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CropBooster-P

Deliverable No. 1.2

Title: Preparatory document for discussion during workshop with SHG on yield improvement

Start date of the project: **November 1st, 2018** / Duration: 36 **months**
Planned delivery date: March 2019
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Work package: WP1 / Task: 1.2

Work package leader: ULANC
Deliverable leader: VIB

Version: Final

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Dissemination level	Public

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1. Partners and fields of expertise

Organisation name	Short name	Country	Area(s) of specialization
Københavns Universitet	UCPH	Denmark	• photosynthesis; regulation of photosynthesis, chloroplast biology, thylakoid membrane • plant development, microProteins, tissue culture
Consiglio Nazionale delle Ricerche	CNR	Italy	• photosynthesis: estimation of the diffusion resistances to CO2 in leaf mesophyll; study of the relationship between electron transport rate and photosynthesis; study of CO2 refixation in leaf mesophyll. Stress physiology: study of the effect of biotic and abiotic stresses on photosynthesis limitations and plant productivity. Biosynthesis and emission of biogenic volatile organic compounds: study of the relationship between isoprenoid emissions and photosynthesis; study of the relationships between biogenic emissions and environmental pollution. • protein synthesis, structural maturation, transport and degradation in the secretory pathway of plant cells, Protein co-translational and post-translational modifications, Molecular chaperones and enzymes assisting protein structural maturation, Abiotic stress response, Seed storage proteins, Ribosome-inactivating proteins, Wheat structural genomics
Europese Organisatie voor Wetenschappelijk Plantenonderzoek	EPSO	Belgium	
Heinrich-Heine-Universitaet Duesseldorf	UDUS	Germany	• photosynthetic carbon assimilation and yield, such as C3/C4 photosynthesis, photorespiration, synthetic biology approaches to mitigate the effects of photorespiration. We also have some background in source/sink relationships and their influence on yield as well as the role of rapid acclimation to fluctuating environmental conditions (i.e., change in light intensity)
Julius Kuehn-Institut Bundesforschungsinstitut fuer Kulturpflanzen	JKI	Germany	• employing new molecular technologies in agriculture (classic GMO, GE, Synthetic biology), but also novel crops, from basic science to molecular farming or agricultural production/passing statements on the safety of GMO • exploring the application of GE methods in different plants with different traits, technologies. The activity is targeting to get an

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Organisation name	Short name	Country	Area(s) of specialization
			overview of GE applications and impacts at the molecular/plant level • genome editing in different plants
Centre National de la Recherche Scientifique	CNRS	France	• transmembrane ion transport with strong connexions to: - plant nutrition: nitrate uptake and distribution as well as essential and toxic metal (Fe, Mn, Zn) uptake, transport and seed storage - control of stomatal aperture • photosynthetic electron transport, especially regulation of photosystem II, alternative electron transport pathways, production site of the different reactive oxygen species and acclimation responses • biochemistry, metabolic engineering and functional analysis of plant metabolism
University of Nottingham	UNOTT	UK	• plant and crop physiology, photosynthesis, agronomy, drought, nutrient use efficiency, nitrogen (predominantly wheat and rice)
Institut National de la Recherche Agronomique	INRA	France	• crop modelling, crop management, GxExM interactions, yield gap analysis, grain yield, biotechnology, high troughput phenotyping, climate change (sunflower, soybean, fruits, vegetables)
ARVALIS Institut du vegetal	ARVALIS	France	• crop nutrition (quantity-quality) and its link with genetics, physiology, nutrient cycling in the soil, climatic and abiotic stress (cereals, maïze and potatoes)
Lancaster University	ULANC	UK	• improving yield and water/nutrient use efficiency of crops (including tobacco, wheat, rice and cowpea) primarily by manipulating photosynthesis, both by exploiting natural variation and by creating new variation using gene editing, conventional GMO and synthetic biology
Vlaams Instituut voor Biotechnologie	VIB	Belgium	• understanding determinants of plant yield (Arabidopsis, wheat, maize) focusing on the identification of the genetic mechanisms underpinning plant organ growth (e.g. cell division and cell expansion) and abiotic/biotic stress responses
Wageningen University and Research	WUR	The Netherlands	• photosynthetic physiology and plant environmental physiology, with some crop and plant physiological modelling expertise - both C3 and C4

