D2.5: Report on current and future user demands

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Executive Summary

Objectives

The improvement of crop performance to address the challenges imposed by climate change and in view of a continuous increases of the world population (and its needs for wellbeing and healthy diet), is a major goal to establish a sustainable agriculture.

In this scenario phenotyping is at the forefront of future plant breeding and selection, and the plant phenotyping community must confront with the need to accurately measure diverse traits of an increasingly large number of plants (and genotypes or ecotypes) to successfully address novel challenges beside a sheer rise of plant productivity, such as increasing plants adaptability to resource-limiting environments and resilience to stress, and successful implementation of low-input agriculture with selected and appropriate plants.

Technological advancement is the basis to foster the development of phenotyping centres, while data standardization, acquisition and reusability must be considered as major objectives. Thus, future trends in the development of plant phenotyping need the integration of different experts and disciplines (spanning biological sciences, computer science, mathematics and engineering) with a multidisciplinary view trying to identify a common language, and pipelines to endure a fruitful collaboration between technology developers, providers of infrastructures and increasingly different categories of users.

This deliverable gives a snapshot on current EMPHASIS activities, users and stakeholders, and maps existing and future demands of plant phenotyping in order to meet the user expectations towards plant phenotyping infrastructures in a long-term view, facilitating science- and technology-based strategy developments and policies.

Rationale

Exploring the user and stakeholder demands is a continues and evolving process that is fundamental for the long-term sustainability of EMPHASIS as a distributed infrastructure.

The user demands presented in this deliverable is the result of data acquisition implemented by EMPHASIS-Prep through two surveys launched in 2017 and 2018 to explore the phenotyping community as a whole.

The data of the surveys were combined with bibliographic sources, by means of a bibliographic analysis to measure the phenotyping scientific production, research and trends, and that was taken into account to draw the current and future user demands.

The future demand for plant phenotyping also considered the burning necessity to efficiently integrate the different communities involved in plant phenotyping, here defined as plant phenotyping integration process.

Main results

To define the current and future user demands, we identified the EMPHASIS users, and mapped the demand accordingly to the following categorization:

- Demand for phenotyping in general;
- Demand for access to infrastructures and data;
- Demand for innovation;

- Demand for training;
- Demand for modelling.

From this analysis it emerges: 1) an increasing demand for training, especially keyed at training for imaging and bioinformatics; 2) an increased demand for access the phenotyping infrastructures 3) the need of a even wider and more integrated community to address phenotyping challenges and foster complementation across different disciplines.

Contents

Documents used in the preparation of this deliverable:

- Deliverable 2.2
- Deliverable 2.4
- Deliverable 3.1

Introduction

In 2017, at its early stage of activity, EMPHASIS -PREP started the analysis of the plant phenotyping user demands at European level. Several initiatives were implemented to get a clearer picture of plant phenotyping installations, users and their needs and expectations (see deliverables D.3.1 and D.2.1-2.3).

The data acquired mainly lay on two surveys and several workshops, launched with the overall aim to record and examine the plant phenotyping scenario in all its aspects. The second survey focused in particular on gathering information on the phenotyping users and user demand.

Moreover, a very large body of literature has been collected in the recent years, which provides additional useful information to evaluate the users demand. Finally, a lively activity of social networks and websites offer a third valuable source to assess plant phenotyping activities and initiatives.

While the community integration process, undertaken by EMPHASIS-PREP, has led to a dynamic and rapid increases of the knowledge of phenotyping stakeholders and users, it will require further investigation and mapping in order to align the EMPAHSIS activities with the forthcoming user demands.

This document reports the current status of the phenotyping user demands and formulates hypothesis on the future demands, on the basis of the data collected by EMPHASIS in its preparatory phase. This does not constitute an end-point: Identification, engagement and mapping of the EMPHASIS users will continue through the implementation and operation phases, as part of the continuous process of understanding the community and its demands in a distributed research infrastructure for plant phenotyping.

1. Overview of the plant phenotyping user demands

Plants develop dynamic phenotypes from the interaction of the plant genetic background with the environment (including both the natural environment and the farming activities in case of crops). Therefore, plant phenomics does not aim to solely associate one genotype to one phenotype in a given condition (e.g. in a controlled environment), but rather characterize the plasticity of the plant phenome when exposed to a range of environmental conditions (Tardieu et al., 2017). Understanding the contribution to phenotype development and changes across plants' lifetime in a permanently changing environment is essential for the advancement of basic plant science and its translation into application including breeding and management for more productive and climate-ready crops.

In particular, the plant research community has been confronted with the need to accurately measure diverse traits of an increasingly large number of plants to increase the adaptation to resource-limiting environment and low-input agriculture (Pieruschka and Schurr, 2019).

Novel technologies have been developed, specifically during the last two decades, through novel sensors, automation, and quantitative data analysis have facilitated such tasks. Developments in sensor technology have led to a substantial increase in the assessment of complex plant traits such as growth, development and yield (traits), tolerance, resistance and resilience to stress, leaf, root and whole plant architecture, and many other important plant traits.

Moreover, the number of stakeholder interested in phenotyping has increased rapidly. To comply with increasing, new and more sophisticated user demands large-scale phenotyping research platforms have been set up and are organized within national phenotyping facilities with a range of high-tech applications in climate rooms, greenhouses and in the field (Rosenqvist et al., 2019).

Large investments have been made for plant phenotyping in terms of funding, research, and high-tech installations in Europe, Australia, North America and Asia, to address the need of experimentation and critical mass, and to efficiently use existing synergies and competences in plant phenotyping (Pieruschka and Schurr, 2019).

In this context, EMPHASIS will operate to address the increase need of plant phenotyping community by analyzing and engaging the range of interested stakeholder. Interaction with the phenotyping community, in its wider term, allows us to point out focus areas, challenges, and bottlenecks in plant phenotyping and to analyze the current and future user demand and orientation. A deeper view on the analysis of the future user demand and orientation is presented in the paragraphs below.

1.1 The plant phenotyping landscape

Plant phenotyping is comprehensively defined as the assessment of complex plant traits such as growth, development, tolerance, resistance, architecture, physiology, ecology, yield (Li et al., 2014). Modern plant phenotyping relies on two main approaches: (i) non-destructive measurements to be able to follow a trait over time on the same specimen although in possibly variable environment, and also considering the natural development and ageing of single organs and whole organisms; (ii) high-throughput measurements, to be able to screen at similar conditions many genotypes (Costa et al., 2019a). Recently, modeling was included in the strategies for assessing and increasing the effectiveness of new phenotyping techniques in plant breeding (van Eeuwijk et al., 2019)

The increasing investments of academia and research institutions in Europe allowed to build large-scale research infrastructure for automated plant phenotyping, such as 1) installations for low to high resolution, high-throughput phenomics in climate rooms and greenhouses; 2) semi-controlled field systems for high-throughput phenomics and 3) network of practical field experiments for lean phenotyping (Rosenqvist et al., 2019).

Furthermore, the increased demand of plant phenotyping emerges in the elevated number of phenomics publications, which has expanded almost 100% in the last five years. Remarkably, Europe is the most active in publishing about plant phenotyping, with a total of 46 % of the total publications worldwide (Costa et al., 2019a).

The multidisciplinary involvement of competences when dealing with plant phenotyping has evolved further in recent years now also involving expertise about: (i) sensor development, automation and usage, (ii) -omics in the broadest sense, (iii) plant ecology, physiology, pathology, and interactions with other organisms and (iv) (bio)informatics and statistics.

Plant phenotyping is rapidly evolving. Hence there is a strong necessity of rapidly catching novel needs and demands for immediate update and upgrade of dedicated infrastructures, e.g. providing tools and resources for phenotyping the valuable genomic resources available.

A number of projects have been initiated to utilize and further develop the phenotyping infrastructures: Arabidopsis phenotyping (AGRONOMICS) and projects to develop technology for phenotyping different crops and plant organs (SPICY; EURooT) paved the way to the EU funded FP7 project EPPN (2012-2015 European Plant Phenotyping Network, http://www.plant-phenotyping-network.eu/). EPPN, as a starting community project, provided transnational access to 23 experimental plant phenotyping installations across Europe. The project has resulted in 66 transnational access experiments and more than 50 peer reviewed publications. Based on the success of EPPN and the increasing demand for plant phenotyping, a H2020 advanced community project, EPPN2020, was approved (2017-2020) providing the opportunity for almost 200 potential plant phenotyping transnational access experiments and integrating 31 key plant phenotyping installations in 11 European countries.

Furthermore, the COST Action "The quest for tolerant varieties - Phenotyping at plant and cellular level" started in 2011 and created a network and very intense interactions of European scientists with expertise on phenotyping, various omics areas, and plant physiology.

Since early development of the discipline, several international initiative and projects included phenotyping as an experimental cornerstone, and numerous phenotyping working groups were activated. For example a number of experts to promote and optimize the use of phenotyping to support wheat improvement was supported by the Wheat Initiative (https://www.wheatinitiative.org/wheat-phenotyping-to-support-wheat-improvement).

Growth and development of the plant phenotyping landscape has generated the opportunity and the demand for coordinated data generation, management, analysis, integration across platforms, new measurements and experiments. Given the complex nature of big data acquired by plant phenotyping, the quality of data across the entire data acquisition pipeline has rapidly become a key issue. One goal of modern phenomics is the integration of data into structured and searchable databases following the FAIR principle (findable, available, identifiable, reusable). This includes collection and analysis of metadata with clear measurement protocols and the development of a procedure of controlled data quality. This data portal can be developed upon existed initiatives as the Minimum Information About a Plant Phenotyping Experiment (miappe.org) and BrAPI as interface for exchanging plant phenotype and genotype data between crop breeding applications.

1.2 Main features of plant phenotyping user demands

1.2.1 The current plant phenotyping infrastructures in Europe

In order to generate interaction and synergies in the existing plant phenotyping communities, several plant phenotyping infrastructures were established at country level. Many of these infrastructures falls into the five EMPHASIS pillars as defined in the criteria list for infrastructures (See deliverable D 2.1).

An infrastructure database was developed by EMPHASIS-PREP Work Package 2 (See deliverable D 2.3, https://emphasis.plant-phenotyping.eu/database). This deliverable revealed that, at European level, there are 182 plant phenotyping installations of controlled conditions, intensive fields and networks of field phenotyping infrastructures. Among them, 112, that is the majority of phenotyping infrastructures, are controlled conditions installations (i.e., in glasshouses and controlled environment chambers) with a focus on shoot and canopy phenotyping and on species of agronomic importance, dominated by cereal crops; whereas 70 installations refer to phenotyping in field with respectively (i) 25 highly equipped fields located mainly in France, Germany, Belgium and the UK - with a focus on the major industrial agricultural productions (cereals, oil crops) in Europe - and (ii) 45 installations are networks of lean fields that have been identified as geographically scattered in pan-Europe, focused on crop research, e.g. cereals crops, in agriculture relevant conditions, with phenotyping on mainly canopy and yield, and with an increased use of unmanned aerial vehicle (UAVs) in field phenotyping.

Furthermore, virtual platforms as modelling and data management systems, have been mapped. A total of 116 modelling application for plant phenotyping, have been identified. A large proportion 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). The data management systems for plant phenotyping are ranging from custom solutions to larger information systems compliant with FAIR criteria and EPPN2020 requirements (for a deeper analysis, see deliverable D.2.4).

1.2.2 The plant phenotyping users and stakeholders

The identification of EMPHASIS users and stakeholders and the promotion of activities for stakeholder engagement is fundamental to EMPHASIS work and reflects its commitment to building a more coordinated phenotyping community.

