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Trees and crops for the future, TC4F Annual report 2020

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Chairmen of the boards / Göran Ståhl & Håkan Schroeder

The research programme Trees and Crops for the Future (TC4F) is funded by the Swedish Government as a Strategic Research Area. SLU coordinates the programme, to which Umeå University and Skogforsk also substantially contribute. TC4F develops knowledge to support society's shift from fossil-based to bio-based economies through research at the frontiers of plant molecular biology, genetics, plant breeding, silviculture, and agriculture, combined with cross-disciplinary research. TC4F is divided into two sub-programmes: T4F focussing on trees and forests and C4F focussing on agricultural crops.

During 2020, T4F and C4F have been actively preparing for a third research phase through evaluating activities during the second phase and through developing new long-term research goals and programmes. Thus, 2020 has been to some extent a transitional year, but in the same time as new plans have been developed the researchers within the two sub-programmes have continued to deliver top-class scientific results, as can be seen in this annual report. These results are urgently needed for finding novel solutions that can underpin sustainable forestry and agriculture in times of change.

Göran Ståhl
T4F, Chairman of the board

Håkan Schroeder
C4F, Chairman of the board

C4F Program director / Eva Johansson

C4F – Crops for the Future

C4F focus on the development of sustainable new plant-based products through the use of modern technologies to contribute to a circular bioeconomy in Sweden. In 2020, by entering a new phase of the program, C4F has ensured a continuation of strong research to be carried out in its important areas of research. C4F has continued its tradition to act as a connecting thread to other initiatives developed on the basis of its activities such as SLU Grogrund, The Plant Protein Factory, Mistra Future Foods, LTV Plant Protein, Plant Link etc. Through the start of the third phase, five novel projects, based on high quality research in the C4F thematic research area, have been initiated to start in 2020; i.e. Plant protein fractionation, products thereoff and their feasibility, Cd and bread-making quality in wheat under varying climate and the use of the latest advanced methods, Quality and quantity improvement of oil and protein in oilseed crops, Authophagy and modulation for crop improvement, and Study of C-flux allocation in crops for quality improvement. C4F also welcome a new PI as project holder in 2020, namely Alyona Minina. Simultaneously as C4F is striving towards involvement of new researchers and projects, continuity of successful stories are secured, by finalizing ongoing projects in the areas of starch and protein qualities, structures and functionality, regulations of carbon flow, proteinbased biostimulants, production of insect pheromones in plants and domestication of Lepidium. C4F contributes to ensuring the strong and stable research environments needed to enable successful production of high quality research around these tasks resulting in sustainable new plant-based products.

T4F Program director / Michael Gundale

T4F – Trees for the Future

Trees and Crops for the Future – TC4F – is focused on developing sustainable plant production in agricultural and forestry contexts in Sweden. The concept of sustainability is as important today as it has ever been. As climate change progresses, two important aspects of sustainability production must stay in clear focus. Firstly, we must manage our production systems so they are resilient and can tolerate a changing climate. Secondly, we must be sure that our production systems can help mitigate climate change, by promoting a circular bioeconomy that is less reliant on high carbon emitting industries, such as fossil fuel combustion and cement production.

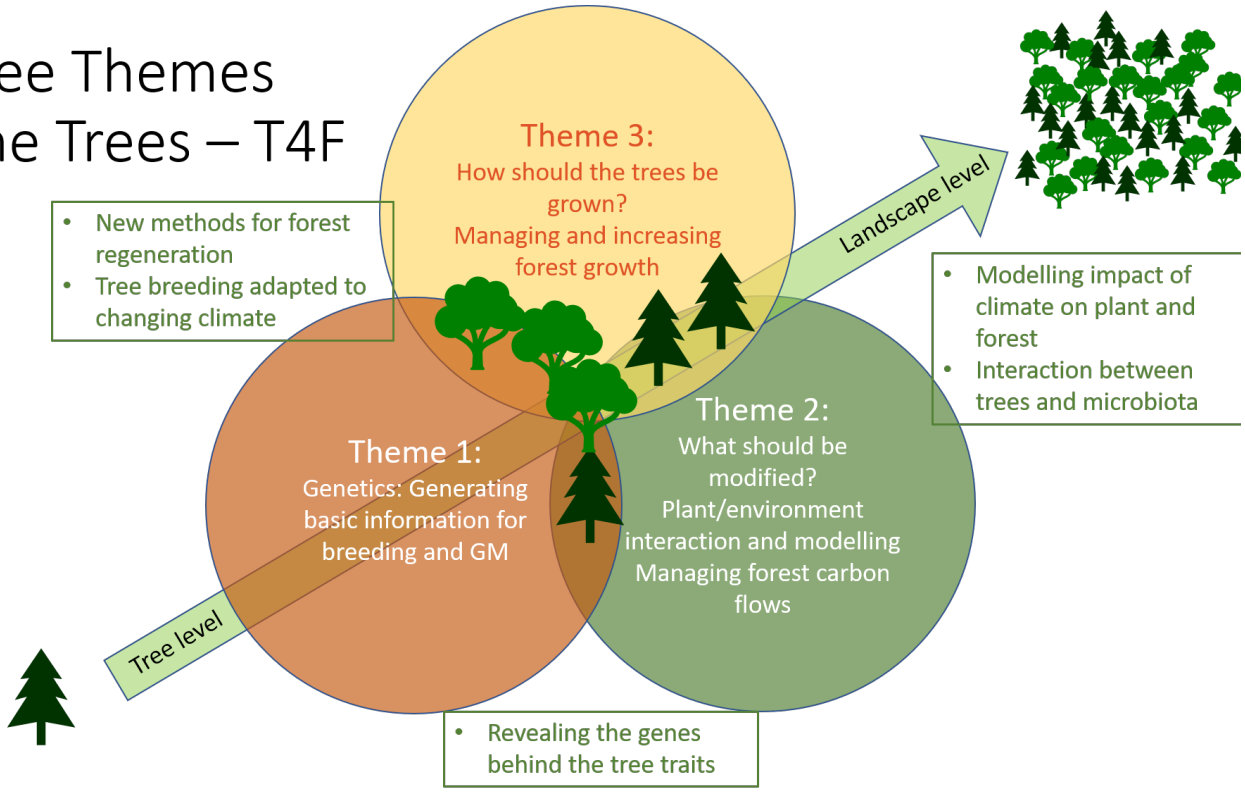
Year 2020 marked the end of the previous five-year research plan, which meant several projects came to a close, and publications that have carried over into 2021. This is reflected by a continuation of high impact publications, for example

- Müller et al. "A single gene underlies the dynamic evolution of poplar sex determination. Nature Plants 6: 630–637,
- Pryzbyla-Toscano et al. "Gene atlas of Iron-containing proteins in Arabidopsis". The Plant Journal
- Yang et al. "Two dominant boreal conifers use contrasting mechanisms to reactivate photo-synthesis in the spring". Nature Communications
- de Oliveira et.al "Carbon and water relations in perennial Kernza (Thynopyrum intermedium): an overview", Plant Science, 295, 110279
- Ibáñez et al. "Effects of Soil Abiotic and Biotic Factors on Tree Seedling Regeneration Following a Boreal Forest Wildfire". Ecosystems (2021).

Within this context, I have been appointed as the new program director for "Trees for the Future (T4F), the forests component of TC4F". A new 5-year program phase has begun in 2021, addressing overarching aspects of sustainability, with three new focal research themes.

The first of these themes is focused on genetics and breeding for the future. This work will be carried out largely by the two departments at Umeå Plant Sciences Center (UPSC) and Skogforsk, which will continue to develop a genetic toolbox for breeding

Three Themes
4 the Trees – T4F



the most vigorous and resilient trees for the future. The second theme is focused on forest composition, where researchers at SLU and Skogforsk will research which native and exotic species provide the most optimal growth under which environmental conditions, and further study how species mixtures can enhance forest growth and resilience. The third research theme will focus on how a range of forestry activities impacts soil carbon, which is critical because soils can contain between 2-20 times as much carbon compared to in forest biomass. Thus, changes in soil carbon stock as a result of forestry is a very important dimension of climate mitigation benefits of forestry.

In additional to new fundamental and applied research within these research themes, the T4F program will also initiate two new forest experiments in the coming years, one focused on forest genetics and another focused on tree species mixtures. These experiments are still in the planning phase, and will be set up in the next few years. Another important goal of T4F in the coming years is to continue to recruit young researchers in these research topics, so that we can produce strong researchers and managers that will be prepared to address these important topics well into the future, as their importance to society becomes even more clear.

Photo: Anke Carius

THEME REPORTS AND RESEARCH PORTRAITS

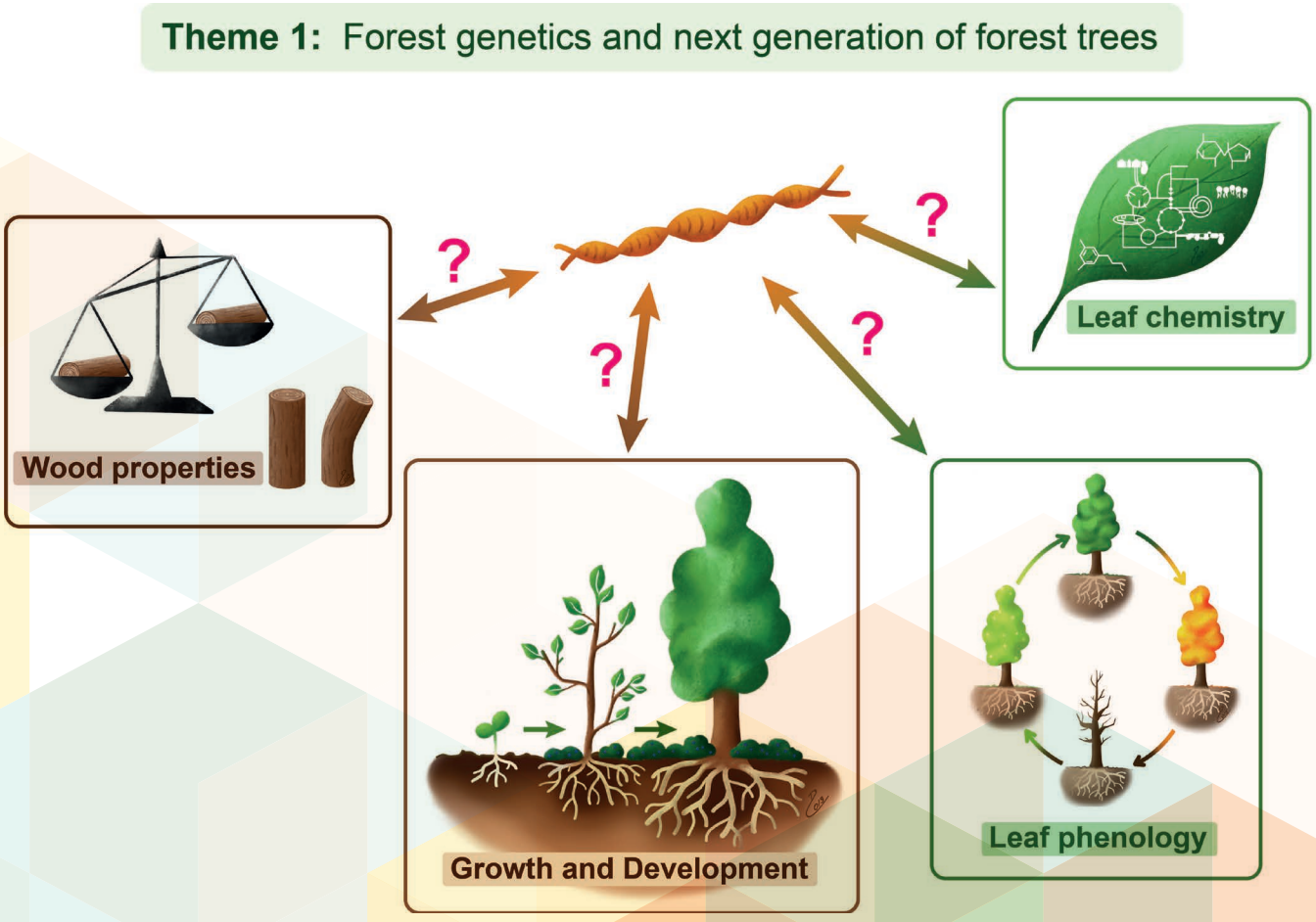
THEME LEADER: STEFAN JANSSON

Theme 1 - Forest genetics and next generation of forest trees

The work in Theme 1 on novel forest trees bridges basic research at Umeå University and SLU with operational breeding at Skogforsk. Many basic scientific findings of the project results from the analysis of trees that are in breeding programs and/or are interesting for forestry. Activities within Theme 1 confirm that our scientific environment is producing leading research on forest genetics and genomics with relevance for forest tree breeding.

A very significant proportion of the funding of Theme 1 is used for research infrastructure (e.g. tree transformation, bioinformatics, field experiments and cell wall analysis), supplementing other project funding. This infrastructure is used by most research groups connected to UPSC but the research output of these groups is not listed, only activities of research group that got direct support from TC4F.

Significant progress has been made in the analysis of conifer genomes. Most relevant for breeding is the finding that genomic predictions may shorten the breeding cycle length roughly by 50%, compared to pedigree methods (Calleja-Rodriguez et a. 2020). This may be the most obvious example on how the knowledge and resources created by T4F researchers in the huge conifer genomic programs that has been run over the last decade, is getting translated into practice.



Winter-green conifers in Rosinedal, Vindeln, Sweden

Important findings for operational tree breeders are also the that 1) selfing rate is around 3 % and external pollen contamination around 34 % in pine seed orchards (Hall et al, 2020) 2) marker selection is useful in multivariate genomic predictions when low-heratibility traits are targeted (Klápšteˇ et al. 2020) 3) new knowledge of disease resistance, it seems as is – at least in Pinus radiata – that selection for resistance against one disease may also confer resistance to others (Ismael et al, 2020).

The analysis of the mitochondrial genomes of Norway spruce (Sullivan et al. 2020), Siberian larch (Putintseva et al. 2020) and pines (Xia et al. 2020) may not have direct impact on breeding but opens up new roads towards, for example, analysis of parentage in both natural and bred conifer populations (the mitochondrial genome is maternally inherited). The identification of a novel photosynthetic protection mechanism "spill-over quenching" that enables conifers to be winter-green (Bag et al. 2020), and knowledge about its regulation (Grebe et al. 2020), has importance for basic science, but may in the longer perspective get practical use. The publication of this mechanism was probably the most internationally recognized output of the program in 2020, Der Spiegel in Germany published for an article describing this finding.

The breakthroughs in the analysis of Populus (aspens and poplars) has, in general, less impact on practical forestry but more on fundamental science, although some of it like the description of the recombination landscape in the genome (Apuli et al. 2020), sex determination (Müller et al. 2020) – aspens are dioic where individuals are either mailes or females - and speciation (Wang et al. 2020) provides general knowledge important for breeders. Studies in Populus has also provided clues to the understanding of tree phenology (Lihavainen et al. 2020) and wood formation (Kucukoglu et al. 2020). Finally, T4F researchers have also been involved in genetics and genomic studies of oak (Gao et al. 2020), Platycladus orientalis (Jia et al. 2020) and azaleas (Yang et al. 2020).

Like previous years, the visibility of the activities of the theme has also come through abundant participation in the societal debate, although the debate on these issues has for obvious reasons been overshadowed by the debate on pandemics.

Time to look at the whole forest!

Meet Michael Gundale, the new program director for T4F (the forest component of T4F). Michael has been a participating researcher in the TC4F program since its inception, over 10 years ago. In 2020, Michael became a full professor in Forest Vegetation Ecology, and has now been put in charge of leading a group of coordinators tasked with writing the T4F research plan for the next 5 year program period. Now that this new program plan has been approved, Michael will coordinate its implementation.

Michael is a forest ecologist who strives to understand how forests function, and apply this knowledge to the improved management of forests. His research focuses on factors such as plant-plant interaction, plant traits, plant interactions with soil biota, and plant influences on soil carbon accumulation. His work spans both the basic end of the research spectrum, as well as many applied dimensions.

