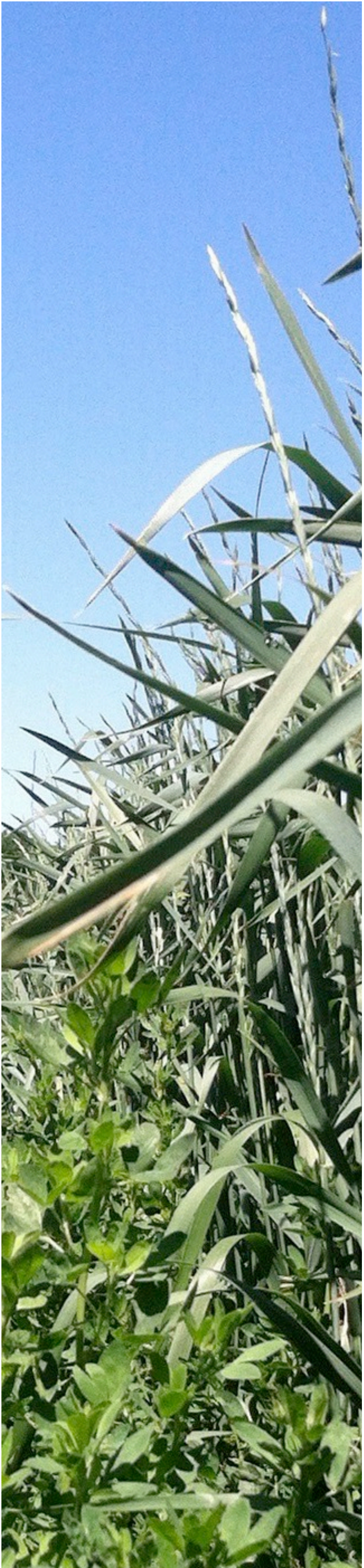


Pathways to a Perennial Future

Swedish – American Perennial Polycultures Research Cluster (SwAPP)

1. Introduction

This document describes a long-term agricultural research programme, initiated jointly by four research groups located at Lund University, Swedish University of Agricultural Sciences (SLU) in Alnarp and in Uppsala and the Land Institute in Salina, KS, USA. The aim of the programme is to begin to take perennial grain crops from a scientific vision to fully operational food systems. This requires both ingenuity and perseverance. The initiative is bold and the rewards may be extraordinary for humanity.

2. The Vision

Our research agenda is driven by a vision of a thriving future agricultural landscape that responds to some of the most pressing problems of our time. Imagine a landscape that nourishes a growing population in a warmer world, while stewarding the soil and the diversity of plants and animals that sustain us. This landscape provides meaningful jobs moving towards a solar-based and circular economy while revitalizing rural communities and re-valuing the important work that farmers do for society. It is characterized by more localized food networks that bring producers and consumers closer together. It reduces soil disturbances and degradation, retains nutrients and therefore restores and maintains the ecological integrity of agricultural lands. It relies on the use of agrochemicals – fertilizers, herbicides and pesticides – only in exceptional cases rather than as normal practice. It is based on crop diversity in space and time and the cultivation of hardy and resilient perennial species, reducing the risks associated with extreme weather events and pest infestations. This future landscape not only protects from soil erosion and environmental pollution, it also helps mitigate climate change through decreased agricultural inputs and a significant increase in soil carbon sequestration.

This vision of a radically new agriculture is not only desirable, it is necessary. Climate change, biodiversity loss, soil degradation, environmental pollution, rural decline and decreasing economic opportunities for farmers are just some of the major challenges that the sector is facing. The necessity for a radical transformation of the agricultural sector can be described by three imperatives: the environmental imperative, the climate imperative, and the social imperative.

