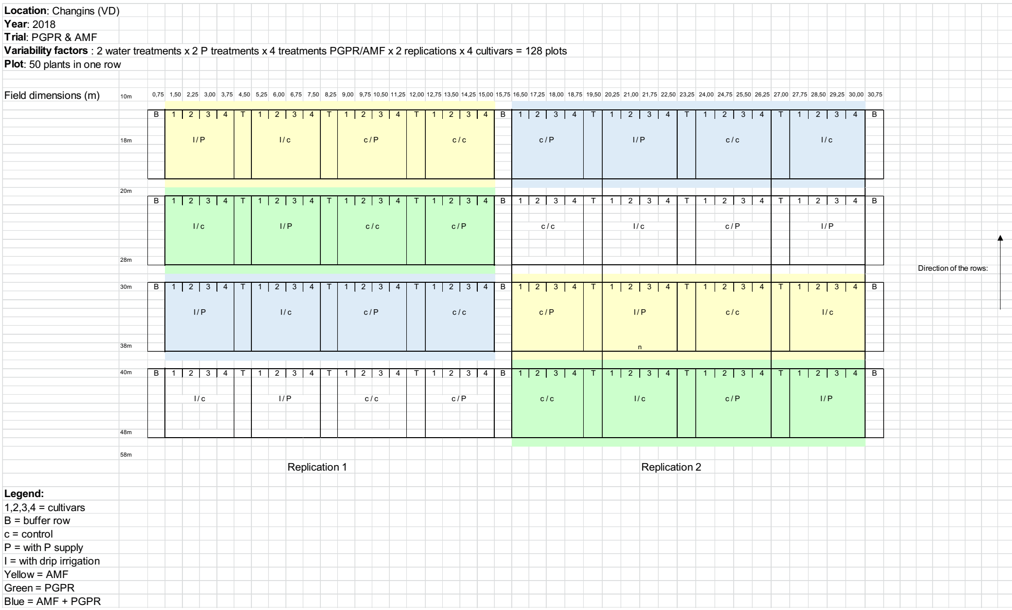
- Trial of crop rotation with grain legumes
    - Factorial treatment design: 2 previous crops in the rotation (rye – cv. Ryefood and soybean – cv. ES Mentor), 2 water treatments (full irrigation and induced water stress), 2 N treat-

ments (supply of 120N and no N supply) x 4 varieties (cv. Désirée, one local cultivar and two references) x 4 replications.

- Field design: Split-Plot design with the previous crop as main plots and the combinations of water and N treatments as subplots. The varieties are distributed in the elementary plots with one variety per row of 25 plants. The seedling rate is one seed piece per 0.33 m with a 0.75 row spacing. The elementary plots are surrounded by two rows of potatoes as buffer zone.




- Trial of microbial inoculants
  - Factorial treatment design: 2 to 4 inoculants (to be determined by T3.1), 2 water treatments (full irrigation and induced water stress), 2 P treatments (supply of 60 P and no P supply) x 4 varieties (cv. Désirée, one local cultivar and two references) x 2 to 4 replications.
  - Field design: Split-Plot design with the inoculants as main plots and the combinations of water and P treatments as subplots. The varieties are distributed in the elementary plots with one variety per row of 25 plants. The seedling rate is one seed piece per 0.33 m with a 0.75 row spacing. The elementary plots are surrounded by one row of potatoes as buffer zone.




## T3.2 Bread wheat on-station trials in Switzerland by Agroscope

- Trial of crop rotation with grain legumes
    - Split-plot design with the previous crop as main plots and water and N treatments as sub-plots: two pre-crops (winter barley and winter peas), two water treatments (low and high water availability), two N treatments (high and low N supply) and four winter Bread Wheat genotypes (CH Nara and three additional identified through phenotyping in WP2). The experiment will be conducted with three replications.
- Trial of microbial inoculants
    - Split-plot design with N supply (high vs low) as main plots and the combination of winter Bread Wheat genotypes and microbial inoculants as subplots (CH Nara will be the local genotype and additional genotypes that will be identified through phenotyping in other work packages). The experiment will be conducted with three replications.

## T3.2 Bread wheat trial of reduced tillage in organic farming in Switzerland by FiBL

- Split-split-plot design with tillage (ploughing vs. reduced tillage) as main and fertilisation type and rates (unfertilised, NPK and slurry application with two intensity levels) as sub-treatment (total 10 treatments, 4 replicates, 40 plots). Plots will be further divided in 2 subplots where the four Bread Wheat genotypes (another division in 4 strips à 2x12 m) will be replicated in time (2018/19 and 19/20). The local genotype is WIWA, the other genotypes to be identified in WP2.

# WP4

## T4.3 Evolutionary breeding of durum populations in IT and HU (maybe F as well)

- 2017/2018: On-station multiplication of durum population originating from the Solibam project in HAS Agricultural Centre (by kind contribution of Péter Mikó)
- Test sowing of EPO material of Jacques David in winter 2017 (if still possible), and spring 2018 in Hungary.
- Sowing in September 2018 of mixed populations, on station (complete block design) and on farm (stripe design).
- Parameters: Protein, Carotenoids, Yield, winter hardiness, gene flows, change of gene frequencies

# WP5

## T5.2 Potato on-farm trials

- Factorial treatment design: 2 innovations (one standard i.e. standard NPK rate, no innovation; one innovative i.e. 25% less N or P fertiliser + inoculant/legume in rotation) x 4 varieties of potatoes (reference, local, 2 genotypes); non-replicated; note that the standard innovation with reference variety is the control, this must be replicated twice to allow statistical analysis (Bayesian approach); therefore, a total of 9 plots per field
- Demonstration strip design; size of plot to be dictated by farmer equipment

## T5.2 Durum wheat on-farm trials

- Factorial treatment design:
  - Option A: where only Durum Wheat genotype mixtures are tested
    - Reference genotype with standard NPK, standard irrigation (control replicated twice)
    - Local genotype with 25% less N and no irrigation
    - Genotype mixture 1 with 25% less N and no irrigation
    - Genotype mixture 2 with 25% less N and no irrigation
    - A total of 5 demonstration strips on each farm
  - Option B: DST + Durum Wheat genotype mixtures tested
    - Reference genotype with standard NPK, standard irrigation, no DST (control replicated twice)
    - All four genotype treatments with 25% less N and no irrigation + DST
    - Three genotype treatments with 25% less N and no irrigation (no DST)
    - A total of 9 demonstration strips on each farm
- Demonstration strip design; size of plot to be dictated by farmer equipment

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### T5.2 Bread wheat on-farm trials

- Factorial treatment design: 2 innovations (one standard i.e. standard NPK rate, no innovation; one innovative i.e. 25% less N + innovation) x 4 varieties of Bread Wheat (reference, local, 2 genotypes); non-replicated; note that the standard innovation with reference variety is the control, this must be replicated twice to allow statistical analysis (Bayesian approach); therefore, a total of 9 plots per field

  Note that it is desirable to have the same innovation tested across a given network. Otherwise, the value of the experiments/trials is greatly reduced.