One research area Michael has worked on is growth of Pinus contorta, which he considers a model species to study exotic species introductions. It is a native tree species to the Northwestern USA, where Michael studied at the University of Montana, earning an undergraduate degree in Wildlife Biology and a PhD in Forestry.

When Michael came to Sweden 13 years ago, he was not only surprised to find that P. contorta was planted in Sweden, but also that these plantations were outperforming comparable northern American Pinus contorta forests. Michael has carried out research showing how interactions between this tree species and microbes in Sweden may contribute to this growth difference.

Another major focus of Michael's research program involves investigating how forest plants affect soil carbon turnover. Boreal forests can hold between 2 to 20 times as much carbon in their soils compared to aboveground biomass, so these relationships are very important for understanding how the net carbon balance of Swedish forests changes through time. Michael's research on soil carbon has focused on understanding the fundamental processes of forest carbon inputs via aboveground and belowground plant structures versus soil carbon outputs that occur through microbial decomposition. He has studied how factors such as nitrogen fertilization, tree species identity, or forest genetic variation changes the balance between soil carbon inputs and outputs.

His research line, "biochar management", seeks to understand whether soil carbon stocks and forest growth can be enhanced through a novel management approach where forest waste products are charred, and applied to forest soils. Carbon sequestration by forests is one of the most promising means to mitigate climate change caused by carbon dioxide accumulation in the atmosphere, however, climate change will also change the composition of the forests and potentially also their ability to store carbon. T4F has in the last years created a network of researchers studying different ways to alter forest composition, for example by changing the genetics, choosing native or exotic tree species, or deciding to manage forests as monocultures or mixtures.

All of these factors can potentially influence carbon accumulation in the soil, and Michael is very excited that T4F will strengthen key collaborations that will improve understanding of what controls forest productivity and carbon storage. "There is already extensive knowledge about the single tree, but actually, we do not really know how a certain genotype will behave when it is planted at the scale of a whole forest!"

The next phase of T4F will help us look into this whole forest perspective. Skogfors, the forestry research institute of Sweden, that is also involved in T4F, has recently shared more information about their long term field experiments with T4F researchers, and Michael is especially excited about experiments where single genotypes have been established as whole forest stands, and have been replicated. This gives researchers the opportunity to investigate how genes are expressed in a forest context, how biotic and abiotic differences in the environment affect forests that are genetically are different. When replicated experimental forest plots are created with different genotypes, it is possible to see how those genes interact with their environment to control key ecosystem properties.

Bridging basic research in genetics, forest composition, and soil carbon within an applied context of forest management is one of the most important aims of T4F moving forward. As climate change develops further, Gundale says, "It will be increasingly important to manage forest for both a high level of resilience and productivity, and to promote their role in sequestering carbon in order to stabilize the global C cycle and mitigate climate change. Both basic and applied science is needed to accomplish this."

THEME LEADER: VAUGHAN HURRY

Theme 2 - Growth and interaction with the environment - current and future

Research in Theme 2 deepens our understanding of the important carbon and nitrogen cycles, and the effects of climate change. Examples of research topics include plant responses to rising temperatures and increasing dry spells, process-based models for predicting vegetation responses to a changing climate and soil studies using metagenomics and microdialysis.

The focus of Theme 2 has been to develop and provide tools to increase sustainable biomass yield from our existing forests. Ongoing climate change, driven by rising atmospheric CO2 concentrations, is increasing air temperatures and the incidence and severity of heatwaves, with linked increases in the incidence and severity of drought.

To develop the knowledge base to achieve this goal, it is essential that we understand the responses of trees to these different biotic and abiotic factors stemming from plant-climate and plant-soil interactions: and to mathematically quantify the impacts of these different factors not only on tree growth but also on ecosystem biodiversity, resilience and robustness in response to change. Therefore, within Theme 2 we have been working at scales ranging from remote sensing data to molecular genetics, spanning not only forest tree responses but also the responses of the linked microbial metacommunities. This ability to analyze the responses not only of forest trees but also of forest and soil microbiomes and metatranscriptomes now make it possible for us to assess the linked functional consequences of these different trophic-level responses to climate change and forest management.

Amanita muscaria fruiting body

photo Anke Carius

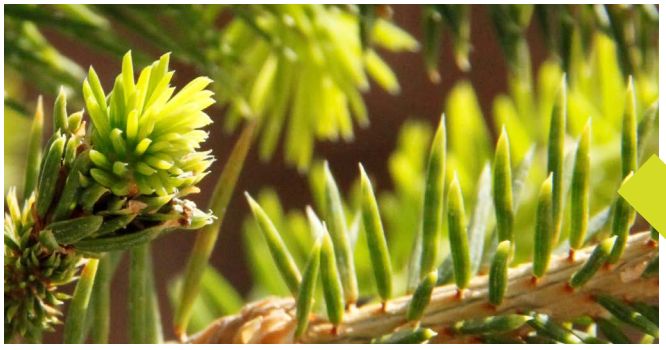
Main findings

- The methods we have developed for both metagenomics and metatranscriptomics have enabled us to show that atmospheric pollution (N-deposition) and forestry practice (fertilization) change the composition and function of the fungal and bacterial microbial communities associated with Norway spruce and Scots pine stands. This has generated important insight how these changes in microbial communities alter basic soil processes and change the capacity of these boreal soils to cycle and store carbon (Haas et al., 2018; Bonner et al 2019).
- The data and progress made within Theme 2 enabled us to obtain both a SciLife Lab biodiversity co-funded sequencing grant and a WABI/NBIS long-term support bioinformatics projects to validate and extend our metagenomics approach (Schneider et al, 2021). Ongoing research focusses on Norway spruce to identify how altered nutrient conditions not only change soil community composition but to identify the fungal genes that encode elicitor proteins that drive changes in the Norway spruce root transcriptome (Law et al., submitted). These studies are now being followed up for Scots pine (Schneider et al, in progress; Law et al in progress).
- The methods developed in this program are also being applied to studies of how seedlings recruit their microbiome during establishment on clear-cut sites and how this can be enhanced through local additions of organic and inorganic nitrogen (Castro et al, submitted; Schneider et al, in progress).
- During phase 2 we have developed a technique to simulate root exudation in forest soil using microdialysis membranes to test the role of different exudates in attracting microbial partners to the root. The microbes colonizing microdialysis membranes simulating root exudation have been visualize with scanning electron microscopy and the micro-scale diversity of microbes colonizing the membranes have been identified with DNAseq. We have characterized the influence of these soil microbes on plant root nutrient (Buckley et al manuscript submitted to Soil Biology and Biochemistry). Taken together, this novel approach will enable us to establish quantitative studies of carbon and nitrogen exchange within plant-microbial communities, establishing the importance of nitrogen for future forest growth under increased atmospheric CO2 concentrations.

Experimental setup for microdialysis.
photo Anke Carius

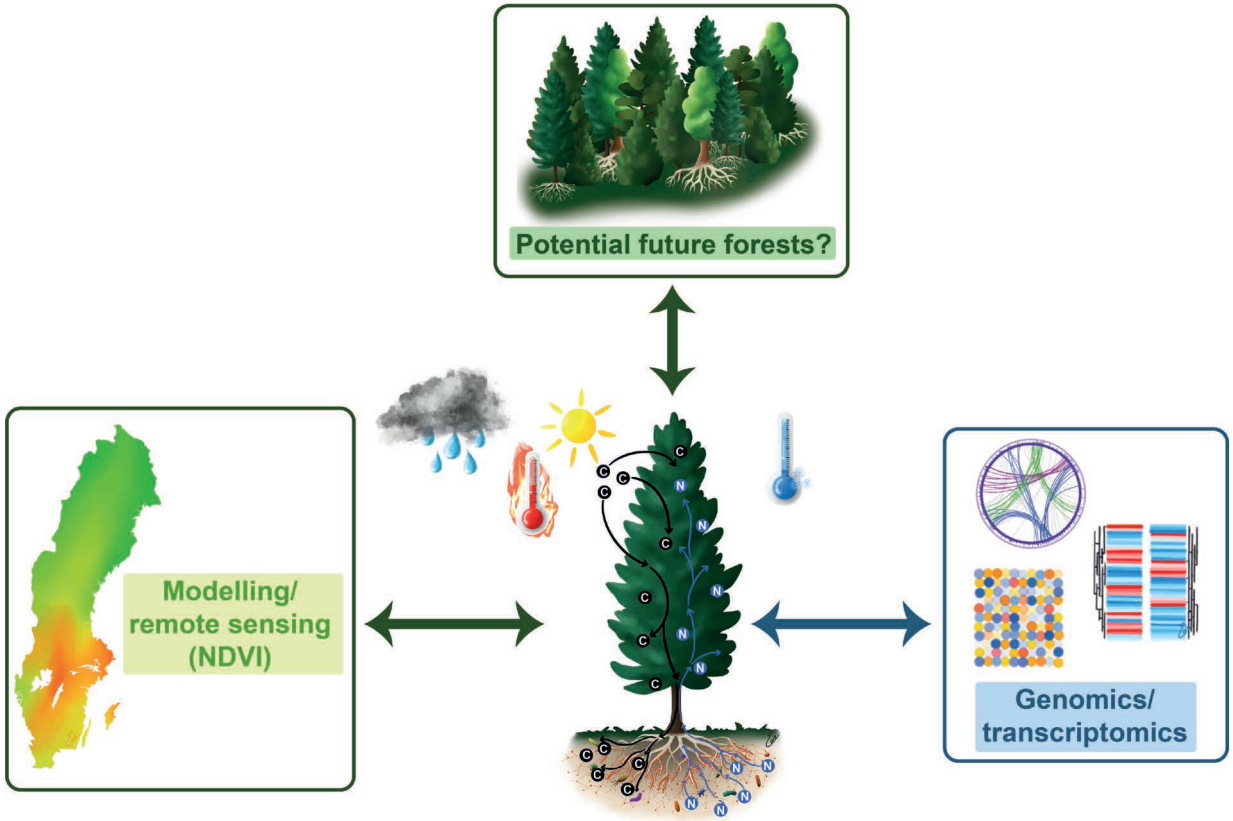
- We continue to make extensive use of the genomic resources developed by Theme 1 to assay abiotic stress responses in Norway spruce and Scots pine that will be key features in future efforts to breed to climate-resilient genotypes suited to future forestry. Namely, we have assessed the response of Norway spruce to elevated CO2, elevated season warming (Robinson et al, in prep), drought (Haas et al 2021; see also Feng et al, 2018 & 2019) and cold/freeze acclimation (Vegara et al, submitted). This work is integrated into the KAW genome project for Norway spruce and Scots pine. New cold and drought stress experiments have been performed on Scots pine by a TC4F-funded PhD students (supervised by NS). This further integrates activities in Themes 1 and 2 with the larger conifer genomics efforts ongoing at UPSC and will enable comparative network analyses both among the conifer species and between coniferous species and angiosperms.

- At the leaf to plant scale, we have used process-based models to establish the role of plant traits such as photosynthetic rate and avoidance of thermal damage for cumulated assimilation and risk of high temperature damage under future warmer and drier climates in the boreal forest (Ruiz-Pérez et al, 2019; Ruiz-Pérez et al, 2020) and explored the mechanisms behind tree responses to drought, using a combination of models and data (Feng et al. 2018, 2019; Vico et al. 2017).



Leaf, plant and landscape level. T4F aims to connect research on all levels of the forest.
Photos Anke Carius

Theme 2: Growth and interaction with the environment
- current and future -



At the landscape scale, we have used meteorological data and Normalized Difference Vegetation Index (NDVI) to assess the importance of different climatic variables on forests NDVI, extending the analyses over the whole of Scandinavia (Ruiz-Pérez and Vico 2020) and reviewed the linkages between climatic conditions and indicators of ecosystem productivity, identifying the current knowledge gaps (Messori et al 2019). We are now determining what are the local climatic drivers and global climatic indices driving the terrestrial carbon cycle, and the lag with which they affect vegetation indices, like NDVI and Enhanced Vegetation Index (EVI) (Wu et al, in preparation).

Societal value

The metagenomics protocols we established have been deployed to study how different fertilization sources and seedling planting/establishment strategies influence recruitment and integration of the fungal metacommunity into the rhizosphere of newly planted seedlings. This work is in collaboration with Holmen Skog AB and STT, therefore representing direct industrial application and benefit from the work developed in Theme 2.

Nitrogen Fertilisation and the Underground Stock Exchange

Simon Law is from Perth, Australia and studied at the University of Western Australia. Since his PhD in seed germination, he has been passionate about unravelling developmental processes in plants on a gene regulatory level.

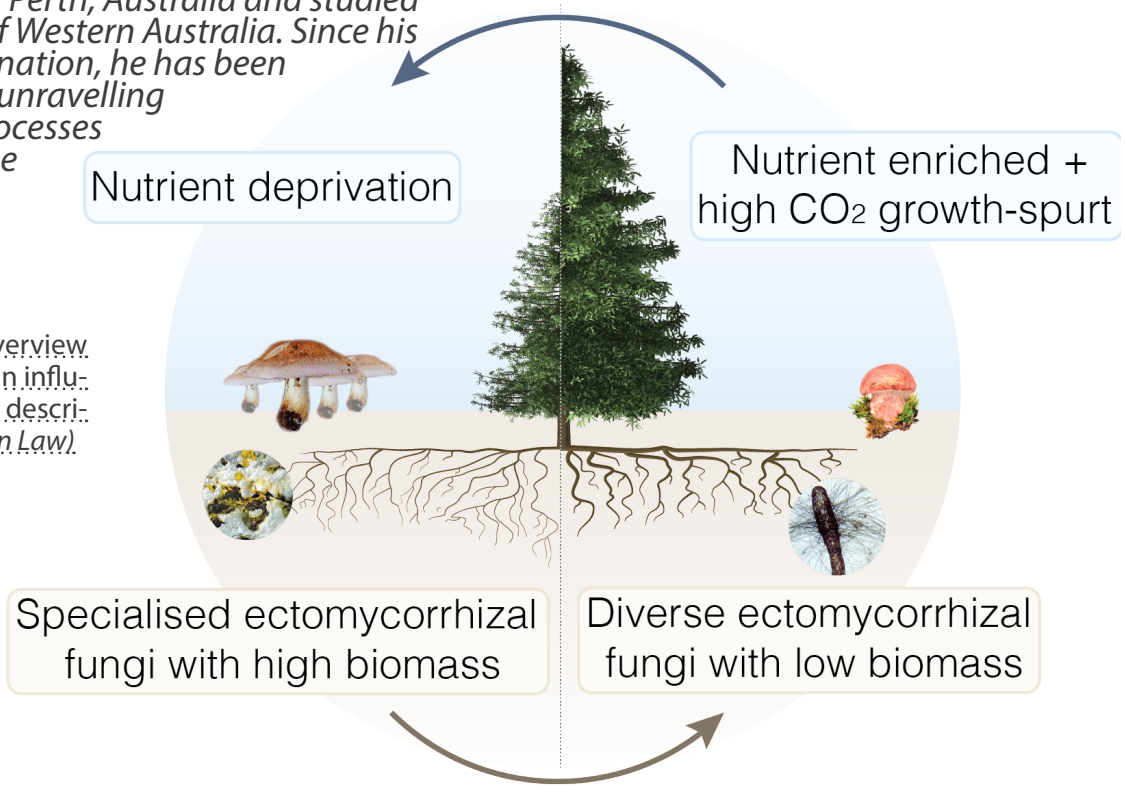


Fig. 1: Schematic overview of how fertilization can influence boreal forests as described in the text. (*Simon Law*)

After his PhD, Simon was keen to travel as far as possible for his next project. Fortunately, the Umeå Plant Science Centre offered just that, an institute with a very good reputation on the other side of the globe. At UPSC, he first did a transcriptomic analysis of leaf senescence in the lab of Olivier Keech, a part of Theme 1 of T4F, investigating the genetic events necessary for a leaf to die in an organized manner, so all nutrients can be recycled. His current project describes the development of ectomycorrhiza in boreal forests. Boreal forests make up about one third of the forests on earth, an area of about 16,6 million square kilometres. Nutrients in boreal forest soils are extremely scarce, so trees require highly specialized mycorrhizal symbionts that help the tree to extract nutrients and minerals from the soil and receive sugar in return. Growth is relatively slow in boreal forests, due to cold temperatures and limited nutrient accessibility so in commercially used parts of the forests, fertilization with nitrogen is an interesting option.

