VILLUM FONDEN

DEEP FRONTIER

Challenging one last frontier: Understanding and improving deep rooting

Deep Frontier International Workshop
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DEEP ROOTED CROPS FOR FUTURE FOOD PRODUCTION
Can we use subsoil resources and deep-rooted crops
to produce more food in a sustainable way?

Key points presented or discussed in workshop session 1-5

Session 1: *Methods for deep root research (2-5 meters depth) - How can we experimentally investigate deep rooting and associated functioning?*

- Need for an estimate of potential deep soils at the global scale
- Still a lack for appropriate methods to recognize presence of roots
- Deep root occupy a tiny proportion of the soil volume - finding them is hard work
- Root biomass/length is not an indicator for root activity
- Study the impact of deep roots more than the deep root per se
- Non-invasive techniques are desperately needed
- Methodology depends on the questions asked – ask questions more carefully
- Breeding genotypes for deeper roots, use of soil coring
- No shoot driven variation
- Soil structure creates a variability that makes correlation hard to find.
- Soil coring gives an actual measurement of the root in situ
- Measure soil properties at the same time while doing the coring.
- Good for breeding for molecular markers, but seems hard to see this technique being used by breeders.
- Shovelomics functions to describe root architecture and associated genes.
- High-throughput approach X-ray tomography to digitalize the root crown and extract traits.
- Maize root colonized by fungi - hyphae can be segmented out.
- The fancy box, 3D root architecture and real-time monitoring of resources fluxes
- No method is sufficient alone to capture all the biology we wish, integrative approaches are needed
- Image analysis approach to distinguish root type of Cassava plants.
- Identifying genes that are involved in storage roots development.
- Use modelling approach (OpenSimRoot) to test trait like root angle or rooting depth.
- Challenges to keep everything less costly for developing countries.
- Interaction between root and soil porosity should be a topic of interest for the future.
- 3D approaches (ex. Xray tomography) seems the best suited for that.
- Soil coring seems more appropriate to catch long term trends like under forest ecosystems.
- Necessity to stay perseverant as activity, growth and thus value of deep roots might be variable.

Session 2: ***Cropping systems – Which crops and cropping systems can facilitate deep rooting and how to utilize these?***

- Root growth in the soil change the environment by dry/wetting cycle and mucilage.
- Complexity increases with plant age.
- Depletion profile at the root surface and the slope of the profile depends on mycorrhizal abundance, mineral matrix, etc.
- Techniques exists to look at some very precise physiological processes (ex. C13 deposition of a root hair)
- There are many factors affecting carbon deposition which we still do not know to a large extent (ex. root length distribution with depth).
- Gradient in microbe abundance between the rhizoplane>rhizosphere>bulk soil.
- Persistence of the change in soil structure over time but lack of information at depth (> 60 cm)
- Roots of a single crop compete for the same resources especially at older ages. Might not be applicable for deep roots were root length is low. Root hairs matters!
- QTLs for yield and yield stability.
- Root Architecture mutant.
- High variation in root angle, which is supposed to be a significant trait to get deep roots. Found 3 associated QTLs.
- Importance of the precrop and biopore formation and their influence on root growth.
- Biopores are preferential pathways for root growth.
- 5-20% of the roots were found in the biopores which also means that roots do not growth only in biopores.
- Evidence using in-situ endoscopy that root can leave biopores and are not "stuck" to them.
- The soil that support annual crop were developed under perennial vegetation.
- Two approaches for perennial breeding, wide hybridization (perennial sorghum and rice) and domestication (Intermediate wheatgrass & Silphium).
- Inheritance of the trait deeper root but lack of effect on the yield (yield is decreasing as crop grow older).
- Silphium absorption of nitrogen down to at least 2m
- Intercropping of alfalfa and intermediate wheatgrass, differences in the O18 signature suggesting they are using different resource pools.
- When doing selection on seedlings, is the phenotype also useful in the field? Does it affect yield?
- Screening for seminal root angle, managed to identify the QTL but also found differences in rhizosheats, different rate of exudates?
- Below 1.2m some varieties of wheat are better at extracting deep water.

Session 3: ***Enhancing resource use through deep rooting – What is the potential for water and nutrient uptake by deep rooted crops?***

- Are roots functioning at depth (2-5m)?
- Can we get benefits from deep roots?
- Do we have cropping systems to make good use of them?
- What is the scale of the opportunity to use deep soils globally?
- Australian case study - "Use more of the soil and more of the season" – by using better rotation, control of summer weeds, no-till, early sowing and new varieties with longer coleoptile. Combining these strategies and yields were increased significantly
- APSIM model – predicted effects of " new agronomy"
- Legacy effect important
- The uplift of soil nutrients by plants: Biogeochemical consequences across scales
- Vertical distribution of Ca, Mg, K and P
- Climate and soil-age conditions affect nutrient uplift and retention by plants
- Water mining from the deep critical zone by apple trees growing on loess
- Soil water deficit in deep soil increased with tree age

- From America to the holy land: disentangling plant traits of the invasive Heterotheca subaxillaris, in a few decades only, the length of the roots of this American-native annual increased from 1.5 to > 5 m and it became a perennial that survives the dry summer period
- Root distribution and soil water profile down to 14 m depth
- High deep water uptake despite low root density
- More fine root production in deeper roots
- Xylem and aerenchyma at depth adapted to low oxygen and high water transport
- Nutrient acquisition from subsoil
- Optimizing the crop sequence for subsoil resource use
- With deep rooted pre-crops, yield stability and thus static resilience is increased
- Controlled traffic farming improves root growth, yield, mineralization, N uptake
- More deep roots increase sustainability of system, when crop N status does not interfere