- Demonstration strip design; size of plot to be dictated by farmer equipment

# 4. PROTOCOLS FOR MODELLING, STATISTICAL CALCULATIONS, FARMERS INTERVIEWS AND STAKEHOLDER ENGAGEMENT

## WP1

**Crop model calibration**

In order to calibrate a CSM (Crop Simulation Model) there are several steps to follow. The main aim is to minimize the error between simulated vs. observed data. Firstly, it is important to select an appropriate dataset for calibration. To obtain an optimal calibration in terms of crop growth and development a dataset where no water or nutrient stress is present, as well as no biotic stresses are recorded. Basically, a dataset where yields are closer to yield potential situations. Two or more years are needed to calibrate a model. Often it is not easy to get such experiments, however if multiple years data are available for a given experiment then few years where higher yields were recorded will be chosen for calibration.

As a proper calibration practice the order of calibration is firstly soil water content, then phenology, then crop growth, then yield. However, in most situation soil water content is not available or some CSM only report crop phenology and growth as output. Therefore, as a minimum data set needed for calibration are observed flowering, maturity, and grain yield. Any additional data will greatly improve the ability of the model to simulate a given dataset. The CSM will be firstly calibrated against flowering date until the errors between simulated vs. observed data are minimized. Then, maturity date and after yield and yield components are calibrated.

**Crop model evaluation**

After a CSM has been calibrated it needs to be evaluated. The dataset to be used would be the ones where either water or nitrogen (or both in combination) are limiting. That is because we will evaluate the ability of model to simulate simulations that are below the optimal conditions. The same steps and issues regarding observed data that are discussed above apply here. The error between simulated vs. observed outputs are compared and the user will decide which level or error is acceptable.

If after model evaluation there is not good agreement between simulation and observation then a modeller should think where the issues lies, is this because there were no initial conditions (their lack is the main cause of failure of model evaluation), or because parameterization was wrong, or because the model used is not the right one for the task? Or maybe because some equations within the model are wrong? All these questions and steps can be optimized by a modeller who had enough experience in applying models for crop production.

The accuracy of the simulations in reproducing the observations can be evaluated using one of the following statistical indices:

$$D = Y_i - \hat{Y}$$

$$Bias = \frac{1}{N}\sum_{i=1}^{N} D_i$$

$$MSE = \left(\frac{1}{N}\right)\sum_{i=1}^{N}(D_i)^2$$

$$RMSE = \sqrt{MSE}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|D_i|$$

$$RRMSE = \frac{RMSE}{\bar{Y}}$$

$$EF = 1 - \frac{\sum_{i=1}^{N}(Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{N}(Y_i - \bar{Y})^2}$$

$$D - Index = 1 - \frac{\sum(Y_i - \hat{Y}_i)^2}{\sum(|\hat{Y}_i - \bar{Y}| + |Y_i - \bar{Y}|)^2}$$

Where $Y_i$ is the observed value, and the $\hat{Y}$ is the corresponding model's output. The Bias calculates the averages of the deviations (D) where N is the total numbers of data points to be compared. MSE is the Mean Square Error and its square root is the Root Mean Square Error (RMSE); $\bar{Y}$ is the average of the $Y_i$ values (Wallach et al., 2006).

# WP6 – Stakeholder engagement plan

Multi-stakeholder dialogue is necessary for the development of new innovative methods and techniques for water and nutrient use efficiency in order to understand the opportunities and potential obstacles to their utilisation. All Work Packages require some level of stakeholder interaction and engagement and the stakeholder analysis and engagement plan template will assist Work Packages to achieve dialogue and interaction throughout the course of the project. It comprises two key elements:

- Stakeholder analysis template which will help to identify relevant stakeholder groups (see Annex A) and analyse their respective interests in, and potential involvement with, the project's objectives and outputs. Guidance on successful engagement is also provided in Annex B.

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- Stakeholder engagement plan template which outlines two methods and timetable for engagement with specific stakeholder and end-user groups. Annex C provides a way of keeping an updated list of engagement activity that is designed to be high level and easy to complete. Annex D is a template for a more intensive recording period should this be appropriate at a particular stage of the project.

Previous experience suggests that stakeholder analysis and planning for stakeholder engagement in a multi-actor project needs to be seen as an iterative process. One size does not fit all and for some participants the process will be somewhat removed from their previous experience. The process asks science leads in the WPs to think somewhat differently in relation to 1) how they interact with stakeholders as they develop their science and also 2) who these stakeholders are and how their input can enhance science development. At this stage we have included a comprehensive engagement plan that may generate some concerns from the science leads with respect to their ability to complete it. The engagement plan can be adapted to suit particular research contexts and this can be revised.

Thus, it will likely be necessary to revise this plan in response to feedback from scientist and stakeholder alike as well as new understandings that may arise during the course of the project. It is proposed that WP6 keeps abreast of developments and then revise the plan whenever there are significant changes or additions to be made.

## Stakeholder Analysis

This section describes how the stakeholder analyses can be carried out and explains how the information can be organised in the tables (i.e. according to stakeholder groups, roles and interests, and prioritisation of importance and influence).

A stakeholder analysis is the process of identifying:

- The right individuals and groups to involve in your project
- What roles they should play and at which stage
- Who to build and nurture relationships with
- Who to inform and consult
- How to ensure the process is inclusive

Carrying out the stakeholder analysis can help to:

- Predict possible areas of conflict
- Identify relationships between stakeholders
- Consider the relevant expertise needed from each stakeholder
- Decide upon the most appropriate methods for engagement
- Determine their level of influence, willingness to engage, and potential impact on the project (or the project's potential impact on them)

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The main steps used to conduct the stakeholder analysis in each case study region are as follows:

1. Create a list of stakeholders
2. Identify their interests and roles in relation to the project
3. Prioritise them according to their importance to, and influence over, the project

The following questions can guide this process:

- Who are the stakeholders?
- What will the stakeholder(s) want or expect from the project? (If everyone's motivations can be clarified from the start, there will be less confusion and stakeholders are more likely to be satisfied with the outcomes.)
- What are the likely benefits for them?
- What resources will the stakeholder wish to commit to the project, if at all?
- What interests do they have that may conflict with the project?
- Is the group diverse enough, i.e. is there gender, ethnic and regional balance in the project?

In order to investigate stakeholder inter-relations it will also be useful to ask the following questions[1]:

- How does the stakeholder regard others and is regarded by others on the list?
- What partnerships/linkages exist between stakeholders?
- Who is responsible for making decisions relating to policy, finance, uptake of technologies?

The first step in the stakeholder analysis for a given case study is to identify the stakeholders. This can be done primarily through brainstorming among project partners in a given case study region. The project team may not know all the potential stakeholders that could be involved, and a 'snow-balling' technique is likely to be applied whereby stakeholders are consulted on who else should be involved.