What happens when a forest is fertilized?

Primarily, Simon works on investigating the interaction between trees and their ectomycorrhizal fungal partners at the transcriptomic level, looking at which genes are expressed in both the tree and fungi simultaneously. The fine roots of Norway spruce is sampled, so mRNA of the tree and all root associated fungi are co-captured in the same

Fig.2: A wood decaying fungus (photo: Simon Law)

sample. Notably, this approach reveals not only the composition of the fungal community, but their active functions and symbiotic coordination with host tree processes.
This research shows that the mycorrhizal community changes significantly when these soils become nutrient enriched from fertilization. The tree becomes less dependent on highly specialized "super nitrogen extraction fungi" that have a high biomass and can degrade even very resilient, lignin containing plant litter. Instead, less specialized, flexible fungal species become successful (see fig. 1).

The community becomes more diverse but less efficient as nitrogen is abundant. The highly specialized species disappear. Many of the fungi are very robust as they integrate melanin in their chitinous cell walls, slowing down the degradation of their own biomass. They need to produce less biomass and they have smaller fruiting bodies. There is no need for the elaborate degradation of ligneous, woody material as nutrients are accessible.

In combination with rising temperatures and higher CO2, nitrogen fertilization can lead to a growth spurt for the tree. Altogether, in this scenario, the amount of carbon that is sequestered in the forest increases. This means that fertilization with nitrogen will change the mycorrhizal community and this, together with rising temperatures and CO2 levels can increase the amount of carbon that is stored in boreal forests. However, growth spurts also lead to a quick deprivation of the provided nutrition, so that the new mycorrhizal community would no longer be able to meet the trees needs and eventually, yet a new community with highly specialized fungi would need to be established.
More research is needed to find out how a boreal forest would optimally be fertilized to avoid regular destabilization events of the ectomycorrhizal community, how this would influence the overall well-being of the forest, and how carbon sequestration and productivity would be influenced. However, Simon's research gives rise to an interesting model of a natural regulatory system in boreal forest that can be used for future forest optimization towards growth and carbon sequestration that could help to fight climate change.

Text Anke Carius, *Photos Simon Law*

THEME LEADER: URBAN NILSSON

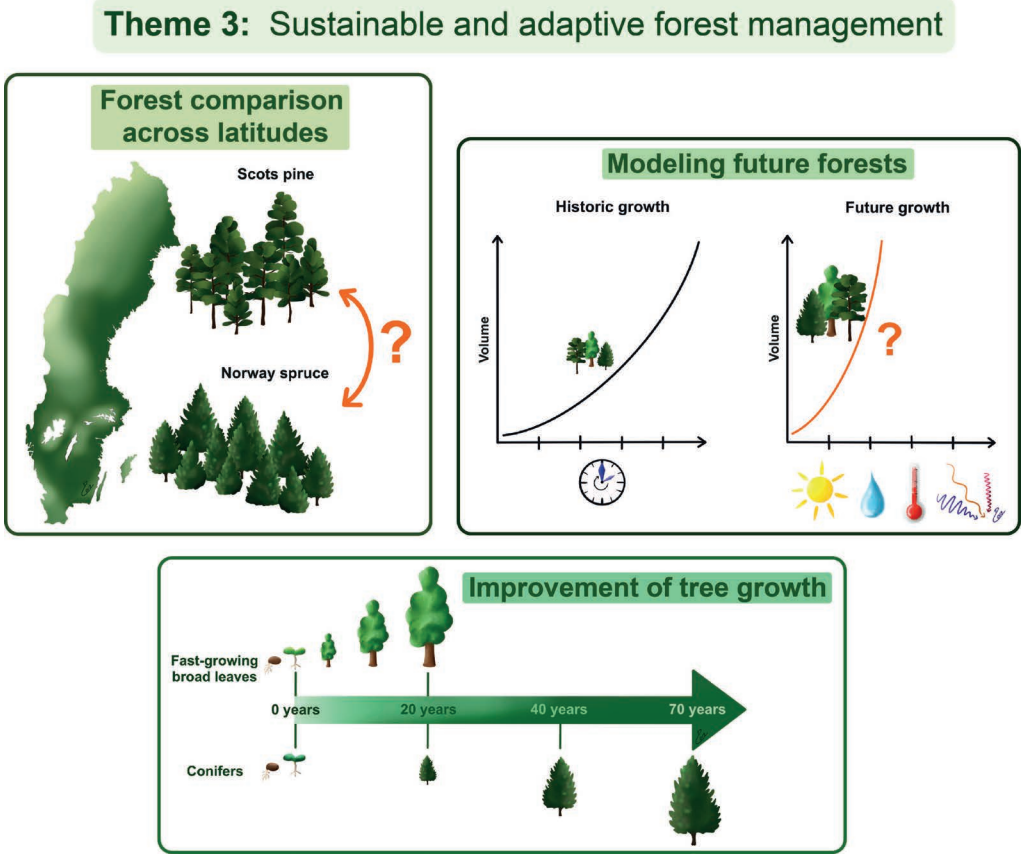
Theme 3
- Sustainable and adaptive forest management

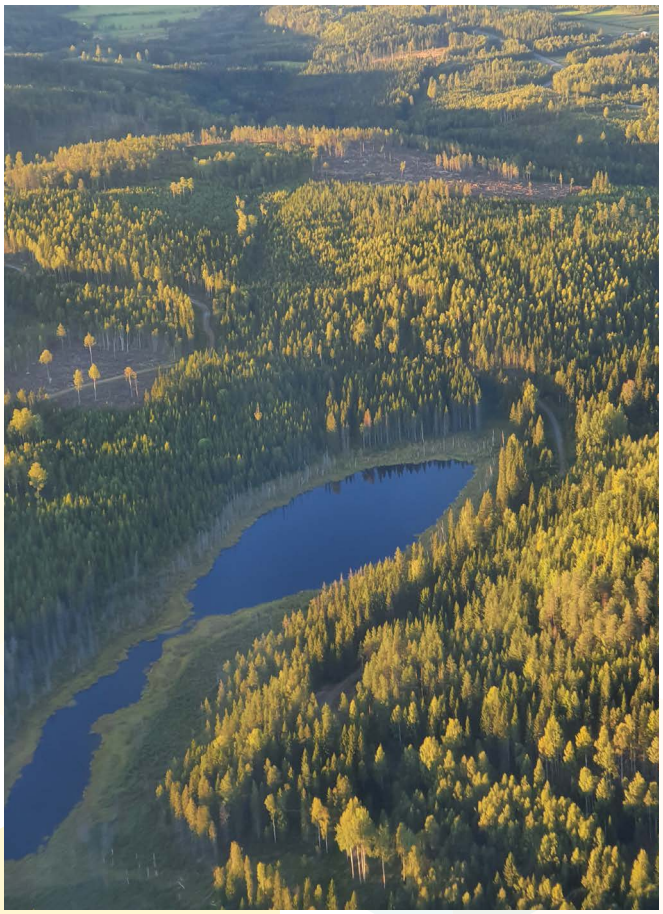
Theme 3 aims to develop new tools and knowledge for a sustainable use of our forest resources. New site-index calculation based on climate indices, management methods for poplar and hybrid aspen, models for genetically improved Scots pine and establishment of mixed forests are some of the topics in the program.

Overall progress and main findings of research in Theme 3 during 2020

During 2020, activities in Theme 3 were concentrated on continuing projects that were started during the previous TC4F phase. The first student, Oscar Nilsson, studied silviculture in Scots pine and Norway spruce in southern Sweden. Oscar defended his thesis in December 2020.

The second PhD-student, Theresa Ibanez, studied regeneration in the fire-area outside Sala. She collected and analyzed data from field experiments. She has also finished a green-house study that was analyzed and reported during 2019. She will defend her thesis in 2022. The third PhD-student, Martin Goude, completed empirical growth models and hybrid growth model for Scots pine and Norway spruce in Sweden. Martin will defend his thesis in 2021.





The fourth PhD-student, Gustav Ståhl, started during 2018 in a project on carbon sequestration. In addition to the progress of these four PhD students, a variety of research topics and activites have progressed.

As one example, we have investigated how ecosystem fire regimes in P. sylvestris dominated boreal forests impact post-fire fungal communities, and whether and how salvage logging may induce fungal community differentiation between fire regimes. We showed that crown-fire intensity is better linked to fungal community change than ground-fire-induced loss of soil organic matter. Severe crown-fire led to replacement of ectomycorrhizal- and litter-associated fungi by stress-tolerant ascomycetes.

We also found that salvage induced larger shifts in fungal communities in areas with low crown-fire severity. Further, we have shown regenerating seedlings (in particular that of spruce) following fire benefits from soil microbiota that are supported by alive overstory trees, and that biotic soil components may be of larger importance than that of soil abiotic properties resulting from fire. Work has also involved data collected from a warming experiment to test for the effects of fire regime and logging on tree seedling growth and associated root symbionts. In addition, we have also assessed how burn severity and salvage-logging impact soil CO2 fluxes, and nutrient availability post-fire. This work has also yielded additional funding from FORMAS (project started in 2020).

Finally, the group has also studied the effects of forest fires on the stocks and recovery rates of C in boreal forests and shown that if the fire return interval shortens to ≤100 years in the future, many boreal forests will be prevented from reaching their full C storage potential.

In addition, we established a new tree-species experiment with Scots pine, Norway spruce, birch, aspen and poplar on forest-land and former agricultural land. In addition, mixed species experiments with Scots pine/Norway spruce and Norway spruce/birch have been established. All three experiments are long-term and will be managed by the Unit for Field-Based Research.

Further, a synthesis project in order to describe possibilities for using poplar as raw-material for future bio-fuels started during 2020. The project incorporates the whole chain from growth, production capacity, economy and production of fuel. Together with Bio4Energy, poplars of different size are scanned with lasers in order to estimate biomass.

Finally, new results on production of Norway spruce and Scots pine showed that Scots pine was unexpectedly competitive, even on relatively fertile sites that formerly had been considered as spruce-sites. These results will be published during 2021 and have the potential to significantly change choice of tree-species in southern Sweden. We also submitted a manuscript on a new production-model for planted birch. The model shows that production of genetically improved birch (Ekebo5) is in line with production of Norway spruce on medium fertile sites. Together with colleagues in Finland and Norway, we published new mortality functions for tree-species in Scandinavia.

In what way is research in Theme 3 contributing to social benefit?

Research in Theme 3 is part of an applied nature and is done in close collaboration with the forest-sector and other stake-holder categories. Research conducted in Theme 3 is frequently reported in popular forest magazines.

During 2020, we have, due to Covid, had very little physical contacts on excursions and seminars for practical forestry. However, we have participated in several webinars, and this will be an activity that will continue.

C4F LEADERS: EVA JOHANSSON AND LI-HUA ZHU

C4F- Crops for the Future

All the projects within C4F have been conducted in principle as planned with good progress in 2020, while some delays in experimental work happened in some cases due to Covid-19. A number of peer-reviewed articles of high quality have been published, while a number of manuscripts submitted or in preparation are in the pipeline for publication.

The overall progress within C4F

All the projects within C4F have been conducted in principle as planned with good progress in 2020, while some delays in experimental work happened in some cases due to Covid-19. A number of peer-reviewed articles of high quality have been published, while a number of manuscripts submitted or in preparation are in the pipeline for publication. A couple of new PhD students have been recruited and establishment of a Grogrund research school associated with C4F is in progress.

Newly funded research grants associated with the C4F program have been initiated. Computational modeling tools for plant proteins and especially for the gluten proteins, which have previously not been targeted due to their size, have been developed. Unique research on functionalized plant proteins obtaining absorbent capacities not previously reported, has resulted in patents, several papers in good journals and in a doctoral thesis.

Latest advanced imaging techniques have been used in analyzing plant product qualities for food purposes. The latest genome editing technique, CRISPR/Cas9, has been applied more and more as an efficient molecular tool for basic research and for crop improvement. Efficient protoplast-based methods for producing transgene-free mutants by CRISPR/Cas9 have been established for important crops included within C4F. By regulating carbon allocation, we have obtained biofuel-rice, rice lines with improved disease resistance, and high fructan or high starch barley varieties, respectively.

Important insight into molecular regulation of autophagy and new tools for modulating and monitoring autophagy in crop models, *Arabidopsis thaliana* and *Nicotiana tabacum*, have been generated (Fig. 1). Research outcomes and associated outreach activities deal with new knowledge and information on novel potential uses of plant oils, proteins, starches and other compounds which can be used as food, feed and different industrial applications.

The program contributed to emerging of new research areas such as bio-based composites for food and non-food uses, possibility of crop improvement by regulating autophagy process, potential medical uses of plant-produced proteins and renewable sources of plant produced insect pheromones for pest management. The plant protein factory is now running in full speed and SLU Grogrund has continued to support more novel projects in 2020. Due to Covid-19, physical participation in national and international conferences has not been possible in 2020.

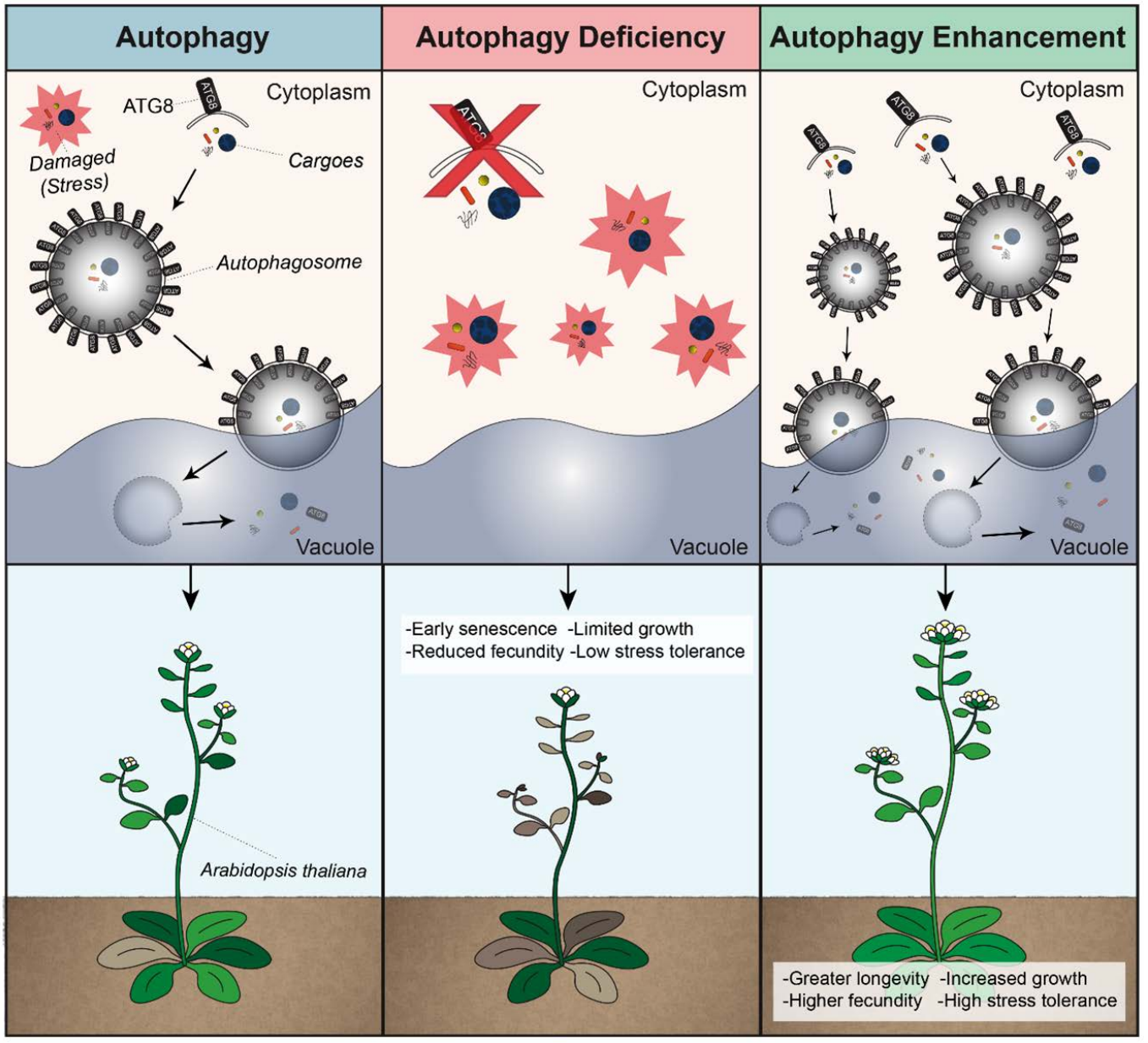


Fig. 1 Autophagy is a major catabolic process in eukaryotes. Upon activation of autophagy, there is a bulk or selective sequestration of cargoes into compartments called autophagosomes, which are double-membraned vesicles that later fuse to an acidic compartment where the cargoes are degraded. The process is coordinated by AuTophaGy-related (ATG) proteins, among them is ATG8 that plays a central role in the formation of autophagosomes by becoming directly incorporated into the double membrane. Autophagy deficiency or enhancement has shown to have significant effects on plant growth and stress resistance. Figure prepared by Dr. Adrian Dauphinee.