2. Meetings and teleconferences

The following F2F meetings and teleconferences took place:

- **20th of November 2019 – F2F meeting**
  What? Kick-Off meeting CropBooster-P project in Wageningen
  Who? Partners involved in CropBooster-P project
  Where? WU/WUR, Wageningen, The Netherlands
- **28th of November 2018 – TELECONFERENCE**
  What? Teleconference to set space and general framework of the CropBooster-P project
  Who? Task leaders of WP1 + several WPL
- **13th of December 2018 – TELECONFERENCE**
  What? Kick-off call with SR - Teleconference to explain the concept of scenario building and define an outline of Task 1.1
  Who? Task leaders of WP1 + Sommerrust (SR)
- **17th of January 2019 – TELECONFERENCE**
  What? Status quo call with Sommerrust (overview of trends and key uncertainties obtained through the brain downloading exercise)
  Who? Task leaders Tasks 1.1 and 1.2 + SR
- **22nd of January 2019 – TELECONFERENCE**
  What? Update teleconference with Task leaders of WP1
  Who? Task leaders of WP1
- **24th of January 2019 – F2F meeting**
  What? Handover WPL1 from VIB (Marieke Louwers) to ULANC (Martin Parry)
  Who? Rene Klein Lankhorst, Marieke Louwers, Martin Parry, Jeremy Harbinson and Alexandra Baekelandt
- **31th of January 2019 – TELECONFERENCE**
  What? Status quo call with SR (concerns, comments, initial long list of trends, manage expectations for workshops)
  Who? WPL1 + SR + task leaders WP1
- **18th of February 2019 – TELECONFERENCE**
  What? Update call Task 1.4
  Who? Task leaders WP1 + People of INRA involved in Task 1.4
- **27th of February 2019 - TELECONFERENCE**
  What? Teleconference to provide task update + define the scope of data assimilation and collection format
  Who? Task leaders of WP1
- **15th of March 2019 - TELECONFERENCE**
  What? Teleconference to discuss the format of data collection, level of detail, deliverables and assigned responsibilities according to expertise and areas of interest. Created shared folder for internal data collection. Data collection in progress.
  Who? WP1 Task 1.4 partners
- **3rd of April 2019 – F2F meeting**
  What? F2F Meeting to finalize the common understanding of the output of WP1
  Who? Leader WP1 and task leaders of WP1
  Where? VIB, Ghent, Belgium
- **4rd of April 2019 - TELECONFERENCE**
  What? Status quo call with SR (define/rephrase proxy variables, set expectations for 2-day workshop, which are key for the Scenario building exercise)
  Who? SR + Task leaders of WP1

The following F2F meetings and teleconferences are scheduled in the future:

- **11th of April 2019 - TELECONFERENCE**
  What? Follow up call Task 1.2
  Who? Partners involved in Task 1.2 + Task leader
- **16th-17th of April 2019 – F2F meeting**
  What? 2 day workshop event, Day1 → scenario building workshop, Day2 → impact workshop
  Who? Day1→ core team (WPL, Task leaders of WP1, Sommerrust), Day2 → core team + SHG + EU policy members
  Where? plantETP, Brussels, Belgium
- **15th of May 2019 - TELECONFERENCE**
  What? Follow up call Task 1.2
  Who? Partners involved in Task 1.2 + task leader
- **25th of June 2019 – F2F meeting**
  What? ExCom meeting discussing the progress of the CropBooster-P project
  Who? Participant list is not yet finalized.
  Where? ULANC, UK
- **11th of September – F2F meeting**
  What? Update F2F meeting on progress within WP1
  Who? Participant list is not yet determined.
  Where? Location is not yet determined.

