EMPHASIS

D2.3. Mapping: list of existing and upcoming Infrastructures

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EUROPEAN INFRASTRUCTURE FOR PLANT PHENOTYPING

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Executive Summary

Objectives

The objective of EMPHASIS-prep is to develop a long term, distributed, pan-European infrastructure for state-of-the-art plant phenotyping experimental installations, which aims to improve crop performance to cope with climate changes and to keep pace with population growth. To tackle these global challenges, novel approaches to identify improved plant phenotypes and explain the genetic basis of agriculturally important traits are required. The new and existing plant phenotyping platforms use non-destructive, image-analysis based determination of the phenotype of plants and allow for a characterization of plant traits.

Plant researchers require to test the improvement of plant and crop performance by using all categories of plant phenotyping infrastructure (as described in the deliverable **D2.1. criteria list** for plant phenotyping infrastructure) which can and should be combined together in a multiscale plant phenotyping approach, ideally, within a coordinated infrastructure, linked with an integrated data management system for storing and analysing (meta)data, and with modelling platforms associated with the phenotyping platforms.

To be able to form this distributed plant phenotyping infrastructure and understand the comparability and/or differences between installations, it is essential to map the capacity, throughput, focus of plant phenotyping, species used in the installations, use of data management systems, and many more details about the installations. A key objective of EMPHASIS-PREP is to map the existing and upcoming infrastructures for controlled conditions to enable multi-scale phenotyping with open access to installations. Moreover, to test crop performance in a changing climate, setting up large experiments in different natural environments is needed, and mapping the field phenotyping facilities in Europe to form networks of fields is highly recommended.

Rationale

The mapping exercise has been done by EMPHASIS-PREP partners in extensive collaborations and discussions with the national plant phenotyping community in Europe. Extracting detailed information of the existing and upcoming infrastructures was done through surveys and workshops. Four regional workshops have been organized in different regions of Europe. Plant scientists of these regions were asked to present their plant phenotyping infrastructures and activities. Moreover, during these workshops networking moments and breakout sessions were allowing discussion on the demand of the plant phenotyping community and the criteria of EMPHASIS plant phenotyping infrastructure. Starting with this information the pillars of EMPHASIS could be confirmed in the criteria list, deliverable 2.1.

Furthermore, work package 2 (WP2), together with WP3 and WP4, developed multiple surveys to extract more details of these infrastructure. By this, an EMPHASIS database could be generated that contains information about the installation name, detail of the phenotyping installations set-up and experimental design, contact information, access models of the local infrastructure and meta-data details. Based on this database it was possible to develop a map which visualizes the different installations per region.

Main Results:

With the mapping efforts 182 plant phenotyping installations of controlled conditions, intensive fields and networks of fields have been mapped and stored in the EMPHASIS-PREP database.

Phenotyping under controlled conditions (i.e., in glasshouses and controlled environment chambers) represented the largest number of installations (112), the majority of which are automated. Most installations focus on shoot and canopy phenotyping and on species of agronomic importance, dominated by cereal crops; while a smaller number addresses root properties.

Phenotyping in field has been identified in 70 installations, with:

- 25 highly equipped fields located mainly in France, Germany, Belgium and the UK. The focus is on the major industrial agricultural productions (cereals, oil crops) in Europe, the exception being *Arabidopsis* that mostly serves basic research purposes. The installations use a large variety of equipment to monitor the crop properties and environmental conditions and generate high throughput datasets.
- 45 installations of networks of lean fields have been identified geographically scattered in Europe. The first and foremost aim of these field trials is crop research, as e.g. cereals crops, in agriculture-relevant conditions, with phenotyping on mainly canopy characteristics and yield. Many of these lean field sites increasingly use UAVs.

Virtual platforms as modelling and data management systems, have been mapped. A total of 116 plant models have been mapped. Many of these models are developed in France, Germany, Netherland and United Kingdom. The plant models are developed by different groups and for different aims, leading to a considerable diversity of species studied (e.g. legume species, crop species, perennial species…) and model predictions (e.g. prediction of root or shoot characteristics at plant or regional scales). An overview of the models is available under: https://emphasis.plant-phenotyping.eu/modelling

The data management is (partly/ in some sites) shifting from homemade solutions to some global e-infrastructures compliant with FAIR criteria and EPPN^{2020} requirements defining i) environmental and plant measurements ii) statistical analysis of phenotyping experiments, iii) information systems. These e-infrastructures are based on web services. These services facilitate the interactions between different installations and aim at linking EMPHASIS information within the so-called EMPHASIS-layer that will provide a unified models allowing single entry point queries in different information systems.

Finally, the broader European research infrastructure landscape has been analysed in order to identify potential synergies.

Contents

The Plant Phenotyping infrastructure landscape in Europe

The mapping journey

Four regional workshops have been organized, in different locations in Europe, to extract the existing and upcoming plant phenotyping infrastructures in pan-Europe. Plant scientists were asked to present their plant phenotyping infrastructures and activities during these workshops. The kick-off workshop was organised in Lisbon, in March 2017, were plant researchers of Italy, France, Portugal and Spain presented their existing and upcoming plant phenotyping installations and activities. The same was done in Vienna in April 2017 with presentations of national representatives of Czech Republic, Austria, Cyprus, Romania and Serbia. The third workshop was organised as a satellite-workshop of the SEB conference, on the 4th of July, in Gothenburg. The countries UK, Denmark, Finland, Norway and Sweden presented the national plant phenotyping landscape. Finally, in November 2017, a last dedicated regional workshop was organised, that time as a European plant phenotyping conference. The countries Belgium, Estonia, Germany, Ireland and Poland presented the plant phenotyping landscape. The description of the national plant phenotyping landscapes in Europe have been made public via the EMPHASIS homepage to foster information exchange across Europe and allow regular updates by the communities.

Starting with this information the criteria list could be made and pillars of EMPHASIS could be confirmed (see Deliverable 2.1). The journey to understand the plant phenotyping landscape in pan-Europe was initiated.

As described in detail in the criteria list, infrastructures were categorized in 5 plant phenotyping infrastructure categories:

1. Plant phenotyping in (semi-)controlled conditions.
2. Intensive field experiments in highly equipped field sites or semi-controlled field sites.
3. Field sites with minimal equipment, which could be combined in a network of fields with different environmental conditions.
4. Modelling platforms to support plant phenotyping data analysis.
5. Information systems for plant phenotyping data management supporting open science.

Parallel with the regional workshops, work package 2 (WP2), together with WP3 and WP4, had developed a first EMPHASIS survey for the plant phenotyping community to extract more details of these infrastructures. The survey was made available for participation by end 2017. With this survey, 136 installations were mapped in Europe, including 89 installation for controlled condition phenotyping (53%), 23 intensive field installations (14%), 31 lean fields (19%) and 24 modelling installations (14%). This information was analysed and used as a basis to develop an EMPHASIS-mapping database. Furthermore, out of this database a virtual map was created, and even though this map was still under development, by mid 2018 this map was published on the EMPHASIS website and made available to the benefit of the plant phenotyping community. The content of the map is constantly open for updates by the national communities, especially by the EMPHASIS Support Group members functioning as main link between EMPHASIS and the national communities. This virtual map (example shown in figure 1) contains the existing plant phenotyping installations in Europe for the installations of categories: controlled conditions and lean field and intensive field as provided by the national communities. Those are the physical installations in specific locations. Including virtual installation in this map would not be logical.

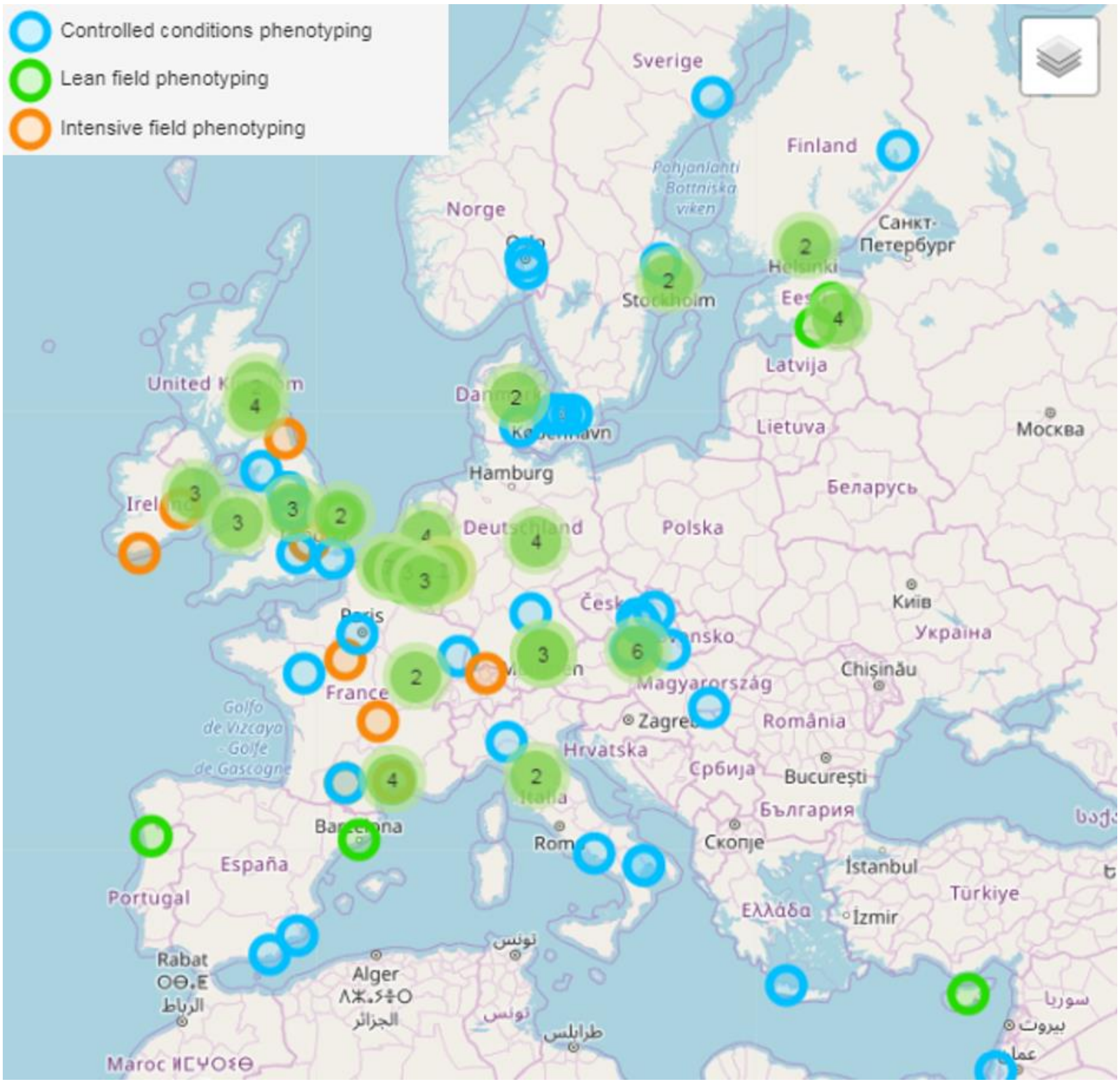

***Figure 1**: An example of the virtual map created to visualise the distribution of plant phenotyping infrastructures in pan-Europe. Picture taken of the website of EMPHASIS, in August 2019. For more information please go to https://emphasis.plant-phenotyping.eu/database*

In 2018, thematic workshops were organised to extract demands of the specific communities and bringing awareness to the mapping activities. Accordingly a 'field phenomics workshop' has been organised in September 2018, where more than 70 field scientists participated in both industry and academia, as also two modelling workshops have been organised in April and September 2018. At those events, modellers have discussed in detail their demands and position in the plant phenotyping world. Moreover, also in 2018, a second mapping survey was developed to extract more plant phenotyping installations and to increase the details on the infrastructures that were already mapped. This survey yielded extra infrastructures. This information was then added to the EMPHASIS mapping database, which by mid-2019 counted almost 200 plant phenotyping infrastructures in pan-Europe. The overall results of the different mapping activities will be described in the main results.