Detailed research findings and progress

The Problöja project with funding from Vinnova and TC4F was finalized in 2020 with unique research results on which proteins and how to properly functionalize these proteins in order to obtain high superabsorbent properties on the produced materials. We have distinguished the wheat (Fig. 2) and the potato proteins as two target plant protein sources for superabsorbents and also differentiated functionalization routes suitable as sustainable alternatives. The superabsorbents produced contributed high uptake properties for water and salt solutions while the blood absorption was exceptional in speed. The research has resulted in two patents and the formation of a consortia to take the results further to real applications.

The VR and TC4F funded research on computational simulations of plant proteins to understand functional properties has finally started to generate significant results in 2020. The plant proteins under study are extremely difficult to investigate through simulations due to their enormous size, the gluten proteins are building the largest protein polymers in nature.

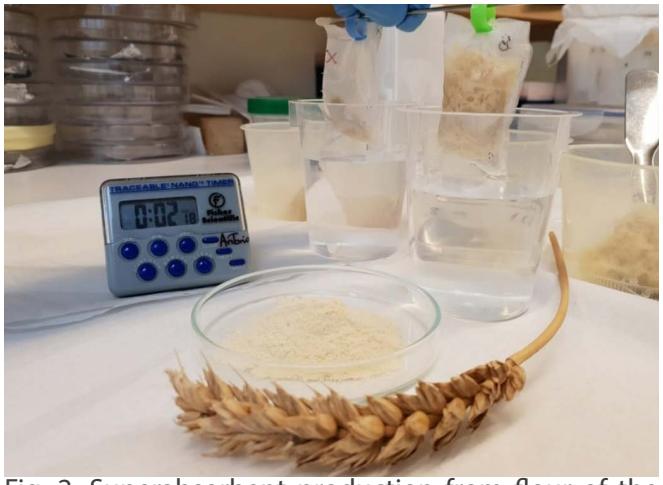


Fig. 2: Superabsorbent production from flour of the wheat grains. Photo by Antonio Capezza

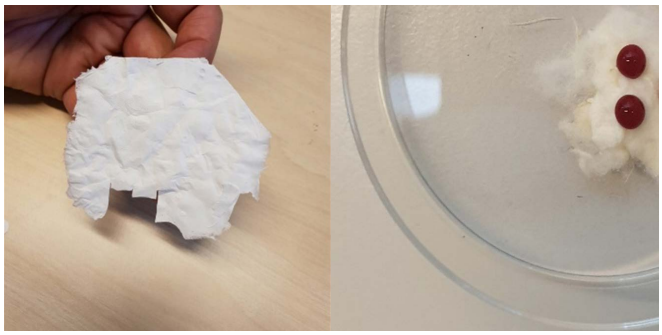


Fig. 3. Plant protein based textiles of various types and their absorption properties; a) paper-like gliadin fiber mat; b) wheat gluten textiles absorbing blood. Photos by Ramune Kuktaite

In collaboration with researchers at KTH and LU, we were able to simulate structural features on these proteins in the plant cell, previously not reported, that explains why some of them are forming internal while others are forming external cross-links while synthesized. Here, the hydrophobicity around cysteines seemed to be of high relevance. The model explaining disulphide bond formation at cell level will contribute significantly to further understanding of disulphide bond formation at processing.

We obtained the knowledge about how the properties and structures of the protein-rich crop foods (gliadin edible foams) are steered by the use of different additives. New intriguing results in the area of plant protein fiber textiles indicated that after specific treatment of the fibers it is possible to tune these fibers for repellent/absorbing applications (Fig. 3) and two manuscripts are in preparation. New results on the climate impact (e.g. heat and prolonged drought) on the protein composition in wheat indicated the genotype being a key player for the strength of the proteins. Differently, a negative effect of heat and prolonged drought was observed for the protein concentration.

Fig. 4. Cultivation of rice in Uppsala

We have characterized starch from faba beans in comparison with wheat starch and initiated tests of mixed gels of protein, starch and fibers from faba beans. We have also performed tests on addition of arabinoxylan to bread and the result is under evaluation. Two manuscripts on pea protein and nanofibrils are prepared and one has been submitted. Due to Covid-19, the X-ray scattering analysis on nanofibrils, connected to the VINNOVA project, was delayed, while the pre-experiments in the flow cell has been done at KTH.

The branching density is one of the most important features for the rate of retrogradation, while retrogradation is critical for product quality aspects such as product appearance and shelf life. We have developed and published a useful method for determination of the branching density in amylopectin in order to connect starch structure and its physical properties. With this method, we can measure the branching density in a large number of samples for providing a good statistical evidence for correlations with physical properties. The method has been applied on barley lines with a systematic variation in a transcription factor controlling the starch synthesis. The results are under evaluation. The starch composition and amylose structure have been studied on the CRISPR/Cas9 edited lines with reduced or eliminated the synthesis on amylose in potato and one manuscript on this is under review.

Basic research regarding health effects of dietary fibres as well as health effects of phenolic compounds in food products was the fundament for the side stream project, associated with to an EIP Agri. project. While it is established that dietary fibres have a range of beneficial health effects, as do phenolic compounds, the difference in physiological response depending on the type of fibre and the role of the phenolics is yet to be understood. By investigating the fibres and phenolics in the broccoli leaves, this would highlight the levels of these components in this resource for new food products, and contribute to future interest in utilization of the unharvested broccoli leaves. The results from previous investigations of side streams of broccoli were summarized and published and the licentiate thesis Content of dietary fibre and phenolic compounds in broccoli side streams was defended in 2020. We have evaluated broccoli leaves left in field for their possible use as new healthy ingredients in food products. The results showed that broccoli leaves contain valuable components which can be interesting to be used as food ingredients, and that the connection between fibres and phenolics is important to further elucidate.

We have found that the overexpression of the *AtWRI1* gene in rice can increase the oil content in straw by ca 2 folds compared with wild type, indicating a high potential for biofuel purpose. A manuscript on this is in preparation. We have also found that overexpression of one important gene in Nipponbare rice could significantly increase the resistance to rice blast and planthopper, providing a new potential for reducing usage of fungicides and pesticides (Fig. 4). At least 10 barley varieties with high fructan or high starch have been developed and SNP markers on the traits have also been developed for identifying superior individuals from cross populations for further breeding.

We have proven that genome editing is a useful method to redirect carbon flow by modifying promoters of transcription factors (TFs) and to clarify interactions between TFs in different seed development stages. The work with oil induction in wheat endosperm has been extended with seed X-ray imaging and nutritional evolution. Underground oil regulation has been complemented with transcriptomes and metabolic evaluation of Cyperus metabolism. We have enabled the synthesis of 12:1 – 16:1 pheromone precursors, where 14:1 and 16:1 are on levels for commercial application.

Research is now intensified on Lindera plant species (oil containing 10:1, 12:1 and 14:1 fatty acids) on finding novel genes and enzymatic to utilize for improved Camelina lines (basic research with applied outcome). Further focus is on wax esters which have been developed with the added benefit of carrying fatty alcohols being true pheromone blend constituents. Mating disruption tests for two different major pests have been conducted using pheromones derived from oil of our first Camelina line cultivated on a larger scale. Improved Camelina lines with the same target compound have been produced and additionally Camelina lines with novel target compounds destined for upscaling and pheromone production. Final experiments with collaborator and later incoming postdoc have been delayed due to COVID-19. One manuscript has been published and three manuscripts are under preparation regarding the results presented above.

For wax ester (WE) production, samples from crosses between 35S:FAR.kana x 35S:PES2.kana have been sent for WE analyses. To simplify selection of double expressors, 35S:FAR.hyg x PES. kana crosses with different selectable markers have been done. Tobacco transformations and crosses were finalised. Some FARxPES crosses displayed an extreme dwarf phenotype, not observed in parents. WE analysis in generated crosses/transformants will be done during 2021.

We have finalized the crambe project and produced valuable transgenic lines with improved oil qualities, which can be further explored for any possibility to perform larger field trials in areas where interest in cultivating GM crops exist through international collaborators. For other oilseed crops, we have put significant efforts in developing protocols for protoplast regeneration of field cress and rapeseed in order to build a strong Swedish base for genome editing of these species in a near future. We have early reported the establishment of a highly efficient protoplast regeneration protocol. We have now established an efficient protoplast-based genome editing method by CRISPR/Cas9 for field cress. Using this method, we have generated mutant lines of field cress (Fig. 5) that have mutations in GTR1 and GTR2 genes for reducing the glucosinolate content in seeds by blocking transport of glucosinolates from

vegetative tissues to seeds. Further molecular, chemical and phenotypical studies on these lines will be done once homozygous lines are available. Significant progress on development of protoplast regeneration protocol for rapeseed has also been achieved. Two manuscripts about these results are in preparation.

Using transcriptomics, bioinformatics and gel-shift analysis, we have narrowed down the number of potential autophagy-regulating transcription factors (TFs) from 2,300 to two main candidates: ANAC046 and ANAC055. The impact of ANAC046 on the expression of AuTophaGy-related (ATG) genes has been validated by RT-qPCR. ATG protein level analyses are ongoing. Newly generated ANAC055-overexpressing plants will be employed to explore the role of ANAC055 and its ATG targets in Arabidopsis stress response.

A photoaffinity labelling (PAL) assay for use in planta was developed to identify the protein targets of autophagy enhancers identified through our chemical screen. Through collaboration with the Chemical Biology Consortium of Sweden (CBCS), diazirine photo-activatable probes were added to the molecules. Arabidopsis seedlings were used to develop the PAL assay and samples have been sent for proteomic analysis through support from an EPIC-XS grant (VIB, Belgium).

The current methods for measuring autophagy require laborious sampling of plant material, which do not allow to track dynamics of the pathway. We aim to establish non-invasive methods for quantifying autophagic activity in planta. For this, we engineered two types of reporters: (i) dual-luciferase reporter that shows decrease in luminescence upon upregulation of autophagy; (ii) split-luciferase-based reporter, which luminescence increases proportionally to autophagic activity.

Fig 5. Gene-edited field cress plants with pods and flowers. Photo by Li-Hua Zhu.

We have finalized the hemoglobin project, associated with a SSF project. The expression of the human Mb and A1M proteins in the leaves of Nicotina benthamiana have been successful and purified proteins have shown functions similar to the native ones. Two articles about these results have been published, which have attracted attention from food and medical industries. We are now finalizing the work with XTEN attached to fetal hemoglobin to stabilize the protein and a manuscript is in preparation. There is a high potential to use our methodology to express important proteins from various sources for producing plant-based proteins for diverse applications.

In what way the research has contributed to social benefit

The ultimate goal of C4F is to contribute to social benefits in some ways. Some projects are closely connected to or have been transferred to UDIs or EIPs, one way to transfer TC4F knowledge into product-based projects, thus benefiting to the society.

The UDI project "Plant Protein Factory" that is an outcome of TC4F ended in 2020. It generated a lot of results that have to be evaluated and several of the partners are interested in a continuation for further development into reality. The Faculty together with the department has the idea for a continuation for the Plant Protein Factory pilot to be stored and run as an academic facility.

The Problöja project on superabsorbents also has results that calls for a transfer to applications which will be searched for. Moreover, the new knowledge obtained on composite materials can be further explored in development of nutritious food (protein rich and dietary fiber rich) with specific structures and making Sweden more self-sufficient.and bio-based textile materials. Varying climate impact results on the protein quality can be further used in wheat breeding programs striving towards breeding of climate resilient crop. Faba beans, oat, peas, rapeseed, potato are Swedish crops with a good nutritional profile that are concerned within the C4F program. They can be a good plant based protein alternative to soy-products and gluten. Legumes can help with nitrogen fixation when incorporated into an intercropping system, which will thus enrich the soil and reduce over fertilization.

The new type of starch with improved product quality is for food and non-food applications. Starch with increased amylose content have nutritional benefits since it has more slow carbohydrates. Slow carbohydrates can potentially decrease our insulin response and thereby reduce the risk to develop type II diabetes. Our research on retrogradation can in the long run reduce food waste by prolonging product shelf life. Crystallizations and other inter-molecular interactions are also important for material applications, that will be studied further in this project.

Potential use of side streams of broccoli leaves would contribute to an increased resource efficacy in the broccoli production and better production economy, which would in turn contribute to increasing Sweden's degree of self-sufficiency as more food can be harvested in the same production area.

The new concept of C-flux has generated new cereal lines that can add values for biofuel production for living purpose and reduce dependence on fossil oil, reduce usage of fungicides and pesticides and increase production of yield and quality. Insect pheromones for pest management is non-toxic and produced from a renewable resource contrasting to pesticides will be beneficial to sustainable agriculture.

The general public is already aware of the pivotal role of autophagy in medicine, including its anti-aging and anti-neurodegenerative effects. We strive to convey information about the importance of studying plant autophagy for improving crop fitness and productivity.

Novel transgenic or mutation lines of oilseed crops with improved oil qualities contribute to increased plant oil production for food, feed and industrial purposes, and consequently reducing the fossil use and benefiting the environment.

Successful expression and characterization of functional heme-binding proteins in plants contribute to social benefits through providing more plant-based proteins for potential nutritional and medicinal applications in future. Our publications in this project have attracted some industrial contacts for exploring potential investment.

Vice program leader Li-Hua Zhu

How C4F takes basic research to application to be used

The most of the projects in C4F have a character of more towards applied research, meaning that we have tried to transfer the known knowledge from basic research in oil, protein and starch as well as material science into potential applications in one way or another.

Some good examples are:

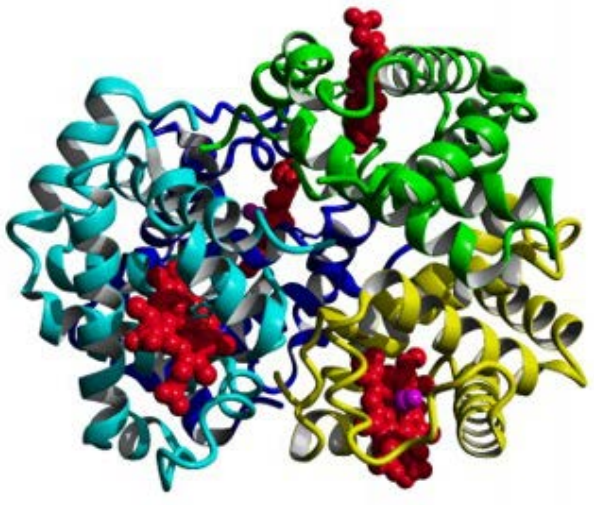
1. Protein fiber textiles
2. Establishment of Plant Protein Factory
3. Protein-rich food
4. SUSAP – Sustainable superabsorbents
5. Plant protein fiber textiles and absorbents
6. Monitoring Cd absorption in wheat
7. Climate stable wheat
8. Initiation of EIP project in broccoli.
9. A single gene can be used to generate biofuel rice for food purpose
10. Pheromones from a plant production source for pest management is a good example of going from basic science on specific pheromone compounds their genetic background in e.g. moths to applications in production and pest management.
11. Understanding the relationship between microstructure of starch, proteins and fibers and their different attributes in food and different industrial applications.
12. Expression and characterization of important human heme-bindning proteins in plants for potential nutritional and medicinal purposes.