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3. WP1 Task 1.1 – input for 2-day Scenario Building workshop (Brussels)

List of trend considered for Scenario Building

Trends (in alphabetical order):

1) Aging Population
2) AI & Big Data
3) Alternative Nutrition Sources
4) Animal Welfare
5) Biofortification
6) Biotech
7) Blockchain
8) Cheaper Food
9) Circular Bioeconomy
10) Climate Change
11) Cultivar / Species Mixtures
12) Decline of Pollinators & Biodiversity
13) Declining Chemistry for Pest Control
14) Diet-related Chronic Diseases
15) Do-it-Yourself
16) E-Commerce
17) Economic Pressure on Farms
18) Electrification
19) Environmental Concerns
20) Fair Trade
21) Globalization
22) Healthy Lifestyle
23) ICT on the Rise
24) Increased Mechanisation
25) Intellectual Property
26) Land-Use Pressure
27) NBTs & Genetic Modification
28) Offering of Meat Alternatives
29) Organic Farming
30) Plant Beneficial Microbes
31) Population Growth
32) Power of the Online Public
33) Product & Research Regulation
34) Public Engagement in Research
35) Reduction of / Altered Genetic Resources Circulation
36) Renewable Energy
37) Resource Scarcity
38) Rising Disposable Income
39) Risk Sensitivity
40) Robotics
41) Self-Tracking / Quantified Self
42) Sustainability
43) Transparency
44) Urban Farming / Greenhouses
45) Urbanization

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Example of trend card

Trend Card

Plant Beneficial Microbes

Description

As the discovery of new synthetic pesticides has become increasingly costly, the biopesticide market has been growing, including the exploration and use of plant beneficial microbes. These can act preventatively, suppress diseases, enhance the availability of nutrients and promote plant growth and rooting.[1]

Facts & Figures

- Increasing investment of agri start-ups in microbiome[2]
- Ca. €400M spent on "microbiome related research" in the first 2 years of H2020 (EU), investment up to €130M foreseen until 2020[3]
- The global human microbiome market would be worth USD 0.3 billion by 2019, and reach USD 0.7 billion by 2023[4]
- Rising number of scientific papers on microbiome research (2769 [2012] to 8431 [2016][5]

Stakeholders & Influencers

- Researchers/startups (seek funding, innovate)
- Consumers (demand)
- Farmers (supply)
- Supermarkets/retail (promotion)
- Government (regulation)
- NGOs (certification)

Related (Sub-)Trends

Pesticide free agriculture, Sustainability, Bio Boom

Relevancy: CropBooster-P

- Influence on land use, crop sustainability and productivity
- Reduced acceptance of conventional CPM
- Influence on food prices
- Enable new business models
- Certification and regulation (synthetic pesticides/fertilizers vs. biologicals)

Sources: [1]Poleatewich, A. (2018), "Utilizing beneficial microbes in a systems approach to plant disease management". [2]Waltz E. (2017), "A new crop of microbe startups raises big bucks, takes on the establishment", Nat Biotechl. 8;35(12):1120-1122. [3]EU MICROBIOME R&IMAPPING, DG RTD presentation. [4]OECD (2017), "The Microbiome, diet and health: Towards a science and innovation agenda", OECD Science, Technology and Industry Policy Papers, No. 42, OECD Publishing, Paris. [5]European Commission, Directorate-General for Research and Innovation (2018) Study on mission-oriented r&i on food system microbiomes by A. Małyska,

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4. Work plan for Tasks 1.2 and 1.5

Overall work plan

To facilitate data collection, Task 1.2 is divided into distinct phases:

1. Generating template for data collection (see below), task division among the partners according to their expertise and areas of interest (by end M5)
2. Data collection/completing data collection template (by end M7)
3. Compilation and completing the gaps and arranging the collected information in a comprehensive format (by end M8)
4. Digest the outputs of Task 1.2, 1.3 and 1.4, identify overlaps, trade-offs, etc. and align the data obtained by the different subtasks to generate a 'Research toolbox'.