Session 4: *Carbon storage in deep soil through deep rooted crops – amounts and controlling factors, incl. root and soil microbiology?*

- Roots leads to formation of soil organic matter
- In grasses 16%, and in annual crops 10% of gross assimilated C ends up the soil (grasses have longer period, advantage of perennials).
- Crops loose around 40% of carbon to soil, net rhizodeposition is around 15%
- Decrease of microbial biomass much slower with depth than roots / rhizosphere C, the turnover is much slower
- In topsoil biological processes dominates aggregate formation, in subsoil physical processes dominates
- Hotspots of microbial activity in rhizosphere, detritussphere, biopores, drilosphere, aggregate surfaces, on 5% of area the activity is 10x higher
- Soil inorganic carbon important especially in subsoil and in arid regions
- CO_2 efflux from carbonates by N fertilization induced soil acidification (unidirectional flux)
- Microbes as plants second genome
- Nutrient mobilization, promoting hormones, nutrient/water uptake, degradation of pollutants, plant probiotics, UV protection
- Microbiomes are shaped by activity
- Knowledge is driven by technology, only 20% covered by sequencing
- For archaea the situation is more or less similar in sub-/topsoil
- Bacteria more differentiated in topsoil than in subsoil, in subsoil there is a strong differentiation between bulk soil and rhizosphere and drilosphere
- Function different between top-/subsoil, nitrate reductase reduced in subsoil, denitrification increased
- Seed microbiome affected from where seeds has been grown, not much in barley, higher variability in grasses
- Dead roots: major contributor to SOM
- Root quality – main driver of decomposition
- Litter quality: impact soil decomposers strategy and efficiency
- Enzyme activity, high quality litter: low enzyme efficiency, but higher activity, low quality litter: vice versa
- Differences in anatomy leads to differences in decomposition
- Stoichiometry important for deep soil C sequestration
- Does diversified cropping systems increase carbon storage in deep soil?
- Intercropping enhances soil C, but only in topsoil
- Plant diversity increase soil C
- Perennial crops, increased carbon or increased decomposition

Session 5 – *Research agenda: Contribution of deep rooted crops to sustainability targets - What is the potential of deep rooted crops and cropping systems for contributing to sustainable development goals and how do we quantify this?*

Future research

- Understanding, improving and using deep roots for production
- We need basic, operational and geographical knowledge
- Zoom in and zoom out
- Do not assume max rooting depth – measure
- Deep root functioning, few deep roots under unfavorable conditions, unevenly distributed, short period of activity – in annual crops, how is effect linked to low density and uneven conditions?
- Important to look at productivity, inputs, ecosystem services – will deep roots deliver on these parameters and are there tradeoffs?
- Transporters in roots to see what they do, look at genes
- What is the limiting factor – functions of roots should be linked to specific conditions
- Roots are the spatially most plastic organ a plant have – more knowledge of genes
- Is grafting a possibility?
- How plants make growth decisions, to make long roots or not
- Hypothesis forming studies within microbiology – remember bad guys
- Also look at 60-100 cm - have to go through the top-soil to get there

Methods

- Good measurements in time and space, more minirhizotron imaging tools to make it easier
- Shafts - imaging and samples at the same time – good to compare a structured soil with one that has been re-filled – then it could be decided which treatments to compare across sites, and then specific treatments at one site
- We are dealing with systems and species that differ across the world – but many studies have been about wheat under widely different conditions – use that knowledge
- When we are doing modelling we make plentiful of assumptions, we characterize soils in layers and assume they are homogeneous, a lot of assumptions – but not so in the real world – models typically don't deal with pores and cracks and stuff like that but that will affect results – it requires that we have some understanding to put it better into play.
- AI based models – learn from the data we give it – more complex relationships could be predicted
- Root distribution – differences can be hard to see – we need to couple them to function
- Breeding – phenotyping facilities
- Modifying root angle, maybe we jump to conclusions with ideotypes – plasticity more important – phenotyping is of paramount importance
- Screening lines with different traits
- Not possible to make rapid measurements when looking at deep roots – QTLs is difficult – call for measures that are more indirect.
- Ask the plant what is important – look at QTLs - we can identify QTLs for plasticity
- You can also target one specific environment and the you do not want plasticity – some are breeding for that
- From mutants you can get to genes more easily and then editing – avoiding a lot of cards to play with
- You still need to evaluate 100000 plants in the field!

Soils

- Interesting dynamic when roots have to grow through dry soil to reach water
- Soil as a covariate, how roots distribute, some cracks and pores not used

- Soil quality, soil health, remember that it is also part of the functions of roots, organic matter, microbial processes
- Link not only organic C but also inorganic C and effects of roots, bio-geochemistry
- Deep roots can be detrimental to calcareous soils
- Is carbon sequestration happening in deep soil, if not then why? More priming in subsoil, unless the main effects depend on nutrient availability in subsoil?
- Distribution of nutrients with soil depth – often same distribution as roots, but especially water availability can be higher in the deep layers
- Hydraulic lift – possibility of lifting water from deep roots to more shallow layers making nutrients more available

Systems

- Resilience – in perennials, some roots may not be necessary this year but may come in handy next year
- Resilience is important – but if we want to study how this is increased, it should be studied in a broader context – have a more clear perspective on how resilience affects food production systems
- Increasing variability with climate change – breeding for a specific environment will be less valid in the future
- Predictability of subsoil water important, are we all really addressing the same problem? Australian system is very different from many other systems
- Context is important
- Roots have many more functions, greater spatial and temporal variability in function than aboveground
- Global scale – trees – oceans
- Zooming out - include landscape level and perennials
- Remember also other management
- GxExM
- Think of roots as a skeleton that can be expanded or reduced depending on conditions