2.1. The environmental imperative

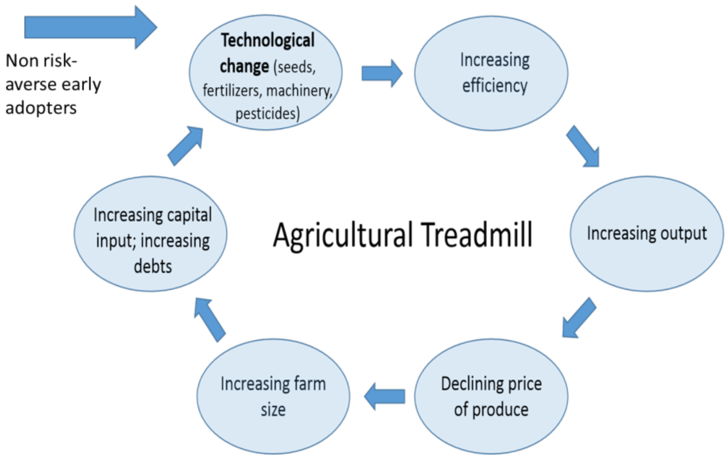
Modern agriculture is one of the sectors with the highest environmental impacts. Agricultural soils, which are the foundation for life and one of the most important resources we have, have been degraded, depleted and polluted as a consequence of decades of intensive, agrochemical-dependent farming practices. But agriculture itself as it has been practiced for the last 10,000 years has inherent shortcomings. For example, soils that are frequently tilled and left for long periods of time without cover commonly experience erosion, a process by which valuable top soils are washed away at rates much faster than they are formed. A recent study by the FAO (FAO, 2015) goes as far as estimating that at current rates of soil degradation, the world only has 60 years of harvests left. Agricultural systems are also responsible for nutrient runoff into ground and surface waters, leading to long-term pollution and disruption of marine ecosystems. The conversion of diverse natural ecosystems to agricultural lands based on a narrow range of crop species, together with frequent application of pesticides also has far-reaching effects for biodiversity and wildlife that often performs important ecosystem services for society. A well-documented example is the recent concern about how widespread use of glyphosphate-based herbicides may cause cancer (Cressey, 2015) and affects various insects, including honey bees, upon whose pollination the agricultural sector depends (Goulson, Nicholls et al., 2015). About 90% of all plant species, including 75% of our food crops, are entirely or partly dependent on animals, usually insects, for their pollination (Klein, Vaissiere et al., 2007). Pollination by insects and other animals significantly increases the size, quality and stability of the harvests of 70% of our food crops (Kremen, Williams et al., 2007).

2.2. The climate imperative

Agriculture and the food system in general are major contributors to climate change. They are responsible for about 17% of direct greenhouse gas emissions – mainly from ruminant animals and the application of fertilizers – and another 7-14% through indirect land use change (OECD, 2015). Recent studies estimate that most agricultural soils today have soil organic carbon levels that are 30 to 75% lower than they originally contained (Stavi & Lal, 2013). Modern farming also tends to be energy-intensive, relying on high levels of fossil fuel use. At the same time, climate change is expected to have far-reaching impacts on the agricultural sector. A more unpredictable and extreme climate is likely to make farming more challenging, causing more extreme weather events such as flooding and droughts, introducing new pests and diseases, and therefore may potentially reduce yields and profits (Field, Barros et al., 2014). Strong consensus exists that major staple crops, including wheat, maize, and rice, will be damaged by the impacts of climate change (Challinor, Watson et al., 2014; Liu, Asseng et al., 2016; Rosenzweig, Elliott et al., 2014). For example, already with 1°C global temperature increase, the global wheat yields are projected to decline by 4.1 to 6.4% (Liu, Asseng et al., 2016). A transition to more sustainable agricultural practices that both reduce greenhouse gas emissions, and are more resilient to future climate change is therefore one of society's key priorities.

2.3. The social imperative

The concept of the agricultural treadmill, originally conceived by William Cochrane (Cochrane, 1958), is more valid than ever. The agricultural treadmill refers to the cycle of technological change, reducing the cost of production and increasing farm sizes, as illustrated in the figure on the right. The socio-economic implications of the treadmill are that a minority of early non-risk-aversive adopters of new technology reap the benefits of that new technology, while the majority of farmers are forced to adopt the technology in order to reduce their costs under increasing competition and falling prices. This process is further exacerbated by the increasing consolidation of the agricultural inputs sector (Howard, 2015) (seeds, pesticides and synthetic fertilizers) by which prices are increased due to the reduction of competition. As a result, agriculture is under economic stress and decline (Carolan, 2016). In many cases this implicates the social fabric of rural societies and results in social stress and decline (Cloke & Little, 2005).