Data collection template

- **MAPPING - Bibliography:** a comprehensive literature survey to identify pathways, processes and genes that have the potential to increase the yield potential
- **GAPPING - Gaps:** identification of the gaps there are in our current knowledge that may optimize yield in crop species
  - ➔ **A 'mapping' and 'gapping' approach to identify pathways, processes and genes of which the potential can be exploited using a range of different technologies to increase Yield in distinct crops.**

5. Deliverables

The following deliverables are scheduled for WP1 Task 1.2 and 1.5:

Number	Deliverable Title	Lead beneficiary	Type	Dissemination level	Delivery month
D1.3	Assess and digest the outcome and recommendations of the workshop regarding yield improvement as input for Task 1.5	VIB	Report	Public	M8
D1.8	Deliver Matrix and Report discussing strategy forward for future plant research in Europe that can be used as input for subsequent WPs – Report of recommendations, gaps, enablers in the identified toolbox	VIB	Report	Public	M12

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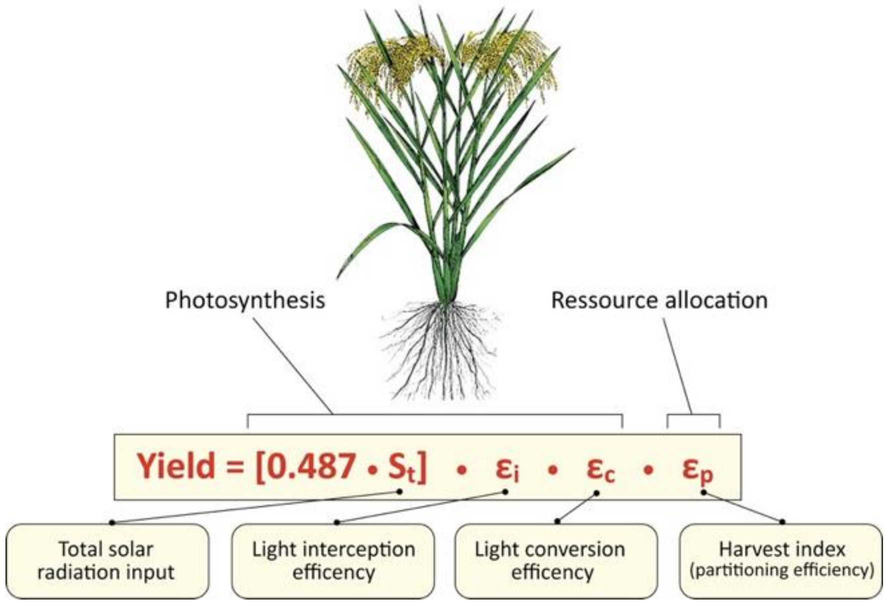
6. To be discussed at the workshop

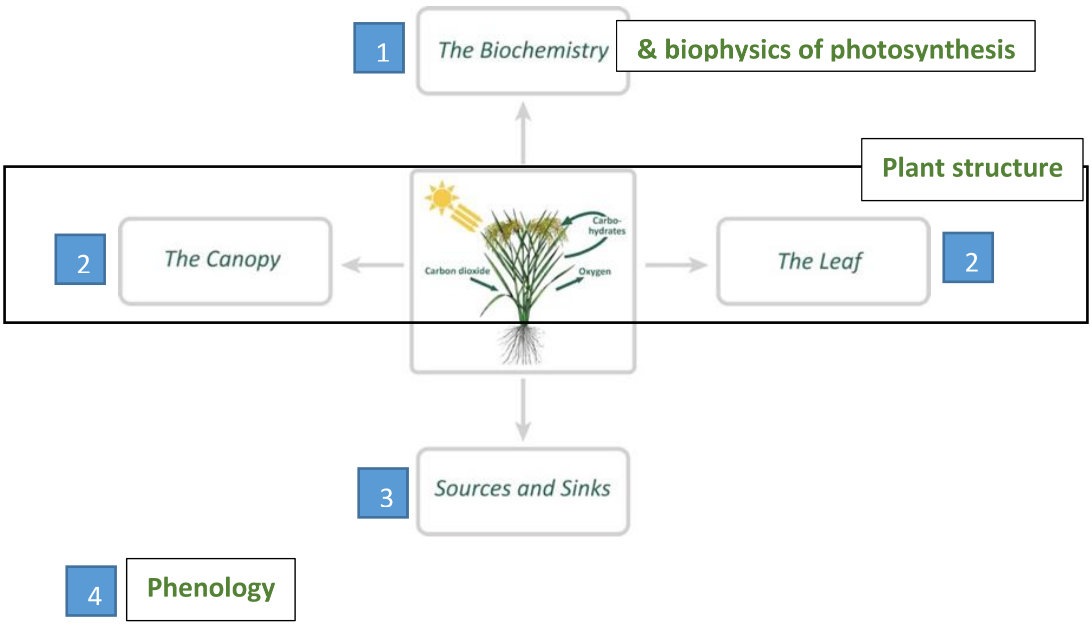
What determines/affects YIELD POTENTIAL (genetic basis) – YIELD DETERMINANTS?
Which plant traits/functions have a putative genetic basis and do we have to take into account in this project because they may determine plant YIELD POTENTIAL?
YIELD POTENTIAL <-> actual yield (YIELD POTENTIAL+SUSTAINABILITY)