While this deliverable summarises the current (October 2019) state of mapping results, the EMPHASIS mapping journey will continue throughout the preparatory phase, the implementation phase and the operation phase. This deliverable is thus seen as a fundamental starting point, intended to support the EMPHASIS business plan. However, the rapidly developing European plant phenotyping landscape will require further mapping activities to turn mapping results into a viable, demand-driven, up-to-date EMPHASIS service throughout all phases of the EMPHASIS life cycle.

Main Results

With the mapping efforts, as described above, 185 plant phenotyping installations of in controlled conditions, intensive field plant phenotyping and network of fields have been mapped so far. As the database is linked to a virtual map, to visualise the location of the installation, and modelling plant phenotyping installations and data management systems can run on virtual computers or servers, these two virtual categories of plant phenotyping installations were taken up in a separate software based database. A total of 116 plant models are present in the database (see: https://emphasis.plant-phenotyping.eu/modelling). The mapping of phenotyping data management systems was challenging. Three "full systems", matching the criteria of WP3, were identified, more on the results of this below, and in the gap analysis report (**D2.4.**)

Although the EMPHASIS-PREP mapping activities gained a lot of information about the plant phenotyping installations, it needs to be noted that this is a snapshot of what EMPHASIS-PREP was able to extract based on its efforts, mainly surveys and workshops. The participation and responses of the national communities could be a gap in the data compilation of the database. This issue will more deeply discussed in the report of deliverable **2.4. Gap analysis**.

The majority of the installations in the EMPHASIS database are controlled condition installations (63%), followed by network of fields (22%) and highly equipped fields (13%).

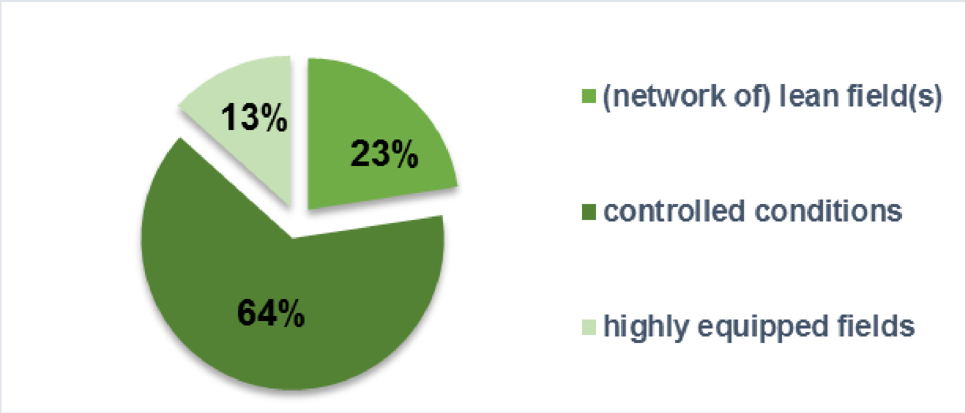

Figure 2*: The distribution of mapped installations in the categories network of fields, controlled conditions and highly equipped fields.*

The database contains plant phenotyping installations of 22 countries within Europe. The majority of the installations mapped during this exercise, are located in the United Kingdom (66), Belgium (30), Germany (24) and France (14). These installations vary significantly in size and investment cost, including smaller phenotyping installations in growth chambers all the way to bigger field networks. The database includes further details of the installations as for example, category of installation, phenotyping focus, details about the environmental conditions and how these are measured, details about species that can be evaluated, and many more. These details made it possible to extract very relevant information about the existing installations in Europe and will be described below in detail in the part called "Mapping results of Plant Phenotyping infrastructure pillars within EMPHASIS".

Mapping results of Plant Phenotyping infrastructure pillars within EMPHASIS

1. Phenotyping installations in (semi-)controlled conditions for high-resolution and high-throughput phenomics.

Phenotyping installations under controlled conditions allow the investigation of the variability of measured plant traits as a response to well-defined and monitored environmental conditions with a capacity of several hundreds to thousands of plants. Facilities may also be linked to high precision platforms for *deep phenotyping* with lower throughput (tens to hundreds of plants) with measurements over shorter timescales (weeks) and time steps (minutes to hours). For detailed definitions, see **D2.1 criteria list** or *https://emphasis.plant-phenotyping.eu/Infrastructure_Categories*

1.1 Localisation of Plant phenotyping in (semi-)controlled conditions

A total of 112 infrastructures in 19 countries were identified as *phenotyping installations under controlled conditions* (Figure 1.1). 109 are based in Academia, three in Industry.

Figure 1.1: *Pan-European plant phenotyping installations under controlled conditions. Data from https://emphasis.plant-phenotyping.eu/database.*

1.2 Phenotyping Focus

65 installations reported their focus as shown in Figure 1.2. A majority (58%) focus on canopy and shoot measurements. 11% solely focus on roots and a similar proportion (12%) focus on both. The “other” category (11%) includes facilities that investigate interactions with pathogens, micro-organisms and abiotic stresses.

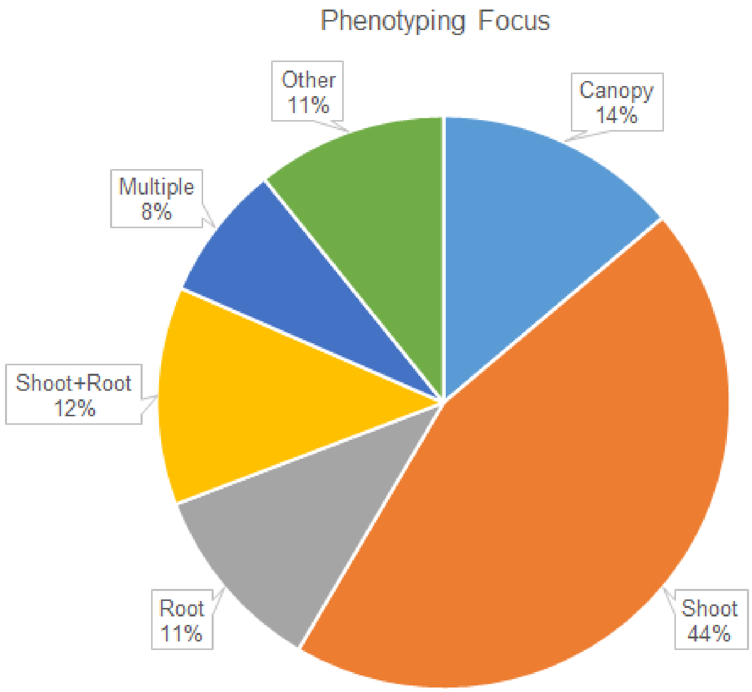

Figure 1.2: *Focus of phenotyping installations under controlled conditions*.

1.3 Species Studied

A total of 62 installations reported the plant species studied, with most platforms phenotyping multiple species (Table 1.1). Crop species of agricultural and horticultural importance make up the majority (78%) of phenotyped species. Wheat and *Arabidopsis* are the individual species most studied - with 58% of installations reporting phenotyping wheat and 53% reporting phenotyping *Arabidopsis*. Cereals and grasses are the most common grouping of plants studied (39% of all reported species). Wheat is the most commonly phenotyped cereal crop (34% of reported cereals), followed by barley (23%) and maize (20%). The "other" category includes *Medicago spp.*, sunflower, olive, grapevine and duckweed. 63 installations reported their ability to phenotype transgenic plant material, with a majority (70%) having the facilities to do so when necessary.

Plants studied	**Percentage of responses**
Cereal Crops and Grasses	39%
Tomato, lettuce, vegetables	12%
Arabidopsis	11%
Brassicas	7%
Trees	7%
Legumes	4%
Potato	4%
Tobacco	3%
Sugar beet	3%
Other	12%

Table 1.1 *Plant species studied in phenotyping installations under controlled conditions.*

1.4 Automation and throughput

A majority of reporting installations (67%) are automated, with the automation systems equally divided between plant-to-sensor (e.g., conveyors) and sensor-to-plant (e.g., scanner) approaches (67 respondents, Figure 1.3). The number of plants phenotyped per single experiment ranged from 9 to 12,000, with ~50% of infrastructures in the range 100-500 plants per experiment. This represents an annual throughput of 25 to 190,000 plants per installation (58 respondents, Figure 1.4).

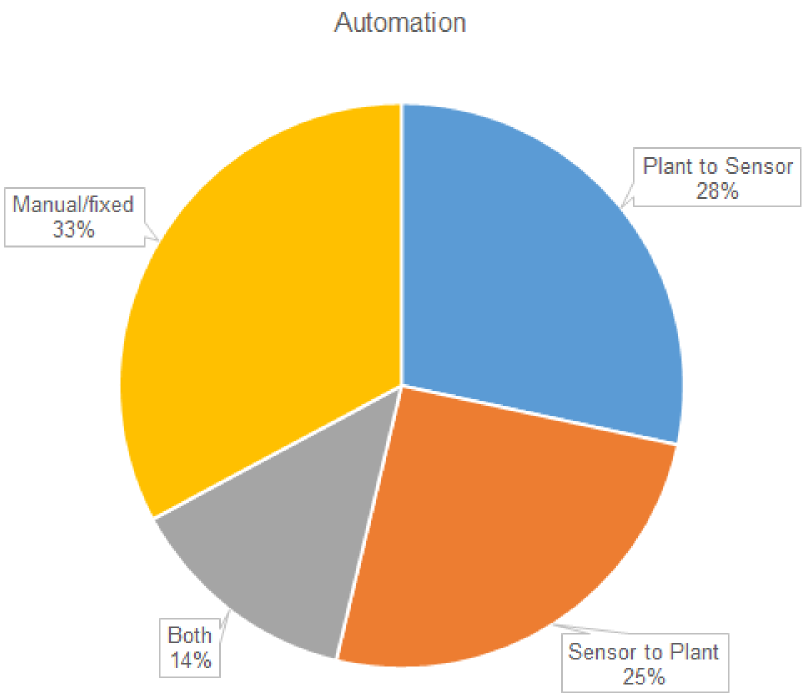

Figure 1.3: *Automation approaches in phenotyping installations under controlled conditions*