A series of activities were performed towards the identification of the EMPHASIS users and stakeholders leading to the definition of both categories (Fig. 1), and extensively reported in the deliverable D 3.1 “Communication strategy with different stakeholders.

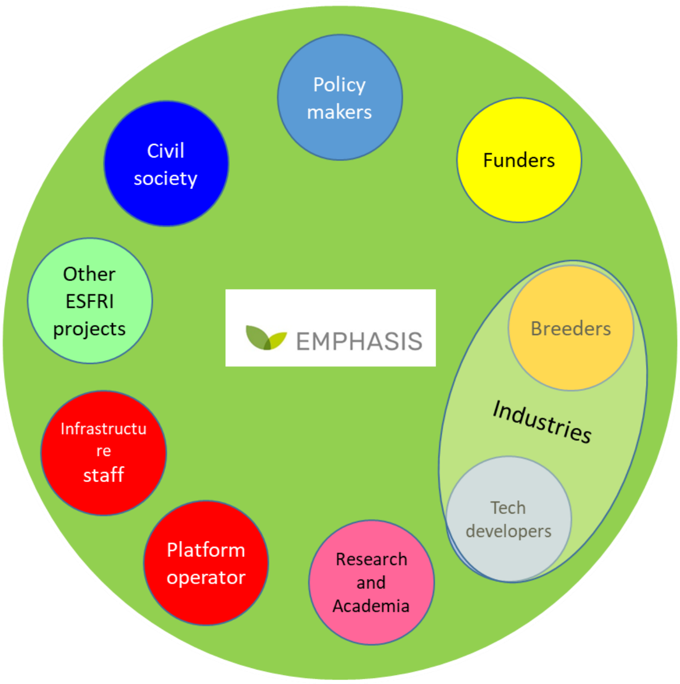

Fig. 1 - Stakeholders and users in the field of plant phenotyping

EMPHASIS-PREP implemented multiple important engagement activities with a positive impact on increasing its stakeholders:

- The 2018 survey "Do you need plant phenotyping" (see results on the EMPHASIS website: https://emphasis.plant-phenotyping.eu/index.php?index=207);
- The EMPHASIS LinkedIn account (linkedin.com/company/emphasis-on-plant-phenomics)
- Newsletter (https://emphasis.plant-phenotyping.eu/News)
- Support group meetings: Meeting with representatives of 24 national plant phenotyping communities across Europe
- Workshops (see D2.3) as for example:
    - field phenomics workshop to engage with the field phenotyping community in both private sector (breeders) and public sector (agriculture oriented academia).(The full report of this workshop is available on the EMPHASIS website: https://emphasis.plant-phenotyping.eu/meeting_reports);

These activities sensibly rise the EMPHASIS visibility, expanding the general participation to EMPHASIS and enlarging the industrial partnership (Fig. 2) (See WP2 deliverable D 2.3 "List of existing/upcoming infrastructures".)

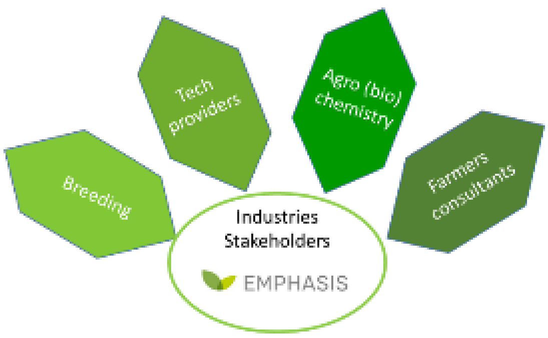

Fig. 2 - Examples of the industries categories involved in plant phenotyping in Europe

The surveys undertaken in 2017 (Annex 2) and 2018 (Annex 3) gave a wider picture of the phenotyping users.

The results of the 2017 survey showed some important features leading to stakeholder identification. The number of survey respondents was 136 and among those, there were 72 users, 35 operators of installations; 29 head of the local infrastructures; 17 managements of training and education and 4 heads of national infrastructures.

The survey participants mainly belonged to University (53%), and research organizations (41 %), with lower contribution from industries (5%) and funders (1%). The greater contribution came from the researchers that mainly use controlled conditions to run the experiments (72%) and performed phenotyping mainly of plant organs (shoots, roots). The key traits in which the audience was interested reflected the high participation of researchers and were mainly abiotic stresses and functional traits (78 and 72%, respectively, see deliverable D.3.1 for details).

In 2018 the number of respondents significantly increased involving a broader number of industries.

320 individuals participated in the survey. The most represented category was again the scientific community (72 %, bringing together junior scientists, senior scientists, and PhD students), followed by breeders (14%), technology developers, modellers (8 and 9% respectively) and technical staff (5%). Most of the participants in the survey were from public research organizations (67% of the participants are from research institutes and universities) but a relevant fraction was from the private sector (20% of participants); See Deliverable D2.2.

2. Current user demands

In the light of above, it is worth to highlight that there are considerable changes in the landscape of phenotyping infrastructures, reflecting the growing interest into plant phenotyping and its applications.

Within the last decade, large-scale phenotyping research platforms have been set up with a range of high-tech, automated installations in climate rooms, greenhouses and in the field, to accommodate the widest user demand (See deliverable D 2.3).

When interrogated (multiple answers allowed), the phenotyping users reached by EMPHASIS surveys, expressed their interest mainly towards: access to training (62.5 %); expand the research network (50 %); access to installations (47%); access to data (39%) and support innovation (42%).

On this basis, we can represent the EMPHASIS user demand as:

- Demand for phenotyping in general;
- Demand for access to the infrastructures;
- Demand for innovation;
- Demand for training;
- Demand for modelling;
- Future user demand.

2.1 Demand for plant phenotyping in general

The rising interest into plant phenotyping is demonstrated by the increasing number of user categories participating in the surveys. Note however that participants to the surveys remain keyed at plant research and plant breeding activities, and that 73% of the participants (235 out of 320) already use plant phenotyping in their activities.

The surveys also revealed that a wide range of species is currently analyzed using high throughput phenotyping (Fig. 3 and 4).

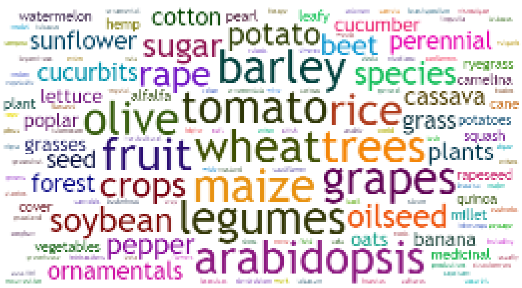

Fig. 3 - Word cloud representation of main plant species phenotyped, as revealed form the EMPHASIS surveys

Cereals are the most phenotyped species (see Fig. 4 for a more accurate distribution of phenotyping interest within the cereal plants), although fruit trees showed an increased interest in comparison with 2017 data where perennial crops were only 1% of the crops studied. This shows an increased application of plant phenotyping also towards horticultural species. Interestingly, the results of the survey reflected the overall European crop production as reported in literature (see Costa et al., 2019b).

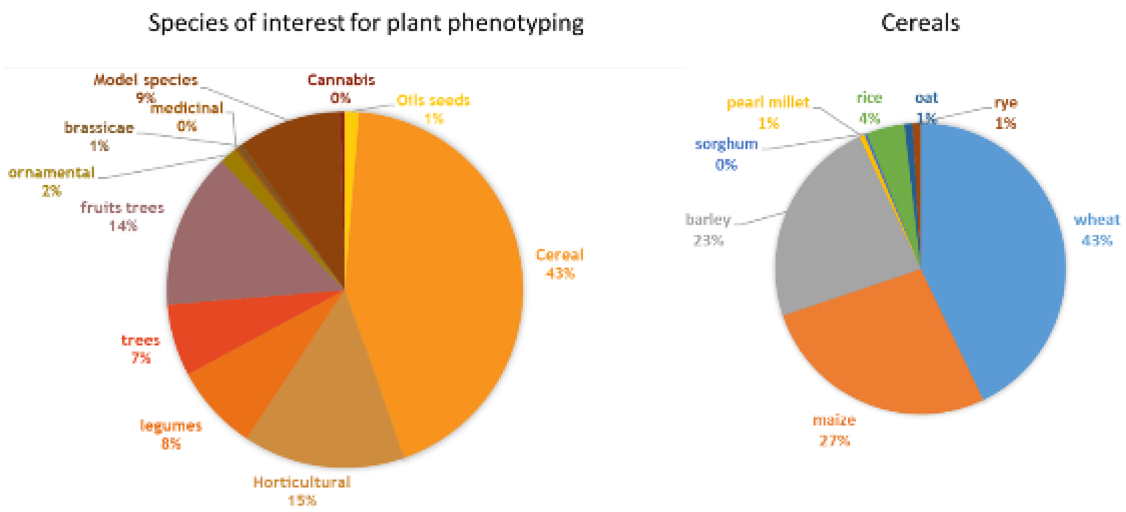

Fig. 4. Groups of crops phenotyped in Europe.

From the analysis of the user demands it emerged that referring at current and future activities one of the main expectation towards EMPHASIS, it is represented by the EMPHASIS support for expanding their networks especially in terms of project consortiums.

Generally speaking an increasing number of projects are successfully funded, which also indicate growing critical mass and growing interest of research and innovation policies toward phenotyping (e.g. INTERPHENO http://interpheno.rd.ciencias.ulisboa.pt/, WineClimAdapt or, VINBOT http://vinbot.eu/, ECOFE https://www.ecofe.eu/, and also see Costa el al., 2019b or multisite based field phenotyping projects, see Deliverable 2.3).

In addition, an increasing number of workshops and congresses are including dedicated sessions on plant phenotyping in their programs (See Table 1 for the list of 2019 and 2020 initiatives, and some of those forthcoming).

Table 1 - Events providing dedicated sessions for plant phenotyping

Event	Year	Website
Botanikertagung 2019 International Plant Science Conference	2019	https://www.botanikertagung2019.de/
63° congress of Italian Society of agricultural genetics	2019	
RDA France (Paris)	2019	https://rdafrance2019.sciencesconf.org/
Synergies for Sustainable, Open and Responsible Research (Porto, Portugal)	2019	https://www.opensciencefair.eu
International Congress on Biophysics of Photosynthesis: from molecules to the field	2019	http://www.biophysicsofphotosynthesis2019.eu/
IPPS 6th International Plant Phenotyping Symposium	2019	https://ipps2019.plant-phenotyping.org/
SEB 2020	2020	http://www.sebiology.org/events/event/seb-prague-2020
ICROPM 2020	2020	https://www.alphavisa.com/icropm/2020/
Plant Biology Europe	2020	https://europlantbiology2020.org/
Wageningen Business day: finding answers together	2019	https://www.wur.nl/nl/activiteit/Business-Day-Finding-answers-together-1.htm
8th Plant Genomics and Gene Editing Congress: Europe	2020	http://www.global-engage.com/event/plant-genomics/
Phenome	2020	https://phenome2020.org/
International Symposium of the Society for Plant Breeding: Digital Breeding	2020	https://gpz2020.boku.ac.at/
9th International Symposium on Root Development	2020	https://rooting2020.com/
11th International Symposium on Grapevine Physiology and Biotechnology	2020	https://isgpb2020.com/
European Plant Phenotyping Conference	2021	
XXXI International Horticultural Congress: IHC2022	2022	https://www.ishs.org/symposium/640

2.2 Demand for access to the phenotyping infrastructures

The request to access installations is one of the main demand for the user community (Fig. 5).