Suggestion to use **two graphics** to guide us through this exercise:

(1) The yield equation (Monteith as conceptual inventor, but modified by many people)



(2) The framework in which photosynthesis is embedded in the plant/the canopy and by which factors, at the various levels, it is influenced. The facets/scales of photosynthesis[5]:



1. Biochemistry & biophysics/photochemistry of photosynthesis

- Primary processes of photosynthesis
    - Light harvesting/light dissipation/regulation mechanisms
    - Pigment composition
    - LUE (Light Use Efficiency of electron transport)

- Carbon assimilation – Photosynthesis (also highly sensitive for drought and heat stress (SUSTAINABILITY))
    - Rubisco and other photosynthetic enzymes
    - Photosynthesis limitations (Rubisco, electron transport, TPU or end-products)
    - Chloroplast-cytosol transporters (phosphate/dicarboxylic acids etc)
    - Sucrose – starch balance within the chloroplast
    - Calvin cycle (as a limiting factor, i.e. SBPase)
    - Photorespiration
    - Photosynthetic acclimation
    - Mitochondrial (dark) respiration
    - Photosynthetic induction
    - Pathway C3 vs. C4 or mixed (transgenes?!)
    - Sugar pathway

- Photoprotection
    - NPQ
    - Oxidative stress
    - Melher reaction
    - Photosynthetic by-products, proxies, signaling and protective molecules (e.g. pigments-hormones-vocs by MEP pathway, COS)
    - Photosynthesis enzymatic and non-enzymatic antioxidants

2. Plant structure/morphology

~ influence of plant architecture on canopy photosynthesis

- **Canopy with the LEAF as the plant's central organ of photosynthesis**

    - Erectness of leaves (leaf angles) (see (Ort *et al.*, 2015), (Perez *et al.*)
    - Phyllotaxy
    - Leaf forms (simple vs. compound leaves)
    - Leaf area/surface ratio
    - Leaf area density
    - Self-shading
    - Compactness (<-> rosette: not relevant for cereals, can be manipulated through crop density)
    - Leaf size/growth rate (sensitivity for drought and heat stress (SUSTAINABILITY))
        - Cell division → cell number
        - Division – expansion transition
        - Leaf expansion → cell expansion → cell size (major determinant of ε_i from Monteith)
        - Leaf life-time/senescence

    - Leaf anatomy

~affects both the interception of light and its distribution within the leaf as well as the diffusion of CO2 from the substomatal cavity to the mesophyll cells and the chloroplasts within (mesophyll conductance)

- Cuticula thickness
- Wax/cutin ratio and content
- Leaf thickness/structure
  - Mesophyll thickness
  - Mesophyll structure (in dicots: palisade vs. spongy parenchyma
  - Vein densities and structure (bundles sheath)
  - Mesophyll conductance:
    - Cell-wall thickness
    - Sc/Sm
  - Positions of mitochondria relative to chloroplasts
  - Chloroplast density
- Stomata densities, distribution and location
- Whole-leaf stomatal resistance and mesophyll resistance affecting the re-assimilation of respired and photorespired CO_2 (e.g. rice and wheat, also higher in young vs. old leaves)