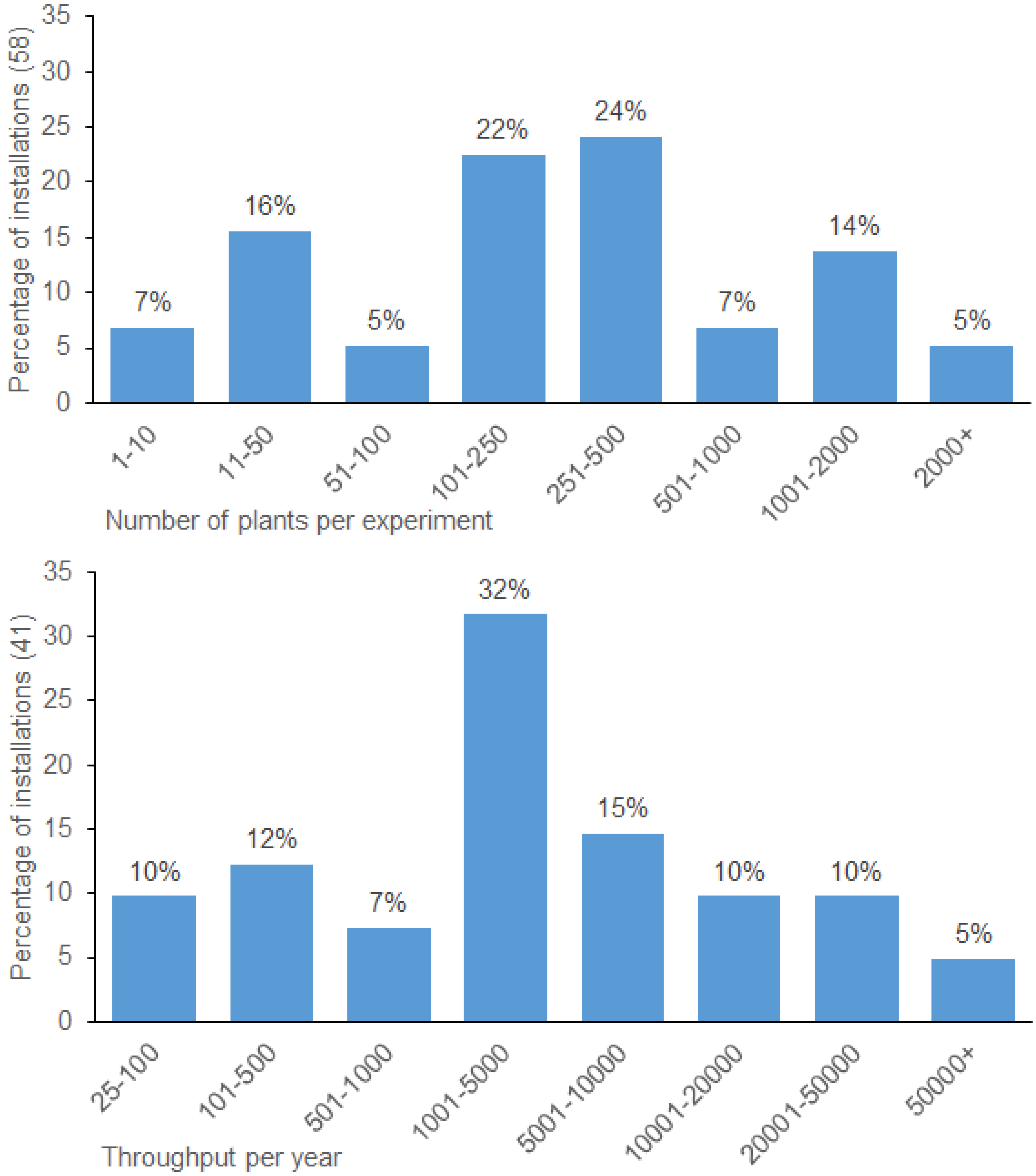

***Figure 1.4:**. Throughput in phenotyping installations*

1.5 Sensors

A total of 31 installations reported the phenotyping sensors in use in their installations. Most installations use multiple modalities and almost all sensors are imaging devices (Figure 1.5). Visible light colour cameras (RGB, single frame and video cameras) are the most common sensor (26% of reported sensors), followed by fluorescence (16%) and multispectral systems (12%). Reported sensors in the “other” category include luminescence and reflectance sensors.

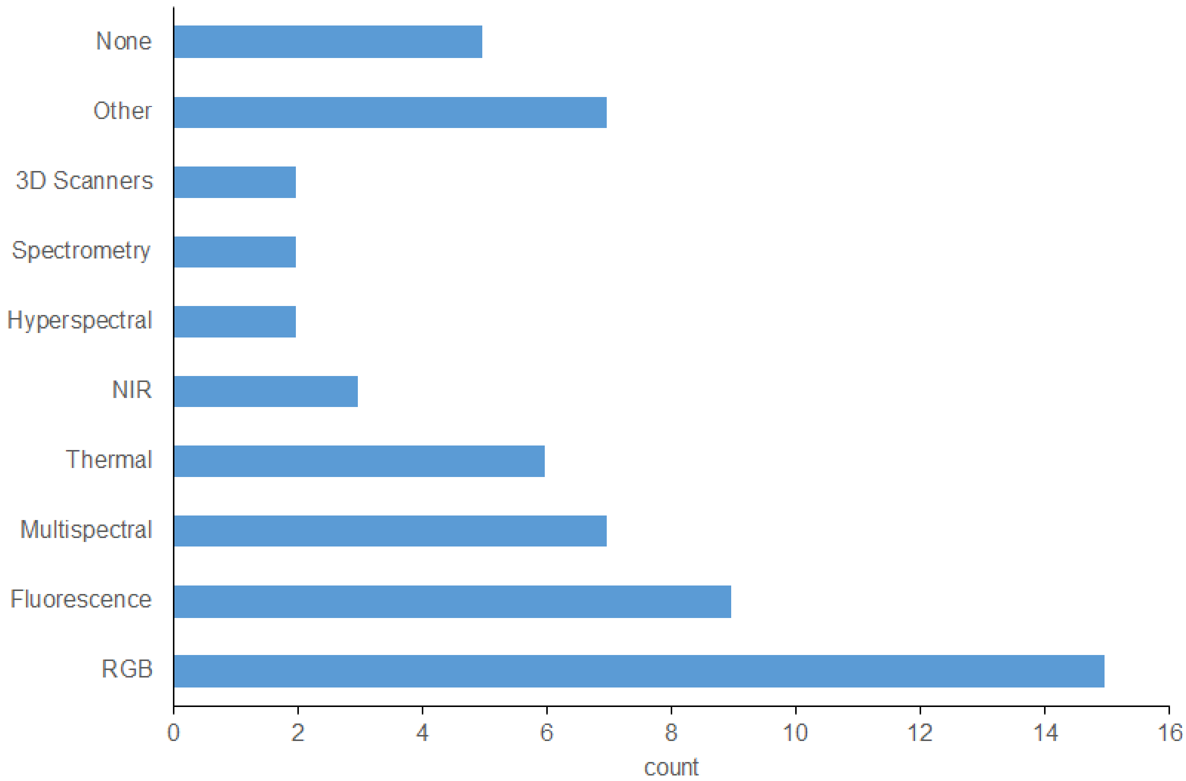

Figure 1.5: *Sensors in use in phenotyping installations under controlled conditions*

1.6 Treatments

56 infrastructures reported the treatments and conditions that can be applied to plants during phenotyping. All infrastructures can apply multiple treatments, with the range varying from two to eight separate treatments (Figure 1.6). Water stress (drought and flooding) is the most commonly applied treatment (27% of reported treatments), followed by nutrient stress (19%) and chemical treatment (13%). The “Other” treatments include, soil compaction, salinity and mechanical stresses.

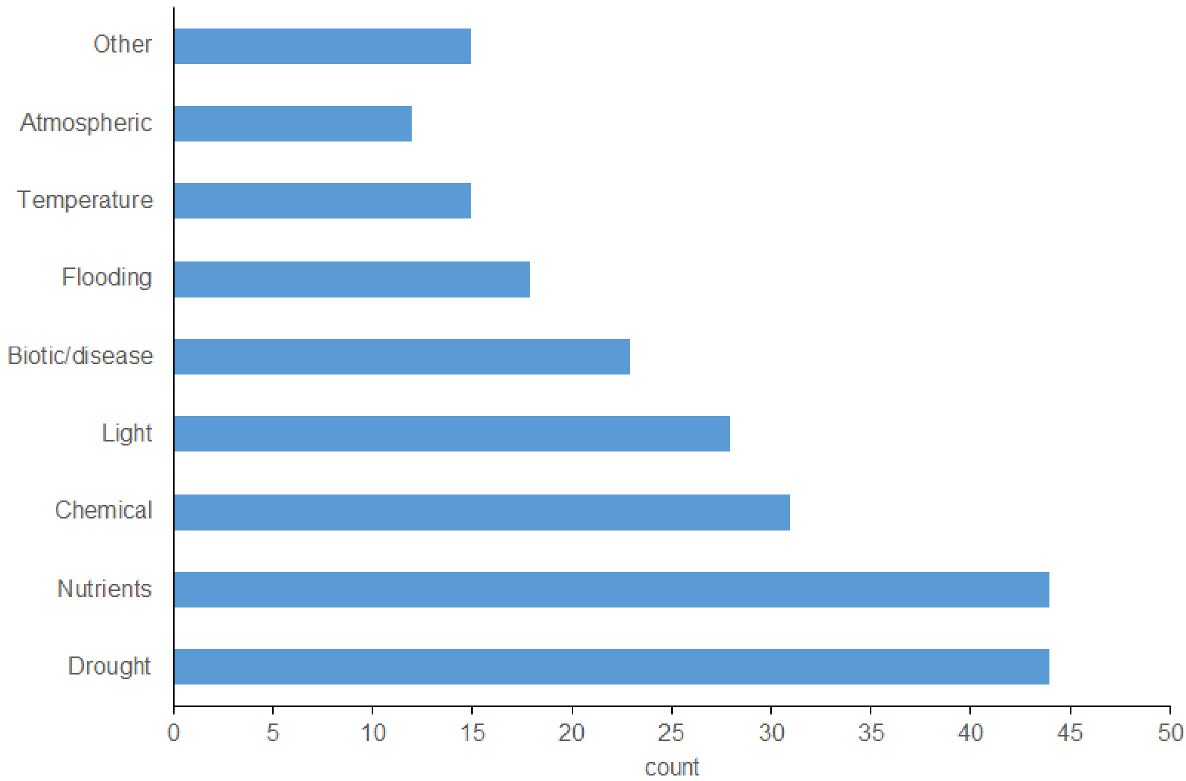

Figure 1.6: *Treatments available in phenotyping installations under controlled conditions*

2. Field experimental sites (network of lean and highly equipped fields)

The EMPHASIS criteria list (**D2.1**) describes two categories of field phenotyping installations: intensive field installations and network of lean field installations. A total of 70 infrastructures (45 lean field and 25 highly equipped) in 14 countries were identified with the mapping activities of EMPHASIS-PREP. Although it is estimated that this result could be higher, as responses on surveys were lower than expected from some countries. This issue will be discussed more in detail in the report of **D2.4 Gap analysis**.

While Intensive field installations are located mainly in France, Germany, Belgium and the UK, network of fields are found geographically scattered in Europe.

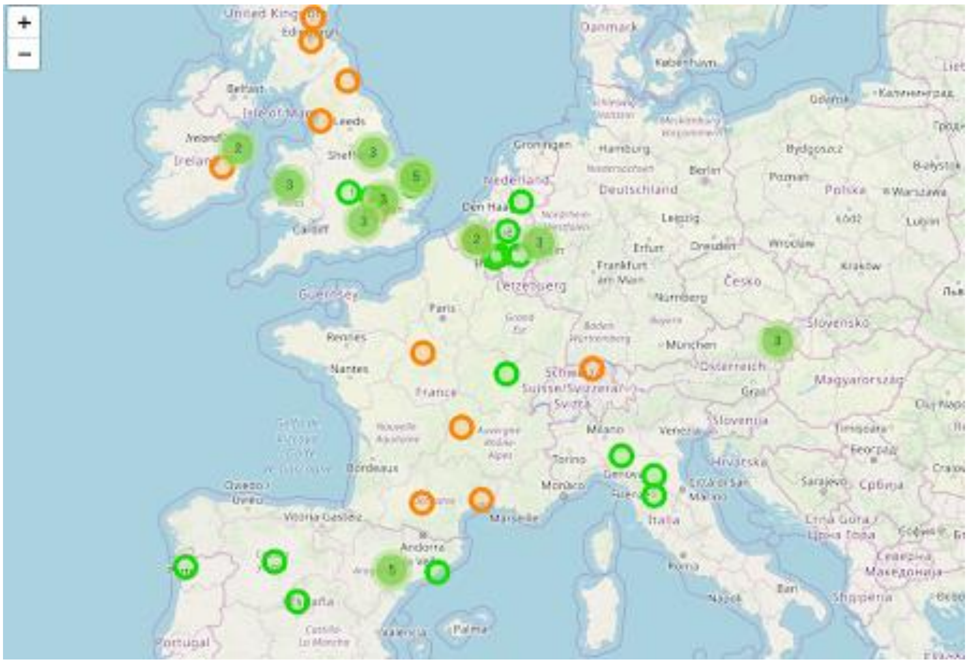

Figure 2.1: *Pan-European plant phenotyping field installations, including highly equipped fields (orange) and network of fields (green)*
Data from [*https://emphasis.plant-phenotyping.eu/database*](https://emphasis.plant-phenotyping.eu/database)***.***

Mapping Intensive field experiments in highly equipped field sites

A total of 25 infrastructures in 7 countries identified as *phenotyping installations under highly equipped fields* (Figure 2.1).

2.1 Phenotyping Focus

As expected "canopy" has the biggest share of phenotyping focus, with 50% of the installations focusing on it. The shoot focus and field focus come next with 11 out of 25 installations focusing on it. Finally flowering and root only concern a couple of installations (3 and 2). Most of these traits are measured by imaging, either carried by drone or autonomous vector.