The potential stakeholder groups are listed below:

Public sector

- National government
- State land management services
- Political authorities prescribed by national laws (e.g., elected representatives at village or district levels)
- Agencies with legal jurisdiction over the relevant natural resources (e.g., a state park agency with or without local offices)
- Local governmental services (e.g., education, health, forestry and agriculture extension)
- Government authorities at district and regional level
- Staff and consultants of relevant projects and programmes

[1] For an overview of stakeholder analysis methods including methods for investigating stakeholders relationships see Reed, M.S. et al. 2009 "Who's in and why? A typology of stakeholder analysis methods for natural resource management" *Journal of Environmental Management* 90:1933-1949. A particularly useful method is the 'Actor-linkage' matrix.

- Local and regional media

Private sector

- Landowners
- Relevant businesses and commercial enterprises (from local cooperatives to international corporations)
- Industry bodies
- Staff and consultants of relevant projects and programmes
- Local, regional and national media

Non-government organisations

- Community-based groups (e.g., self-interest organizations of resource-users, neighbourhood associations, gender or age-based associations, etc.)
- Non-governmental bodies that link different relevant communities (e.g., a council of village representatives, a district-level association of fishermen societies)
- Relevant non-governmental organizations (e.g., dedicated to environment or development) at local, national and international level
- Cultural and voluntary associations (e.g., a club for the study of unique national landscapes, an association of tourists)
- Staff and consultants of relevant projects and programmes
- Environment or development groups at local, national and international level

Research Agencies

- Universities and other research establishments

International stakeholders (European level)

- Staff and consultants of relevant projects and programmes
- European Commission (SEC GEN, DGs RTD, AGRI, ENV and JRC)
- International government bodies (e.g. UNICEF, FAO, UNEP, EPPO)

A basic checklist for potential stakeholders is shown in Annex A.

Categories such as gender, age, disability and ethnicity may cut across stakeholder groups, or may be represented as sub-groups, for example a local NGO that supports an ethnic minority group in their struggles for access to land. Note that some stakeholders could be included in more than one group in the stakeholder analysis.

In the context of SoLACE, the stakeholder analysis also helps to identify and focus attention on stakeholders who could be involved in the design or development of technologies and/or potential end users. However, 'end-use' can be seen on a continuum rather than as a discrete group of individuals or agencies that will be able to use the toolbox directly themselves. A typology of end users is proposed below:

a) Direct users of the technology who are trained in its use, or who were involved in its development.
b) Indirect users, i.e. stakeholders who may contract or request direct users to conduct assessments via the technologies on their behalf.
c) Interested users, i.e. stakeholders who may wish to be consulted during the development or use of the technologies to improve the quality of assessments for scenarios of relevance to them.
d) Passive users, i.e. those who use the results of analyses to inform their own work but do not wish to be involved (e.g. policymakers and planners).

The stakeholder analysis prioritises stakeholders according to their perceived importance and influence.

Important stakeholders are those that are key to the project's success and whose problems, needs and interests are considered priorities for the project. The following questions may help identify important stakeholders:

- Do they have an interest in the project?
- Do they have a need or problem related to the project?
- Will they affected by the results?
- Do they have information you need?
- Do they look after the interest of people who will be affected by the results?

Influential stakeholders are those who may have some power over the project. They may exert some influence which affects the project positively or negatively and/or they may be able to coerce or persuade others into making decisions about the project. To identify whether stakeholders are influential it may help to ask:

- Do they control decisions about the project?
- Do they exert an influence or power over the project?
- Do they have important connections e.g. to politicians, or budget holders?
- Do they have high standing within the X 'community'?
- Can they affect the image of the project?

For the purposes of SoLACE, 'importance' and 'influence' have been combined, and presented in a single column in the stakeholder analyses in the Annexes. This is because the two terms will likely overlap in the majority of cases e.g. few stakeholders may be regarded as important but not influential, and vice versa. Stakeholders will be given high priority in the stakeholder analyses if they were either important or influential or both. However, if the distinction between importance and influence is considered helpful, this can be flagged up in the analysis report for that particular stakeholder.

Some social groups are likely to be under-represented in land-use related decision-making, and a special effort is required to ensure that they are identified and involved appropriately in the project. In UK such positive engagement to promote equality (e.g. according to gender, ethnicity and disability) is a legal requirement for all public authorities and their partners. This approach should be adopted as best practice in all stakeholder engagement and dissemination activities in the project.

When identifying stakeholders, it is also important to think about representation and about the relationship between an individual and their organisation, and between an individual and individual researchers. For example, many of the stakeholders listed above are groups, but you will probably know a particular person who is working in the organisation. As you get to know a stakeholder colleague better, they may offer you personal as well as professional representative information. This is not a problem as long as you are mindful of needing representative perspectives as well.

In addition, not all people are equal in stakeholder terms; some individuals have more knowledge and skills in relation to a project than others. There is thus a balance in considering representation and individual knowledge and skills. Some people will be easier to engage; also something to remember.

With all stakeholders, it is important to make the prioritisation process transparent and to note the reasons for selection of stakeholders so that any queries about who is eventually involved in the project can be answered.

## Stakeholder engagement plan

After the stakeholder analysis has been completed the next step is to prepare a stakeholder engagement plan that outlines how the project will involve each stakeholder that has been identified. The engagement plan template is given in Annex B and can be structured around each task. It allows for occasional and intensive recording of engagement to get a wider sense of the nature of the engagement across the project over time.

For each task, the table uses separate columns to provide the following:

- The lead Work Package
- Dates for carrying out and completing the task
- A description of the stakeholder engagement activity associated with the task, and the objectives, scope and desired outcomes
- The stakeholder groups (and actual representative) involved in the activity
- The level of engagement for each stakeholder group listed in the previous column according to three categories (inform, consult, involve – see below)
- The method and type of forum for engagement (meetings/workshops, surveys, one-to-one, focus groups, online forum, road shows, stakeholder networks, stakeholder panels or committees, public meeting or forums etc.)
- Whether or not the task has been completed, and by whom
- Stakeholder feedback and comments on the engagement activity

As mentioned in the previous section, three broad levels of engagement have been highlighted in the plan. Stakeholders are thus:

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- involved in its design and implementation;
- consulted about key elements and/or
- informed about the project and its outputs.

This typology can be seen as a simplified version of Arnstein's Ladder of Participation, which identifies a continuum of public engagement as follows: citizen control, delegated power, partnership, placation, consultation, informing, therapy, and manipulation. The 'higher' levels of participation should not be seen as necessarily 'better'; rather we need to identify the appropriate level of engagement (and means of engagement) for each stakeholder that optimises mutual benefits while minimising associated costs such as 'stakeholder fatigue'.