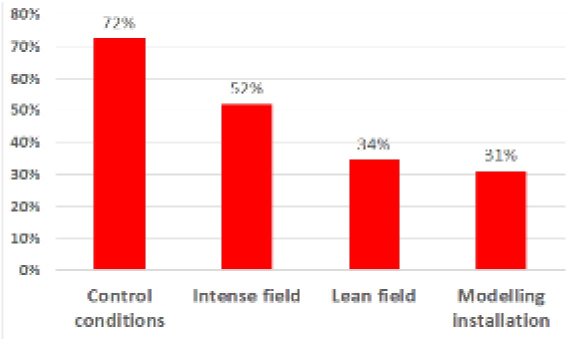

Fig. 5. - The most demanded infrastructures

Considering that academic researchers were the main represented users of plant phenotyping in EMPHASIS surveys, it is not surprising that control conditions infrastructures are the most requested installations for access, followed by intense field, lean field and modelling.

The demand is mainly oriented to study abiotic stresses with drought, heat and nutrients main stress factors to be investigated. Biotic stresses are also largely represented as a research field requiring phenotyping (Fig. 6).

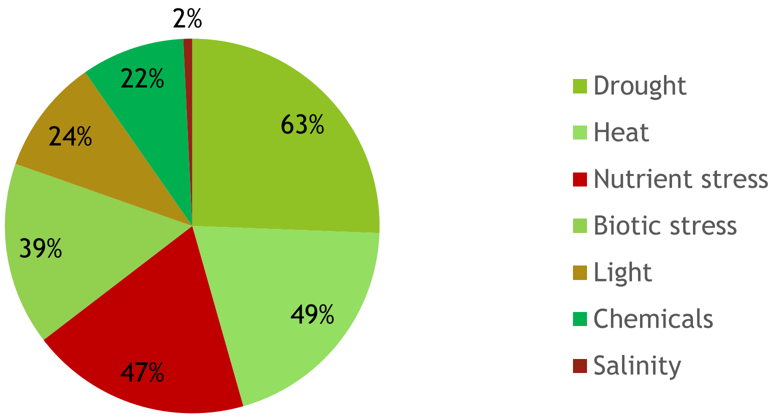

Fig. 6 - Treatments adopted in phenotyping studies

A detailed analysis of the demand for access each infrastructure has been deeply reported in deliverable D2.1 (https://emphasis.plant-phenotyping.eu/lw_resource/datapool/systemfiles/elements/files/d42b5106-0ae5-11ea-b1c5-dead53a91d31/live/document/EMPHASIS-PREP_D2.1_Criteria_list.pdf).

and deliverable D 2.2 https://emphasis.plant-phenotyping.eu/lw_resource/datapool/systemfiles/elements/files/165e15fe-0ae6-11ea-b1c5-dead53a91d31/live/document/EMPHASIS-PREP__D2.2_Criteria_list_user_demands.pdf):

The demand for access to the EMPHASIS infrastructures gained from D2.1 and D2.2 is summarized as follows:

- *Demand for access to semi-controlled environment infrastructures*: Scientists showed high interest in accessing all size of semi-controlled conditions installations, while breeders expressed higher interest toward large capacity infrastructures;

- *Demand for access to intensive field*: While scientists do not show a prevalent orientation toward a specific size of field trials, modelers and breeders showed a clear orientation towards small and bigger field plots respectively;

- *Demand for access to modelling platforms*: Almost all EMPHASIS user categories (scientists, breeders, technology developers and technical staff) will consistently increase the access to models to represent the traits of interest in the future;

- *Demand for access to data management*: Data management is mainly requested by technology developers, while less scientists directly involved.

2.3 Demand for innovation

Plant phenotyping, based on innovative non-destructive image analysis, data management, and modelling, has emerged as a cutting-edge technology playing an important role in plant and agronomic sciences, namely, to design new crops, characterize the responses of genetic resources to the environment, and improve breeding and management of crops (i.e. through precision agriculture). Implementation of such technologies is crucial and represents both a power and a limit of high throughput phenotyping. Discovery of innovative technologies that allow plant phenotyping to investigate a growing number of traits is perceived as an important demand.

Albeit very rapidly evolving, mapping of phenotyping technologies revealed that image-based systems as RGB, thermal and hyperspectral still play the key role. Low cost equipment is strongly emerging in the technology panorama (Fig. 7) together with custom systems, both based on optical measurements.

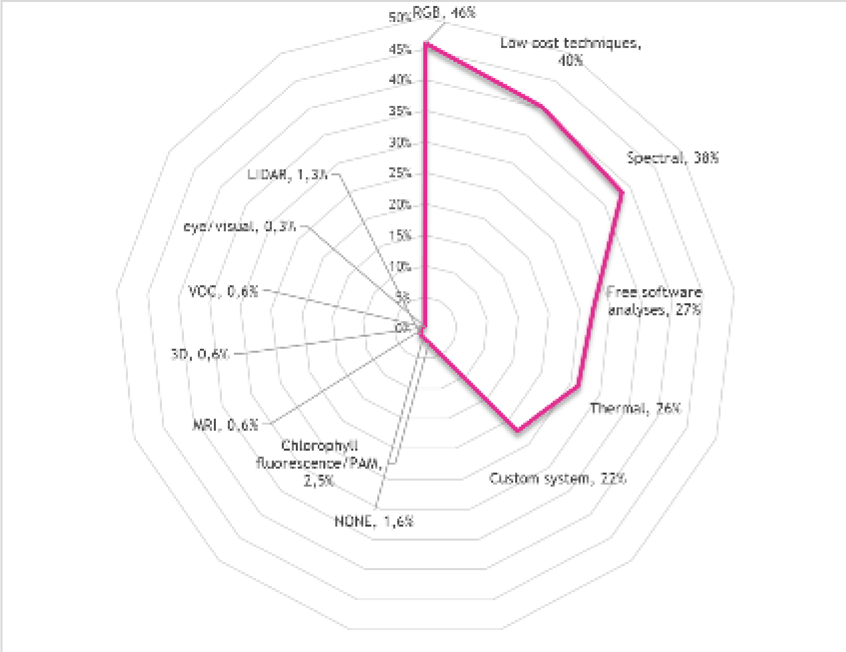

Fig. 7- Mapping of plant phenotyping used technologies

To meet the request of innovation in plant phenotyping, technology developers mainly require an expansion of the research network (76%), testbed for validation, access to data and training (60% in both cases), funds for the development (52%), access to installations (48%, Fig. 8).

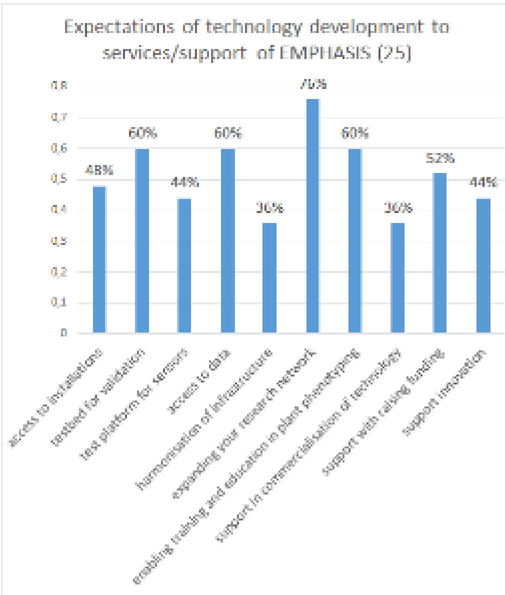

Fig. 8 - Technology developer demand

2.3 Demand for Modelling

In the last years the development of computer models of plant functioning and growth is becoming a more and more important tool for plant phenotyping. For details on types of models and their use within the phenotyping framework see D2.1 (Criteria list for infrastructure) and D2.4 (Gap analysis).

EMPHASIS therefore explored the demands toward modelling in the second surveys, especially aiming at understanding who is using models and for which purposes.

As a result, about half (47%) of the survey participants is using models, and they are mainly scientists, modelers and breeders (Fig. 9).

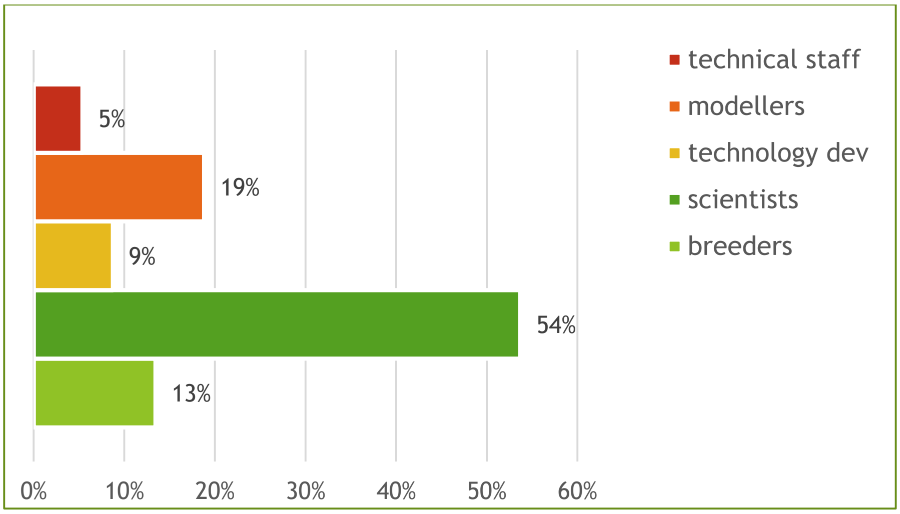

Fig. 9 - Modelling user demand

The demand of models is oriented mainly to represent plant growth (25%), yield (20%), soil water or nutrients (14%), and plant architecture (13%) (see Table 2).

Table 2 - Traits currently described with models

Major traits analysed with models	% of hits /total answers
Plant Growth	25%
Yield	20%
Soil water or nutrients	14%
Plant Architecture	13%
Genomics	10%
Atmospheric conditions	9%
Plant hydraulic	6%
Other	2%

2.4 Demand for training

To increase knowledge in plant phenotyping by training is one of the major tasks of EMPHASIS and, as inferred from the surveys, it is also highly demanded by users.

Sixty-two percent of the participants expect training activities to be a service provided by EMPHASIS in particular concerning imaging, but also addressing the use of technologies and bioinformatics (Fig. 10) (See also deliverables D 3.2 and D.2.2).

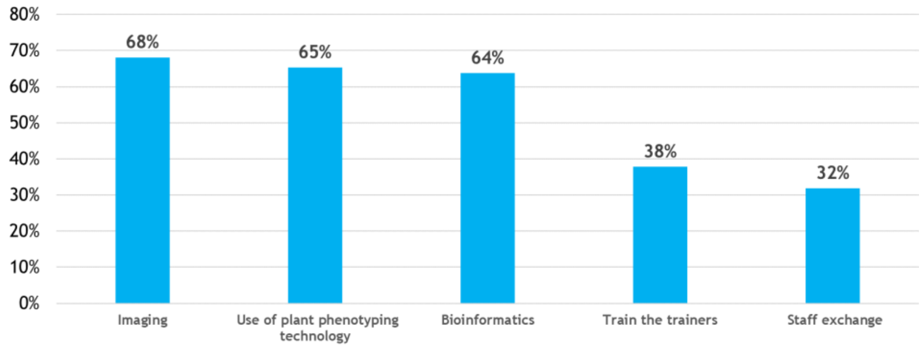

Fig. 10 - Most requested topics for training in plant phenotyping

The survey results showed difference in preferences expressed for training activities within each category of users (multiple choices allowed). Academic scientists were more interested in training for plant phenotyping technologies (77%), imaging (72%) and bioinformatics (66%). This in comparison with breeders that expressed interest in training in plant phenotyping technologies (78%), bioinformatics (67%) and imaging (59%), while less interest was expressed for training the trainers and staff exchange. Technology developers showed high interest in imaging, use of plant phenotyping technologies and bioinformatics (64, 56, 52% respectively). Modellers showed interest in training on plant phenotyping technologies (79%) and imaging (69%) followed by bioinformatics (55%), while their interest in train the trainers and staff exchange was lower (28% and 38% respectively). The technical staff, was equally interested in bioinformatics and staff exchange (44%) and showed high interests in imaging and use of plant phenotyping technologies (81% and 75%).