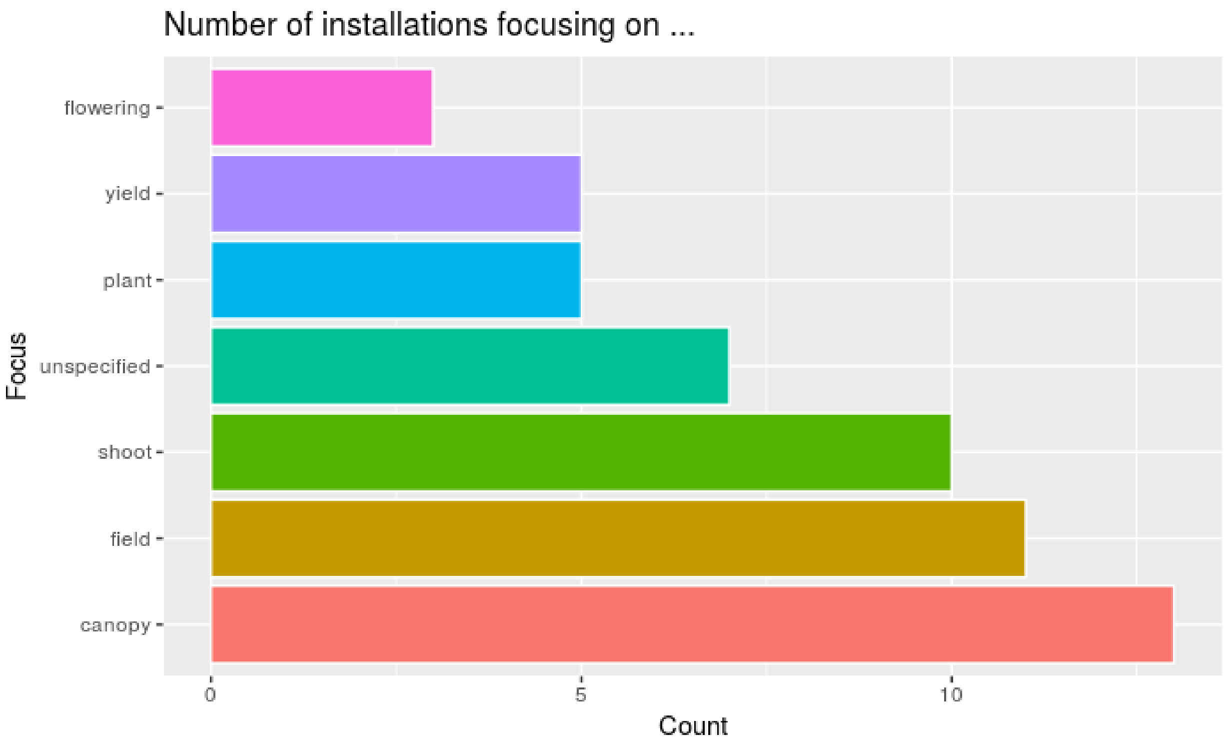

Figure 2.2 *The different phenotyping focuses in highly equipped fields installations.*

2.2 Species studied

The range of species under study is very wide, even considering only highly equipped fields as attest the big share of "other species", gathering all the different species that represent less than 3% of the responses. An installation can have studies concerning different species and thus are counted multiple times. The sum is not 25 as an installation is not dealing with a single species.

A large number of studied species are not specified, but certainly fall into the subsequent categories: cereals, legumes, oil crops.

The cereals including wheat (10.4%), maize (6.3%), barley (7.8%), are the most studied species, followed by legumes and oil crops. The vast majority of these species are the major industrial productions in agriculture in Europe, the exception being Arabidopsis that only serve research purposes.

	Species	Percentage of responses
1	wheat	10.4
2	unspecified	9.1
3	barley	7.8
4	maize	6.3
5	arabidopsis	6.2
6	tomato	4.2
7	cereals	4.1
8	oilseed rape	3.4
9	potato	3.1
14	others species	37.6

***Table 2.3** The different species studied in highly equipped fields installations.*

Field experiments using minimal equipment, linked as a network of fields

Field experiments using minimal plant phenotyping equipment are performed outside, in agriculturally-relevant and breeding-like conditions, which allows investigation of the genetic variability of measured plant traits as a response to differences in field management, soil composition, or environment by multiple climatic regions. Monitoring of the environmental conditions (i.e. abiotic and biotic conditions) should allow to understand differences in plant or crop performance and could explain statistical outliers which are not due to genetic variation of the species.

A key objective for EMPHASIS will be to increase the capability of networks of field trials, number and geographical / climatic coverage, and the coordination of existing infrastructures and their integration to facilitate analyses of plant performance across climatic gradients, the development of appropriate phenotyping methods and statistics. The scientific communities involved here are; biologists, geneticists, statisticians, agronomists, breeders, modellers and specialists of information systems and technology development.

For detailed definitions, see **D2.1. criteria list** or : https://emphasis.plant-phenotyping.eu/lean_field

2.3 Focus of phenotyping

Out of the 45 in total mapped networks of fields in Europe, 73% (27) of these installations have provided data for focus of phenotyping. All of them focus at least on canopy or shoot research, 55% of those also claim to analyse yield or at least perform an analysis of reproductive parts of the plants, and a small amount (11%) can also do root system analysis in the field.

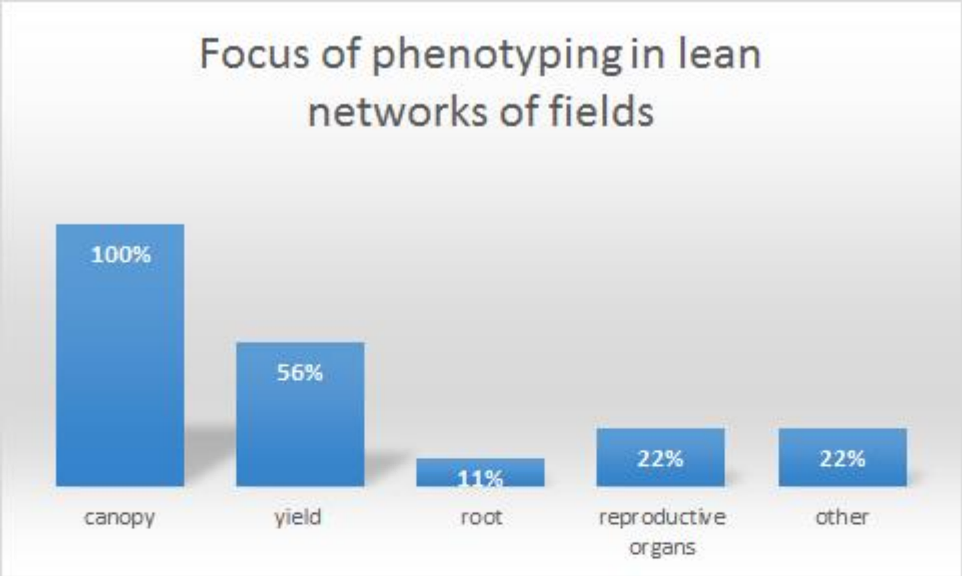

Figure 2.4.: Focus of phenotyping in lean network of fields in pan-Europe. Mapped by EMPHASIS-PREP (results of mid 2019)

2.4 Carrier systems

22 installations provided details of the use of one or more carrier systems during fields phenotyping experiments. More than half (64%) of those say at least to use Unmanned aerial vehicle (UAV's) to carry sensors as RGB cameras, hyperspectral or thermal sensors, UAVs are broadly classified into four groups, namely parachutes, blimps, rotocopters and fixed wing systems. These findings are not surprising as simple imaging techniques involving UAVs and, probably, satellite imaging in the near future, become increasingly available and cheaper (Araus and Kefauver, 2018). The immense potential of remote sensing technology in plant breeding applications and with continuous reduction in UAV costs and development of protocols for imaging and analysis, UAV-based selection of superior breeding lines and clones will accelerate germplasm enhancement of crops and may increase related genetic gains (Chawade et al, 2019). 23% of the field installations claim to use mobile ground based systems, and the same amount 23% said to have a sensor to plant system, without specifying the details of the carrier system, this could both UAVs, mobile systems or even handhelds.

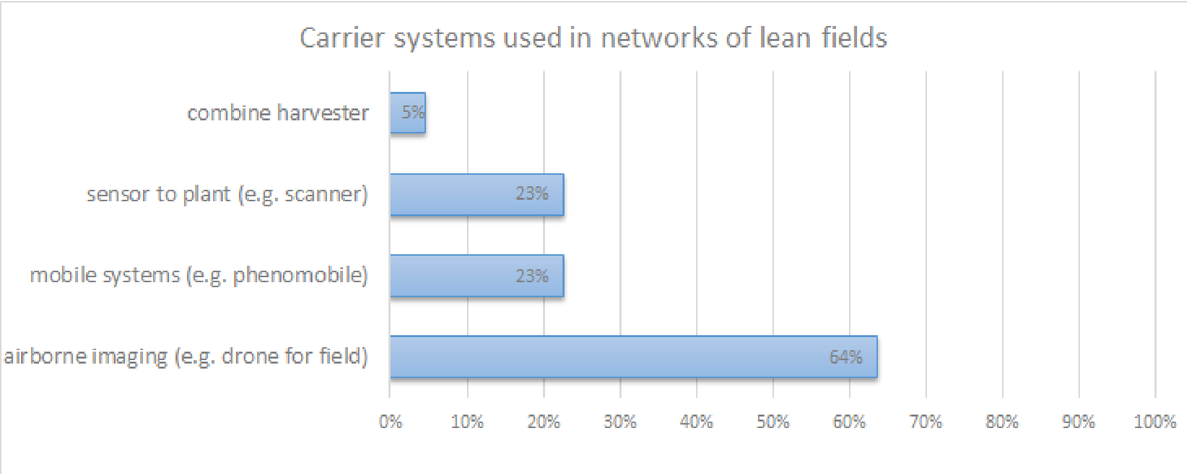

Figure 2.5.: Most commonly used carrier systems in network of lean fields in Europe. Mapped by EMPHASIS-PREP (results of mid 2019)

2.5 Species studied

Fields have the advantage not to be designed for a specific crop or species as for example controlled condition or even highly equipped field, and most fields have a big range of possibilities of cultivating on demand of the experiment. Nevertheless, its noticed that field phenotyping is done in Europe mostly on cereals as wheat (67%), barley (49%) and maize (26%). This is followed by brassica and potato (19%). Also different kinds of trees are phenotyped, mostly olive trees and fruit trees (9%) and equal amounts analyse sugar beet. These results are from a total of 43 installations in the mapping results that reported the commonly grown plant species in the field installations. From these results it is clearly noticeable that the most important industrial farmed crop species, as cereals wheat, barley and maize, have the main priority in field phenotyping.

Species	Percentage of responses
Wheat	67%
Barley	49%
Brassica	26%
Maize	26%
(fruit)tree	9%
Sugar beet	9%
Potato	19%
Tomato	7%
vegetables	9%
unspecified	21%

Tabel 2.6.: Commonly grown plants in lean neworks of fields in Europe, in percentages. Mapped by EMPHASIS-PREP (results of mid 2019)

2.6 Treatments

Next to monitoring biotic and abiotic stress that comes with the environment of field cultivated plants, some treatments could be performed, and then be evaluated by phenotyping the plants or plots. Out of the 45 field networks, 24 responded to have at least some form of treatment that is done in the field. Most of them are able to do drought treatments (59%), probably by lowering irrigation. 27% are able to do disease treatments, and allow pathogens in the field, which could be by lowering disease control and phenotyping natural appearing pathogens or by inoculation of fields with specific pathogens. Others have specific systems to allow excessive water availability or flooding in the field (27%). Nutrient stress is only 18% of the times possible in field networks and also chemical stress is not that commonly done (18%).