Numerous sources of advice are available on how to carry out successful stakeholder analysis and engagement (see references below). A list of 15 principles of engagement has been developed by SustainAbility (2007: 3-4), which offers useful guidance for the stakeholder engagement activities of the project. They are reproduced in Annex B.

WP6 plans to monitor and evaluate the effectiveness and quality of engagement processes and activities by asking stakeholders where possible to provide feedback on the multi-actor process. A flexible approach will ensure that revisions and improvements can be developed iteratively. This process may also lead to revisions of the stakeholder analysis and engagement plan.

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# Annexes

## A. Checklist for stakeholder identification

| Stakeholder* | stakeholder group | | | |
|---|---|---|---|---|
| | Public | Private | NGO | Research |
| Individuals (e.g., owners of land holdings and companies) | | x | | |
| Families and households (e.g., long-term local residents) | | x | | |
| Traditional groups (e.g., extended families and clans) | | x | | |
| Community-based groups (e.g., self-interest organizations of resource-users, neighbourhood associations, gender or age-based associations, etc.) | x | x | x | |
| Local traditional authorities (e.g., a village council of elders, a traditional chief) | x | x | x | |
| Political authorities prescribed by national laws (e.g., elected representatives at village or district levels) | x | x | x | |
| Non-governmental bodies that link different relevant communities (e.g., a council of village representatives, a district-level association of fishermen socie-ties) | | | x | |
| Local governance structures (administration, police, the judicial system) | x | | | |
| Agencies with legal jurisdiction over the relevant natural resources (e.g., a state park agency with or without local offices) | x | | | |
| Local governmental services (e.g., education, health, forestry and agriculture extension) | x | | | |
| Relevant non-governmental organizations (e.g., dedicated to environment or development) at local, national and international level | x | x | x | x |
| Political party structures (at various levels) | x | | | |
| Religious bodies (at various levels) | x | x | x | |
| National interest organizations (e.g., a workers' union — also called people's associations) | x | x | x | |
| National service organizations (e.g., the Lions Club) | | | x | |
| Cultural and voluntary associations (e.g., a club for the study of unique national landscapes, an association of tourists) | x | | x | |
| Businesses and commercial enterprises (from local cooperatives to international corporations) | | x | x | |
| Universities and research organizations | | | | x |
| Local banks and credit institutions | | x | x | |
| Government authorities at district and regional level | x | | | |
| National governments | x | | | |
| Foreign aid agencies | x | x | x | x |
| Staff and consultants of relevant projects and programmes | x | x | x | x |
| International government bodies (e.g., UNICEF, FAO, UNEP) | x | | | x |
| International unions (e.g., IUCN) | x | x | | x |

*Adapted from: 'Checklist for stakeholder identification' (Borrini-Feyerabend, 1997).

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### B. Guidance for successful stakeholder engagement

1. Engage on issues that matter: focus on clear objectives and material business needs that require action. Show how engagement will add value.
2. Be ready to act: use engagement to drive decisions, not as a public relations exercise. Remember stakeholders have limited time.
3. Engage the right stakeholders: ensure the process is inclusive and diverse. Consider stakeholders' expertise, level of influence, willingness to engage and impact on the project.
4. Engage empowered representatives who are able to take decisions on behalf of their constituents and have the mandate to 'step out of the comfort zone'.
5. Determine shared value: ensure that each stakeholder benefits directly from the engagement and understands how the others benefit.
6. Agree rules of engagement: establish the scope, objectives, roles, rules and risks of engagement at the beginning. Agree on the process for decision making, conflict resolution and evaluation.
7. Manage expectations: make certain that all parties have realistic ambitions and agree on clear outcomes of the engagement. Stakeholders' perspectives are used to inform decision-making, but the responsibility for the decision rests with the project partners.
8. Provide adequate resources: time, money and people, to ensure success. Where appropriate, reimburse stakeholders for their time and expenses, or allow them to nominate a charity to receive an equivalent amount as a donation.
9. Choose the right format: e.g. private meetings, roundtable discussions, stakeholder panels, etc, to achieve the objective of engagement.
10. Level the playing field: be sensitive to perceived or actual power differences and facilitate the process to allow fair participation. Facilitators should be objective and trusted, striving to amplify stakeholder voices where required.
11. Listen to (critical) stakeholder views: ensure engagement is a dialogue and not a one-way information feed. Allow stakeholders to voice their views without restriction and fear of penalty or discipline.
12. Build trust: take time to build trust based on the personal chemistry of the individuals and the common values of the organisations involved. Commit to long term relationships with stakeholders.
13. Be open: responsive, consistent and timely in communications. Communicate well in advance, document the engagement rational and processes and allow for stakeholder feedback.
14. Be accountable: link the engagement process to core business decision-making and corporate governance. Provide clear actions and/or response following the engagement.
15. Look beyond the engagement: learn from the engagement. Involve stakeholders to assess the steps of both the processes of engagement as well as its outcome. Examine whether any next steps are required.

*Adapted from 'Principles of engagement' (SustainAbility, 2007: 3-4).

### C. Occasional recordings of important stakeholder engagement

| Activity (include link to Milestone/ Deliverable if relevant) | Project members involved | Date | Stakeholder engagement activities associated with this task | Stakeholders present | Level of participation | Engagement methods | Task completed by | Key discussion points | Outcomes |
|---|---|---|---|---|---|---|---|---|---|
| *Kick off meeting* | *All team* | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

### D. Stakeholder engagement record – intensive recording

| Activity (include link to Milestone/Deliverable if relevant) | Project members involved | Date | Stakeholder engagement activities associated with this task | Stakeholders present | Level of participation | Engagement methods | Task completed by | Key discussion points | Outcomes |
|---|---|---|---|---|---|---|---|---|---|
| **Year 1 Feb/Mar 2015**<br><br>**2 week period** | | | | | | | | | |
| *Kick off meeting* | *All team* | | | | | | | | |
| | | | | | | | | | |
| **Year 2 Sep/Oct 2015** | | | | | | | | | |
| | | | | | | | | | |

# 5. PARAMETERS MEASURED AND CALCULATED - DEFINITIONS AND PROTOCOLS

This section is organized in three different sub-sections: 1) there is a list of Parameters and their definitions that are measured or calculated within SolACE, 2) there are definitions of concepts, such as Nitrogen Use Efficiency, Water Use Efficiency, or model calibration, that are central to the project, and 3) there are detailed protocols on how data are collected within SolACE tasks.

## 5.1 Parameters measured and calculated in SolACE

*There is an extensive table of parameters derived from the ICASA Data Standards that contains the coding we use for each parameter. WP Leaders shall signal in the table which parameters are relevant from the data standard for their WP work, and in this document only these shall be listed together with their codes and definitions. In case new parameters need to be added to the data standard, this shall be signalled in the excel table, and shall be coded and defined here.*

WP1: The data for the modelling will be arranged around the concept of **"Minimum Data Set" (MDS)** that is the minimum amount of data needed to run, calibrate, and evaluate the model. In addition, other data [**"Additional Data" (AD)]** that will be available will greatly improve model calibration/evaluation. The following parameter list will eventually grow as the project proceeds because it will depend on experiments that might not be yet planned by other WPs. This list of data and the variable header is linked to the SolACE Data Template which is dealt with in T1.2.