Since much of the technological change in agriculture has been ignorant about environmental and ecological repercussions, the treadmill has also contributed to an acceleration of the environmental problems described above. As a result, the diversification of agriculture based on agro-ecological principles has the potential to improve not only the production of food but also the economic value of the produce, employment opportunities, as well as increasing the resilience to natural and social stressors.

2.4. Research topics

Together, these three imperatives lead us to a number of more concrete questions that need to be answered in order to achieve the future agricultural vision outlined above. For example, we need to start asking:

- What would it take to eliminate land degradation on intensively used croplands?
- How can already degraded croplands be rehabilitated while maintaining production?
- What would it take to produce low-carbon meat and dairy products of the highest quality?
- How can agriculture reverse the emission of greenhouse gases and instead sequester carbon?
- How can agricultural landscapes reverse nutrient leakage and instead retain and recycle the nutrients?
- How can the use of agrochemicals (such as pesticides and synthetic fertilizers) be minimized while maintaining high productivity?
- How can the economic viability of farms improve while reducing their environmental impacts?
- How can agriculture revitalize rural societies?
- How can agriculture contribute to healthier and more sustainable food systems?
- How can agriculture provide a basis for a more circular economy?

Researching these questions demands that we see the challenge of agriculture as an *interlinked social, economic and ecological question.* The solution that we propose, below, does exactly that.

3. The Solutions

A wide range of solutions have been tested in order to "fix" agriculture. In spite of the tremendous financial and human resources expended, however, the challenges described above remain and in some cases have become even more troublesome (Foley, Ramankutty et al., 2011). In response to this, researchers at The Land Institute in Salina, Kansas (USA) have proposed a radically different approach to the problem. They have suggested that natural ecosystems provide the best standard for evaluating the performance of agricultural ecosystems, as well as the best models for improving on them. Natural ecosystems are remarkably productive, build soil fertility, leak very few nutrients, keep diseases and insect outbreaks in check and grow on contemporary sunlight rather than fossil energy inputs. What would it take for agriculture to be more like a natural ecosystem? It turns out that the answer is rather simple. It would need to consist of mostly perennial species, and be more diverse than present agroecosystems.

Naturally occurring plant communities, whether forests, prairies, deserts, savannahs, or tundra, are almost universally dominated by diverse perennial species. Perenniality – the ability of plants to grow, set seed, and then re-grow year after year is therefore central to the agricultural vision outlined above. By providing year-round soil coverage and uniquely large belowground carbon inputs from roots, farmers growing perennial crops will sequester more carbon, reduce greenhouse gas emissions, reduce nitrogen and phosphorus contamination of freshwater and marine ecosystems, and reduce weed competition, minimizing the need for tillage or herbicide applications. With perennial soil cover, farmers stand to greatly reduce soil erosion, potentially turning agriculture into a soil-forming ecosystem, much like the natural ecosystems it replaced (Crews, Blesh et al., 2016). Initial research suggests that soils conditioned by perennials may culture beneficial soil microorganisms that have been illusive to annual crops dependent on frequent soil disturbance. Perennial agroecosystems have the potential to improve with age, while annual-based cropping systems are set back to a low-functioning, plant-free starting point, year after year.

The idea that agriculture needs to be more perennial is a dramatic departure from the way humans have grown most of their cereal, oilseed, pulse and fibre crops in the last 10,000 years. The other feature of natural ecosystems that many agree will improve agriculture is diversity. The idea of growing multiple crops species in close proximity is not new to agriculture, but has been largely forgotten in industrialized countries over the last century as mechanization and chemical inputs have made it possible and economically advantageous to grow large stands of individual crops. Diversity can play a critical role in helping to keep plant-loving insects and diseases in check. Diversity also tends to enhance productivity because resources such as sunlight, water, and nutrients are used more efficiently when species with different resource requirements grow together. With carefully designed intercrop systems, called polycultures, agriculture can capture the benefits of diversity seen in nature. As in nature, the diversity within crop species can bring additional resilience to biotic and abiotic stresses in a future perennial cropping system.

4. Research Needs

In order to achieve the agricultural vision outlined above, by way of the adoption of perennial agroecosystems, new and intensified research programmes are needed on a number of levels. The research agenda that we propose here consists of five main parts:

1. Plant breeding, that aims to increase and support ongoing plant breeding on new perennial grain crops and
2. Cropping systems ecology research to understand use of these crops in the design of highly functional and sustainable agroecosystems;
3. Upscaling the cultivation of perennial grains, starting with Kernza™;
4. Markets and products development;
5. Transition that aims to investigate the social, economic and environmental implications of a perennial agricultural future, the obstacles that might be encountered, and how they can be overcome.