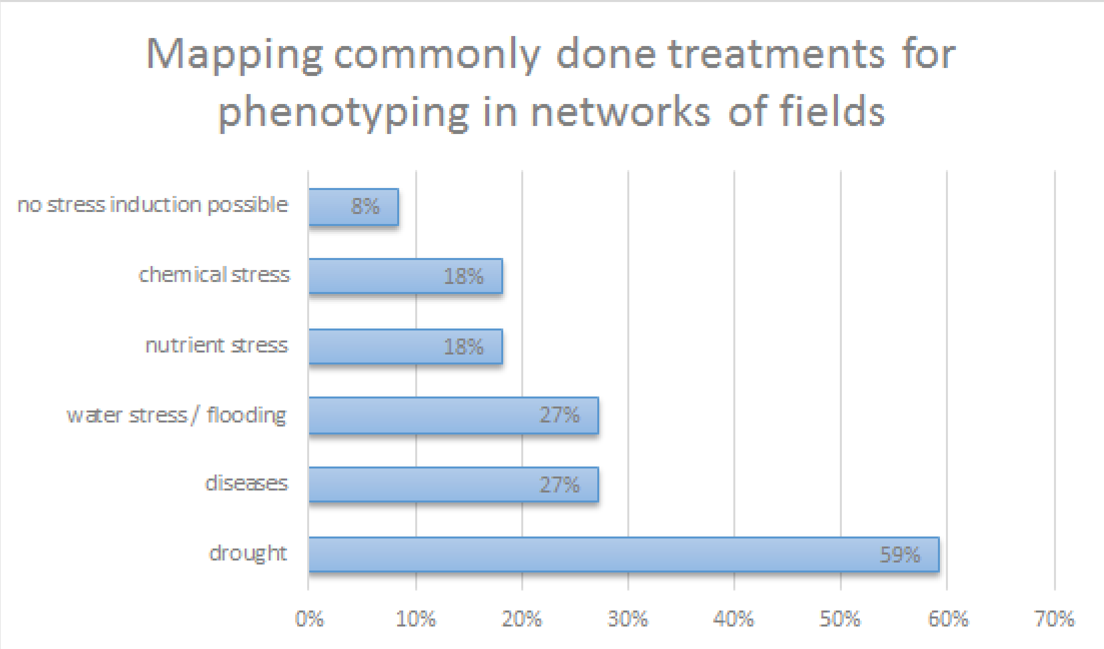

Figure 2.7.: Commonly done treatments in field phenotyping. Mapped by EMPHASIS-PREP (results of mid 2019)

2.7 Analysis of past and current plant phenotyping field networks

Several examples of ongoing experiments in multi-climatic networks for field experiments were retrieved from online resources. The existing multi-climatic field networks are either organized by public organizations or from private companies spanning from agricultural science, ecology and regulatory tasks for chemicals development. This highlights the interdisciplinary of an EMPHASIS field pilot service. In the following table you can find a list of established field networks*.

Acronim of the project	Name of the field networks	Website	Topic	Species	# Sites	Sites locations	Approach
Public research institutions							
ECOFE	European Consortium for Open Field Experimentation	https://www.ecofe.eu/	agricultural sciences	wheat, maize	12	Europe	networking existing field stations across Europe
ALTER-NET	A Long-Term Biodiversity, Ecosystem and Awareness Research Network	http://www.alter-net.info/msr	ecological and socio-ecological research			Europe	calls to co-financed diverse multi-site research (MSR) activities simultaneously conducted across Europe with a significant added value due to its pan-European character
Research trials	Author: Canè et al 2014	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4257993/	Root QTL analyses	wheat	5	Europe , North Africa	
ITEX	International Tundra Experiment	https://www.gvsu.edu/itex/	impacts of warming on tundra ecosystems				They ensure multiple locations but setting standars to obtain the warming of the ecosystems.
Private companies							
SOLVAY	STIMUL project	https://www.solvay.com/en/innovation/open-innovation/european-life-projects/life-stimul-project/organization-2018-field	Organization of field trials for biostimulants application	sunflower, beetroot, soybean, corn, rapeseed	91	Europe	
Eurofins	Eurofins agroscience services	https://www.eurofins.com/agroscience-services/	soil and crop health, fertilisation, feed value and food safety				
Agrolab		http://www.agrolab.dk/?page_id=31	provide within the Regulatory landscape and Field phase development of chemicals, including pesticides, bio pesticides or biocides			EU North zone	GEP accreditation, can arrange pan-european multi site trials
SGS		https://www.sgs.be/en/agriculture-food/seed-and-crop/contract-research-services/field-trials/glp-field-trials					GEP and GLP field trials
Charles river laboratories		https://www.criver.com/sites/default/files/resource-files/Field Trials.pdf	chemicals, agrochemicals, bio pesticides			north and south europe	GLP and GEP accredited field bases

Table 2.8.: The table shows selected examples of existing field networks used for plant phenotyping and is not an exhaustive list of all field networks.

3. Modelling

The plant phenotyping space is too immense to observe all combinations of genotypes by growth stage by environmental conditions. Therefore, capturing the essence of the observed phenomics data in models turns out as a pivotal approach. Feeding phenome data into structural plant models (SPMs), functional-structural plant models (FSPMs) and process-based crop simulation models (CSMs) is a way to derive predictions of integrated (e.g. yield) or functional traits (e.g. root system architecture) for existing or new genotypes and across a wide range of target environments or management practices. For an overview see: https://emphasis.plant-phenotyping.eu/modelling

These three categories of models differ in the levels of detail, the scales studied and the processes considered, as described in the deliverable 2.1. criteria list for infrastructure. More precisely:

- SPMs explicitly describe plant morphology and can be associated to virtual plant models. The models incorporate a parameterisation of development that allows for a detailed simulation of the evolution of the plant 3D structure and shape,

- FSPMs simulate aspects of plant response and growth as governed by physiological processes which are in turn driven by local environmental conditions at the plant organ level. It is a versatile tool to simulate plant development, reproducing plant topology and geometry in response to environmental and internal factors (e.g. resource allocation). Depending on the application domain, it integrates different physical and physiological processes and varies in the level of detail for the spatial representation of the plant (from individual organs or sets of organs to entire plants),

- CSMs simulate the development and growth of a crop in relation to environmental conditions and management practices. Models do not consider individual plants but can incorporate genetic traits. They are typically designed to be spatially one-dimensional, just considering differences in canopy or rooting pattern in the vertical direction. Some crop models are two-dimensional, representing heterogeneity of an intercrop or agroforestry system using a block structure. They cannot explicitly account for plant plasticity in growth and functioning at the organ level in relation to local conditions, because they do not describe the plant structure and shape.

3.1 Mapping of plant models

A total of 116 plant models (11 SPMs, 34 FSPMs and 71 CSMs) in 26 countries were identified (Fig. 3.1). The majority of these models are developed in Europe (73%, 85% and 50% of the SPMs, FSPMs and CSMs involve one European country in their development). The larger number of CSMs (71) compared to SPMs and FSPMs (11 and 34, respectively) can be explained by the long history of CSMs (since 1950; Jones et al. 2017). Later (in 1990) and parallel to crop modelling efforts elsewhere, a “plant architectural modelling” approach was initiated (de Reffy et al. 2016).

The SPMs and FSPMs are mainly developed in France (64% and 32% of the SPMs and FSPMs, respectively; Fig. 3.1). The main reason for that is certainly that France had developed precursory labs (e.g. UMR AMAP (INRA) or VIRTUAL PLANTS team (INRIA)) and tools involved in “plant architectural modelling” (e.g. AmapSim, GreenLab or OpenAlea; Barczi et al. 2007; Pradal et al. 2008).

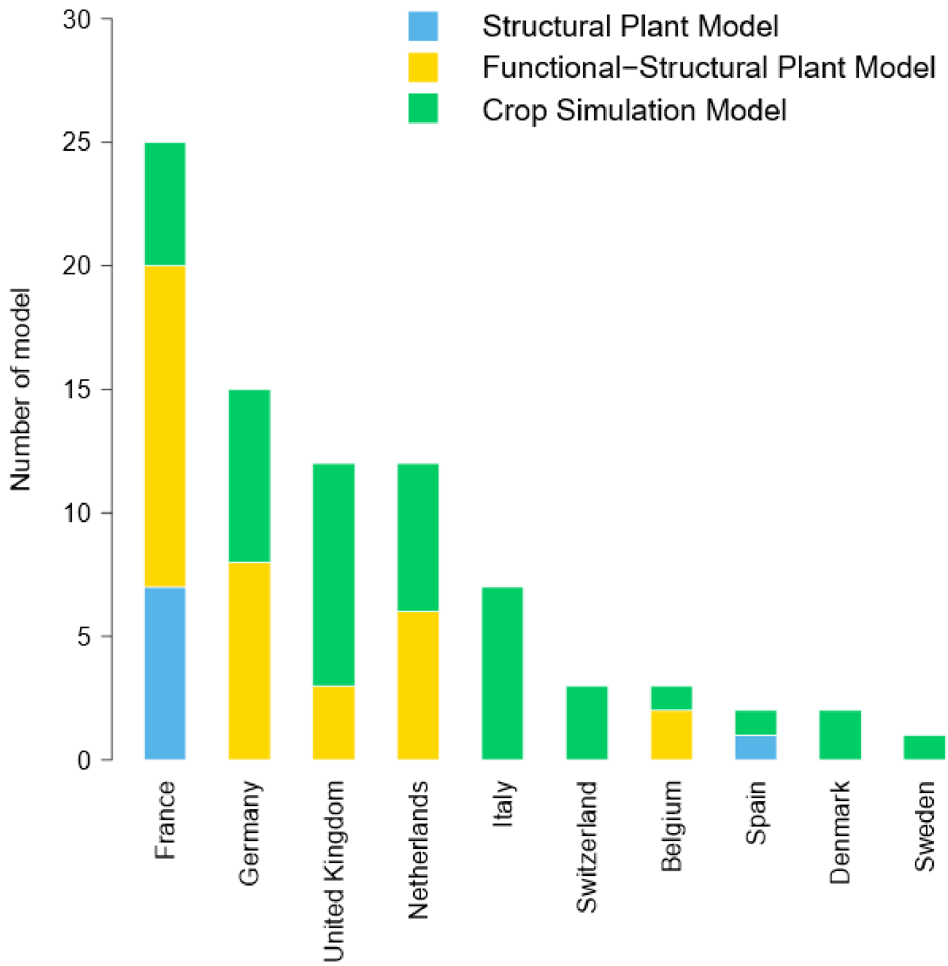

Figure 3.1. Histogram of the number of models by European countries. Each bar is split by model category using specific colors (blue: Structural Plant Model, yellow: Functional-Structural Plant Model, green: Crop Simulation Model).

3.2 Species studied

The range of plant species simulate is very wide (Fig. 3.2). The cereals including wheat, maize and rice are the most studied species (50, 50 and 39 plant models simulate wheat, maize and rice, respectively; Fig. 3.2). However, a large range of legume species (e.g. soybean or pea, 35 and 22 models, respectively; Fig. 3.2), perennial species (e.g. cotton or grapevine, 20 and 9 models, respectively; Fig. 3.2) or grass species (e.g. *brassica nigra*, 15 models) can also be simulated by plant models (Fig. 3.2).

As the name suggests, the CSMs are more designed to study crop species (50%, 50% and 32% of CSMs are used to simulate wheat, maize and rice, respectively). On the contrary, the SPMs and FSPMs seem less specific to crop species and are also able to simulate a large diversity of plant including perennial species (e.g. grapevine, cotton or apple tree; Fig. 3.2).

Each model category is characterized by generic (e.i. models enable to simulate many annuals, perennials, legumes or grass plants) and more specific plant models (e.i. models developed to simulate one species only), allowing the simulation of a diversity of plants from annual to perennial species. We estimate that 31% of the FSPMs, 27% of SPMs and 40% of CSMs can be defined as “generic” (model enable to simulate more than four different species).