**N.B. this is a non-exhaustive list, a complete list of variable can be found at:**
**https://docs.google.com/spreadsheets/d/1MYx1ukUsCAM1pcixbVQSu49NU-LfXg-Dtt-ncLBzGAM/pub?output=html#**
**The variables highlighted on this list are the ones that are required as part of the Minimum Data Set (MDS); any other variable measured is additional and will greatly help the modelling of the crop.**

### Weather data:

*Daily weather data for one or more years (e.g. 3 years or 30 years). Preferably a long-term weather data series would be needed (e.g. 1980-2017). The variables needed as MDS are:*

- **WID:** Weather station ID, Identifier of the weather station;
- **WST_NAME:** Name of the weather station;
- **WST_LAT:** Latitude of the weather station (in Decimal, WGS84);
- **WST_LON:** Latitude of the weather station (in Decimal, WGS84);
- **WST_ELEV:** Elevation of the site (in m above the sea level);
- **YEAR:** Year of the record (4-digits, e.g. 1980);
- **MONTH:** Month of the record (2-digits, e.g. 04);
- **DOY:** Day of year (2-digits, e.g. 365);
- **SRAD:** Daily solar radiation (MJ $m^{-2}$ $d^{-1}$);
- **TMAX:** Daily maximum air temperature (°C);
- **TMIN:** Daily minimum air temperature (°C);
- **RAIN:** daily rainfall (mm);

- **RHUMD:** Relative humidity (%);
- **VPRSD:** Air vapour pressure (kPa);

## Experiment details:

- **TRTNO:** Treatment number;
- **RP:** Treatment replicate;
- **FE:** Fertiliser level;
- **WLE:** Irrigation level;
- **Brief description of what the experiment is about (e.g. water and N interaction)**
- **YEAR:** year of the experiment (4-digits, e.g. 2018);
- **MONTH:** month in which any sampling/management operation occurred (2-digits, e.g. 03);
- **DAY:** Day of the month in which the sampling or management (e.g. fertilisation) takes place (2-digits, e.g. 31);

## Management:

- **CRID:** Crop ID;
- **CUL_ID:** Cultivar, line or genotype identifier;
- **CUL_NAME:** Cultivar name
- **ICPCR:** Previous crop name residue (e.g. wheat = WH, this is to be found in the data dictionary of T1.2);
- **ICRIP:** Residue incorporation percentage (%);
- **ICRAG:** Residue above-ground weigh (dry weight basis kg $ha^{-1}$);
- **PLYR:** Planting year (4 digits, e.g. 2018);
- **PLDOY:** Day of year of planting (3-digits, e.g. 105 or 002);
- **PLPOP:** Plant population at planting (number $m^{-2}$);
- **PLRS:** Row spacing (cm);
- **PLDP:** Planting depth (cm);
- **IR_TOT:** Total amount of irrigation applied during the whole growing season (if applicable) (mm);
- **IR_#:** total number of irrigation applications from sowing to harvest;
- **IRYR:** Year in which irrigation was applied during the growing season, relevant for experiment that are planted in November of one year and harvested in the next year (4 digits, e.g. 2017, 2018);
- **IRDOY:** Day of year in which irrigation is applied (3-digits, e.g. 004);
- **IROP:** Irrigation operation (e.g. furrow, sprinkler, drip) (3-digit code which is listed in detail in the ICASA data standard defined in T1.2);
- **FEN_TOT:** Total amount of Nitrogen (N) applied during the growing season (kg N $ha^{-1}$);
- **FEN_#:** Total amount of N applications during the growing season;
- **FEYR:** Fertilizer application year (4-digits, e.g. 2017);
- **FEDOY:** Day of year in which the fertilizer is applied;
- **FECD:** Fertilizer material (e.g. urea, ammonium nitrate, and so on; a complete code is reported in the ICASA variable standards highlighted in T1.2);

- **FEACD:** Fertilizer application method (e.g. broadcast incorporated, banded on surface, and so on, a complete code is reported in the ICASA variable standards highlighted in T1.2);
- **FEDEP:** Fertilizer application depth (cm);
- **FEAMN:** N in applied fertilizer (kg N $ha^{-1}$);

## Soil:

- **SLDLB:** Soil depth at the bottom of the layer (cm);
- **SLCLY:** Soil clay content (%);
- **SLSIL:** Soil texture, silt (0.05 to 0.002 mm), weight percent of fine earth (%);
- **SLSND:** Soil texture, sand (0.05 to 2.0 mm), weight percent of fine earth (%);
- **SLCF:** Soil texture, coarse fraction (>2 mm), weight percent of fine earth (%);
- **SLSAT:** Soil water, saturated ($cm^3$ $cm^{-3}$);
- **SLDUL:** Soil water, drain upper limit ($cm^3$ $cm^{-3}$);
- **SLLL:** Soil water, lower limit ($cm^3$ $cm^{-3}$);
- **SKSAT:** Saturated hydraulic conductivity (cm $h^{-1}$);
- **SLBDM:** Soil bulk density when moist for layer (g $cm^{-3}$);
- **SLOC:** Total soil organic carbon by layer (%);
- **SLNI:** Total soil nitrogen by layer (%);
- **SLPHW:** pH of soil in water, from profile description;
- **INISW:** Initial water concentration by layer (Volumetric water, %);
- **SWGS:** Soil water content at depth during the growth season (Volumetric water, %);
- **SWHA:** Soil water content at harvest (Volumetric water, %);
- **SWXM:** Extractable soil water at maturity (mm);
- **AMIN:** Initial $NH_4$ concentration, as elemental N on a dry weight basis, by soil layer (mg $kg^{-1}$);
- **NHSLD:** NH4 measured during the growing season (g $Mg^{-1}$);
- **NOSLD:** NO3 measured during the growing season (g $Mg^{-1}$);
- **NIIN:** Initial $NO_3$ concentration, as elemental N on a dry weight basis, by soil layer (mg $kg^{-1}$);
- **NIAM:** N, inorganic in soil at harvest maturity (kg N $ha^{-1}$);