Though these five components figure in the development of a diverse and perennial-based agriculture to varying degrees, all are essential to achieve the agricultural vision outlined above.

Foundational research on plant breeding and crop systems ecology lay out the necessary steps for the development and domestication of new perennial crops, and their integration in a diverse agroecological landscape. Cultivation of these crops then needs to be upscaled in a sustainable way, appropriate crop management regimes established, and marketable products developed. This process feeds back into the plant breeding and crop systems ecology components, for example through the selection of crop characteristics (taste, protein content, etc.) that are required for the development of certain products. At the same time, the transition to perennial agroecosystems will initially need to confront the conditions of current agricultural practices, with social and economic institutions that are oriented towards largely monoculture-grown, annual crops and that might therefore provide obstacles to a full transition. These socioeconomic contexts might affect both the terms on which foundational research on perennial agriculture is carried out, and the conditions under which upscaling, market development and marketization can occur.

5. Swedish – American Perennial Polycultures Research Cluster (SwAPP)

Research on this long-term vision will be carried out by an emerging research cluster of four research institutions: LUCSUS (Lund University), SLU at Alnarp, SLU at Uppsala and the Land Institute in Salina, KS, USA. Each of these partners has their own competencies which complement each other. The research cluster is initially led by a core team consisting of one representative from each of the founding organisations. The mission of this group is to build a strong and functional research consortium while the organisation and operation of the research will be discussed and negotiated with funders. Below is a short description of the core team and the four research institutions. In addition to the research institutions, we envisage close collaboration with other partners, including stakeholders from agriculture and the food sector.

Tim Crews is Director of Research and an ecologist at The Land Institute in Salina, Kansas. He oversees a team of 8 Ph.D researchers and a staff of technicians, field assistants and interns that conduct perennial crop breeding and genomics research, and research on ecological intensification of perennial cropping systems. Crews' research focuses on intercropping perennial cereal and legume crops. He also collaborates with other researchers to understand how soil carbon dynamics and the soil microbiome differ under perennial and annual agroecosystems. Crews is an adjunct faculty member at the University of Kansas and Northern Arizona University, and has been a visiting scientist at CSIRO in Australia, at Rothamsted Research in the United Kingdom.

Erik Steen Jensen is Professor of agricultural sciences at The Swedish University of Agricultural Sciences in Alnarp. He responsible for the SLU research unit "Cropping systems Ecology" which is developing multifunctional and sustainable cropping system considering ecosystem services, product quality, environment health and climate change. He has a background as agronomist and soil scientist and has developed a profile as teacher and researcher within agroecology. He has 36 years of experience within research on design and assessment of sustainable cropping systems, organic farming, legumes, carbon nitrogen and cycling and symbiotic N_2 fixation. He has authored more than 120 ISI publications (h-index 40, February 2016). He is one of the top-cited researchers on intercropping in temperate agroecosystems. He has significant experience as coordinator of major Danish/Swedish and EU interdisciplinary and multi-institutional projects (e.g. INTERCROP and Grain Legumes). He is a member of the Royal Swedish Forestry and Agricultural Academy, The French Agricultural Academy and Agroecology Europe.

Lennart Olsson is Professor of Geography at Lund University and the founder of LUCSUS (Lund University Centre for Sustainability Studies), for which he was the director until August 2016. He was also the PI and coordinator of the Linnaeus Centre LUCID (Lund University Centre of

Excellence for Integration of Social and Natural Dimensions of Sustainability). His research fields include human-nature interactions in the context of agriculture, land degradation, climate change and food security in Africa and globally. He is currently associate editor of the journals: Ecology and Society, and the new journal Global Sustainability. He has had research positions in Australia, USA and Hong Kong and participated in several international assignments including the IPCC and UNEP-GEO assessments. He was coordinating lead author (CLA) for the chapter on livelihoods and poverty (Chapter 13) in IPCC's 5th Assessment Report, WG II, 2011-14, and CLA for the chapter on Land Degradation in the IPCC Special Report on Climate Change and Land (SRCCL) in 2017-19.