Remarkably, the results of the survey showed low request for “train the trainers”, which might be due to the fact that most participants of the survey are not involved in training today and do not see themselves as trainers. Whereas, a low number of participants is actively involved in training (For a deeper analysis see D 3.2).

For the results for the private sector, training and education was again a most requested service, but support to innovation emerged as one of the main activities that they expect from EMPHASIS. Furthermore, it’s remarkable that 1/3 of company representatives mentioned access to installations and to data as a demand.

3. Future user demands

3.1 Future trends in plant phenotyping

Because plant phenotyping is such a growing field, characterized by rapid innovation and growing participation of different users, to predict the future phenotyping demand is an extremely complex process. However, the 2018 survey posed a specific question to the participants: “Do we need plant phenotyping?”. The following analysis is based on the response that 98% of the interviewed people (289) affirmed that they will use plant phenotyping in the future for their activities.

Among those, 71% of the participants declared that they expect that future analysis capacity will increase consistently. This includes both public and private sector (Fig. 11) as also indicated in more details in the deliverable D2.3.

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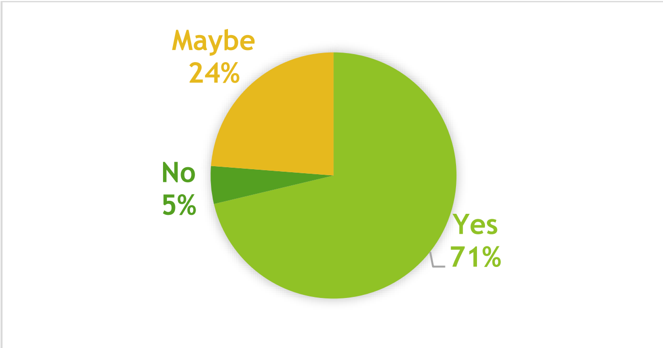
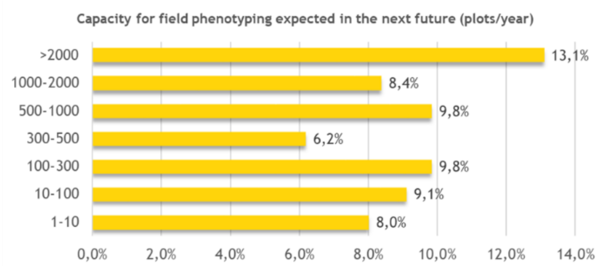


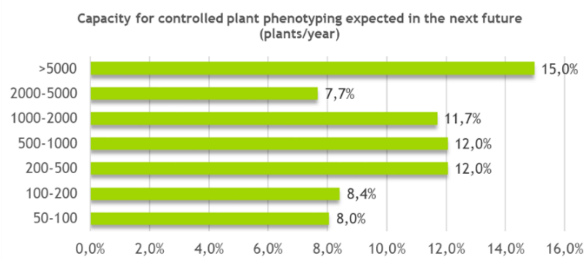
Fig.11 - Will you use plant phenotyping in the future?

In particular, an increased need of capacity as number of plots /year emerged for field phenotyping (Fig 12A). The demand for a large number of plots/year tested in fields was raised in 30 % of the cases by private companies (mainly breeding companies) and the rest from academic institutions (70%).

When future demands for capacity of plant phenotyping in controlled conditions were assessed, it was again clear that an increased capacity to analyze more plant/year (5000) is demanded by 15% of participants (Fig. 12B).



A



B

Fig. 12A and 12B - Future capacity demand in semi controlled and intense field infrastructures.

The interest in specifically increasing the capacity of field phenotyping in the future is consistent with the results of the 2017 survey where 50% of the participants considered field phenotyping as the main challenge for plant phenotyping infrastructures (see Fig 13).

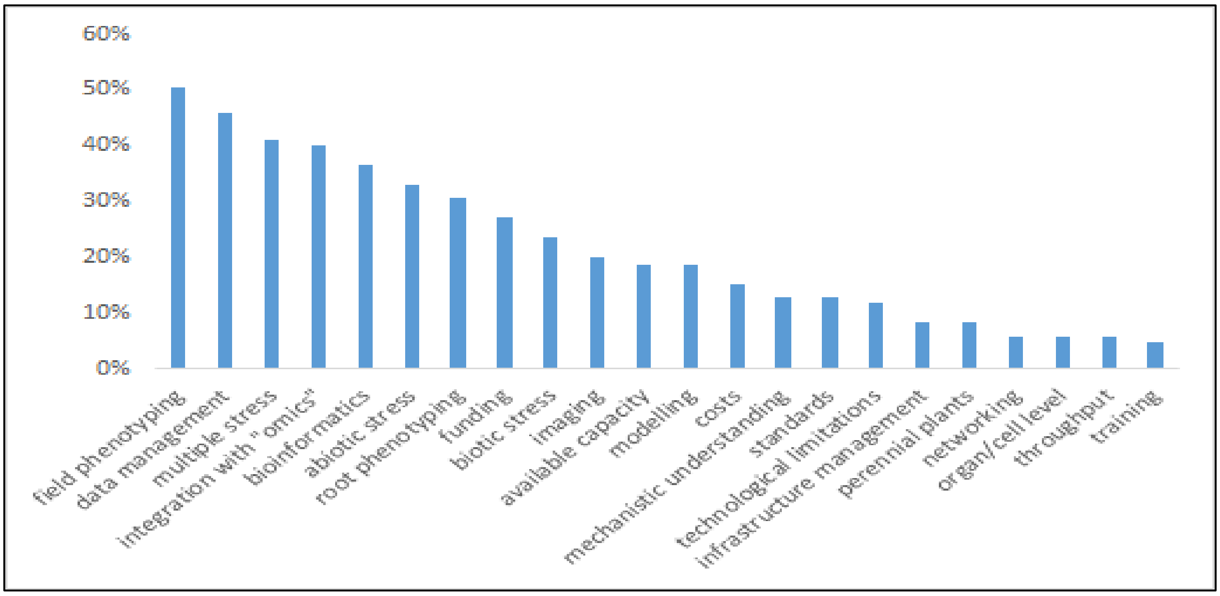


Fig. 13 - Survey (2017) data. Question: What is the biggest challenge in the future of plant phenotyping, according to your vision.

About the most challenging traits to be considered in future plant phenotyping activities, functional traits will continue to have central role. Plant phenotyping will be considered the way to overcome the bottleneck in functional studies where genomic data should be correlated with the observed phenotype (Fig. 14).

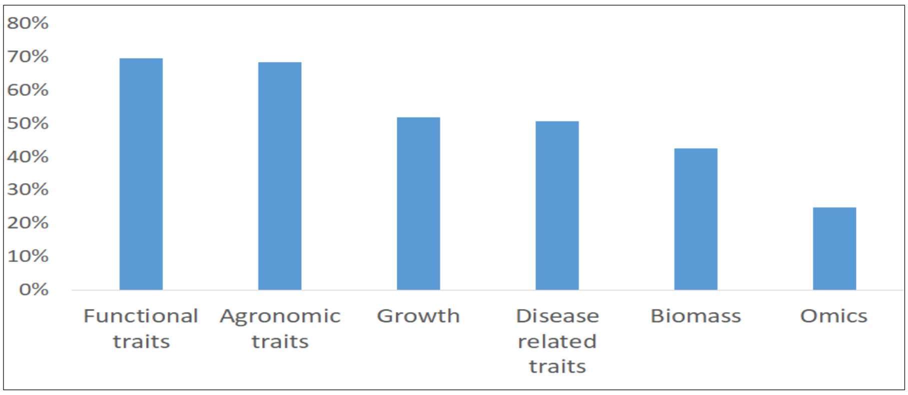


Fig. 14 - Prediction of traits that will be analysed with plant phenotyping

Within the phenotyping panorama the use of the modelling infrastructure will surely increase in the next years.

This is based on the survey data where 83% of the participants affirmed they will use modelling in combination with phenotyping experiments, thus prompting EMPHASIS in the development of a modelling platform that collect a whole set of tools spanning from crops to model plants (See paragraph 3.2.1).

3.2 The plant phenotyping integration process

3.2.1 Integration of phenotyping platforms and data

Increasing integration of information across High throughput plant phenotyping (HTPP) facilities (indoor, greenhouse or field) or different biological levels is crucial for more efficient plant phenotyping (Coppens et al., 2017). In parallel, it also allows improved data analysis/processing and enhanced modelling capabilities by combining different types of expertise (Costa et al., 2019b).

An interesting example is the development of the Quantitative Plants Platform (https://quantitative-plant.org/) that presents tools for plant image analyses and modelling made with joint efforts between institutions: Jülich , UV Louvain and the EMPHASIS project.

The use of field-phenotyping technologies to monitor plant/crop responses should be expanded to enhance assessment of larger numbers of varieties/replicates under natural growth conditions at a lower cost. Moreover, strongly depends on the recruitment of multidisciplinary teams involved in research programs and projects, especially where there is still a lack of skills and educational background for phenotyping issues. Furthermore, successful field phenotyping is in need of multi-site and multi-year field experimentation to be able to generate statistical relevant data, which leads to the elevated demand towards access to field phenotyping infrastructures.

The emerging request is to harmonize the existing protocols for experiments settings and for data analysis, especially in open filed multisite trials. To address this issues, the EMPHASIS has included in its portfolio services two pilot projects, respectively harmonization and field pilot services, with the overall aim to address the needs of sharing protocols and establish a network of fields. Moreover, a preliminary map of the existing field station for field phenotyping have been implemented by WP2 (https://emphasis.plant-phenotyping.eu/database), with the final aim of facilitating the establishment of a field phenotyping community have been developed. This will be soon implemented with a list of the technologies available in the field stations to facilitate the development of a networks devoted to field phenotyping experiments.

3.2.2 Integration of the phenotyping community

Direct quantification of the phenotype includes diverse structural and functional aspects. Only few of them are nowadays covered by technologies, therefore limiting usefulness and overall capacity of plant phenotyping, especially when used to assess complex functional traits, like photosynthetic efficiency, or biotic and abiotic stress resistance/tolerance/resilience. It is important that more technological advances spanning from plant morphology traits, or chemical phenotypes and metabolomes, be pursued and novel techniques be integrated in plant phenotyping platforms, also expanding the phenotyping community.

From the 2018 survey, new communities interested in plant phenotyping already emerged. For example, the ecologists, not considered before, expressed a certain interest in applying plant phenotyping in their activities (see Fig. 15).