My dream is to make the world free from anemia

"Here I feel free to do the research that I'm interested in. I am looking for new ways to solve the problems with anemia in the world."
Selvaraju Kanagarajan, one of our researchers in TC4F, produces hemoglobins in plants.

Selvaraju Kanagarajan, or Selva as most people call him, grew up as the only child in a farming family at the countryside in Tamil Nadu, India, with cows, dogs and cats as best friends. The family cultivated vegetables, fruits, sorghum and rice, and throughout his life Selva has had a great interest in plants. Today he is a researcher at SLU in Alnarp, and studies how heme-binding proteins can be produced in plants with help of gene technology and how oilseeds quality can be improved through genome editing.

– I use plants for so called molecular farming, which means that the proteins of interest are made inside the plant cells and can be extracted and used for nutritional and pharmaceutical purposes, Selva explains.



Hemoglobin Structure, picture: Magnus Carlsson

Selvaraju Kanagarajan has a master's degree in horticulture and a PhD in biotechnology. He moved from India to Kalmar University in 2009, went to Örebro University a few years later and came to SLU, Alnarp in 2015.

– I learned a lot about protein chemistry during my postdoc in Kalmar, but since I have a background in plant biotechnology, I was very happy to come to SLU with all its facilities for plant research and a lot of colleagues in the same research area as myself, he says.

In the strategic research area C4F, Selva focuses mainly on the production of human fetal hemoglobin and phytoglobins (hemoglobins from plants), proteins that are important components for oxygen transport and iron supply in our diet and for preventing anemia, respectively. Due to safety challenges and production problems, there is a need of new ways to produce these proteins for both medical and nutritional uses in the world. Heme-binding proteins, produced in plants, could for example be used as additives in plant-based burgers.

– A lot of people suffer from anemia in the world today, especially women and children, and my mission within science is to contribute with something that can make the world free from anemia, with the help of plants, Selva says.

Plants have their own heme-proteins, but our intestines are designed to absorb and use the heme from the hemoglobins found in animals.

– That is the reason, we want to produce human hemoglobin for pharmaceutical use in plants, says Selva.
Moreover, Selva also combines his skills in crop biotechnology with nanotechnology together with research colleagues in India.

– We are trying to use nanoparticles to make fertilizers and pesticides that can be absorbed by crops in a more efficient, environment friendly way, to reduce the amount of chemicals applied in agriculture.

He likes the working environment in Sweden.
– The feeling of academic freedom is the main reason for me to stay here. But I'm also happy because the people in Sweden speak English very well, which makes it easy to live here.

Selvaraju Kanagarajan

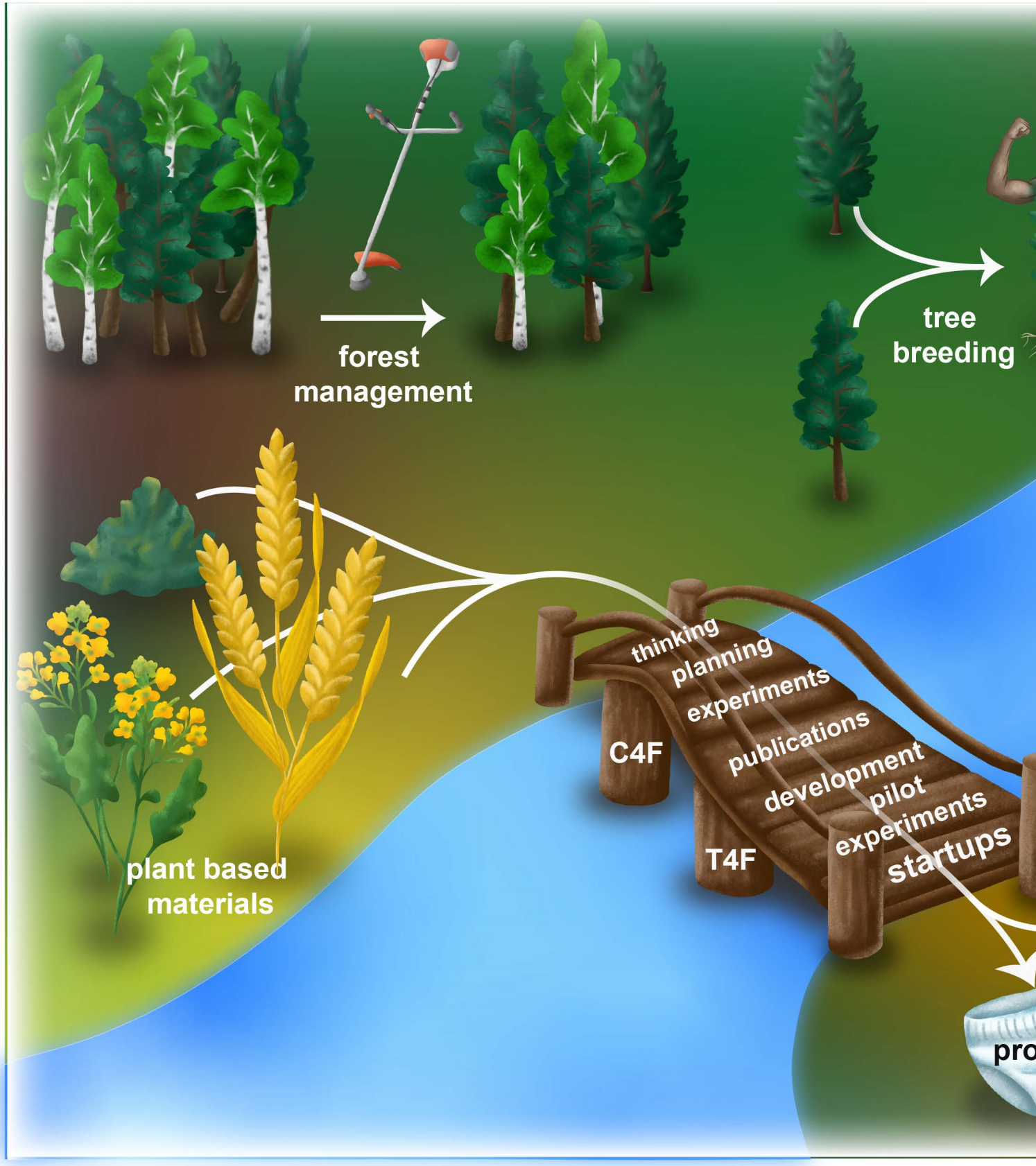
Tobacco Plants that are used for hemoglobin production in Selva's lab. Picture: Li-Hua Zhu

The year 2020 has been a challenging year due to the covid-19 regulations of social distancing.

– There has been both pros and cons for me this year. The pandemic has affected the experimental part of my work. But on the other hand, I got a lot of time to write research applications and manuscripts, says Selva.

In his spare time Selva enjoys being with his daughter.
– By working a lot from home I got more time to spend with her, since I save ca. 2 hours on my way biking to work and back to home. .
As a result of the corona restrictions Selva has started a healthier life by using his bike instead of taking the bus.
– I hope my new lifestyle will keep me more healthy and the pandemic will be over soon so that we can live and work in a normal way.

Text: Lisa Beste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Bridging Basic Research to Application in TC4F

The research program TC4F takes fundamental research to application in many different ways. Here, some examples are illustrated.

In theme 1 specific tree breeding leads to specific traits in trees that then are raised in optimized plant schools for plantation in the forests of the future.

Theme 2 developed new fertilization methods that now can be applied to ensure the best tree growth and development. Theme 3 focuses on forest maintainance and develops new methods for forest brushing, even for mixed forests.

Program part C4F develops many plant related products, for example superabsorbent materials from wheat protein and plant based oils and fuels.

TC4F publications and activities 2020

The four themes of TC4F have published 69 articles in T4F and 27 in C4F in peer-reviewed scientific journals. Read here how many have been involved with supervision of students, teaching, received other grants and contri buted to popular scientific activities.

Authors marked in **bold** represent researchers that have been financed by, or are associated to, TC4F.

Theme 1
- Forest genetics and next generation of forest trees

Scientific publications

During 2020 Theme 1 has published 25 peer reviewed scientific articles in international journals. Authors marked in bold represents researchers that have been financed by, or are associated to, the research program.

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widely cultivated azaleas. Nat Commun. 2020;11(1):5269.

16. Boussardon C, **Keech O**, Cell type-specific isolation of mitochondria in Arabidopsis. Methods in Molecular Biology, book chapter. Methods i Molecular Biology2020.

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18. Gao J, Liu Z-L, **Zhao W**, Tomlinson KW, Xia S-W, Zeng Q-Y, et al. Combined genotype and phenotype analyses reveal patterns of genomic adaptation to local environments in the subtropical oak Quercus acutissima. Journal of Systematics and Evolution. 2020;59(3):541-56.

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Dennis Eriksson, Mariette Andersson, Erik Andreasson, Per Hofvander, Stefan Jansson, Anders Nilsson, Paul Tenning, Li-Hua Zhu, Annika Åhnberg- Låt kraften f i gensaxen förbättra våra grödor. SvD 17/10 2020

Richard Bradshaw, Ulrika Egertsdotter, Pär Ingvarsson, Ola Rosvall, Harry Wu, Ove Nilsson (ed.). (2020). Grankloner i svenskt skogsbruk. Future Forests Rapportserie 2020:1. ISBN: 978-91-576-9716-5.

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Theme 2 -
Growth and interaction with the environment - current and future

During 2020 Theme 2 has published 21 peer reviewed scientific articles in international journals. Authors marked in bold represents researchers that have been financed by, or are associated to, the research program.

1. Abreu IN, Johansson AI, Sokołowska K, Niittylä T, Sundberg B, Hvidsten TR, **et al**. A metabolite roadmap of the wood-forming tissue in Populus tremula. New Phytologist. 2020;228(5):1559-72.

2. Apuli RP, Bernhardsson C, Schiffthaler B, Robinson KM, Jansson S, **Street NR**, et al. Inferring the Genomic Landscape of Recombination Rate Variation in European Aspen (G3 (Bethesda). 2020;10(1):299-309.

3. **Bassiouni M**, Good SP, Still CJ, Higgins CW. Plant Water Uptake Thresholds Inferred From Satellite Soil Moisture. Geophysical Research Letters. 2020;47(7):e2020GL087077.

4. Berghuijs HNC, Wang Z, Stomph TJ, Weih M, Van der Werf W, **Vico G**. Identification of species traits enhancing yield in wheat-faba bean intercropping: development and sensitivity analysis of a minimalist mixture model. Plant and Soil. 2020;455(1):203-26.

5. Breinl K, Di Baldassarre G, Mazzoleni M, Lun D, **Vico G**. Extreme dry and wet spells face changes in their duration and timing. Environmental Research Letters. 2020;15(7):074040.

6. Colesie C, Stangl ZR, **Hurry V**. Differences in growth-economics of fast vs. slow growing grass species in response to temperature and nitrogen limitation individually, and in combination. BMC Ecol. 2020;20(1):63.

7. de Oliveira G, Brunsell NA, Crews TE, DeHaan LR, **Vico G**. Carbon and water relations in perennial Kernza (Thinopyrum intermedium): An overview. Plant Science. 2020;295:110279.

8. Manzoni S, Chakrawal A, Fischer T, Schimel JP, Porporato A, **Vico G**. Rainfall intensification increases the contribution of rewetting pulses to soil heterotrophic respiration. Biogeosciences. 2020;17(15):4007-23.

9. Marini L, St-Martin A, **Vico G**, Baldoni G, Berti A, Blecharczyk A, et al. Crop rotations sustain cereal yields under a changing climate. Environmental Research Letters. 2020;15(12):124011.

10. Mrad A, Manzoni S, Oren R, **Vico G,** Lindh M, Katul G. Recovering the Metabolic, Self-Thinning, and Constant Final Yield Rules in Mono-Specific Stands. Frontiers in Forests and Global Change. 2020;3(62).

11. Müller NA, Kersten B, Leite Montalvão AP, Mähler N, Bernhardsson C, Bräutigam K, **et al.** A single gene underlies the dynamic evolution of poplar sex determination. Nat Plants. 2020;6(6):630-7.

12. Mähler N, Schiffthaler B, Robinson KM, Terebieniec BK, Vučak M, Mannapperuma C, **et al**. Leaf shape in. Ecol Evol. 2020;10(21):11922-40.

13. Raderschall CA, Vico G, Lundin O, Taylor AR, Bommarco R. Water stress and insect herbivory interactively reduce crop yield while the insect pollination benefit is conserved. Glob Chang Biol. 2021;27(1):71-83.

14. Ruiz-Pérez G, **Vico G**. Effects of Temperature and Water Availability on Northern European Boreal Forests. Frontiers in Forests and Global Change. 2020;3(34).

15. Su Z, Zeng Y, Romano N, Manfreda S, Francés F, Ben Dor E, **et al.** An Integrative Information Aqueduct to Close the Gaps between Satellite Observation of Water Cycle and Local Sustainable Management of Water Resources. Water. 2020;12(5):1495.

16. Sullivan AR, Eldfjell Y, Schiffthaler B, Delhomme N, Asp T, Hebelstrup KH, **et al**. The Mitogenome of Norway Spruce and a Reappraisal of Mitochondrial Recombination in Plants. Genome Biol Evol. 2020;12(1):3586-98.

17. Tamburino L, Di Baldassarre G, **Vico G**. Water management for irrigation, crop yield and social attitudes: a socio-agricultural agent-based model to explore a collective action problem. Hydrological Sciences Journal. 2020;65(11):1815-29.

18. Wang J, **Street NR,** Park EJ, Liu J, Ingvarsson PK. Evidence for widespread selection in shaping the genomic landscape during speciation of Populus. Mol Ecol. 2020;29(6):1120-36.

19. **Vico G,** Tamburino L, Rigby JR. Designing on-farm irrigation ponds for high and stable yield for different climates and risk-coping attitudes. Journal of Hydrology. 2020;584:124634.

20. Yang FS, Nie S, Liu H, Shi TL, Tian XC, Zhou SS, **et al.** Chromosome-level genome assembly of a parent species of widely cultivated azaleas. Nat Commun. 2020;11(1):5269.

21. **Yang Q,** Blanco NE, Hermida-Carrera C, Lehotai N, **Hurry V**, Strand Å. Two dominant boreal conifers use contrasting mechanisms to reactivate photosynthesis in the spring. Nat Commun. 2020;11(1):128.

Interviews and presence in media

Vico G (2020) Lägre produktivitet att vänta i svenska skogar, SverigesRadio Vetenskapsradion Nyheter, July 6th, 2020, https://sverigesradio.se/sida/artikel.aspx?programid=406&artikel=7508443

Vico G (2020) Privata dammar kan rädda framtidens lantbruk, in SverigesRadio P4 Uppland, June 27th, 2020, https://sverigesradio.se/sida/artikel.aspx?programid=114&artikel=7503750

Scientific presentations

Bassiouni M, Vico G (2020), Stomatal optimization models ranked by predictive and functional accuracy at ecosystem scales, AGU Fall Meeting, online, December 2020

Su Z, Zeng Y, Romano N, Manfreda S, Francés García F, Ben Dor E, Szabó B, **Vico G**, Nasta P, Zhuang R, Francos N, Mészáros J, Tendayi Rwasoka D, Retsios B (2020) An Integrative Information Aqueduct to Close the Gaps between Global Satellite Observation of Water Cycle and Local Sustainable Management of Water Resources (iAqueduct), EGU2020: Sharing Geoscience Online

Vico G, Tamburino L, Rigby JR, Di Baldassarre G (2020) Defining the most suitable source of irrigation water for farmers and communities: a socio-agricultural model, EGU2020: Sharing Geoscience Online

Manzoni S, Chakrawal A, Fischer T, Porporato A, V**ico G** (2020), Modelling respiration pulses at rewetting as a stochastic process, EGU2020: Sharing Geoscience Online

Messori G, **Ruiz-Perez G**, Manzoni S, **Vico G** (2020), Reviewing the role of precipitation and soil moisture in driving the terrestrial carbon cycle variability in Europe: recent advances and known unknowns, EGU2020: Sharing Geoscience Online

Berghuijs HNC, Weih M, Van der Werf W, **Vico G** (2020), A minimal mixture model for cereal legume intercropping, iCROPM Crop Modelling for the Future, Montpellier, France, 3-5 February 2020

Popular scientific presentations at meetings or excursions

Street, NR. 2020. Leaf shape in Populus tremula is a complex, omnigenic trait. Departmental presentation at UC Davis, California, USA. Jan 12.