## Plants:

- **LAID:** Leaf area index on a given day ($m^2$ $m^{-2}$);
- **CWAD:** Tops dry weight on a given day (kg $ha^{-1}$);
- **CWAA:** Tops dry weight at anthesis (kg $ha^{-1}$);
- **CWAM:** Tops dry weight at maturity (kg $ha^{-1}$);
- **GWAM:** Tops dry weight at maturity (kg $ha^{-1}$);
- **GPR%M:** Grain protein concentration at maturity (%);
- **ADOY:** Anthesis date as Day of Year (3 digits, e.g. 004);
- **MDOY:** Growth stage of physiological maturity in Day of Year (3 digits, e.g. 170);
- **YEAR:** Year in which the measurement has been made (e.g. the year in which anthesis was recorded, 4 digits e.g. 2018);
- **CNAA:** Nitrogen in above ground plant parts at anthesis (kg N $ha^{-1}$);
- **CNAM:** Nitrogen in above ground plant parts at maturity (kg N $ha^{-1}$);
- **GNAM:** Grain N at maturity (kg N $ha^{-1}$);

- **GN%M:** Grain N concentration at maturity (%);
- **SNAM:** Stems N at maturity (kg N $ha^{-1}$);
- **TNIM:** Total N at maturity (kg N $ha^{-1}$);
- **CN%D:** Tops (i.e. canopy) N concentration (%);
- **UNAM:** Tuber N at harvest (kg $ha^{-1}$);
- **UWAD:** Tuber dry weight (kg $ha^{-1}$);

# WP5

## T5.2 Potato on-farm trials

It is anticipated that a technician/research associate will visit the farms a few times each year for sample/data collection. Soil sampling will be done on at least one of these occasions. For potatoes, a visit to collect whole plant samples just prior to senescence will take place later in the season. A final visit will be required for tuber harvest, yield assessment and soil sampling.

Parameters to measure:

- Soil
    - for initial characterisation, only once at beginning of trials (from FiBL template): SDEPTH, CLAY, SILT, SAND, STONE, BD, OM, TN, PHW
    - Every year sometimes in winter/prior to planting: PEX
    - For potatoes following legumes where NitUE will be studied
        - Soil mineral N sampling (AMIN, NIIN) prior to planting to rooting depth (suggest 60 cm for potatoes, often divided into two horizons: 0-30 cm and 30-60 cm). Note: for soil mineral N analysis samples are usually frozen until analysis.
        - Soil mineral N sampling (AMHA, NIHA) post-harvest to same depth. This provides an indicator of N leaching risk.
- Management – all relevant parameters as listed in FiBL template (including YMP)
- Plant
    - From FiBL template: EDATE, PB89, PB89P, PB89N, YMPP, YMPN

Calculated parameters P studies i.e. with inoculants:

- AVP = Total P[2] from fertiliser (kg P/ha) or available P from organic fertiliser (kg P $ha^{-1}$)
    - Where no amendments have been applied, it is not possible to calculate AVP (P supply)
- PUE (phosphorus use efficiency; kg DM (kg $P)^{-1}$) = YMP/AVP
- PUp89 (P uptake GS89; kg P $ha^{-1}$) = PB89P x PB89/100
- PUpE89 (P uptake efficiency; unitless) = PUp89/AVP
- PUtE89 (P Utilization Efficiency; kg DM (kg $P)^{-1}$) = YMP/PUp89
- HI (harvest index; unitless) = YMP/PB89
- PHI (P harvest index; P accumulated in the biomass at harvest/total P accumulated GS89; unitless) = (YMPP x YMP/100)/PUp89

[2] Be very careful with units for fertiliser P. In many places the standard unit of P in fertilisers is $P_2O_5$. This is NOT the same as P. 1 kg $P_2O_5$ x 0.437 = 1 kg P

Calculated parameters N studies i.e. where grain legumes are included in the rotation:

- AVNF (available nitrogen from fertilisers; kg $ha^{-1}$) – this is the total N in mineral fertilisers; for organic N sources, it should be the ammonium-N + nitrate-N in the organic material based on laboratory analysis
- SMNIN (soil mineral N initial; kg N $ha^{-1}$) = (AMIN + NIIN)(mg/kg) x BD (g $cm^{-3}$)/10
- TAN (total available N; kg $ha^{-1}$) = SMNIN + AVNF
- Nit-UE (kg DM $(kg\ N)^{-1}$) = YMP/TAN
- Fert-Nit-UE (fertilizer Nit-UE; kg DM $(kg\ N)^{-1}$) =YMP/AVNF
- NUp89 (N Uptake GS89; kg N $ha^{-1}$) = PB89N x PB89/100
- NUpE (nitrogen uptake efficiency; kg N $(kg\ N)^{-1}$) = NUp89/TAN
- NUtE (nitrogen utilization efficiency; kg DM $(kg\ N)^{-1}$) = YMP/NUp89
- NHI (nitrogen harvest index; kg N $(kg\ N)^{-1}$) = YMPN/PB89N

### T5.2 Durum wheat on-farm trials

Parameters to measure:

It is anticipated that a technician/research associate will visit the farms a few times each year for sample/data collection. Soil sampling will be done on at least one of these occasions. For Durum wheat, no mid-season visits are required for sampling purposes, but at maturity, close to harvest time, whole plant samples should be collected for assessment of harvest components. Post-harvest a visit may be required for mineral N sampling.

- Soil
  - for initial characterisation, only once at beginning of trials (from FiBL template): SDEPTH, CLAY, SILT, SAND, STONE, BD, OM, TN, PHW, PEX
  - Soil mineral N sampling (AMIN, NIIN) prior to planting to rooting depth (suggest up to 90 cm for Durum wheat, often divided into three horizons: 0-30 cm, 30-60 cm and 60-90 cm). Note: for soil mineral N analysis samples are usually frozen until analysis.
  - Soil mineral N sampling (AMHA, NIHA) post-harvest to same depth. This provides an indicator of N leaching risk.
- Management – all relevant parameters as listed in FiBL template (including YMP)
- Plant
  - From FiBL template: WHA, WGRAIN, WNGS, WNHA, GRN, GNUM, TKW, SPN, STNGS, STNHA, LFNGS, LFNHA

Calculated parameters:

- AVNF (available nitrogen from fertilisers; kg $ha^{-1}$) – this is the total N in mineral fertilisers; for organic N sources, it should be the ammonium-N + nitrate-N in the organic material based on laboratory analysis
- SMNIN (soil mineral N initial; kg N $ha^{-1}$) = (AMIN + NIIN)(mg $kg^{-1}$) x BD (g $cm^{-3}$)/10
- TAN (total available N; kg $ha^{-1}$) = SMNIN + AVNF
- Nit-UE (kg DM $(kg\ N)^{-1}$) = WGRAIN/TAN
- Fert-Nit-UE (fertilizer Nit-UE; kg DM $(kg\ N)^{-1}$) =WGRAIN/AVNF

- NUp (N Uptake harvest; kg N $ha^{-1}$) = WNHA (may need calculating from yield of harvest components and N analysis of these)
- NUpE (nitrogen uptake efficiency; kg N (kg $N)^{-1}$) = NUp/TAN
- NUtE (nitrogen utilization efficiency; kg DM (kg $N)^{-1}$) = WGRAIN/NUp
- HI (harvest index; kg grain (kg $biomass)^{-1}$) = WGRAIN/WHA
- NHI (nitrogen harvest index; kg N in grain (kg N in $biomass)^{-1}$ at harvest) = GRN/WNHA

## T5.2 Bread wheat on-farm trials

Parameters to measure:

It is anticipated that a technician/research associate will visit the farms a few times each year for sample/data collection. Soil sampling will be done on at least one of these occasions. For Bread wheat, no mid-season visits are required for sampling purposes, but at maturity, close to harvest time, whole plant samples should be collected for assessment of harvest components. Post-harvest a visit may be required for mineral N sampling.