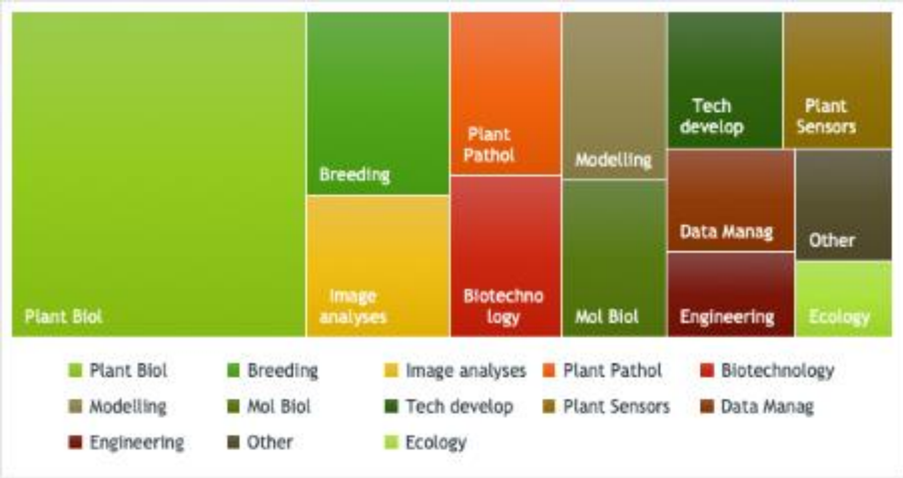


Fig. 15 - The European Plant Phenotyping community

The future phenotyping demand reflects the need of an integrated communities to foster the complementation across different disciplines, which has already clearly emerged from the scientific congress attended by the EMPHASIS stakeholders (Fig. 16).

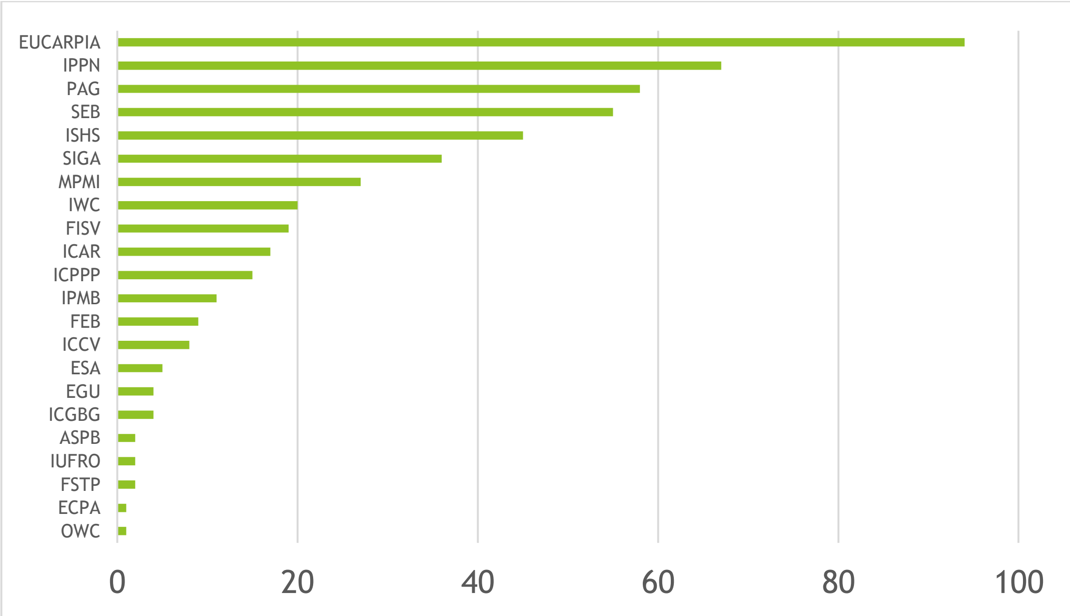


Fig. 16. The European Plant Phenotyping Community [IPPN (International Plant Phenotyping Network); OWC (Organic World Congress); FSTP (From Seed to Pasta); ECPA (European Congress of Precision Agriculture); IUFRO (International Union Of Forest Research Organizations); ASPB (American Society of Plant Biologists); ICBBG (International Conference on Grape Breeding and Genetics); EGU (European Geosciences Union); ESA (European Seed Association); ICCV (International Conference on Computer Vision); IPMB (International Congress on Plant Molecular Biology); ICPPP (International Conference on Photoacoustic and Photothermal Phenomena); ICAR (International Conference on Arabidopsis Research); FISV (Federazione Italiana Scienze della Vita); IWC (International wheat congress); MPMI (Molecular plant microbe interaction); SIGA (Società Italiana Genetica Agraria); ISHS (International Society for Horticultural Science); SEB (Society for Experimental Biology); PAG (Plant and Animal Genome); IPPN (International Plant Phenotyping Network); EUCARPIA (European Association for Research on Plant Breeding)].

Conclusions

Plant phenotyping has rapidly emerged, in the past decades, as a major tool to address the ongoing challenges in the field of agriculture and food production. It is generating many new opportunities to address and contribute to solve the urgent problems related to food security and environmental protection in a rapidly changing planet. From surveys and analyses undertaken by EMPHASIS-PREP partners a clear emerging aspect is that the power of plant phenotyping rests on its multidisciplinary approach, involving different disciplines and expertise, to in-depth understand how plants perform, and will perform, in current and future climate conditions.

The growing plant phenotyping community requests training, new technologies, and access to multiscale infrastructures, under controlled condition, in the field or access to models and data, to address the global challenges above, also expanding tests and measurements on plants other than major crops. Additionally, from the plant phenotyping community emerged an urgent need of improving data analysis and modelling.

To foster new and emerging use of plant phenotyping and to achieve its undisputed potential, we still need to expand the infrastructure capacity, implement the new technologies seamlessly into the workflow of users, develop proper access opportunities, and establish data management systems that allow data exchange interoperability across installations, locations, and experiments.

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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 WPLeader 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.*

Annex 2-Survey 2017

Introduction to the questionnaire

The preparatory phase of EMPHASIS aims at the development of a long-term sustainable strategy for a user driven operation, building, upgrading of plant phenotyping infrastructure. In order to develop the strategy and establish a business plan for EMPHASIS we are in the process of performing a mapping of infrastructure, user demand etc. and strongly depend on the support of the European plant phenotyping community for a reliable representation of the status quo of the plant phenotyping community.

The questionnaire focuses on current demand and provision of research infrastructures in plant phenotyping. We greatly appreciate your help, this 15-20 minutes questionnaire will help us mapping the current situation in Europe. The results of the survey will be anonymised before publication and the raw data are available to European plant phenotyping upon request.

Please proceed to the EMPHASIS homepage for further information about the project, its preparatory phase, up-to-date information about participation opportunities and contact details: http://emphasis.plant-phenotyping.eu

Multiple= (multiple selection possible)

1 Basic information

For every person filling in the survey

No.	Question	Choices
B1	Please fill in your name	Free text
B2	Please fill in your location (City)	Free text
B3 single	Please fill in the country	□ LIST of EU countries to be checked □ Please specify (...)
B4	Please fill in your e-mail	Free text
B5	What is your position within institution	Free text
B6 singel	What is the type of your organisation?	1 University 2 Research performing organisation 3 Industry 4 NGO

B7 multipe	What is your field of work?	1 Plant Biology 2 Biotechnology 3 Breeding 4 Data management 5 Ecology 6 Molecular Biology 7 Technology development 8 Image analysis 9 Engineering □ Other (please specify)
B8 multiple	What is your function with respect to plant phenotyping approaches?	1 Head of the national infrastructure 2 Head of the local infrastructure (institute or organisation) 3 Head of the data management infrastructure 4 Operator of installation 5. Management of training and education 6 Users 7 Technology developer

A '*national infrastructure*' is an organized group of *local clusters* on a national level with a certain form of governance, recognised by national authorities (in particular the respective ministry or national instance).

A '*local infrastructure*' is a group of *installations* that share governance, a common (or at least highly interoperable) e-infrastructure with an information system that manages the data of the installations in the *local cluster*, common rules for cost calculation and pricing, user access and, usually, a common user committee or selection committee. The *local cluster* usually contains all of the installations at one site, and connected to one or more institutions.

An '*installation*' is defined as a set of equipment (e.g. sensors and associated acquisition hardware and software, vectors, often used in automated or semi-automated mode), operated and maintained by an organized group of persons, who handle this set of equipment and use a set of pipelines or standardized procedures for the analysis of the data originating from the *installation*. User access is for one or more *installations* at a time, resulting in specific datasets that can be analysed per se. The calculations of full cost and pricing are at the level of *installation*

2 National infrastructure

Questions to **member of the EMPHASIS SG / head of the national infrastructure**
If B8 -1 is checked

Definition:
A *'national infrastructure'* is an organized group of *local clusters* on a national level with a certain form of governance, recognised by national authorities (in particular the respective ministry or national instance).

Specific description of the national infrastructure

NI1 single	Is there a national infrastructure in your country	□ YES □ NO
NI2 single	IF YES: Name of the national infrastructure	Free text
NI3 single	If NO Do you intend to build a national infrastructure and apply for funds? Then go to 3 Local infrastructure	□ YES □ NO
NI4	Please list the institutions involved in the national infrastructure	Free text
NI5 single	How is your national infrastructure organised	□ Legal entity □ Project □ Joint Research Unit □ Network □ Memorandum of Understanding □ Other: (free text)
NI6 single	Do you have long term funding to support the management national infrastructure?	□ Yes □ No
NI7 single	Does a national e-infrastructure linking institutions exist?	□ Yes □ No

3 Local infrastructure (description of the institution)

Questions to the **head of the local infrastruture, institute director** etc.
If B8-2 is checked

Definition:

A *'local infrastructure'* is a group of *installations* that share governance, a common (or at least highly interoperable) e-infrastructure with an information system that manages the data of the installations in the *local cluster*, common rules for cost calculation and pricing, user access and, usually, a common user committee or selection committee. The *local cluster* usually contains all of the installations at one site, and connected to one or more institutions.

Description of the local infrastructure

LI1 multi	How can a pan-European infrastructure support your work/research? (multiple selection possible)	□ support and coordination in building new infrastructure □ harmonisation of infrastructure efforts □ expanding your network □ enabling training and education in plant phenotyping □ support commercialisation of technology □ support with raising funding □ support innovation □ other (free text)
LI2 Multi	How many scientists and technical staff are working in the field of plant phenotyping in your institute/company/organization (in 2016? *A junior scientist (to those organisations and countries where it is applicable) has at least a Bachelor, Master or PhD degree and is working in the organisation for less than 6 years; a PhD student is a student with a Master degree and who works towards a PhD degree; a post-doc has a PhD degree and has a temporary contract; a senior scientist has at least a PhD degree and has usually a permanent position (he/she could also be a PI).*	□ Junior scientists (number) □ PhD students (number) □ Post-doc (Number) □ Senior scientists (number) □ Technical staff (number)

LI3 Multi	What services are offered by your infrastructure?	□ providing access □ providing data □ supporting technology transfer □ training of technical RI staff □ training of management RI staff □ staff exchange programs □ specific training for users □ others (please specify)
LI4 Multi	Please describe the user profile	□ National Users (number%) □ European Users (number %) □ Extra-European Users (number %) □ Industry (number %) □ Academia (number %)
LI5 single	Please estimate the costs of investment for the infrastructure (construction incl. manpower, technical equipment etc.)	□ <1M □ 1-10 M □ 11-20 M □ 21-50 M □ 51-100 M □ Other
LI6 Single	Please estimate the average annual cost for operation (maintenance etc.)	□ <100 k€ □ 100-200 k€ □ 201-500 k€ □ 501 k€-1 M€ etc. □ 1-5 M€ □ 5-10 M€ □ 10-50 M€ □ Other