Collaboration with industry and/or other parts of society

- Joint projects with Holmen Skog AB looking at fungal metacommunity structure of Norway spruce and Scots pine seedlings under contrasting N treatments.
- Giulia Vico was invited as external expert to the ending meeting of a Skogsstyrelsen project, focusing on identification of the effects of heat and drought on southern Sweden forests, in combination with pests
- Vico G, Forests under drought… and heat, Skogsstyrelsen, Katrineholmn, Sweden, November 25th, 2019

Other funding that has been received partially or fully due to the TC4F research

- 2019-2021: "Large-Scale Atmospheric Variability driving changes in the Terrestrial Carbon Cycle and Storage" Applicants: G Messori (main applicant; Uppsala University, Sweden), G Vico, G Ruiz-Pérez (SLU), C Beer, S Manzoni (Stockholm University, Sweden). Financer: Swedish Research Council for Sustainable Development (FORMAS), Annual Open Call. Amount: 3 million SEK/290 k€ (2018-00968)
- 2018-2022: "Innovative modelling approaches for the identification of boreal forest management strategies under a changing climate", Applicants: G. Vico (main applicant), G. Ruiz-Pérez (SLU), S. Launiainen (LUKE; Finland). Financer: Swedish Research Council for Sustainable Development (FORMAS), The National Research Programme on Climate: Future Pathways. Amount: 6.5 million SEK/635 k€ (2018-01820). Financer: Swedish Research Council for Sustainable Development (FORMAS), Annual Open Call. Amount: 3 million SEK/290 k€ (2018-00968)

Education

a) **PhD theses, MSc theses, Bachelor theses**

Forsmark, Benjamin. Impact of nitrogen deposition on carbon stocks in coniferous forest soils -Insights from experiments with low and high nitrogen addition rates. Date for dissertation: February 14, 2020.

Karlström, Jacob. 2020. 30 ECTs MSc thesis: Interactive online gene network visualisation. Umeå University.

Burge, Rasmus. (Male) 2020. 30 ECTs MSc thesis: Identifying long intergenic non-coding RNAs during somatic embryogenesis in Norway spruce. Umeå University.

b) Supervision and teaching

Nordin, Annika. Main-supervisor for MSc-candidate Tinkara Bizjak. N2-fixing in needles of pine in a N addition experiment. Date for dissertation: September, 2020.

Nordin, Annika. Course organizer and teaching at the course "Ekologi och trädbiologi", (SG0023), 15 ECTS, SLU.

Street NR. Main supervisor for PhD-candidate Schneider, Andreas. Tentative title: The microbiomes of Swedish forest trees under the influence of environment and different nitrogen fertilisation. Expected date for dissertation: June 2022.

Street NR. Main supervisor for PhD-candidate Canovi, Camilla. Tentative title: Identifying functions of long non-coding RNAs in Norway spruce. Expected date for dissertation: June 2023.

Street NR. Main supervisor for PhD-candidate van Zalen, Elena. Tentative title: Applications of machine learning for improving candidate gene selection in abiotic stress of Norway spruce and Scots pine. Expected date for dissertation: Sept 2023.

Street NR. Main supervisor for PhD-candidate Kalman, Teitur. Tentative title: Chromatin structure and dynamics on conifer species. Expected date for dissertation: Sept 2026.

Street, NR. Course organiser and teaching on the course "Functional Genomics: Theory", (5BI0211), 7.5 ECTS, Umeå University.

Street, NR. Course organiser and teaching on the course "Applied Functional Genomics", (5BI0212), 7.5 ECTS, Umeå University.

Street, NR. Teaching on the course "Bioinformatics and Genome Analysis", (5MO115), 7.5 ECTS, Umeå University.
Street, Nathaniel. Teaching on the course "Introduction to Plant Biology for Sustainable Production", (BI1294) 15 ECTS, SLU Uppsala.

Street, NR. Teaching on the course "Plant biology – for future forestry", 7.5 ECTS, SLU Umeå.

Street, NR. Teaching on the course "Inledande ingenjörskurs i Bioteknik", (5MO072), 7.5 ECTS, Umeå University.

Vico, G. Main supervisor for PhD student Alessio Costa, Department of Crop Production Ecology, SLU, investigating the effects of climatic conditions and crop management on crop yields. Expected graduation: 2024

Vico, G.. Main supervisor for PhD student Xiangyu Luan, Department of Crop Production Ecology, SLU, investigating issues of water use for food security at local to global scales. Expected graduation: 2021

Vico, G.. co-supervisor for PhD student Martin Goude, Southern Swedish Forests Research Center, Faculty of Forest Sciences, SLU, investigating Swedish forests adaptation to climate change. Expected graduation: 2021

Vico, G.. co-supervisor for PhD student James Ajal, Department of Crop Production Ecology, SLU, investigating resource use and productivity of crop mixtures. Expected graduation: 2021

Vico, G. co-supervisor for PhD student Eirini Daouti Lamprini, Department of Ecology, Faculty of Natural Resources and Agricultural Sciences, SLU, investigating weed seed predation. Expected graduation: 2021

Vico, G.., Invited lecturer on 'Proposal writing' at the workshop for PhD students 'How to become a postdoc?', co-organized by the Research Schools in the Faculty of Natural Resources and Agriculture, SLU

Vico, G. lecturer in the master-level course Sustainable plant production across scales: from molecular to field applications, 15 ECTS, SLU

Vico, G., lecturer in the climate change module in the undergraduate-level course Environmental physics – an introduction, 7.5 ECTS, SLU

Jämtgård, S., Teaching on the course "Forest vegetation ecology" (SG0180), 7.5 ECTS, Swedish University of Agricultural Sciences, SLU.

Jämtgård, S., Teaching on the course "Skogsekosystemets kemiska grunder" (G1F), 15 hp, Swedish University of Agricultural Sciences, SLU.

Jämtgård, S., Teaching on the course "Nitrogen cycling in terrestrial and aquatic ecosystems", PhD course within the Research School Focus on soil, Swedish University of Agricultural Sciences, SLU, Uppsala. March, 2019.

Hurry V. Main supervisor for David Castro, PhD student Department of Forest Genetics and Plant Physiology

Hurry V. Main supervisor for Tuuli Aro, PhD student Department of Forest Genetics and Plant Physiology

Theme 3
- Sustainable and adaptive forest management

1. Aldea J, Ruiz-Peinado R, del Río M, Pretzsch H, Heym M, Brazaitis G, et al. Species stratification and weather conditions drive tree growth in Scots pine and Norway spruce mixed stands along Europe. Forest Ecology and Management. 2021;481:118697.

2. Appiah Mensah A, Petersson H, Saarela S, **Goude M, Holmström E**. Using heterogeneity indices to adjust basal area – Leaf area index relationship in managed coniferous stands. Forest Ecology and Management. 2020;458:117699.

3. Bandau F, Albrectsen BR, **Robinson KM, Gundale MJ.** European aspen with high compared to low constitutive tannin defenses grow taller in response to anthropogenic nitrogen enrichment. Forest Ecology and Management. 2020;487:118985.

4. Blaško R, **Forsmark B, Gundale MJ, Lundmark T, Nordin A.** Impacts of tree species identity and species mixing on ecosystem carbon and nitrogen stocks in a boreal forest. Forest Ecology and Management. 2020;458:117783.

5. **Böhlenius H, Nilsson U**, Salk C. Liming increases early growth of poplars on forest sites with low soil pH. Biomass and Bioenergy. 2020;138:105572.

6. de Streel G, Ammer C, Annighöfer P, **Barbeito I,** Bielak K, Bravo-Oviedo A, et al. Mixing has limited impacts on the foliar nutrition of European beech and Scots pine trees across Europe. Forest Ecology and Management. 2021;479:118551.

7. DeLuca TH, **Gundale MJ**, Brimmer RJ, Gao S. Pyrogenic Carbon Generation From Fire and Forest Restoration Treatments. Frontiers in Forests and Global Change. 2020;3(24).

8. **Felton A**, Löfroth T, Angelstam P, Gustafsson L, Hjältén J, **Felton AM**, et al. Keeping pace with forestry: Multi-scale conservation in a changing production forest matrix. Ambio. 2020;49(5):1050-64.

9. **Felton AM, Holmström E,** Malmsten J, Felton A, Cromsigt JPGM, Edenius L, et al. Varied diets, including broadleaved forage, are important for a large herbivore species inhabiting highly modified landscapes. Scientific Reports. 2020;10(1):1904.

10. **Forsmark B, Nordin A**, Maaroufi NI, **Lundmark T, Gundale MJ.** Low and High Nitrogen Deposition Rates in Northern Coniferous Forests Have Different Impacts on Aboveground Litter Production, Soil Respiration, and Soil Carbon Stocks. Ecosystems. 2020.

11. Abreu IN, Johansson AI, Sokołowska K, Niittylä T, Sundberg B, Hvidsten TR, **et al**. A metabolite roadmap of the wood-forming tissue in Populus tremula. New Phytologist. 2020;228(5):1559-72.

12. **Forsmark B, Nordin A**, Rosenstock NP, Wallander H, **Gundale MJ**. Anthropogenic nitrogen enrichment increased the efficiency of belowground biomass production in a boreal forest. Soil Biology and Biochemistry. 2020;155:108154.

13. **Forsmark B,** Wallander H, **Nordin A, Gundale MJ.** Long-term nitrogen enrichment does not increase microbial phosphorus mobilization in a northern coniferous forest. Functional Ecology. 2020;35(1):277-87.

14. Fransson P, Franklin O, Lindroos O, **Nilsson U,** Brännström Å. A simulation-based approach to a near optimal thinning strategy : allowing for individual harvesting times for individual trees. Canadian Journal of Forest Research. 2020;50(3):320-31.

15. **Holmström E**, Nordström E, Lariviere D, Wallin I. Detection of Retention Trees on Clearcuts, a 50-Year Perspective. Open Journal of Forestry. 2020;10:110-23.

16. Kelly J, **Ibáñez TS**, Santín C, Doerr SH, **Nilsson M-C,** Holst T, et al. Boreal forest soil carbon fluxes one year after a wildfire: Effects of burn severity and management. Global Change Biology. 2020;27(17):4181-95.

17. Lindbladh M, Hedwall P-O, **Holmström E**, Petersson L, **Felton A**. How generalist are these forest specialists? What Sweden's avian indicators indicate. Animal Conservation. 2020;23(6):762-73.

18. **Nilsson O**. Growth and modulus of elasticity of selected pine species and hybrids three years after planting in South Africa 2020.

19. Palviainen M, Laurén A, Pumpanen J, Bergeron Y, Bond-Lamberty B, Larjavaara M, **et al.** Decadal-Scale

Recovery of Carbon Stocks After Wildfires Throughout the Boreal Forests. Global Biogeochemical Cycles. 2020;34(8):e2020GB006612.

20. Pérez-Izquierdo L, Clemmensen KE, Strengbom J, Granath G, Wardle DA, **Nilsson M-C,** et al. Crown-fire severity is more important than ground-fire severity in determining soil fungal community development in the boreal forest. Journal of Ecology. 2021;109(1):504-18.

21. Saarela S, Wästlund A, **Holmström E**, Mensah AA, Holm S, Nilsson M, et al. Mapping aboveground biomass and its prediction uncertainty using LiDAR and field data, accounting for tree-level allometric and LiDAR model errors. Forest Ecosystems. 2020;7(1):43.

22. Siipilehto J, Allen M, **Nilsson U**, Brunner A, Huuskonen S, Haikarainen S, et al. Stand-level mortality models for Nordic boreal forests. Silva Fennica. 2020;54.

23. Xu W, Whitman WB, **Gundale MJ**, Chien C-C, Chiu C-Y. Functional response of the soil microbial community to biochar applications. GCB Bioenergy. 2021;13(1):269-81.

PhD-Students:

Alex Appiah Menza. Modelling growth of homogeneous and heterogeneous forests in Sweden. Supervisors: Hans Petersson, Emma Holmström, Kenneth Nyström. Dissertation planned to autumn 2022.

Mostarin Ara. Pre-commercial thinning in planted Norway spruce stands in southern Sweden. Dissertation planned to winter 2022. Supervisors: Urban Nilsson, Mattias Berglund, Nils Fahlvik, Ignacio Barbieto and Erika Olofsson.

Martin Ahlström. Effect of silvicultural treatment on the risk for storm damage in managed forest stands in southern Sweden. Dissertation planned to spring 2020. Supervisor: Urban Nilsson

Felicia Dahlgren. Regeneration of birch on clear-cuts in Sweden. Dissertation planned to winter 2022. Supervisors: Tomas Lundmark, Emma Holmström.

Martin Goude. Hybrid growth models for Scots pine and Norway spruce in Sweden. Dissertation planned to winter 2021. Supervisors Urban Nilsson, Guilia Atttoci, Giulia Vico and Euan Mason

Theresa Ibanez. PhD-student. Started 2017. Supervisors: Nilsson, M-C, Gundale M, and D Wardle.

Axelina Jonsson. Modelling survival and establishment of planted and naturally regenerated Scots pine and Norway spruce. Supervisors: Urban Nilsson, Karin Hjelm and Tomas Lämås

Delphine Lariviere, SSFRC, SLU and Skogforsk. "Retention forestry in commercial thinnings." Assistant supervisor Emma Holmström. Started 2017

Mikolaj Lula. Regeneration of Scots pine in southern Sweden. Dissertation planned to autumn 2021. Supervisors Urban Nilsson, Anna Jensen, Kristina Wallertz, Märtha Wallgren, Renats Trubins and Göran Örlander

Oscar Nilsson. Production of Scots pine and Norway spruce in Sweden. Defended his thesis in December 2020. Supervisors Urban Nilsson & Karin Hjelm

Magnus Persson, Linnéuniversity. "Increased efficiency in commercial thinnings." Assistant supervisor Emma Holmström. Started 2018

Gustaf Ståhl. Climate smart forestry. Supervisor; Tomas Lundmark, Emma Holmström. Dissertation planned to winter 2022.

Master courses:

Emma Holmström was responsible for the master-course "Sustainable Forestry in Southern Sweden".

Marie-Charlotte Nilsson-Hegethorn was responsible for development of the master-programme "Forest Ecology and Sustainable Management".