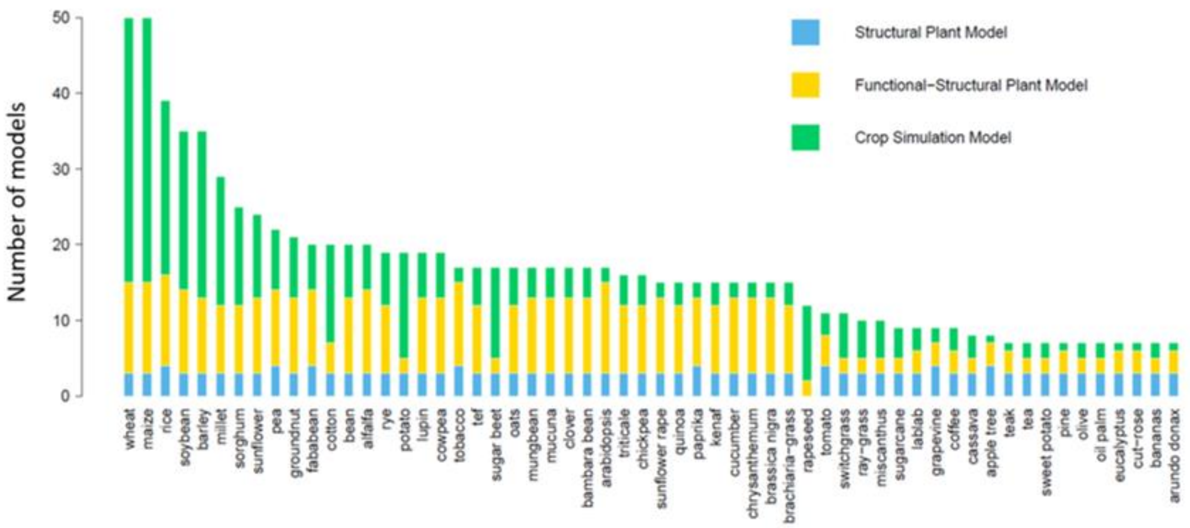

Figure 3.2. Histogram of the number of models by species. Each bar is split by model category using specific colors (blue: Structural Plant Model, yellow: Functional-Structural Plant Model, green: Crop Simulation Model).

3.3 Model scales and focus

The plant models lead to cover a large scale of plant development, from plant organs to global scales (Fig 3.3). According to each model category, the scale level can differ. SPMs and FSPMs consider processes at the level of individual plants and/or organs (73% and 81% of SPMs and FSPMs simulate plant considering organs development). On the contrary, CSMs consider processes at the canopy level characterizing so-called "big-leaf" and "multilayer" models (86% of the CSMs simulate plant development at the field level). The large proportion of the field scale considering all the models (46%) is explained by the large proportion of both FSPMs and CSMs to simulate this scale level (86% and 59% of CSMs and FSPMs, respectively).

The focus of plant model was only reported for the FSPMs and SPMs. A first general observation is that the number of plant model varies with plant organs (Fig. 3.3.b). In particular, a large proportion of plant models are dedicated to shoot (76%; Fig.3.3.b), then to the modelling of roots (16%; Fig.3.3.b) and whole plant (9%; Fig.3.3.b). This distribution can be explained by the intrinsic nature of the object to analyse.

Mature root systems are complex branched structures with diverse range of complex interactions with their soil environment, and the difficulties associated with visualizing and measuring them. It's therefore difficult to study and model the root system and its interactions with the aerial part.

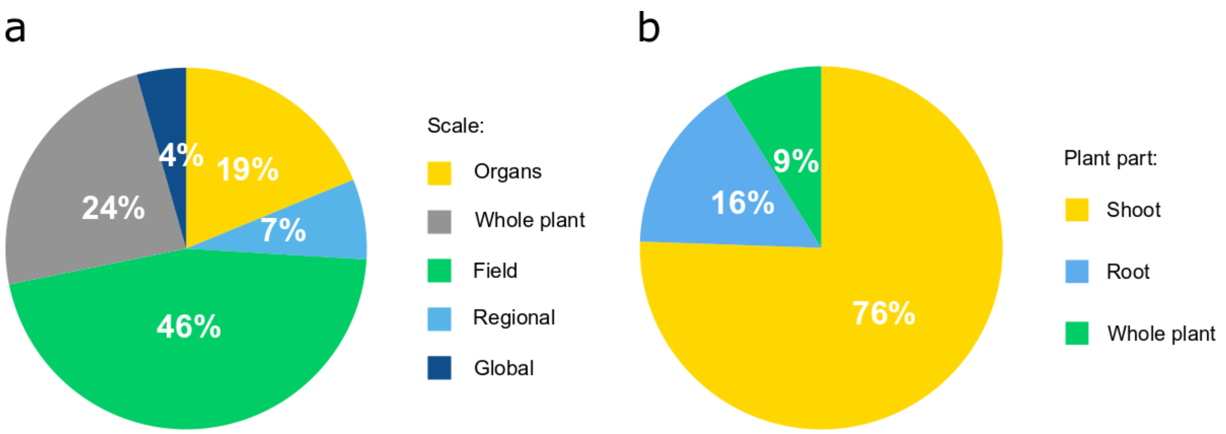

Figure 3.3. Proportion of model by (a) scale level (estimated considering all model categories) and (b) plant part (estimated considering SPMs and FSPMs only).

3.4 Model predictions

The focus of model simulation was only reported for the FSPMs and SPMs. The range of model simulation is wide (Fig. 3.4) and can be related to several factors:

- the diversity of species simulated (Fig. 3.2),
- the diversity of scale levels simulated (Fig. 3.3.a),
- the diversity of plant parts simulated (Fig. 3.3.b),
- the diversity and number of physiological processes integrated.

The shoot architecture, environmental conditions, light-interception and photosynthesis are the most simulated variables (28, 24, 20 and 20 SPMs and FSPMs simulate the shoot architecture, environmental conditions, light-interception and photosynthesis, respectively; Fig. 3.4). The main reason for that is certainly that a large proportion of SPMs and FSPMs are developed to study the aerial part of the plant (Fig.3.3.b).

A general observation is that the number and diversity of model simulations are higher for the FSPMs compared to the SPMs (Fig. 3.4). This distribution can be explained by the more important number of FSPM (11 SPMs and 34 FSPMs; Fig. 3.1) and its higher complexity and capacity of prediction.

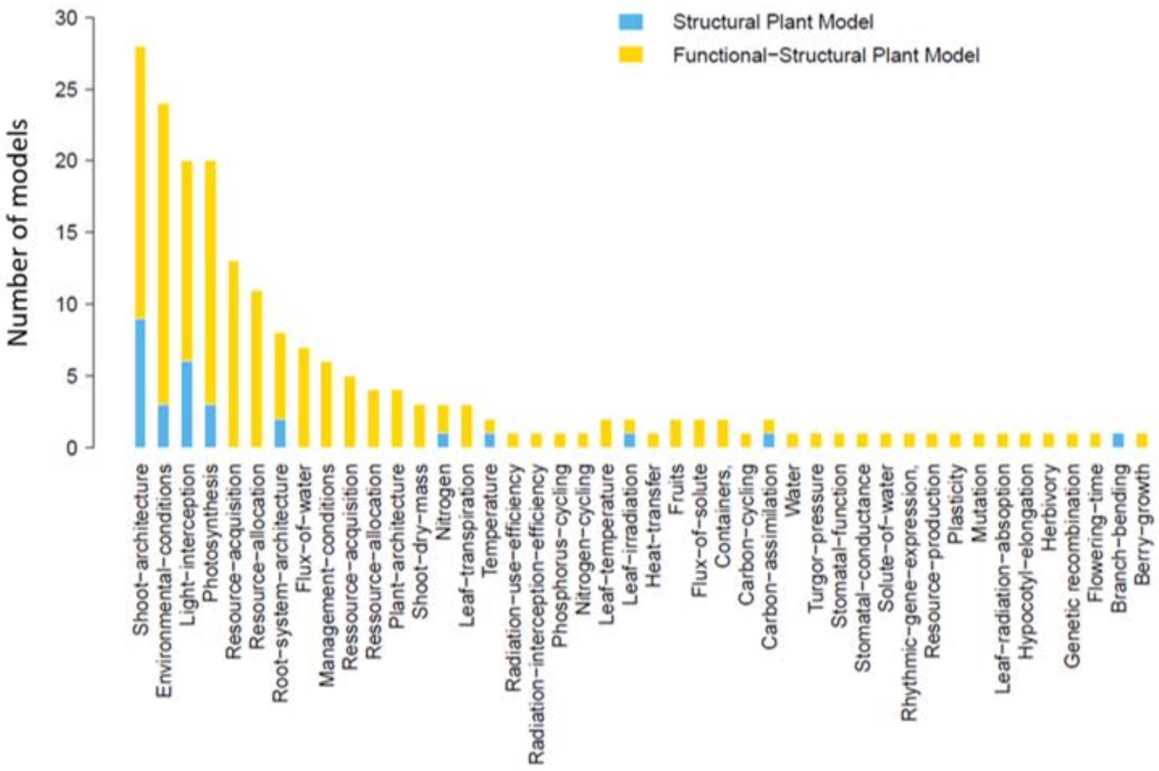

Figure 3.4. Histogram of the number of models by model simulation. Each bar is split by model category using specific colors (blue: Structural Plant Model, yellow: Functional-Structural Plant Model).

3.5 Models in industry

The focus of model use in industry was only reported for 18 models (mainly FSPMs and SPMs). The use of plant models in industry seems well-developed (39% and 22% of SPMs and FSPMs are used by industry or are under discussion for developing decision support systems; Fig. 3.5). According to the survey, the industry uses plant models for three main purposes:

- in breeding to design or identify plant ideotype,
- in field management to optimize planting patterns according to variety and environmental conditions,
- in field prediction to test future weather and environmental conditions, and identify the good practices and managements.

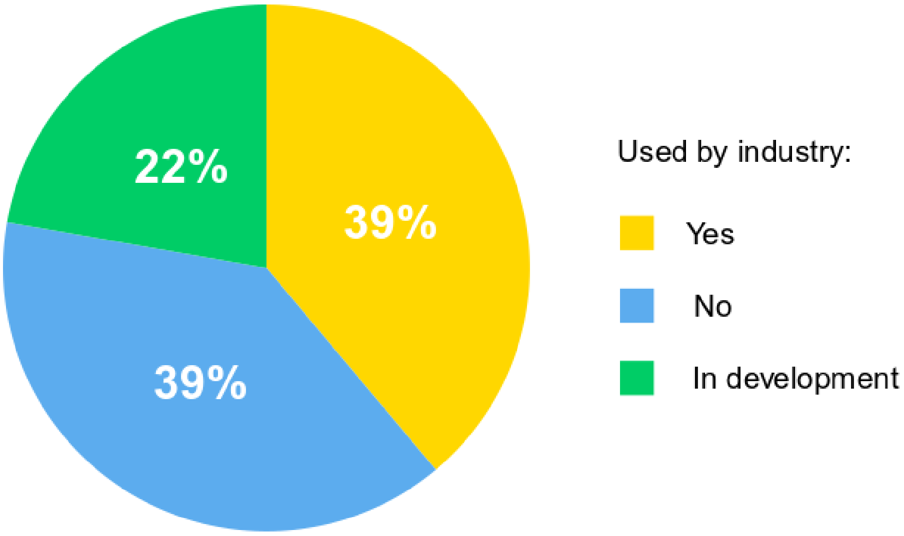

Figure 3.5. Proportion of model used in industry (estimated considering the 18 SPMs and FSPMs only).

4. Mapping of data management systems

In our database, 3 “full software” installations refer to data management or information system following the criteria if EMPHASIS_PREP and EPPN2020. At the moment these are all still being actively developed in use for a limited number of installations. The practises across the network have been the object of a previous deliverable: **D4.1 Map of information systems**. This report was made on 15 different installations. So instead of doing a review of the 3 e-infrastructures that are under development in this database, we can summarise a few outputs of this **D4.1** deliverable.
We have a look at the different practises within the network and see the need of data infrastructures such as PHIS, PIPPA and PHENOMIS.

In order to manage FAIR phenotyping data, a mix of different solutions is adopted. The use of database through web service does not erase completely the use of file system and spreadsheets. And it is the same for computation practises. Using a server or cloud computing for computation does not completely erase the use of personal computers. The use of an information system goes along with the use of web services. This is a standardized entry point to the data. This standardisation allows users to interact with different installations to collect some data for their analysis. This is a core component of the EMPHASIS-layer.