LI7 multiple	Please describe your research infrastructure funding situation in the last year (2016).	□ for investment (number %) □ for operation (number %) □ institutional funding (number %) □ third-party funding (number %) □ □ national funding (number %) □ European funding (number %) □ International funding beyond Europe (number %) □ □ funding guaranteed for less than 3 years (number %) □ funding guaranteed for less than 10 years (number %) □ funding guaranteed for more than 10 years (number %)
LI8 single	Is there a structured procedure for access?	□ Yes □ No
LI9 single	If yes - Is there an independent review process in place?	□ Yes □ No
LI10 multipel	If yes for LI8 - How is the access financed?	□ Access in collaborative projects □ User paying full costs □ Lower rates for academia □ Lower rates for users from organizations / countries with very limited budgets □ No financing model established □ other
LI11 single	Do you have an established e-infrastructure at the local cluster?	□ Yes (e-infra) □ No

Education at the local infrastructure

Questions to the ***heads of the local installation*** *(Person responsible for training and education)*
If B8-5 is checked

ED1 single	*Does your institute/company/organization perform?*	□ *Teaching/Training* □ *Research* □ *Practical usage of infrastructures* □ *All* □ *no teaching (IF no - go to the next section)*
ED2 multiple	*What key disciplines do you address to contribute to the current and future development of plant phenotyping?*	□ *Applied plant biology* □ *Plant physiology* □ *Field conditions* □ *Bioinformatics (data management)* □ *Imaging* □ *Molecular biology* □ *Chemistry* □ *Plant ecology* □ *others*
ED3 multiple	*Which kind of training and education instruments does your institute/company /organization offer in this discipline?*	□ *Lectures* □ *Training Schools* □ *Workshop* □ *Internships* □ *Practicals* □ *Seminars* □ *E-learning (please specify)* □ *others*
ED4 single	*Do you provide training for senior scientists?*	□ *Yes* □ *No*
ED5 multiple	*If yes* *What kind of training do you provide?*	□ *staff exchange* □ *management training* □ *leadership training* □ *other*
ED6 multiple	*Do you provide training for undergraduates/PhD students?*	□ *Yes* □ *No*
ED7 multiple	*If yes* *What kind of training do you provide?*	□ *Lectures* □ *Summer schools* □ *Workshops* □ *other*
ED8 multiple	*How are these education activities funded?*	□ *Institutional funding* □ *Third-party funding* *National funding* *European funding* *International funding beyond Europe* □ *In-kind contribution* □ *other*

ED9 single	*Are these education activities funded on a long-term basis?*	□ *Funding guaranteed for less than 1 year* □ *Funding guaranteed for less than 3 years* □ *Funding guaranteed for less than 5 years* □ *Funding guaranteed for less than 10 years* □ *Funding guaranteed for more than 10 years* □ *other*
ED10 single	*Do you expect that your institute will offer additional education activities in the next years?*	□ *Yes (please specify-free text)* □ *No (please specify-free text)*
ED11 single	*Do you see any possible career prospects after education in plant phenotyping?*	□ *Yes (please specify-free text)* □ *No (please specify-free text)*
ED12	*Which expertise and skills do you see as under threat and /or harder to find amongst e.g PhDs, MSc, and technical staff who work on relevant plant phenotyping disciplines?*	*Please Specify - (free text)*

E-Infrastructure

*Questions to the **heads of the data management infrastructure** (Person responsible for training and education)*
If B8-3 is checked

E1	Do you use a standardized identification system (DOI, URI, etc.)?	□ Yes □ No
E2	Do you use standardized protocols?	□ Yes □ No
E3	Are these metadata organized with standardised language?	□ Yes □ No
E4 mul ti	Which tools are you currently using for data handling and storage?	□ Spreadsheet on computer hard disk □ Database SQL □ NoSQL □ Specialized filesystems
E5	Which computer infrastructure are you currently using for data handling and storage?	□ Server (if yes, which technology)? □ Distributed system like cloud or grid (if yes, which technolog
E6	What is the storage capacity of your computer infrastructure?	Free text

E7	Have you designed a long-term archiving capacity?	□ Yes □ No
E8	Are you using a proprietary information system for storing and handling data?	□ Yes □ No
E9 single	(If yes to the preceding question)	□ Commercial and not open □ Self-developed and potentially open □ Controlled vocabulary □ Potentially connected to an EMPHASIS (or other) information
E10	Are you using external services for data sharing?	□ Yes (if yes: specify) □ No
E11	Are part of platform data confidential?	□ Yes (if yes: specify) □ No
E12	Have you set rules for data access?	□ Yes (if yes: specify) □ No
E13	Cost models: costs may be required for?	□ Data analysis □ Data storage □ other
E14	Are data generated on your platform available through web services?	□ Yes (if yes: specify technology and standard) □ No
E15	Would interfacing your current information system with the EMPHASIS information system cause any administrative/politic problem?	□ Yes (if yes: specify) □ No
E16 multi	What is the data policy at your organisation?	□ Open Access Data □ Time-limited embargo on data □ On site data storage □ Data conservation and storage
E17 multi	What are the data services for users?	□ Data delivery □ Data quality control □ Other
E18	What would be your more crucial need in data storage and handling?	Free text
E19	What would be your more crucial need for data analysis?	Free text
E20	What are your expectations regarding the EMPHASIS information system?	Free text

4 Installations at a local infrastructure

LOOP

Questions to the Scientists running the installations & head local infrastructure
If B8-4 is checked

'*installation*'. An *installation* is defined as a set of equipment (e.g. sensors and associated acquisition hardware and software, vectors, often used in automated or semi-automated mode), operated and maintained by an organized group of persons, who handle this set of equipment and use a set of pipelines or standardized procedures for the analysis of the data originating from the *installation*. User access is for one or more *installations* at a time, resulting in specific datasets that can be analysed per se. The calculations of full cost and pricing are at the level of *installation*

Questions to the **Scientists running the installations**

LI1 multiple	Which installation(s) category you are working with or are building/establishing? If you have multiple installations in the local infrastructure, please fill in a number. Based on the response three different set of questions.	1 *Controlled conditions installations:* controlled climate chamber, growth chamber or greenhouse environment that typically include non- or minimally invasive sensors operated in semi- or fully automated mode. --- # 2 *Field installation:* field site equipped with environmental sensors, potentially environmental manipulation (e.g. FACE or rain-out) complemented with sensors (often linked to vectors) for traits assessment, managed and operated by a dedicated team 2.1 INTENSE FIELD: Field installations allow investigation of plant traits in canopies subjected to natural environments, exposed to natural conditions such as rising CO_2, drought, flooding or limited nutrient availability. They involve extensive and high-resolution recording of the environmental conditions (including abiotic and biotic) and detailed imaging carried by proximal or remote sensing systems. While imaging in the field can be more challenging than in fully controlled environments, such installations allow analysis of crop performance under normal agronomic conditions. --- # 2.2 LEAN FIELD: Field experiments in distributed sites following environmental gradients (e.g. north-south, oceanic - continental) will allow prediction of plant performance in current and future climatic scenarios, and establishment of the link between their performance and underlying traits at the stand level. Europe has a wealth

		of field experimental station run by public research institutes and by private (seed) companies. They allow testing a large number of genotypes in a wide range of conditions that cannot be covered in Intense field sites. Simple phenotyping approaches with significant efficiency become increasing available, and further developments are under way. --- #
		3 *Modelling installation:* particular type of model (climate, process-based, structural, functional-structural), developed, maintained and preferentially distributed and supported by a dedicated team of developers/managers/operators, and potentially linked to *controlled conditions installations* and/or *field installations*, and data analysis pipelines. --- #

General description of the installation

General questions to installation after selecting the category /controlled/Field/modelling
Questions to researchers of the local infrastructure

	Question	Choices
I1	What is the name of the plant phenotyping installation?	Free text
I2 single	Is the installation listed in the IPPN DB (https://www.plant-phenotyping.org/db_infrastructure#/) ?	□ Yes □ No
I3	Is there a website with installation information? If yes please provide the URL.	Free text
I4 single	What is the estimated number of publications related to installation per year on average?	□ < 5 □ 5 - 10 □ 10 - 20 □ > 20
I5 multiple	How many staff members and which types of staff are involved in the management and operation?	□ operational management of infrastructure_ nr.: □ scientific management of projects_ nr.: □ imaging analysis expert_ nr.: □ technician - operation maintenance nr.: □ technician - maintenance_ nr.: □ data analysis scientist _ nr.: □ Other _ nr.:

I6 multiple	Could you provide us with information about the funding? What kind and how many funding do you receive the installations and its operation?	◻ Total budget (€) (life cycle assessment) ◻ __ for investment (%) ◻ __ for operation (%) ◻ __ institutional funding (%) ◻ __ third-party funding (%) ◻ __ national funding (%) ◻ __ European funding (%) ◻ __ International funding beyond Europe (%)
I7 single	Is there a structured procedure for access	◻ Yes ◻ No If yes: is the access: • Local • National • international EU • international
I8 single	Status of the installation	◻ In planning - planned construction and operation:__ ◻ In construction - : planned start: __ ◻ In operation - since : __ ◻ In decommissioning
I9 single	**User profile** Please indicate an estimate percentage of users using the different installations.	User type: ____% Academia ____% Industry ___% internal use

Installations: controlled environment

Depending on the amount of controlled environment installations the local infrastructure has, this should be part should be repeated.

If LI1 - 1 is checked

Questions to the **Scientists running the installations**

	Question	Choices
CI1	Location: climatic zone, coordinates	Dropdown - countries and regions

CI2 multi	Could you provide some information about the environmental monitoring - sensors in this installation?	**atmosphere** □ air temperature, number of sensors_#_, □ relative humidity, number of sensors_#, □ light intensity (PAR), number of sensors_#, □ light Quality (for example red/far-red ratio) measured Y/N □ CO_2 concentration **soil** □ type of container: () pot, () tray, () bulk container, () other; □ Do you know the soil physical properties? Y/N □ Do you know the soil chemical composition? Y/N □ Soil humidity measurement method: free text
CI3 multi	What kind of environmental simulation do you perform?	**chemical treatments/additives (screening for chemical compounds that affect plants)** □ YES □ NO **tracking plant protection application** □ YES □ NO **Atmosphere** □ air temperature: □ air relative humidity: □ light intensity □ light source LED, high pressure sodium, metal halide, fluorescent tube; sun radiation only; Other… □ light quality □ air composition: **soil** □ soil humidity □ soil nutrient/chemical content modification □ soil temperature: □ soil biological treatment □ soil compaction
CI4	Which are the species that are commonly phenotyped at the platform?	Free text

CI5 singel	What is the average duration of an experiment?	◻ <day ◻ 1-5 days ◻ 6-10 days ◻ 10-20 days ◻ 20-50 days ◻ 50 - 100 days ◻ >100 days Other
CI6 multi	What is the capacity of the installation?	◻ Size of the platform ___m2 ◻ Number of plants (fully loaded)___
CI7	Could you give an estimation on the number of plants per experiment?	◻
CI8	What would be a good estimate of the throughput of the installation?: time definition (duration to measure plants / experiment)	◻ ___ h
CI9 multi	Could you provide us with an estimate of the usage of the installation?	◻ _____ Days per year ◻ _____ Plants per year ◻ _____ Samples per year ◻ Other
CI10 multi	What are typical treatment(s) at the platform?	◻ water availability ◻ nutrient stress ◻ temperature stress ◻ light stress ◻ biotic treatments ◻ chemical treatments ◻ no typical treatment only screening ◻ other
CI11 multi	What is the focus of the measurements of the installation?	◻ Canopy ◻ Plant shoot ◻ root system ◻ reproductive organs ◻ cell-level ◻ other