Urban Nilsson was responsible for the master-course "Att forska i skog - Vetenskapsmetodik

PhD-courses:

In-depth course in forest regeneration, 5.0 credits on PhD level. Examiner and teacher on the course. Course leader Kristina Wallertz.

https://www.slu.se/utbildning/program-kurser/kurser/?sprak=en&anmkod=P0062.1920

C4F - Crops for the Future

Scientific publications

1. Berenguer E, **Minina AE**, Carneros E, Barany I, Bozhkov PV, and Testillano PS. 2020. Suppression of Metacaspase- and Autophagy-Dependent Cell Death Improves Stress-Induced Microspore Embryogenesis in Brassica napus. Plant and Cell Physiology https://doi.org/10.1093/pcp/pcaa128
2. **Berndtsson E**, **Andersson R**, **Johansson E**, **Olsson ME**. Side Streams of Broccoli Leaves: A Climate Smart and Healthy Food Ingredient. Int J Environ Res Public Health. 2020 Apr 1;17(7):2406. doi: 10.3390/ijerph17072406.
3. **Capezza AJ**, Cui Y, Numata K, Lundman M, **Newson WR**, Olsson RT, **Johansson E**, Hedenqvist MS (2020) High capacity functionalized protein superabsorbents from an agricultural co-product: a cradle-to-cradle approach. Adv Sust Syst 4:2000110 (13).
4. **Capezza AJ**, Lundman M, Olsson RT, **Newson WR**, Hedenqvist MS, **Johansson E** (2020) Carboxylated wheat gluten proteins – a green solution for production of sustainable superabsorbent materials. Biomacromol https://doi.og/10.1021/acs.biomac.9b01646.
5. **Capezza AJ**, Robert E, Lundman M, **Newson WR**, **Johansson E**, Hedenqvist MS, Olsson RT (2020) Extrusion of porous protein-based polymers and their liquid absorption characteristics. Polymers 12:459.
6. Capezza A, **Newson WR**, Olsson R, Hedenqvist M, **Johansson E** (2020) Method of preparing plant protein based absorbent material and absorbent material thus produced. WO 2020/251467 A1.
7. **Carlsson MLR**, **Kanagarajan S**., Bülow L., and **Zhu LH** 2020. Plant based production of myoglobin - a novel source of the muscle heme-protein. Sci. Rep. (accepted). doi: 10.1038/s41598-020-57565-y
8. **Carlsson MLR**, Kristiansson A., Bergwik J. **Kanagarajan S**., Bülow L., Åkerström B. and **Zhu LH*** 2020. Expression, purification and initial characterization of functional a1-microglobulin (A1M) in Nicotiana benthamiana. Frontiers in Plant Sci. vol.11, 593773. doi: 10.3389/fpls.2020.593773
9. **Ceresino EB**, Johansson, E., Sato H.H., Plivelic, T.S., Hall A. S., **Kuktaite R.**, 2020. Morphological and structural heterogeneity of solid gliadin food foams modified with transglutaminase and food grade dispersants. Food Hydrocolloids, 108, 105995.
10. **Ceresino EB**, **Kuktaite R**, Hedenqvist MS, Sato HH, **Johansson E** (2020) Processing conditions and transglutaminase sources to "drive" the wheat gluten dough quality. Innovative Food Sci Emerging Technol 65:102439.
11. Das O, Kim NK, Hedenqvist MS, Bhattacharyya D, **Johansson E**, Xu Q, Holder S (2020) Naturally-occuring bromophenol to develop fire retardant gluten biopolymers. J Cleaner Prod 243:118552
12. **Dauphinee D**, Olsson JA, and **Minina EA**. 2020. Tandem Tag Assay Optimized for Semi-automated in vivo Autophagic Activity Measurement in Arabidopsis thaliana roots. Bio-protocol. DOI: 10.21769/BioProtoc.3535
13. Fei M, **Jin Y**, Jin L, Su J, Ruan Y, Wang F, Liu C, **Sun C***. 2020. Adaptation of rice to the nordic climate yields potential for rice cultivation at most northerly site and the organic production of low-arsenic and high-protein rice. Front Plant Sci. 30;11:329.
14. **Grimberg, Å.**, Wilkinson, M., **Snell, P.**, De Vos, R.P., González-Thuillier, I., Tawfike, A., Ward, J.L., **Carlsson, A.S.**, Shewry, P., **Hofvander, P.** 2020. Transitions in wheat endosperm metabolism upon transcriptional induction of oil accumulation by oat endosperm WRINKLED1; BMC Plant Biology, Article number: 235
15. Helguera M, Abugalieva A, Battenfield S, Békés F, Branlard G, Cuniberti M, Hüsken A, **Johansson E**, Morris CF, Nurit E, Sissons M, Vazquez D (2020) Grain quality in breeding. In: Wheat quality for improving processing and human health (eds. Igrejas G, Ikeda T, Guzmán C).Springer, Cham, pp 273-307.
16. **Johansson E**, Branlard G, Cuniberti M, Flagella Z, Hüsken A, Nurit E, Peña RJ, Sissons M, Vazquez D (2020) Genotypic and environmental effects on wheat technological and nutritional quality. In: Wheat quality for improving processing and human health (eds. Igrejas G, Ikeda T, Guzmán C).Springer, Cham, pp 171-204.
17. Josefsson, L., Ye, X., Brett, C.J., Meijer, J., **Olsson, C.**, Sjögren, A., Sundlöf, J., Davydok, A., **Langton, M.,** Emmer, Å., Lendel, C. 2020. Potato Protein

Nanofibrils Produced from a Starch Industry Sidestream. ACS Sustainable Chem. Eng. 8: 1058-1067, DOI: 10.1021/acssuschemeng.9b05865

18. **Kim S-Y**., Bengtsson T., Olsson N., Hot V., **Zhu LH*** and Åhman* I. 2020. Mutations in two aphid-regulated b-1,3-glucanase genes by CRISPR/Cas9 do not increase barley resistance to Rhopalosiphum padi L. Frontiers in Plant Science. Vol.11, 1043. doi: 10.3389/fpls.2020.01043.

19. Klionsky D, **Bozhkov PV, Dauphinee D**, **Minina EA** et al. 2020. Guidelines for the use and interpretation of assays for monitoring autophagy (4th edition). Autophagy https://doi.org/10.1080/15548627.2020.1797280

20. Langton, M., Ehsanzamir, S., **Karkehabadi S**, Feng, X., Johansson, M., **Johansson D.P**., 2020. Gelation of faba bean proteins - Effect of extraction method, pH and NaCl., Food Hydrocolloids 103: 105622. https://doi.org/10.1016/j.foodhyd.2019.105622

21. Markgren J, Hedenqvist MS, Rasheed F, Skepö M, **Johansson E** (2020) Glutenin and gliadin, a piece in the puzzle of their structural properties in the cell described through Monte Carlo simulations. Biomolecules 10:1095.

22. Meng J, Lv Z, Zhang Y, Wang Y, Qiao X, **Sun C**, Chen Y, Guo M, Han W, Ye A, Xie T, Chu B, Shi C, Yang S, Chen C. 2020. Precision Redox: The Key for Antioxidant Pharmacology. Antioxid Redox Signal. doi: 10.1089/ars.2020.8212. Epub ahead of print.

23. **Minina EA**, Staal J, Alvarez VE, Berges JA, Berman-Frank I, Beyaert R, Bidle KD, Bornancin F, Casanova M, Cazzulo J, Choi CJ, Coll NS, Dixit VM, Dolinar M, Fasel N, Funk C, Gallois P, Gevaert K, Gutierrez-Beltran E, Hailfinger S, Klemencic M, Koonin EV, Krappmann D, Linusson A, Machado M, Madeo F, Megeney LA, Moschou PN, Mottram, JC, Nyström T, Osiewacz HD, Overall CM, Pandey KC, Ruland J, Salvesen GS, Shi Y, Smertenko A, Stael S, Ståhlberg J, Suarez MF, Thome M, Tuominen H, Van Breusegem F, van der Hoorn RAL, Vardi A, Zhivotovsky B, Lam E and **Bozhkov PV**. 2020. Classification and Nomencalture of Metacaspases and Paracaspases: No More Confusion with Caspases. Molecular Cell 77, 927-929.

24. Muthusamy S, Vetukuri R.R., Lundgren A, Ganji S, **Zhu L-H,** Brodelius P.E and **Kanagarajan S**. 2020. Transient expression and purification of β-caryophyllene synthase in Nicotiana benthamiana to produce β-caryophyllene in vitro. PeerJ April 28:8:e8904. doi: 10.7717/peerj.8904.

25. Ortiz, R., Geleta, M., Gustafsson, C., Lager, I., **Hofvander, P**., Löfstedt, C., Cahoon, E.B., **Minina, E., Bozhkov, P.**, Stymne, S. 2020. Oil crops for the future; Current Opinion in Plant Biology, 181-189.

26. Xia, Y-H., Ding, B-J., Wang, H-L., **Hofvander, P.**, Jarl-Sunesson C., Löfstedt, C. 2020. Production of moth sex pheromone precursors in Nicotiana spp.: a worthwhile new approach to pest control; Journal of Pest Science, 1333–1346

27. Rasheed F, Markgren J, Hedenqvist M, **Johansson E** (2020) Modeling to understand plant protein structure-function relationships – Implications for seed storage proteins. Molecules 25:873-889.

Popular scientific publications (reports etc)

Johansson E, Henriksson T (2020) Proteinkvalitet i vetelinjer med främmande kromosomfragment. Fakta från SLU Partnerskap Alnarp. LTV-fakultetens faktablad 2020:10.

Interviews and presence in media

- Article from Matologi, Stockholm: Stort svinn på fältet – men potential för produktutveckling | Externwebben (slu.se)

- Blast från morot och sockerbeta ska bli framtidens protein. Sydsvenskan 30 Nov 2020

- Grogrund ett nav inom växtförädling. Cerealier 3/20

- Här blir växtrester till närproducerat protein. ATL Lantbrukets Affärstidning. 20 July 2020

- Framtidens mat är både hälsosam och klimatsmart. Cerealier 3/20.

Collaboration with industry and/or other parts of society

- Chalmers University of Technology

- Förening u.p.a.

- ISCA Technologies

- KTH- Kungliga Tekniska högskolan

- Lantmännen

- Lilla Harrie Vallskvam

- Lyckeby Starch AB

- LINXS- MAX IV and ESS network

- LRF

- MariboHilleshög

- North Carolina, USA

- RISE

- Syngenta

- Sveriges Stärkelseproducenter

- Grönsaksmästarna Nordic AB

Other funding that has been received partially or fully due to the TC4F research

Capezza, A. 2020. Bo Rydins stiftelse. Project title: Large-scale extrusion of protein superabsorbents with cellulose fibres for hygiene applications: 3 000 000 SEK

Minina, EA. 2020. Carl Tryggers Stiftelse. Project title: Illuminating the path towards better crops. Amount obtained:: 822 000

Kuktaite R. 2020. Vinnova "Monitoring Cd uptake in wheat using x-rays and neutrons. Amount obtained: 400 000 SEK

Dauphinee, AN. 2020. Carl Tryggers Stiftelse. Project title: Developing new autophagy drugs for improved crop fitness and health. Amount obtained:: 333,000 SEK.

Dauphine, AN. Ballhaus, F, Hicks, GR, Bozhkov, PV, Minina, EA. 2020. EPIC-XS. Project title: Target identification of novel plant-specific autophagy modulators. Estimated Amount: 100,000 SEK.

Langton M. Formas Centrumbildningar för hållbarhet och konkurrenskraft i livsmedelssystemet 2020; Plant-based proteins for health and wellbeing (PAN Sweden). In collaboration with Örebro University, Chalmers University of Technology, Uppsala University, RISE, Lantmännen AB, Orkla Foods Sverige AB, Örebro municipality, Sveriges Stärkelseproducenter, förening u.p.a.(Lyckeby Starch AB), MAX Burger, Maxi ICA Stormarknad Universitetet, Coor, Many ways AB

Zhu, L.-H. Karolina Östbring, Elisabeth Gunnarsson and Anja Persson. 2020. Improvement of seedcake quality of rapeseed for high quality feed and food uses. SLU-Grogrund. 10489750 kr. 2020-2024.

Sun, Q. Lantmännen Research Foundation: "Marker-assisted backcrossing of yin-yang barley with Lantmännen´s elite varieties" for 2020-2021.

Investments in research infrastructure

- Co-applicant and received financing for latest Confocal Laser Scanning Microscope.

- New HPLC equipment installed with autosampler

- HPSEC-MALS-Visc-RI. Size exclusion chromatograph with static light scattering, viscometry and refractive index detector. For determination of molecular weight, size and shape. 1.2 Mkr

-DSC. Differential scanning calorimeter. For determination of phase transitions in starch. 460 kkr

Education

a) PhD theses, MSc theses, Bachelor theses

Jeppsson, Simon. (Male) 2020. The specificities of plant enzymes and their effects on the seed oil quality. Diss. (sammanfattning/summary) Sveriges lantbruksuniv., Acta Universitatis Agriculturae Sueciae, 1652-6880 ; 2020:24. ISBN 978-91-7760-566-9. eISBN 978-91-7760-567-6

Carlsson,Magnus.(Male)2020.Productionofhumanheme-binding proteins in plants for potential pharmaceutical and nutritional uses. Diss. (sammanfattning/summary) Sveriges lantbruksuniv., Acta Universitatis Agriculturae Sueciae, 1652-6880 ; 2020:34. ISBN 978-91-7760-586-7. eISBN 978-91-7760-587-4

Capezza Villa, Antonio José. (Male) 2020. Sustainable Biobased Protein Superabsorbents from Agricultural Co-Products. Diss. (sammanfattning/summary) Sveriges lantbruksuniv., Acta Universitatis Agriculturae Sueciae, 1652-6880. ISBN 978-91-7760-624-6

eISBN 978-91-7760-625-3

Berndtsson, Emilia. (Female) 2020. Content of dietary fibre and phenolic compounds in broccoli side streams. Sveriges lantbruksuniv. ISBN 978-91-576-9740-0. eISBN 978-91-576-9741-7

Ballhaus, Florentine. (Female) 2020. Master's thesis: Investigating plant autophagy with new chemical modulators. Uppsala University.

Henriksson, Ylva. (Female) 2020. MSc thesis: Wheat bran arabinoxylans in breadmaking – Their effect on staling and other quality aspects. SLU

Abrahamsson, Julia (Female) 2020. MSc thesis: Extraction of β-glucan from oat bran – Effect of extraction method and particle size

Nilsson, Lovisa (Female) 2020. MSc thesis: Swedish crops for the use in production of tempeh

b) Supervision and teaching (include supervision of finished and on-going students, include teaching and organization of courses)

Hofvander, Per. Supervisor for Posdoc Shrikant Sharma

Hofvander, Per. Supervisor for Posdoc Kamil Demski

Hofvander, Per. Teaching at the course "Applied Plant Biotechnology" (BI1344), Alnarp.

Hofvander, Per. Teaching at the course "Växters kemi och biokemi" (KE0070), Alnarp.

Grimberg, Åsa. Teaching at the course "Växtförädling och växtfysiologi" (BI1367), Alnarp.

Grimberg, Åsa. Teaching at the course "Odling och kvalitet" (TD0010), Alnarp.

Grimberg, Åsa. Teaching at the course "Advanced plant breeding and genetic resources" (BI1345), Alnarp.

Grimberg, Åsa. Teaching at the course "Växters kemi och biokemi" (KE0070), Alnarp.

Peter Bozhkov and Elena Minina. Main supervisor and co-supervisor, respectively, for PhD-candidate Elander, Pernilla. Tentative title: The role of autophagy in plant lipid turnover. Expected date for dissertation: April, 2022.

Elena Minina, Peter Bozhkov and Adrian Dauphinee. Main supervisor and two co-supervisors, respectively, for PhD-candidate Holla, Sanjana. Tentative title: Monitoring of autophagic flux in planta using luminous reporters. Expected date for dissertation: April, 2023.