- Soil
    - for initial characterisation, only once at beginning of trials (from FiBL template): SDEPTH, CLAY, SILT, SAND, STONE, BD, OM, TN, PHW, PEX
    - Soil mineral N sampling (AMIN, NIIN) prior to planting to rooting depth (suggest up to 90 cm for Bread wheat, often divided into three horizons: 0-30 cm, 30-60 cm and 60-90 cm). Note: for soil mineral N analysis samples are usually frozen until analysis.
    - Soil mineral N sampling (AMHA, NIHA) post-harvest to same depth. This provides an indicator of N leaching risk.
- Management – all relevant parameters as listed in FiBL template (including YMP)
- Plant
    - From FiBL template: WHA, WGRAIN, WNGS, WNHA, GRN, GNUM, TKW, SPN, STNGS, STNHA, LFNGS, LFNHA

Calculated parameters:

- AVNF (available nitrogen from fertilisers; kg $ha^{-1}$) – this is the total N in mineral fertilisers; for organic N sources, it should be the ammonium-N + nitrate-N in the organic material based on laboratory analysis
- SMNIN (soil mineral N initial; kg N $ha^{-1}$) = (AMIN + NIIN)(mg $kg^{-1}$) x BD (g $cm^{-3}$)/10
- TAN (total available N; kg $ha^{-1}$) = SMNIN + AVNF
- Nit-UE (kg DM (kg $N)^{-1}$) = WGRAIN/TAN
- Fert-Nit-UE (fertilizer Nit-UE; kg DM (kg $N)^{-1}$) =WGRAIN/AVNF
- NUp (N Uptake harvest; kg N $ha^{-1}$) = WNHA (may need calculating from yield of harvest components and N analysis of these)
- NUpE (nitrogen uptake efficiency; kg N (kg $N)^{-1}$) = NUp/TAN
- NUtE (nitrogen utilization efficiency; kg DM (kg $N)^{-1}$) = WGRAIN/NUp
- HI (harvest index; kg grain (kg $biomass)^{-1}$) = WGRAIN/WHA
- NHI (nitrogen harvest index; kg N in grain (kg N in $biomass)^{-1}$ at harvest) = GRN/WNHA

## 5.2 Definitions of central concepts in SolACE

# WP1

**Crop Simulation Model (CSM):** a process-based model where daily crop growth, development and yield are simulated as function of soil, weather, management, and crop information. The model is affected by water and nutrient stresses. A crop simulation model uses several inputs, they change from model to model. But, as an overall generalization a CSM uses as input:

- Soil: the soil data are generally needed at depth at given intervals, the details of soil data needed changes among CSM;
- Weather: daily or hourly weather data;
- Management: agronomic management such as sowing, fertilization, tillage and so on;
- Initial conditions: they are usually associated as “boundary conditions” of a CSM, they are initial water and nitrogen content. The Initial conditions are generally measured before sowing.

**Genetic coefficients:** a set of parameters that define a given crop genotype and its development, growth, yield, yield components.

**Model calibration:** a parameterization of the crop model to improve its ability to reproduce phenology, yield and growth of a given dataset.

**Model evaluation:** the comparison of an independent dataset not used for model calibration and the crop model simulation runs for evaluating the ability of the model to reproduce the data patterns.

**Seasonal run:** a set-up of a particular CSM where an experimental set up is reproduced by changing the weather input, but all the other conditions are kept the same (e.g. same initial conditions and management every year). The reader might think a seasonal run as an “experiment” where all the conditions are the same and the only variable change is the weather data. This allows to draw probabilistic functions of the effects of weather/climate on a given management strategy.

**Yield potential simulation:** Is the simulation of crop yield as influenced only by the cultivar genetic, air temperature, air CO2 concentration, and solar radiation. There will not be water or nutrient stress, and no biotic stress.

# WP5 (and all WPs)

Definitions of **Nitrogen Use Efficiency (NUE)**, and other N-related efficiencies have to be agreed upon:

1. **Nit-UE [kg DM (kg N)$^{-1}$]:** which reflects increased yield per unit applied nitrogen (Good *et al.*, 2004). This should be calculated as grain yield divided by the total available N (see Table 3).
    a. Total available N should include a measured or estimated value for mineral N in the soil ($N_{min}$). This is the mineral N available to the crop at the time of growth initiation in the spring; usually Feb/Mar in the UK, measured to rooting depth (a standard depth of 90

cm is used in the UK). The $N_{min}$ value is added to the N available in the fertiliser ($N_{avf}$) to get the total N available to the crop ($N_{tav}$).

  b. In cases where the N available in the soil is not measured or estimated, the $N_{avf}$ only can be used as a proxy for $N_{tav}$. Nit-UE calculated from fertiliser N only, would more correctly be called fertiliser Nit-UE (Nit-$UE_{avf}$).
  c. **Nit-UE = Yield (kg DM $ha^{-1}$)/$N_{tav}$ (kg N $ha^{-1}$)**
  d. **Fert-Nit-UE** = **Yield (kg DM $ha^{-1}$)/$N_{avf}$ (kg N $ha^{-1}$)**