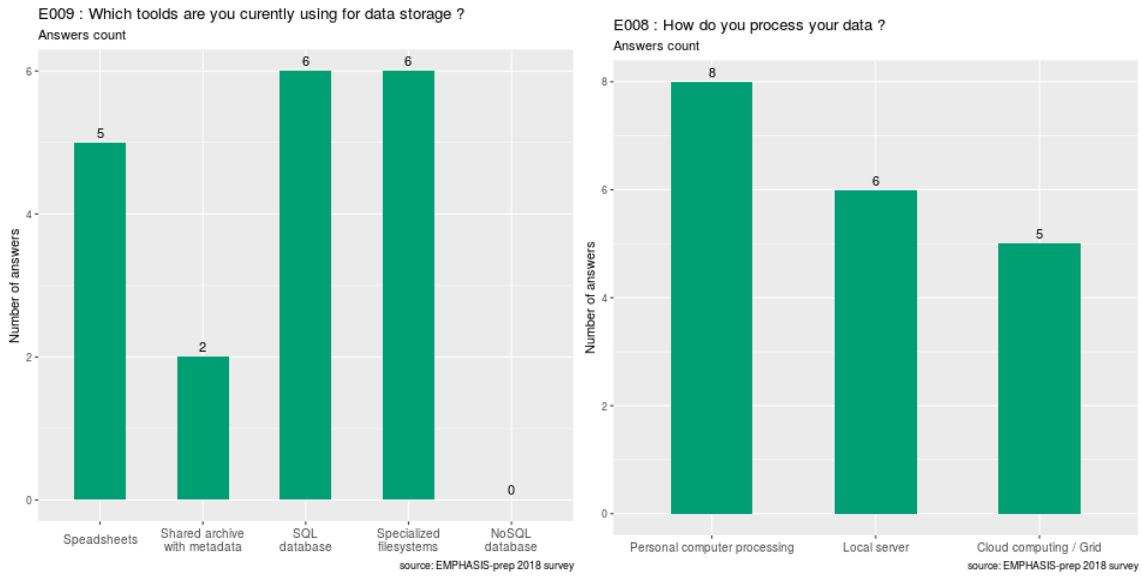

Figure 4: Survey responses on data management related questions.

The amount of data generated and stored each year is very different from one installation to the other. The installations producing images as raw data obviously generate a large amount of data, up to several TBs a year, when others are perfectly fine with a few GB a year.

Industry mapping

Plant phenotyping market analysis

The global phenotyping industry mapping market has been estimated in 2018 to be 137,54 million USD (US Dollars) by industry experts of Grand view research (June 2018), of which about 75% is hardware and 25% software. Because of the rapidly growing human population, the growing demand on food security and quality, and the increasing demand for agriculture to cope with a changing climate, it is expected to drive the growth of the plant phenotyping equipment market even more. Moreover, the developments taking place in phenotyping also drive the transformation of the traditional farming to precision farming industry, and the need to upgrade existing plant phenotyping systems with more advanced tools for example with the rapid development of software and modelling systems as image-analysis results in the prediction that the marked of plant phenotyping will double, to 276,86M USD, by 2025.

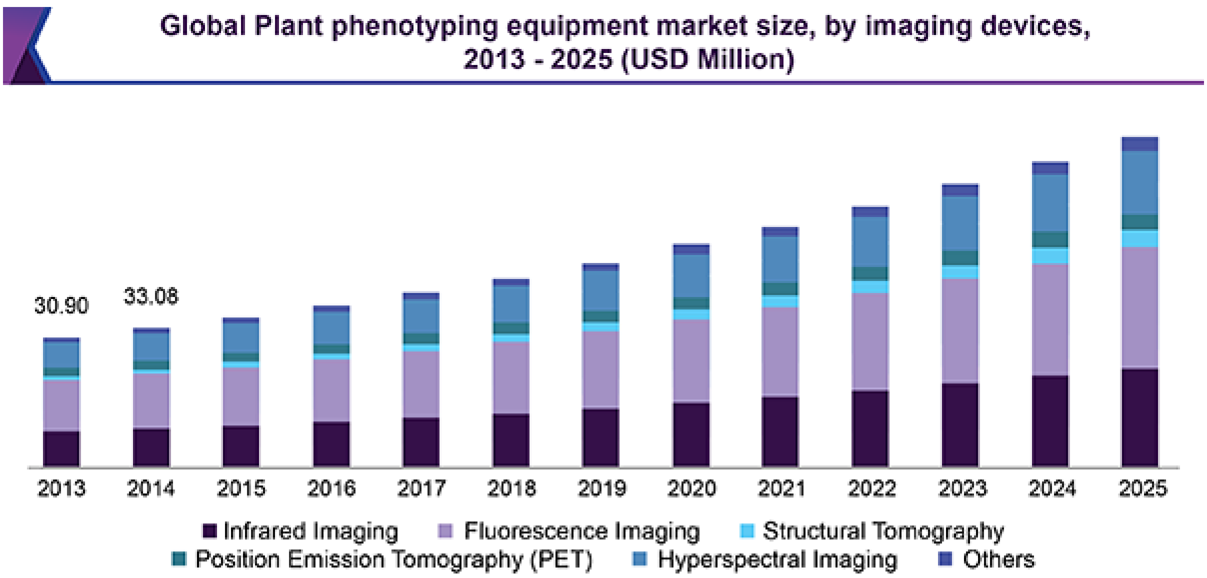

Figure 6.1. Global plant phenotyping equipment market size estimated between 2013 and 2025 - Grand View Research (June 2018)

The European market for plant phenotyping equipment is estimated to 53,31 M USD in 2018 and it is predicted to grow to 102,97 M USD in 2025. This makes Europe the second largest financial region for plant phenotyping, next to North America with 57,98 M USD in 2018. Predictions show that Europe will also experience the second largest growth, with 11,6% CAGR 2019-2025, just behind the Asian Pacific, with an estimation of 13,6% CAGR 2019-2025. This will make the European plant phenotyping market very close to 103 M USD in 2025, which is still a lot higher than the 43,16 M USD predicted for the Asia Pacific in 2025.

The biggest end use of plant phenotyping equipment, globally, is currently estimated to be the segment of field phenotyping, with 87,7 M USD of the total market size. Moreover, the increasing demand for agriculture yield, it is predicted that this number will double by 2025. Nevertheless, the forecast of high-throughput phenotyping platforms in greenhouses is even more promising. The expected growth for greenhouse plant phenotyping is from 34,5 M USD to 75,17M USD, globally, the fastest growing segment. Europe is predicted to follow the same trend, and has currently 30,3 M USD for field and close to 12 M USD for greenhouse systems of the global market. The biggest market growth is predicted to be for UAVs and automated systems, within the hardware section, and within product development as application.

It could be concluded that plant phenotyping equipment is an emerging market that is creating economic opportunities for the manufacturing, chemical, healthcare, and agriculture sectors and have high potential impacts on the environment and socio-economic developments. The predicted growth of plant phenotyping equipment, in Europe and globally, and the position of Europe in this field, will not only depend on the industry as end user, but will also highly depend on investments of the public sector to enable research with this expensive equipment, built by these specialised companies. Moreover, the need for an organised plant phenotyping research infrastructure will make it possible for Europe to keep its leading position and not only develop, but also use phenotyping for scientific state of the art research infrastructure and perform excellence science.

EMPHASIS industry stakeholders

The mapping of the industry phenotyping activities is proven to be more difficult in comparison with the mapping of the plant phenotyping installations and activities for the academic sector. This does not come as a surprise, as companies rely on a competitive market (for more information see D2.4. gap analysis). Nevertheless, plant phenotyping is becoming a central field of research and application in industry resulting in the development of new phenotyping platforms and methods usually driven by the strong demand by users. There is a need for interaction between different stakeholders and an exchange of experience and information related to plant phenotyping technologies, use and application of these technologies in dedicated experiments as well as data analysis and management approaches.

To this end, the WP2 map through several information channels as the 2018 survey (https://emphasis.plant-phenotyping.eu/UserSurvey), social network (linkedin.com/company/emphasis-on-plant-phenomics), the set of EMPHASIS stakeholders from industry interested in plant phenotyping and in the EMPHASIS services.

A database of 447 industries contacts have been built representing 27 countries in Europe and some international countries (See Fig. 5.2).

Figure 5.2: Geographical distribution of the mapped industry stakeholder in pan

Five different classes of industries that expressed an interest in the EMPHASIS project and generally in plant phenotyping were identified: breeders, technology providers, agro- biochemistry, farmers support, food and the industries mapped have been classified and grouped accordingly.

37% of the industries are breeding companies followed by technology providers (24%), agro(bio) chemistry (20%) and farmers consultants (15%, Fig 5.3).

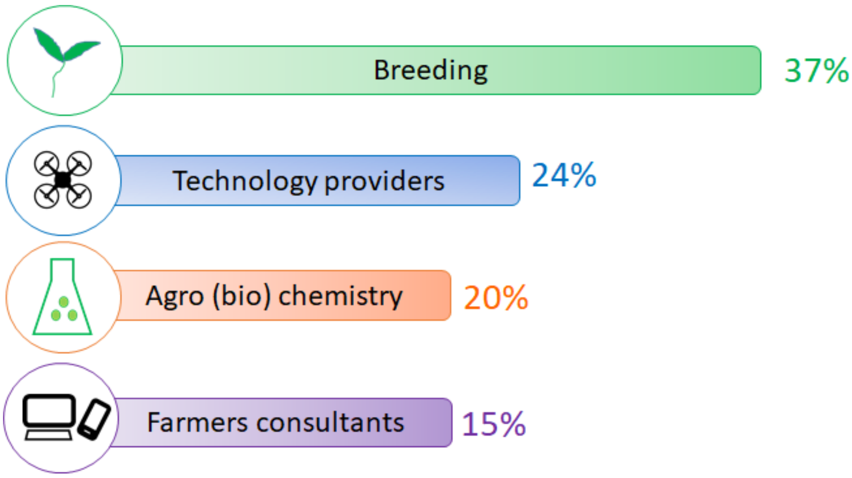

Figure 5.3: Classes of industry that expressed an interest in EMPHASIS

Examples of industry in Plant Phenotyping in Europe.

Below examples of plant phenotyping industry in Europe have been listed. Although it must be highly stressed that these are examples of the industry and that the list is not complete. Definitely spin-offs and SMEs involved in using plant phenotyping installations, in for example breeding or agro(bio)chemical sectores, are more difficult to map. Nevertheless, this list will provide an idea on the current plant phenotyping market.

Breeding companies

Ses-Vanderheave

SESVanderHave is a leading global player in the sugar beet seed sector, specialized in all aspects of the sugar beet production sector, from the development of new and more resistant varieties to multiplication of seeds. SESVanderHave has its headquarters in Belgium's "sugar capital" Tienen, which is also the location of one of the three high-tech factories where our sugar beet seeds are processed. Other factories are located in Kiev (Ukraine) and Alexeyevka (Russia).

Redebel

REDEBEL helps companies to add value when developing, testing and succeeding in obtaining registration of their plant protection products and biocidal products, by performing of the shelf field trial activities, using field phenotyping technologies and regulated agriculture practices.

KWS

KWS is a multinational breeding company, that also has trial sites and breeding stations across Europe. It builds up a long-term position in the growing vegetable seeds market and establish own breeding programs e.g. Dutch company Pop Vriend Seeds is market leader in spinach seeds and forms a cornerstone of the new business activity.

Technology developers

WPS

Netherlands-based horticulture solution company involved but not limited to, greenhouse high-throughput conveyor belt systems and robotic solutions.

Saga Robotics

Norwegian based company. Specialized in automated agriculture robotics for both precision agriculture and research (greenhouse application) purposes.

Phenomix

Based in France, the company develops numerous products such as image processing systems, plant cultivation tools, and plant cultivation systems. The company also provides consultation services to its customers.

Phenospex

A biotech company in the Nederland’s, which develops and provides hard- and software for automated plant screening and plant phenotyping for various conditions.

SMO - WIWAM

SMO is a custom machine building company and automation project developer based in Belgium. SMO joined forces with the VIB research institute to develop a series of plant phenotyping robots under the brand name WIWAM. WIWAM aims to build multiscale phenotyping installations that fit specific research questions. Currently there are 3 standard installations commercially available, but as a custom machine building company SMO also focuses on designing tailor-made plant phenotyping systems.