Peter Bozhkov and Adrian Dauphinee. Undegraduate course organizer and teacher, respectively. Course "Biochemitry", 7.5 ECTS, SLU

Langton, Maud Main supervisor for PhD-student Nilsson, Klara. Title: Integral valorisation of Faba beans molecular compounds to nutritional texturized food products

Langton, Maud Main supervisor for PhD-student Herneke, Anja. Title: Functionalization of nanofibers from plant based proteins

Langton, Maud Main supervisor for PhD-student Johansson, Mathias. Title: Legume based Gels – Microstructure and Texture

Langton, Maud Main supervisor for PhD-student Pietiäinen, Solja. Title: Fractionation of wheat bran to create functional ingredients

Johansson, Daniel P. Co-supervisor for PhD-student Herneke, Anja,

Johansson, Daniel P. Co-supervisor for PhD-student Johansson, Mathias

Nilsson, Klara, and Herneke, Anja. Teaching at the course "Food Technology" (LV0112), 15ECTS, Ultuna

Johansson, Daniel P. Course organizer and teaching at the course "Food Technology" (LV0112), 15ECTS, Ultuna

Nilsson, Klara. Course Co-ordinator" Grundkurs Livsmedelsagronom"(LV0100), 15 ECTS, Ultuna

Herneke, Anja, Johansson, Daniel P., Johansson, Mathias Teaching at the course "Food Chemistry and Physics",(LV0110) 15ECTS, Ultuna

Karkehabadi, Saeid. Course organizer and teaching at the course Food chemistry and food physics (LV0110) 15ECTS, Ultuna

Johansson, Daniel P. Main supervisor Master student Abrahamsson, Julia. MSc thesis Title: Extraction of β-glucan from oat bran – Effect of extraction method and particle size SLU Ultuna 30 ETC

Johansson, Daniel P. and Pietiäinen, Solja supervisors Master student Henriksson, Ylva. MSc thesis Title: Wheat bran arabinoxylans in breadmaking – Their effect on staling and other quality aspects. SLU Ultuna 30 ETC

Johansson, Daniel P. Main supervisor Master student Nilsson, Lovisa. MSc thesis: Swedish crops for the use in production of tempeh

Roger Andersson. Main supervisor for PhD-candidate Xue Zhao. Tentative title: Novel potato starch - New structure descriptors may reveal properties for new applications. Expected date for dissertation: September, 2021.

Roger Andersson. Main supervisor for PhD-candidate Shishanthi Jayarathna. Tentative title: New starch for novel applications. Expected date for dissertation: January, 2024.

Roger Andersson. Course organizer and teaching at the course "Plant food science", (LV0113), 15 ECTS, SLU.

Chuanxin Sun. Main supervisor for PhD-candidate Silvana Moreno. Tentative Title: Cereal breeding using the yin-yang genes as markers. Expected date for dissertation: Dec, 2022.

Chuanxin Sun. Main supervisor for PhD-candidate Jia Hu. Tentative Title: New carbon metabolic rice for

the traits of low methane emission and biotic stress tolerance. Expected date for dissertation: Aug, 2022.

Eva Johansson. Main supervisor for PhD-candidates Joel Mark¬gren, Anna-Lovisa Nynäs, Antonio Capezza, Ashraf Rimsha, Okanlawon Lekan Jolayemi and Yuzhou Lan, co-supervisor for PhD-candidate, Elaine Ceresino and Emilia Berndts¬son, etc.

William Newson. Co-supervisor for PhD candidate Anja Herneke. Tentative title: Functionalization of nanofibers from plant based proteins. Expected date for dissertation: February 2022.

William Newson. Co-supervisor for PhD candidate Antonio Capezza. Tentative title: Novel absorbent Materials obtained from different plant proteins. Defended October 2020.

William Newson. Co-supervisor for PhD candidate Anna-Lovisa Nynäs. Tentative title: Proteins from green biomass for food applications. Expected date for dissertation: November 2021.

Zhu, L.-H. Supervisor for PhD candidate Sjur Sandgren. Tentative title: Genome editing of oil crops. Expected date for dissertation: 2022.

Zhu, L.-H. Supervisor for PhD candidate Oliver Moss. Tentative title: Improvement of seedcake quality of rapeseed for high quality food and food uses. Expected date for dissertation: 2024.

Li-Hua Zhu. Main supervisor for PhD candidate Magnus Carlsson. Thesis title: Production and characterization of heme-binding protein in plants. Defended in June 2020.

Rui Guan. Co-supervisor for PhD candidate Sjur Sandgrind. Tentative title: Genome editing of oil crops. Expected date for dissertation: 2022.

Folke Sitbon Main supervisor for BsC-candidate Linn Nilsson. Genetically modified Tobacco (Nicotiana tabacum) for production of wax esters . 15 ECTS, Uppsala

Kanagarajan, Selvaraju. Co-supervisor for PhD candidate Magnus Carlsson. Tentative title: Production and characterization of heme-binding protein in plants. Defended in June 2020.

Kanagarajan, Selvaraju. Co-supervisor for PhD candidate Sjur Sandgrind. Tentative title: Genome editing of oil crops. Expected date for dissertation: 2022.

Kuktaite, Ramune. Main supervisor for PhD-candidate Sbatie, Lama. Tentative title: Wheat quality in a varying climate. Expected date for dissertation: June, 2023.

Olsson, Marie. Main supervisor for PhD (Licentiate)-candidate Emilia Berndtsson. Licentiate thesis defended successfully 2020-05-29.

Olsson, Marie. Course organizer and teaching at the course "Postharvest – biology and technology after harvest", (BI1235), 15 ECTS, SLU, Alnarp.

Olsson, Marie. Course organizer and teaching at the course "Horticultural products and quality", (BI1285), 15 ECTS, SLU, Alnarp.

Olsson, Marie. Course organizer and teaching at the course "Food today and tomorrow, from different perspectives", (TD0013), 7.5 ECTS, SLU, Alnarp.

Popular scientific presentations at meetings or excursions

Personnel in T4F 2020

Theme 1 - Forest genetics and next generation of forest trees

Name	Gender & Position	Part of full time financed by TC4F
Xiao-Ru Wang	F, Professor	0
Stefan Jansson	M, Professor	0
Pär Ingvarsson	M, professor	0
Ove Nilsson	M, Professor	0
Natuschka Lee	F, researcher/associate professor	0
Olivier Keech	M, Associate-Professor	8%
Nathaniel Street	M, Associate professor	0%
Kathryn Robinson	F, Researcher	50%
Sara Abrahamsson	F, researcher	1%
Ainhoa Calleja-Rodriguez	F, researcher	12%
Mari Suontama	F, researcher	29%
Torgny Persson	M, researcher	3%
Ulfstand Wennström	M, researcher	15%
Johan Westin	M, researcher	23%
Jenna Lihavainen	F, Postdoc	0
Carolina Bernhardsson	F, postdoc	0
Wei Zhao	M, Postdoc	0
Nazeer Fataftah	M, postdoc	0
Xi Wang	F, PhD student	0
Helena Eklöf	F, PhD student	0
Alisa Kravtsova	F, PhD student	0
Alexis Sullivan	F, PhD student	25%
Elena van Zalen	F, PhD Student	100%
Camilla Canovi	F, PhD Student	100%
Sara Westmann	F, PhD Student	0
Teitur Kalman	M, PhD Student	20%
Andreas Schneider	M, PhD student	0
Pushan Bag	M, PhD student	0
David Hall	M, Förste forskningsingenjör	0

Theme 2 - Growth and interaction with the environment - current and future

Name	Gender & Position	Part of full time financed by TC4F
Annika Nordin	F, Professor	25%
Vaughan Hurry	M, Professor	0
Nathaniel Street	M, Associate Professor	12,5%
Giulia Vico	F, Docent	15%
Sandra Jämtgård	F, Researcher	0
Guiomar Ruiz-Pérez	F, PostDoc	100% (Jan-Mar 2019)
Qi Yang	F, Postdoc	100% (Jan-Aug 2019)
Lucia Tamburino	F, postdoc	100% (Sept-mid Oct 2019)
Mark Swaine	M, Postdoc	100% (Jan-Oct 2019)
Simon Law	M, Postdoc	100% (Mar-Dec 2019)
Alexander Vergara	M, Postdoc	100%
Camilla Canovi	F, PhD student	100%
Elena van Zalen	F, PhD student	100%
Tuuli Aro	F, PhD student	10%
Benjamin Forsmark	M, PhD student	80%
Andreas Schneider	M, PhD student	0%
David Castro	M, PhD student	10%
Alonso Serrano	M, Computer engineer	100%

Theme 3 - Sustainable and adaptive forest management

Name	Gender & Position	Part of full time financed by TC4F
Marie-Charlotte Nilsson-Hegethorn	F, Professor	0
Tomas Lundmar	M, Professor	0
Urban Nilsson	M, Professor	0
Euan Mason	M, Professor	20%
Michael Gundale	M, Docent	50%
Henrik Böhlenius	M, Docent	40%
Emma Holmström	F, Researcher	0
Ignacio Barbeito	M, Researcher	50%
Hélène Berthelemy	F, Post-doc	0
Theresa Ibanez	F, PhD student	100%
Gustav Ståhl	M, PhD student	100%
Oscar Nilsson	M, PhD student	100%
Martin Goude	M, PhD student	100%

C4F- Crops for the Future, Personnel

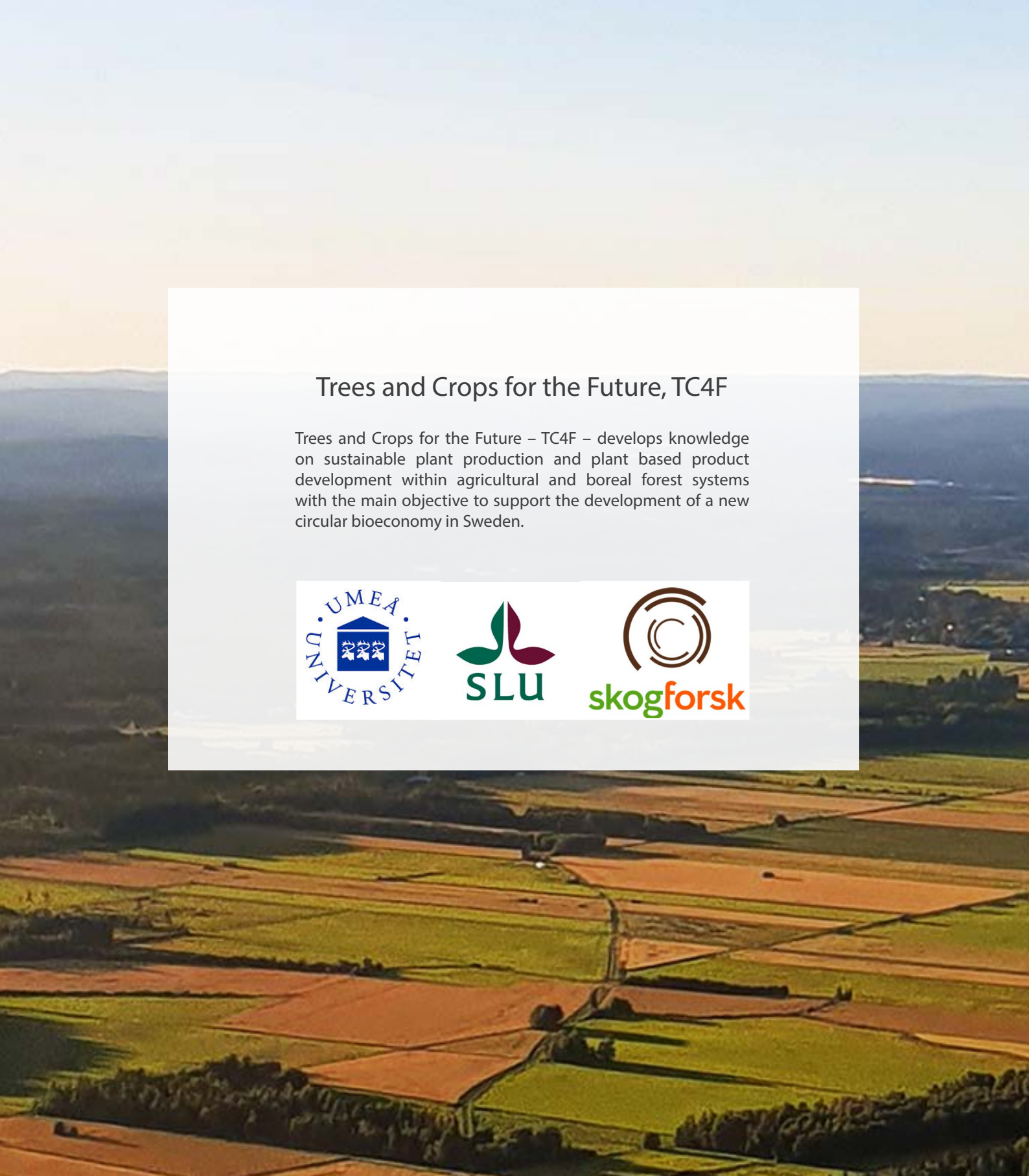
Name	Gender & Position	Part of full time financed by TC4F
Eva Johansson	F, Professor, C4F leader	15%
Li-Hua Zhu	F, Professor, C4F vice leader	10%
Marie Olsson	F, Professor	0
Maud Langton	F, Professor	0
Roger Andersson	M, Professor	0
Anders Carlsson	M, Professor	0
Peter Bozhkov	M, Professor	0
Chuanxin Sun	M, Docent	15%
Folke Sitbon	M, Professor	0
Elena Minina	F, Researcher	17
Ramune Kuktaite	F, Researcher	5%
Åsa Grimberg	F, Researcher	20%
Mariette Andersson	F, Researcher	0
Selvaraju Kanagarajan	M, Researcher	0
Daniel Johansson	M, Researcher	0
Saeid Karkehabadi	M, Researcher	0
Per Hofvander	M, Researcher	0
Jia Hu	F, PhD	0
Sjur Sandgrind	F, Postdoc	50%
Rui Guan	F, Postdoc	0
Anna Åsman	F, Postdoc	0
Yunkai Jin	M, Postdoc	20%
Adrian Dauphinee	M, Postdoc	0
Sungyong Kimi	M, Postdoc	0
Kamil Demski	M, Postdoc	40%
Shrikant Sharma	M, Postdoc	40%
William (Bill) Newson	M, Postdoc	12%
Elaine Ceresino	F, PhD student	20%
Anna-Lovisa Nynäs	F, PhD student	100%
Emilia Berndtsson	F, PhD student	50% Jan-May
Anja Herneke	F, PhD student	0
Klara Nilsson	F, PhD student	50%
Solja Pietaiänen	F, PhD student	0
Silvana Moreno	F, PhD student	5%
Pernilla Elander	F, PhD student	0
Sanjana Holla	F, PhD student	0
Xue Zhao	F, PhD student	30%
Shishanthi Jayarathna	F, PhD student	0
Mathias Johansson	M, PhD student	0
Per Snell	M, PhD student	0
Sungyong Kim	M, PhD student	17%
Magnus Carlsson	M, PhD student	50%
Antonio Capezza	M, PhD student	0
Sven-Erik Svensson	M, PhD student	35%
Joel Marklund	M, PhD student	0
Faraz Muneer	M, PhD student	20%
Florentine Ballhaus	F, Master Student	0
Xinran Liu (Sherry)	F, Internship	0
Kerstin Dalman	F, Research engineer	0
Ann-Sofie Fält	F, Lab technician	10%
Mirela Beganovic	F, Lab technician	25%
Helle Turesson	F, Research engineer	0
Maria Luisa Prieto-Linde	F, Lab technician	0
Anders Ekholm	M, Lab technician	0
Xueyuan Li	M, Research assistant	0

*Researchers listed with 0% have received financing from TC4F earlier which resulted in projects with independent financing.

TC4F Economy 2020

In 2020, TC4F received 28.6 mio SEK of funding which were distributed according to the budget. 101,5% were used. The deficit was compensated by remaining funds from 2019.

	SLU	UmU	Skogforsk	Total
Distributed Funds (tkr)				
Coordination	2 700			2 700
Tema 1 (Stefan Jansson, UmU)	1 985	4 000	1 100	7085
Tema 2 (Vaughan Hurry)	3 678	1 100		4 778
Tema 3 (Urban Nilsson)	7 245			7 245
C4F (Eva Johansson /Li-Hua Zhu)	6 988			6 988
TOTAL	22 596	5 100	1 100	28 796
Costs, spent funds (tkr)				
Coordination T4F	854			854
Coordination C4F	394			394
Tema 1 (Stefan Jansson, UmU)	2 277	4 000	1100	7 377
Tema 2 (Vaughan Hurry)	5 498	1 100		6 598
Tema 3 (Urban Nilsson)	7 407			7 407
C4F (Eva Johansson /Li-Hua Zhu)	6709			6 709
TOTAL	23 139	5 100	1 100	29 339
RESULT				-543



Trees and Crops for the Future, TC4F

Trees and Crops for the Future – TC4F – develops knowledge on sustainable plant production and plant based product development within agricultural and boreal forest systems with the main objective to support the development of a new circular bioeconomy in Sweden.

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