CI12 multi	Define the key traits and how are they measured at the installation	Structural Traits □ biomass □ growth □ architecture Functional traits □ photosynthesis □ water relations □ nutrients □ pigments Agronomical traits □ yield □ biomass □ starch content □ protein cntent □ oil content □ flowering time □ plant disease related traits □ omics
CI13 single	What kind of carrier system do you have?	□ Plant to Sensor: e.g. conveyor belt, gantry/picker □ Sensor to plant □ Combined S-P/P-S □ Manual measurements □ other
CI14 multi	What kind of imaging systems do you use?	□ RGB camera □ Multispectral camera □ Hyperspectral camera □ thermography camera □ Other: free text
CI16	Do you have any other input you would like to provide us concerning the setup of your installation, please do in this box:	□ Free text

Field installation

If IF1-2/ 2.1 /2.2 is checked

Questions to the **Scientists running the installations**

FI1	Location: climatic zone, coordinates	Dropdown country • Free text for coordinates

FI2 multi	Could you provide information about the environmental sensors?	**atmosphere** □ air temperature, number of sensors_#_, □ relative humidity, number of sensors_#, □ light intensity (PAR), number of sensors_#, □ wind speed, number of sensors_# □ precipitation, number of sensors_# □ CO2 concentration, number of sensors_# **soil** □ Do you know the soil physical properties? Y/N □ Do you know the soil chemical composition? Y/N □ soil humidity measurement method: free text □ Do you measure the soil temperature? Y/N
FI3 multi	Environmental Simulation	**Do you have agronomic management practices:** □ YES - could provide us with some details: _____free text □ NO **Do you track plant protection application?** □ YES □ NO **Do you use chemical treatments/additives (screening for chemical compounds that affect plants)?** □ YES - could provide us with some details: _____free text □ NO **Do you track air conditions:** □ Air composition: could provide us with some details: _____free text **Do you track soil conditions:** □ soil humidity □ soil nutrient/chemical content modification □ soil temperature: □ soil biological treatment Y/N □ soil compaction
FI4	Which are the species that are commonly phenotyped at the installation?	

FI5 single	What is the average duration of an experiment?	□ 1-10 days □ 10 - 20 days □ 20 - 40 days □ 40-100 days □ 100 - 200 days □ >200 days Other__
FI6	What is the Capacity of the installation in terms of hectare?	□ Size of experimental field site ___ha
FI7	What is the Capacity of the installation in terms of plots?	Number of plots___ Size of plots___
FI8	Could you give an estimation on the number of plots per experiment?	□
FI9	What would be a good estimate of the throughput of the installation?: time definition (duration to measure plants / experiment)	□ ___h
F10 multi	Could you provide us with an estimate of the usage of the installation?	□ _____ Days per year □ _____ Plants per year □ _____ Samples per year □ Other
F11	Could you provide information concerning the experimental design of an average experiment?	□ Average Amount of repetitions _number or "depends on the experiment" _ □ Statistical design: __free_text____
F12 multi	What is the typical treatment at the platform?	□ water deficit □ irrigation □ elevated CO2 □ nutrient stress □ temperature stress □ biotic treatments □ chemical treatments □ other __ free_text____
F13 multi	Could you provide information on the management practices?	□ Available agricultural equipment _ free_text___ □ Stand time for equilibration _ free_text___ □ other __ free_text____

F14 multi	Define the key traits measured at the platform	Structural Traits □ biomass □ growth □ architecture Functional traits □ photosynthesis □ water relations □ nutrients □ pigments Agronomical traits □ yield □ biomass □ starch content □ protein cntent □ oil content □ flowering time □ plant disease related traits □ omics
F15 multi	Sensor carrier?	□ Drones/Copter □ Manual measurements □ Fixed positioning system □ Gantry system □ Phenomobiles □ other
F16	Do you have any other input you would like to provide us concerning the setup of your installation, please do in this box:	□ Free text

Modelling - installation

Questions to the **<u>Scientists running the installations</u>**

If LI1 - 3 is checked

	Question	Choices
MI1	What is the name of your model and his main purpose (in few words)? Instead of I1	□ Text

MI2 multi	What is the type of your model?	□ Climate model - Model used to generate climatic data (T, RH, Light, etc…) □ Crop Model - (To simulate crop growth and final yield) □ Structure - (i.e. Root system architecture construction based on input parameters) □ Structure-function - (i.e. Water flux determination in function of root architecture development) □ Other: Text___
MI3 multi	Resolution scale: What is the level of process used in the model?	□ Molecules □ Cell □ Organ □ Plant □ Canopy □ Field □ Region □ Other (Specify
MI4 multi	Model objectives? 1= Main Obj. 2= Can do it 3= Impossible	□ Fundamental (understanding processes) 1 2 3 □ Yield/biomass prediction 1 2 3 □ Climate change effects quantification 1 2 3 □ Breeding assistance 1 2 3 □ Phenotyping assistance 1 2 3 □ Other: text 1 2 3
MI5 multi	User's community: Who are the targeted users?	□ Breeders □ Biologists □ Agronomists □ Pedologists □ Hydrologists □ Climatologists □ Others: text

MI6 single	Is your model closely linked with a phenotyping platform	□ Not yet □ Number of related peer-reviewed publications: Number □ Already used in some projects: Number and names □ Robust proof of concept: Yes or no
MI7sinlge	Could you list 2-3 input and output key-variables?	□ Input: □ Output:
MI8 singe	Is the model usually used in parallel/series with another model?	□ YES - Which one: text □ NO
MI9 single	Is the model integrated in an analysis pipeline?	□ YES - Briefly describe □ NO
MI10 multi	Is the model integrated into a simulation platform	□ L-Studio □ Open-alea □ Record □ Other: text
MI11 single	Is the model “open source”?	□ YES - Which license? □ NO

5 For users of RIs

IF B8-6 is checked

Demand for phenotyping

	Question	Choices
DE1 multiple	How can a pan-European infrastructure contribute to your work/research?	□ access to installations □ virtual access to data □ access to models □ development of data standards □ expanding your research network □ enabling training and education in plant phenotyping □ support commercialisation of technology □ support with raising funding □ support innovation □ Other (free text)
DE2 multiple	Within an integrated infrastructure on phenotyping, what kind of infrastructures are you most interested in?	□ *Controlled conditions installations:* controlled climate chamber, growth chamber or greenhouse environment that typically include non- or minimally invasive sensor operated in semi- or fully automated mode. □ *Field installation:* field site equipped with environmental sensors, potentially environmental manipulation (e.g. FACE of rain-out) complemented with sensors (often linked to vectors) for traits assessment, managed and operated by a dedicated team. □ INTENSE FIELD: Field installations that allow investigation of plant traits in canopies subjected to natural environments, exposed to natural conditions such as rising CO2, drought, flooding or limited nutrient availability. They involve extensive and high-resolution recording of the environmental conditions and high resolution trait assessment. □ LEAN FIELD: Field experiments in distributed sites following environmental gradients (e.g. north-south, oceanic - continental) will allow prediction of plant performance in current and future climatic scenarios, and establishment of the link between their performance and underlying traits at the stand level. □ *Modelling installation:* particular type of model (climate, process-based, structural, functional-structural), developed, maintained and preferentially distributed and supported by a dedicated team of developers/managers/operators, and potentially linked to *controlled conditions installations* and/or *field installations*, and data analysis pipelines.
DE3	Key species of interest?	□ free text

DE4 multiple	Please specify the experimental capacity you would currently require?	□ No.: (number)_plants per year □ No.: (number)_plots per year □ No.: (number)_samples / year
DE5 single	Do you expect your future capacity requirement for plant phenotyping to increase	□ YES □ NO
DE6 multipe	What are typical treatments you require for your experiments?	□ soil water deficit □ atmospheric drought □ nutrient stress □ temperature stress □ light stress □ biotic treatments □ chemical treatments □ other

DE7
multiple
	Please identify the key traits you are interested in?	□ STRUCTURAL TRAITS
		  □ biomass
		  □ architecture
		  □ developmental stages
		  □ root properties
		□ FUNCTIONAL TRAITS
		  □ photosynthesis
		  □ water relations
		  □ growth
		□ AGRONOMICAL TRAITS
		  □ sees properties
		  □ yield
		  □ biomass
		□ DISEASE TOLERANCE TRAITS
		□ ABIOTIC STRESS TOLERANCE TRAITS
		□ OMICS
		□ Other

DE8 single	Are you using a proprietary information system for storing and handling data? IF NO go to DE12	□ Yes □ No

DE9 multiple	IF Yes: What information system are you using?	◻ Commercial and not open ◻ Self-developed and potentially open ◻ Using controlled vocabulary ◻ Potentially connected to an EMPHASIS (or other) information system via interface ◻ other
DE10 single	Are you using external services for data sharing?	◻ Yes (if yes: specify) ◻ No
DE11 single	Are the metadata organized with standardised language?	◻ Yes ◻ No
DE12 single	Have you set rules for data sharing?	◻ Yes (if yes: specify - free text) ◻ No
DE14	What are your expectations regarding the EMPHASIS information system?	Free text

Demand for training

If B8-6 / 7is checked

UT1 single	Do you require specific training in plant phenotyping for your current and future activities?	◻ YES ◻ NO
UT2 multiple	What key training and education disciplines do you regard as important for current and future development of plant phenotyping?	◻ Applied plant biology ◻ Plant physiology ◻ Field conditions ◻ Bioinformatics (data management) ◻ Imaging ◻ Molecular biology ◻ Chemistry ◻ Plant ecology ◻ Infrastructure management ◻ Leadership training ◻ Stuff exchange ◻ Technology transfer ◻ others

UT3 single	Do adequate training programmes for users of RIs exist in your country?	◻ YES ◻ NO
UT4 single	Do you see any possible career prospects after education in plant phenotyping?	◻ Yes (please specify) ◻ No (please specify)
UT5	How do you perceive the future training in relation to the needs expressed by the plant phenotyping field?	◻ Please Specify (free text)
UT6	Which expertise and skills do you see as under threat and /or harder to find amongst e.g PhDs, MSc, and technical staff who work on relevant plant phenotyping disciplines for your future research?	Please Specify - free text

6A For technology developer

If B8-7 is checked

Specific questions for technology developer, please extend

TD1 multiple	What services do you offer?	□ Software development □ Hardware development □ Construction of platforms □ Maintenance □ Consultancy □ Engineering □ Training □ Construction
TD2 single	Are you performing experiments with your technology	□ Yes □ No

TD3 multiple	What services/support would you expect from EMPHASIS	□ access to installations
		  □ testbed for validation
		  □ test platform for sensors
		□ access to data
		□ harmonisation of infrastructure
		□ expanding your research network
		□ enabling training and education in plant phenotyping
		□ support in commercialisation of technology
		□ support with raising funding
		□ support innovation
		Other……………………

TD4	Please describe your expectations how EMPHASIS may support your activities?	□ (free text)
TD5 single	How do you consider access to research infrastructures for your research needs in Europe?	□ very good □ good □ sufficient □ not sufficient
TD6 single	How do you consider access to research infrastructures in your country?	□ very good □ good □ sufficient □ not sufficient
TD7 single	Do you have access to phenotyping installations	□ YES □ NO