Lemnatec GMBH

Develops multiscale plant phenotyping technologies and solutions for use in the field, greenhouse, and laboratory. They develop a wide range of technology platforms as e.g. conveyer scanalyser, growscreen rhizo and field scanalyser. Also software solutions that enables operating the sensing equipment, storing the data and metadata, access to all records, and analysis of data are developed by Lemnatec. Since August 2019, LemnaTec GmbH is part of Nynomic AG, that provides a holding structure for technology companies.

Heinz Walz GMBH

Is a producer of photosynthesis measuring systems and provides measuring devices for plant research, based in Germany. Its product offerings include measuring-gas coolers, cold traps, Dewpoint-mirror measuring systems, gas-exchange systems for ecophysiological and physiological research, light measuring equipment, and PAM chlorophyll fluorometers.

Agro (bio) chemistry - phenotyping technology users

BASF SE

BASF is a multinational company mostly involved chemical substances, but has also a big agriculture solution department, with plant phenotyping installations mostly in Belgium. The Belgium biotech innovation centers of BASF SE combines a unique automated smart greenhouse designed for deep and high-throughput phenotyping of numerous plant species with automated state-of-the-art data acquisition technologies and advanced statistical and computational analysis.

Alphea Bio

Concentrates on products that help reduce fertilizer application (biostimulants) and control fungal diseases (biocontrol agents) sustainably in maize and wheat. The spin-off company of VIB is using controlled condition automated plant phenotyping technology to test biostimulants and has the ambition to have field phenotyping test in the near future.

PSI

Based in Czech-republic PSI, Photo Systems Instruments, research centrum owns and sells installations for plant cultivation and automated high-throughput phenotyping of a wide range of plant traits. PSI offer access to instruments and provide professional support of highly skilled technical and scientific personnel. Infrastructure of the PSI Plant Phenotyping Research Center is available for use by visiting scientists and on fee-for-service basis for a wide range of phenotyping and plant cultivation experiments.

Keygene

Keygene is an agricultural biotechnology company based in the Netherlands. The company provides molecular genetics solutions for breeders. Keygene primarily offers plant-based trait platforms, breeding technologies, and bioinformatics & data science solutions.

Identification of synergies within the European research infrastructure landscape

In order to enhance the benefit for its future users and to increase the return on investments of plant phenotyping infrastructure funders, EMPHASIS scrutinised the broader infrastructure landscape. This has led so far to the identification of multiple potential synergies between EMPHASIS and further European infrastructures that have already been addressed via collaborations on different levels and different intensities, driven by the concrete benefits that can be generated.

To the end of enabling access to plant phenomic and genetic data in Europe according to FAIR principles, EMPHASIS has set up a joint strategy process together with ELIXIR[1], a major ESFRI infrastructure in life sciences aiming at managing and safeguarding the increasing volume of data being generated by publicly funded research. This activity has been embedded in the EOSC-Life[2] project, coordinated by ELIXIR and partnered by EMPHASIS, helping to turn the European Open Science Cloud into reality by

[1] https://emphasis.plant-phenotyping.eu/Collaboration_ELIXIR

[2] http://www.eosc-life.eu/

building a digital space for life sciences. Working towards a sustainable infrastructure for agriculture as core element for enabling food security in climate change, EMPHASIS has produced and published a joint strategy with the ESFRI infrastructure AnaEE[3]. While EMPHASIS investigates the phenomes of crop genotypes in the diversity of current and future environments, AnaEE probes the functional responses of ecosystems — including agroecosystems — in current and future environments. Although distinct in their focus and timescales (plant phenotypes over months to years versus ecosystem processes over years to tens of years) and with specific experimental and modelling platforms, these two infrastructures share common objectives of food security and sustainable agriculture[4]. Both infrastructures contribute to the cluster of Environmental and Earth System Research Infrastructures[5], elaborating on creating a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It finally participates in the cluster CORBEL [6]of life science infrastructures, operating a platform for harmonised user access to biological and medical technologies, biological samples and data services. Potential synergies have to be further developed and elaborated during the maturation of EMPHASIS with other Research Infrastructures e.g. Eurobioimaging to utilize common synergies in image analysis, archiving etc.

As for mapping plant phenotyping infrastructures, EMPHASIS will also in the future continue to thoroughly monitor the broader RI landscape in order to make best use of synergies to the benefits of its stakeholders. Accordingly, the already existing partnerships will be evaluated and re-aligned as will be the overall EMPHASIS strategy, currently being developed within Work Package 6 of the EMPHASIS-Prep project.

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

[4] https://emphasis.plant-phenotyping.eu/Ccollaboration_AnaEE

[5] http://www.envriplus.eu/

[6] http://www.corbel-project.eu/home.html

Conclusion, discussion and next steps

The mapping activities of existing and upcoming infrastructure have been possible by engaging with the plant phenotyping community in Europe. Based on the input of users and owners of plant phenotyping installations, through different workshops and surveys, it was possible to develop a database with detailed information of the installations. Moreover, using the information in the database, EMPHASIS-PREP developed and published a virtual map, to the benefit of the plant phenotyping community. For the modelling installations, an online website has been developed, with searching and filtering functionality for plant models.

Phenotyping under controlled conditions (i.e., in glasshouses and controlled environment chambers) represented the largest number of reporting installations. This is perhaps related to the relative maturity of the technologies and the development of national and transnational networks. In Europe, the EPPN and EPPN2020 (https://eppn2020.plant-phenotyping.eu) programmes have fostered transnational access and information and technical exchanges which have driven uptake of these approaches. Historically dominated by model species such as Arabidopsis, a notable feature of the mapping exercise was the current focus on phenotyping species of agronomic importance.

Although field phenotyping is historically not very new, breeders are already looking at plants and crops in fields for hundreds of years, phenotyping in fields have been changing to more objective measurements with image analysis tools and the arrival of field carrier systems like for example phenomobiles. Definitely, also UAVs are getting cheaper and are used more and more.

Phenotyping in networks of lean fields seem to be done mostly on crop species, with cereals, such as wheat, barley and maize as the majority of sown plants. It comes not as a surprise that these major economic important crops are phenotyped so abundantly as climate change and the growing population puts pressure on the global food security. Networks of fields have been existing already for a while on local infrastructure level, but, due to climate change, the importance of field phenotyping networks in different climatological regions have become very clear. Although initiatives have been taken in developing networks of fields across Europe e.g. to analysis the same genotypes in different climatic conditions, it seems EMPHASIS could facilitate such activities in the future with different field related services and EMPHASIS-PREP proposes to test this in field pilot services during its implementation phase.

Installations identified as highly equipped fields tend to address the same goal but with a different strategy. Actually instead of being a network with nodes present if every different climate conditions, high equipment tend to monitor climatic conditions. Equipment such as rainout shelter aims at creating drought stress in field conditions for example.

At first, plant models were developed mostly for crops species to simulate the impact of environmental or management conditions on crop yield. However, the recent development of new model categories

(SPMs and FSPMs) and new data management practices could broaden the models predictions and the scope of the information extracted from phenomics data. Although initiatives have been taken in using models within the phenotyping pipeline, it seems EMPHASIS could facilitate such activities in the future developing an online portal referencing plant models and connecting the models referenced to the EMPHASIS portal.

Concerning the data management, the practices are moving from file system and spreadsheets to information systems and FAIR data management practices, being compliant to the $EPPN^{2020}$ levels. The different information systems that are currently under development tend to achieve this objective and constitute the EMPHASIS-layer.

Obviously, this mapping can only address data on installations, which are made available to EMPHASIS-PREP. Therefore, the mapping cannot be complete and obviously has a bias towards the main contribution countries and partners in EMPHASIS-PREP. Therefore, EMPHASIS will continuously discuss and update the database of existing and upcoming installations, and map with the community at large. Therefore, EMPHASIS-prep establishes a process for revision of the database, fitting in the governance of EMPHASIS and with fixed time lines and responsibilities. The process of revision is being established in close collaboration with WP5 Legal framework / governance and WP 6 Business Planning and will depend on the formation of the EMPHASIS governance.

One of the next steps is making the EMPHASIS database, with most of its details, publicly available. Currently, only a fraction of the data captured by EMPHASIS-PREP is available, and the build of a proper SQL-database has been started. This extensive database could be seen as a service of EMPHASIS to the community to inform plant researchers, from both public and private sector, with these details, which will facilitate collaboration in the plant phenotyping science sector. It will further act as a foundation for the upcoming online catalogue of services, currently being prepared, that will enable access to EMPHASIS-Prep pilot services, eventually leading to an access point of the EMPHASIS service portfolio once being operational as an organisation.

EMPHASIS

Glossary

AnaEE: ANAEE=Analysis and Experimentation on Ecosystem

CAGR: Compound annual growth rate

Canopy: canopy is more than one plant - in CE setups this is the difference between a top-down camera imaging a stand of plants and a conveyor measuring plant by plant…

CSM: process-based crop simulation model

EMPHASIS: European Infrastructure for Multi-Scale Plant Phenotyping And Simulation for Food Security in a Changing Climate- ESFRI listed project

EMPHASIS-PREP: H2020 preparatory phase project of EMPHASIS

ENVRI: ENVRI is the community of the Environmental research infrastructures, projects and networks as well as other diverse stakeholders interested in the environmental research infrastructure matters

EOSC: European open science cloud

ERC=European Research Council

ESFRI: Eureopean Strategy Forum for Research Infrastructure

FACE: (Free-Air CO2 Enrichment)

FAIR: findable accessible interoperable and reusable of digital assets

FSPM: functional-structural plant model

Installation: An INSTALLATION is the elementary level for data acquisition in a specific type of experiments. It stands for other frequently used terms such as ‘platform’, ‘facility’ or others.

KWS: The capital letters "K," "W" and "S" in the name KWS stand for Klein Wanzlebener Saatzucht, which means seed breeding from Klein Wanzleben.

Local infrastructure: A LOCAL INFRASTRUCTURE is a group of installations (see §1.3) located in one site depending on one institution (or more), which share governance committees, a common (or at least highly interoperable) information system, common principles for cost calculation and pricing and a common tool for user access.

PSI: Photo Systems Instruments

RGB: The RGB color model is an additive color model in which red, green and blue light are added together in various ways to reproduce a broad array of colors.

SEB: The Society for Experimental Biology

Shoot: phenotyping focusing on imaging

SPM: structural plant model

SQL database: Structured Query Language for databases

TB: in the context of data management systems: Terabytes

UAV: Unmanned Aerial Vehicle, mostly drones

USD: United States Dollars

Web service: a layer of abstraction between the database technology and the user. This layer facilitates the interaction between user and provider.

WP: work package

WPS: walking plant systems, Netherlands-based horticulture solution company involved but not limited to, greenhouse high-throughput conveyor belt systems and robotic solutions.

Annex 1: Check list

Deliverable Check list (to be checked by the “Deliverable leader”)

	Check list		Comments
Before	I have checked the due date and have planned completion in due time		*Please inform Management Team of any foreseen delays*
	The title corresponds to the title in the DOW		*If not please inform the Management Team with justification*
	The dissemination level corresponds to that indicated in the DOW		
	The contributors (authors) correspond to those indicated in the DOW		
	The Table of Contents has been validated with the Activity Leader		*Please validate the Table of Content with your Activity Leader before drafting the deliverable*
	I am using the EMPHASIS deliverable template (title page, styles etc.)		*Available in “New EMPHASIS Logo, Templates, CI” on the collaborative workspace*
The draft is ready			
After	I have written a good summary at the beginning of the Deliverable		*A 1-2 pages max. summary is mandatory (not formal but really informative on the content of the Deliverable)*
	The deliverable has been reviewed by all contributors (authors)		*Make sure all contributors have reviewed and approved the final version of the deliverable. You should leave sufficient time for this validation.*
	I have done a spell check and verified the English		
	I have sent the final version to the WP Leader and to the Project coordinator (cc to the project manager) for approval		*Send the final draft to your WP Leader and the coordinator with cc to the project manager on the 1st day of the due month and leave 2 weeks for feedback. Inform the reviewer of the changes (if any) you have made to address their comments. Once validated by the 2 reviewers and the coordinator, send the final version to the Project Manager who will then submit it to the EC.*