2. **NUpE (kg N (kg N)$^{-1}$)** which measures the efficiency of N uptake into the plant (Good *et al.*, 2004). This should be calculated as Total N uptake by the crop (grain N + straw N) divided by the total available N (see Table 3), or **NUpE = N-Tup (kg N $ha^{-1}$)/$N_{tav}$ (kg N $ha^{-1}$)**
3. **NUtE (kg DM kg $N^{-1}$)** which is the fraction of the total N in the plant converted into grain ((Good *et al.*, 2004). This should be calculated as the total grain yield divided by the total N uptake by the crop (see Table 3), or **NUtE = Grain yield (kg DM $ha^{-1}$)/N-Tup (kg N $ha^{-1}$)**
4. **Nitrogen Harvest Index (kg DM (kg N)$^{-1}$)** is the N in the grain at maturity divided by the total N uptake at maturity; **NHI = N-Gup (kg N $ha^{-1}$)/N-Tup (kg N $ha^{-1}$)**
5. **Agronomic efficiency (kg DM (kg N)$^{-1}$)** measures the efficiency that the crop converted applied N into yield. AE is calculated as: the yield of the fertilised plots minus the yield of the unfertilised control, all divided by the amount of fertiliser N applied (see Table 1 from Good et al, below for details). Where all of the fertiliser N is not readily available e.g. when an organic N source like compost is used, this can be calculated in two ways:
   a. **$AE_{TN}$ = ($Yield_{fert}$- $Yield_{ctrl}$)/$N_{tf}$**
   b. **$AE_{AN}$= ($Yield_{fert}$- $Yield_{ctrl}$)/$N_{avf}$**
6. **Apparent nitrogen recovery (%)** measures the efficiency of N capture from the soil. ANR is calculated as: Total N uptake in the fertilised treatment subtract the total N uptake in an unfertilised treatment, all divided by the amount of fertiliser N applied. Where all of the fertiliser N is not readily available e.g. when an organic N source like compost is used, this can be calculated in two ways:
   a. **$AR_{TN}$=[(N-$Tup_{fert}$ - N-$Tup_{ctrl}$)/$N_{tf}$] x100**
   b. **$AR_{AN}$=[(N-$Tup_{fert}$ - N-$Tup_{ctrl}$)/$N_{avf}$] x100**
7. **Physiological efficiency (kg DM (kg N)$^{-1}$)** measures the efficiency of capture of plant nitrogen in grain yield. PE is calculated as: the yield of the fertilised plot subtract the yield in the unfertilised control, all divided by the total N uptake in the fertilised plots subtract the total N uptake in the unfertilised plot (see Table 1 below for details). **PE = ($Yield_{fert}$- $Yield_{ctrl}$)/(N-$Tup_{fert}$ - N-$Tup_{ctrl}$)**

**Table I. Definitions and formulae used to describe nutrient use efficiency in plants**

| Eqn | Term | Formula | Definition | Comments | Refs |
|---|---|---|---|---|---|
| 1 | Nitrogen use efficiency | NUE = Sw ÷ N | Sw, shoot weight (DW); N, nitrogen content of shoots (DW) | Does not account for biomass increases | [10] |
| 2 | Usage index | UI = Sw × (Sw ÷ N) | Sw, shoot weight; N, nitrogen in shoots | Takes into account absolute biomass increase | [11] |
| 3 | Nitrogen use efficiency (grain) | NUE = Gw ÷ Ns | Gw, grain weight; Ns, nitrogen supply (g per plant) | Reflects increased yield per unit applied nitrogen | [12] |
| 4 | Uptake efficiency | UpE = Nt ÷ Ns | Nt, total nitrogen in plant; Ns, nitrogen supply (g per plant) | Measures efficiency of uptake of nitrogen into plant | [12] |
| 5 | Utilization efficiency | UtE = Gw ÷ Nt | Gw, grain weight; Nt, total nitrogen in plant | Fraction of nitrogen converted to grain | [12] |
| 6 | Agronomic efficiency | $AE = (Gw_F - Gw_C) \div N_F$ | $N_F$, nitrogen fertilizer applied; $Gw_F$, grain weight with fertilizer; $Gw_C$, grain weight of unfertilized control | Measures the efficiency of converting applied nitrogen to grain yield | [7] |
| 7 | Apparent nitrogen recovery | $AR = (N_F \text{ uptake} - N_C \text{ uptake}) \div N_F \times 100$ | $N_F$ uptake = plant nitrogen (fertilizer); $N_C$ uptake = plant nitrogen (no fertilizer); $N_F$ = Nitrogen fertilizer applied | Measures the efficiency of capture of nitrogen from soil | [7] |
| 8 | Physiological efficiency | $PE = (Gw_F - Gw_C) \div (N_F \text{ uptake} - N_C \text{ uptake})$ | $Gw_F$, grain weight (fertilizer); $Gw_C$, grain weight (no fertilizer) | Measures the efficiency of capture of plant nitrogen in grain yield | [7] |

Where a mid-season (anthesis) total above-ground biomass and partitioning into stems (culms), ears and leaves, was taken, the following parameters will be useful; see (Cox *et al.*, 1986):

8. **Nitrogen translocation (kg N ha$^{-1}$)** is the difference between the total plant N at anthesis (kg N ha$^{-1}$), and the N content of the leaf, stem and chaff at harvest (kg N ha$^{-1}$); **N-trans = N-Tup$_{anth}$ - N-Sup$_{harvest}$**
9. **Nitrogen translocation efficiency (%) = (N-trans/N-Tup$_{anth}$)×100**
10. **Contribution of N redistribution to seed N (%) (Dordas, 2009)** is calculated as the N translocated as a percentage of the N uptake by the grain; **NCont = (N-trans/N-Gup)×100**
11. **Post-anthesis N uptake (kg ha$^{-1}$)** calculated according to (Cox *et al.*, 1985) **PANU = N-Tup$_{harv}$ (kg N ha$^{-1}$) - N-Tup$_{anth}$ (kg N ha$^{-1}$)**

**Potatoes**

Calculation of many NUE parameters in potatoes is more challenging because by harvest time most of the total plant biomass has senesced. Suggested parameters and how to calculate them are listed here.

1. Nitrogen use efficiency: **Nit-UE**; kg DM yield (kg total available N)$^{-1}$
    a. Total available N should include a measured or estimated value for mineral N in the soil ($N_{min}$). This is the mineral N available to the crop at the time of growth initiation in the spring; usually Feb/Mar in the UK, measured to rooting depth (a standard depth of 90 cm is used in the UK). The $N_{min}$ value is added to the N available in the fertiliser ($N_{avf}$) to get the total N available to the crop ($N_{tav}$).
    b. In cases where the N available in the soil is not measured or estimated, the $N_{avf}$ only can be used as a proxy for $N_{tav}$. Nit-UE calculated from fertiliser N only, would more correctly be called fertiliser Nit-UE (Nit-UE$_{avf}$).
2. Nitrogen Uptake (**NUp**; kg N accumulation above ground biomass + kg N accumulation below ground biomass) at GS66 and GS89
3. **NUpE**; NUp/Total available N
4. Nitrogen Utilization Efficiency (**NitUtE**; kg plant dry matter accumulation/plant N accumulation) calculated at GS66 and GS89
5. **HI** is the ratio of tuber DM accumulation (yield) to total plant DM accumulation (biological yield) and it is an important trait for yield improvement in field crops (Zebarth *et al.*, 2004a; Fageria *et*

*al.*, 2008). This can be calculated using the final tuber yield and the biomass of the plant just prior to senescence (GS89).

**NHI** is defined as nutrient uptake in crop (tuber) divided by nutrient uptake in crop plus shoot (Zebarth *et al.*, 2004b). This index is very useful in measuring nutrient partitioning in crop plants, which provides an indication of how efficiently the plant utilized acquired nutrients for crop production (Fageria and Baligar, 2005). Therefore high NHI is associated with efficient N utilization (Fageria and Stone, 2006). This can be calculated as the tuber N accumulation at harvest/plant N accumulation at GS89.