TD8 single	If Yes:please specify	□ In your institution □ In your county □ Transnational In ongoing projects □ other
TD9 single	Are the infrastructures you are currently using sufficient to pursue your experiments?	□ YES □ NO
TD10 single	If NO Please explain why?	□ No access available □ Not sufficient capacity □ Too expensive □ other
TD11 single	Do you have funds to pay for access beyond funding?	□ YES □ NO
TD12 single	If Yes: Please specify	□ Institutional funding □ Third-party funding National funding European funding International funding beyond Europe
TD13 single	If No: Please specify	□ No institutional funding □ Currently no third party funding available □ other

6B For breeders

If B7 - is checked

TB1 single	Do you use phenotyping technology in your breeding programs?	□ Yes □ No
TB2 multiple	How do you assess plant phenotypic traits in your breeding programs?	□ visual assessment □ manual sensors □ optical sensors □ spectral imaging □ thermography □ drones with optical sensors □ yield assessment □ other
TB3 multiple	If TB1= no	□ Yes □ No (if No - end)

	Do you plan to use non-invasive plant phenotyping technology in the future?	
TB4	If TB3 = Yes Please estimate the increase of productivity (new varieties) by application of phenotyping technology?	□ <5% □ 5-10% □ 10-20% □ 20-40% □ >40%
TB5 single	How do you consider access to research infrastructures for your research needs in Europe?	□ very good □ good □ sufficient □ not sufficient
TB6 single	How do you consider access to research infrastructures in your country?	□ very good □ good □ sufficient □ not sufficient
TB7 single	Do you have access to phenotyping installations	□ YES □ NO
TB8 single	If Yes:please specify	□ In your institution □ In your county □ TransnationalIn ongoing projects □ other
TB9 single	Are the infrastructures you are currently using sufficient to pursue your experiments?	□ YES □ NO
TB10 single	If NO Please explain why?	□ No access available □ Not sufficient capacity □ Too expensive □ other
TB11 single	Do you have funds to pay for access beyond funding?	□ YES □ NO
TB12 single	If Yes: Please specify	□ Institutional funding □ Third-party funding National funding European funding International funding beyond Europe

TB13 single	If No: Please specify	◻ No institutional funding ◻ Currently no third party funding available ◻ other

7. Future trend: Plant phenotyping in 2025

For everyone

FT1 Multiple 5 most important!	What do you regard as the largest challenge in plant phenotyping in the future?	◻ abiotic stress ◻ available capacity ◻ biotic stress ◻ bioinformatics ◻ costs ◻ data management ◻ field phenotyping ◻ funding ◻ imaging ◻ infrastructure management ◻ integration with "omics" ◻ mechanistic understanding ◻ modelling ◻ multiple stress ◻ networking ◻ organ/Cell level ◻ perennial plants ◻ root phenotyping ◻ standards ◻ technological limitations ◻ throughput ◻ training ◻ other, please specify ____text

FT2 multiple	What could be key traits in 2025?	☐ **Biomass on the level** ☐ field ☐ canopy ☐ single plant ☐ root ☐ leaf ☐ Reproductive organs ☐ cell ☐ **Growth** ☐ field ☐ canopy ☐ single plant ☐ root ☐ leaf ☐ Reproductive organs ☐ cell ☐ **Functional traits (photsynthesis, transpiration…)** ☐ field ☐ canopy ☐ single plant ☐ root ☐ leaf ☐ reproductive organs ☐ cell ☐ **Agronomic traits** ☐ seed yield ☐ composition ☐ quality ☐ **Disease related traits** ☐ **Omics** ☐ **other free text**
FT3 Multiple (2 in max)	What region(s) do you expect to be leading in the development of plant phenotyping technologies in 2025?	• Europe • Northern America • Southern America • Asia • Africa • Australia Free text: please explain your decision

FT4 Multiple (3 in max)	What trends in IT will have the highest impact on the development of plant phenotyping technologies in 2025?	• Artificial intelligence and advanced machine learning • Intelligent apps • Intelligent things • Virtual reality and augmented reality • Digital twins • Blockchains • Conversational systems • Mesh app and server architecture • Digital technology platforms • Adaptive security architecture Free text: please explain your decision
FT5	How could plant phenotyping contribute to shaping the future of the global food system in 2025?	Free text
FT6	What kind of plant phenotyping Research Infrastructure is lacking in Europe, form you opinion? And how do you think this should develop in the future?	Free text?

Concluding question

Last multiple	How would you be willing to be addressed in the future by Emphasis to collect your ideas on plant phenotyping and on Emphasis?	• Online questionnaire • Face-to-face interview at your location • Online face-to-face interview • Online discussion forum • Others (please specify -> free text)

Annex 3- Survey 2018

Introduction

Do you need Plant Phenotyping?

Why we are doing a survey: the preparatory phase of EMPHASIS aims at the development of a long-term sustainable strategy for a user driven operation, building, upgrading of plant phenotyping infrastructure. In order to develop the strategy and establish a business plan for EMPHASIS we are in the process of performing a general mapping of the interest of diverse users in plant phenotyping, mapping of infrastructure, user demand etc. and strongly depend on the support of the European plant phenotyping community for a reliable representation of the status quo of the plant phenotyping.
Any information about Emphasis the preparatory phase, our vision, and objectives as well as an up-to-date information about participation opportunities and contact details can be found at http://emphasis.plant-phenotyping.eu.
We greatly appreciate your time, this 5-10 minutes questionnaire will help us understanding the demand for plant phenotyping in Europe and to develop a strategy to address this **demand.**

1. Email address *

Something about you

2. Can you please leave us your name ?

3. Can you tell us the name of your Institution?

4. What is your background?

Check all that apply.

- [ ] Breeder
- [ ] Junior Scientist
- [ ] Senior Scientist
- [ ] PhD student
- [ ] Technical staff
- [ ] Technology developer
- [ ] Modeller

Other: [ ] ____________________

5. Which is your country?

Mark only one oval.

- Austria
- Belgium
- Bulgaria
- Croatia
- Cyprus
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Ireland
- Italy
- Latvia
- Lithuania
- Luxembourg
- Malta
- Netherlands
- Poland
- Portugal
- Romania
- Slovakia
- Slovenia
- Spain
- Sweden
- United Kingdom
- Other: ______________________

6. What is your field of work?

Check all that apply.

- [ ] Plant Biology
- [ ] Plant Pathology
- [ ] Plant Physiology
- [ ] Plant genetics
- [ ] Biotechnology
- [ ] Breeding
- [ ] Data management
- [ ] Ecology
- [ ] Molecular Biology
- [ ] Technology development
- [ ] Image analysis
- [ ] Engineering
- [ ] Modelling
- [ ] Plant Sensors

Other: [ ] ____________________

7. Where is your usual working space?

Check all that apply.

- [ ] Laboratory
- [ ] Greenhouse
- [ ] Field
- [ ] Office

Other: [ ] ____________________

8. What are your key species of interest?

Check all that apply.

- [ ] Wheat
- [ ] Tomato
- [ ] Arabidopsis
- [ ] Maize
- [ ] Barley
- [ ] Grapes
- [ ] Olive
- [ ] Fruit Trees
- [ ] Legumes

Other: [ ] ____________________

9. Do you have contact with the phenotyping community?

Check all that apply.

- [ ] EMPHASIS
- [ ] IPPN
- [ ] National Plant Phenotyping Network
- [ ] National Infrastructures
- [ ] EPPN2020

Other: [ ] ____________________

10. Please indicate which National Infrastructure you are in contact with...

____

11. Are you member of a specific research association?

Mark only one oval.

( ) Yes

( ) No *Skip to question 12*

12. Can you indicate which research association?

Check all that apply.

- [ ] FESPB
- [ ] EPSO
- [ ] SIGA
- [ ] EUCARPIA

Other: [ ] ____________________

13. What are the main national and international congresses of your community?

Check all that apply.

- [ ] MPMI
- [ ] ICGBG
- [ ] PAG
- [ ] SIGA
- [ ] IPPN
- [ ] FEB
- [ ] FISV
- [ ] ICPPP
- [ ] IPMB
- [ ] IWGS
- [ ] FSTP
- [ ] ICAR
- [ ] EUCARPIA
- [ ] ISHS
- [ ] OWC
- [ ] INC
- [ ] SEB
- [ ] ICCV

Other: [ ] ____________________

14. Are you involved in plant phenotyping?

Mark only one oval.

- ◯ Yes
- ◯ No

15. Do you plan to use plant phenotyping in your future research activities?

Mark only one oval.

- ◯ Yes
- ◯ No

Please, tell us more about your phenotyping/scientific activities

16. What are typical treatments you require for your experiments or simulations?

Check all that apply.

- [ ] Nutrient stress
- [ ] Temperature stress
- [ ] Biotic treatments
- [ ] Drought stress
- [ ] Chemical treatments
- [ ] Light stress

Other: [ ] ____________________

17. Do you use non-invasive technology to assess the plant traits, and which tools do you use to phenotype plant disease?

Check all that apply.

- [ ] RGB imaging
- [ ] Thermal Imaging
- [ ] Spectral Imaging
- [ ] Custom systems
- [ ] Free software analyses
- [ ] Low cost techniques

Other: [ ] ____________________

18. Do you expect your future capacity requirement for plant phenotyping to increase?

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Maybe

19. What capacity for controlled plant phenotyping do you expect to reach in the next future? (n° of plants / year)

Check all that apply.

- [ ] 50-100
- [ ] 100-200
- [ ] 200-500
- [ ] 500-1000
- [ ] 1000-2000
- [ ] 2000-5000
- [ ] >5000
- [ ] Not applicable

Other: [ ] ______

20. What capacity for field plant phenotyping do you expect to reach in the next future? (n° plots/year)

Check all that apply.

- [ ] 1-10
- [ ] 10-100
- [ ] 100-300
- [ ] 300-500
- [ ] 500-1000
- [ ] 1000-2000
- [ ] >2000
- [ ] Not applicable

21. Tell us... How can EMPHASIS support your work/research?

Check all that apply.

- [ ] Support and coordination in building new infrastructure
- [ ] Harmonisation of infrastructure efforts
- [ ] Expanding your network
- [ ] Enabling training and education in plant phenotyping
- [ ] Support commercialisation of technology
- [ ] Support with raising funding
- [ ] Support innovation
- [ ] Access to installations
- [ ] Access to data
- [ ] Benchmarking technology

Other: [ ] ______________________

What do think about training in plant phenotyping?

22. Do you see any possible career prospects after training in plant phenotyping?

Mark only one oval.

	1	2	3	4	5	
Not really	○	○	○	○	○	Surely will

23. What training activities do you think are important to advance the plant sciences?

Check all that apply.

- [ ] Imaging
- [ ] Bioinformatics
- [ ] Use of plant phenotyping technology
- [ ] Staff exchange
- [ ] Train the trainers

Other: [ ] ______________________

Something about modelling

24. Have you been or are you using models to represent plant traits or their environment?"

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Maybe

25. If yes, which features of plants or their environment do you represent with models?

Check all that apply.

- [ ] Yield
- [ ] Plant growth
- [ ] Plant hydraulics
- [ ] Genomics
- [ ] Soil water or nutrients
- [ ] Atmospheric conditions
- [ ] Not applicable
- [ ] Plant Architecture

Other: [ ] ____________________

26. Are you member of a model-related consortium?

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Other: ____________________

27. In the future, do you think you will use modelling in combination with phenotyping experiments?

Mark only one oval.

	1	2	3	4	5	
Not really	( )	( )	( )	( )	( )	Surely will

28. Do you think modelers can help the phenotyping community?

Mark only one oval.

	1	2	3	4	5	
Not really	⬭	⬭	⬭	⬭	⬭	Surely will

Stay tuned on plant phenotyping news

29. Would you like to receive a regular newsletter?

Mark only one oval.

⬭ Yes

⬭ No