Anna Westerbergh, Associated Professor (Docent) in Genetics and Plant Breeding at the Department of Plant Biology, have long experience in breeding research and trans-disciplinary studies on different starch crops and their wild relatives including maize, barley, wheat and cassava. Her PhD research concerned population genetics and gene ecology of wild plant adaptation to abiotic stresses. In her postdoctoral research at the University of Minnesota, St Paul, MN, USA, she focused on genetic analysis of perennial traits in wild maize relatives. Transdisciplinary studies of cassava genetics and farming has been carried out with researchers and farmers in Uganda, Colombia and Vietnam. Ongoing work in her research group focuses on adaptation to climate changes and climate-smart agriculture and comprises perennial habit in barley and wheat and their wild relatives, waterlogging and drought tolerance in barley, and resistance to pathogens such as viruses in wheat. Her current group of five PhD research scientists has complementary competence in plant breeding, genetics, molecular biology, physiology and bioinformatics. She is highly involved in education as supervisor of PhD and MSc students, Director of Studies of Basic education and course organizer and lecturer at courses in Genetics and Plant Biology. She represents the Faculty of Natural Resources and Agricultural Sciences in the steering group of the SLU Plant Breeding platform.

5.1. LUCSUS (Lund University)

The Lund University Centre for Sustainability Studies (LUCSUS), established in 2000 and with a current staff of 35-40 employees, has an extensive track record working on agricultural questions in a context of sustainability concerns. It does this from a highly interdisciplinary perspective and therefore has a lot of expertise in bridging natural and social science methods and research concerns. The status of LUCSUS as an interdisciplinary centre within the Faculty of Social Science allows it significant freedom to deal with non-academic partners. Within this network, LUCSUS will therefore function as a hub for the consortium, as well as being responsible for the research components that focus on the social, economic and environmental aspects of a transition to perennial agroecosystems.

5.2. SLU Alnarp

The SLU Alnarp research unit on Cropping Systems Ecology (CSE) within the Department of Biosystems and Technology has a staff of c. 15 scientists and technician. CSE has expertise within agroecology, agronomy, nutrient cycling, weed and soil science. The CSE group is doing research on the function, design and sustainability assessment of annual and perennial cropping systems for food and biomass resources to the bio-based economy. Key research areas are: crop diversification in time and space (incl. intercropping), reintegration of legumes in European agriculture and food systems, mitigation of and adaption to climate change in agriculture and integrated weed management. We work with conventional and organic farming systems and involve actors from the agricultural sector in participatory action and learning research processes.

5.3. SLU Uppsala

SLU develops the understanding and sustainable management of biological natural resources through research, education and environmental monitoring and assessment, in collaboration with the surrounding community. At SLU Uppsala, the Department of Plant Biology carries out fundamental and strategic research in plant biology and breeding on agricultural crops, forest trees, biofuel crops and model organisms. The Department of Plant Biology is located at the Uppsala BioCenter, which brings together five departments with strong competence of international standard in plant biology, pathology, microbiology, food science, chemistry and biotechnology of great relevance for agriculture and forestry. The Uppsala BioCenter offers great facilities for breeding activities including state-of-the art greenhouses and climate chambers, and molecular genetics and microscopy laboratories. The Dept of Plant Biology is also a part of the Linnaeus Centre for Plant Biology in Uppsala. Researchers from SLU and Uppsala University meet to discuss functional aspects of plants as well as their interactions with the environment of direct relevance for agriculture, forestry and biodiversity management.

5.4. The Land Institute (KS, US)

The Land Institute is a non-profit research and education organization that was founded in 1976. Research at the Institute focuses on plant breeding and ecology with the goal of creating agroecosystems that use natural ecosystems as models. The Land Institute serves as a nexus for over 20 organizations and research groups involved in some aspect of regenerative, perennial agriculture. Within this current proposed project, The Land Institute will play an important role providing germplasm for plant breeding efforts in Sweden, as well conducting plant breeding and crop ecology research on site in Kansas, USA.

6. Time Plan

The research programme is planned to cover a 15-year period. Total costs for the research program, calculated over 15 years, are estimated at 150 million SEK. This estimate currently does not include any overhead costs, which we anticipate can be covered through co-funding by the involved institutions. The exact details of this arrangement will be negotiated between the participating research institutes and the funders.

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