- Root system
  - Root structure/density (determines soil depth and nutrient availability)
  - Root hydraulic architecture

- Relation of root/shoot interaction
  - Coordination of root and shoot

3. Sink activity

- Source strength (i.e. leaf photosynthesis)
- Assimilate/nutrient availability, uptake, transport, metabolism and partitioning
  - Soil availability
    - Nitrogen availability
    - Carbon availability
    - Phosphorus availability
    - Micronutrient availability (Fe, Zn, Mg, Mn etc)

  - Uptake/assimilation
    - Physiological balance
    - Rhizobia / N-fixation
    - Mycorrhiza
    - Non-symbiotic plant growth stimulating bacteria and microorganisms
    - Mineral nutrient acquisition UE (SUSTAINABILITY)
      - ✓ Nitrogen uptake
      - ✓ Carbon uptake (RUE)
      - ✓ Phosphorus uptake
      - ✓ Other micro and macro-nutrient uptake

  - Balance between uptake and use
  - Metabolism

            - Sucrose metabolism
            - Nitrogen metabolism
                - ✓ Amino acid metabolism
                - ✓ Storage proteins
    - Transport
        - Carbon transfer
            - ✓ Phloem loading control
            - ✓ Sucrose carriers
            - ✓ Apo-/symplastic transport
        - Nitrogen transfer
            - ✓ Nitrate, amino acid and peptide transporters

    - Remobilization from primary sinks (most often leaves) to secondary sinks (most often grain) of carbon, nitrogen and other macro- and micro-nutrients - CO2 recycling by photosynthetic sinks
    - Partitioning
        - Phloem loading/unloading
            - ✓ Nitrogen allocation to the grain (etc)

- Sink strength
    - Sink/grain development, post-flowering
    - Inflorescence architecture
    - Harvest index - Flower/seed number (increasing sink strength, seed filling rate, seed number… (Richards, 2000), (Miralles and Slafer, 2007)
    - Storage compound synthesis

- Sink-source relation
    - Sink-to-source feedback
    - Source-to-sink- feed-forward
    - Sink-source balance coordination
        - Senescence of sink organs (e.g. cereal endosperm)

- Coordination of carbon and nitrogen assimilation, especially during seed filling phase
  ~ the trade-off between yield and quality would need to be mentioned somehow

    - Seed filling dynamics
    - Remobilisation of N from photosynthesizing organs (leaves)
    - (timing of) leaf senescence (i.e. stay-green traits)
    - Trade-off between seed yield and seed protein (NUTRITIONAL QUALITY)

4. Phenology

- Flower development
- Flowering time (Parent *et al.*, 2018)
- Number of leaves before reproductive switch (determinate species)
- Early vigor (Zhao *et al.*, 2019)

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Which TECHNOLOGIES/METHODS do we need to take into account?
e.g. which technological approach might be explored to alter the abovementioned traits/functions of plants and thereby affect plant YIELD POTENTIAL?

GWAS
Conventional breeding
CRISPR-Cas9-mediated gene editing
GMO
TILLING
Genomic selection
Metabolic design
RNA interference
RNA-dependent DNA modification (e.g methylation)
Marker assisted selection
Alien Introgression
MAGIC populations
Synthetic biology
(Biodegradable) chemical compounds
Biostimulants
Biocontrol
Mutagenesis
Participatory breeding
Plastid transformation
Directed evolution
Chlorophyll fluorescence (incl. solar-induced fluorescence for remote assessment of photosynthetic production)

Which METHODS could also be used to facilitate these goals?

Modelling[1,2,3]
Reconstruction
Deep learning
High throughput plant phenotyping (fruit, seed, above/below ground)
Image analysis
Bioindicators/biosensors (provide indication on the nutritional status to optimize fertilization)
Optical sensors (reflectance/chl fluorescence)
Some integrated approaches like GWAS-based crop modelling[4]
Combination of genetic, ecophysiological and crop models
Genomic selection
Prediction of positive/negative effect of QTLs in specific climatic scenarios
Harvest (for algae, both mico and macro, harvesting technologies need to be improved)

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