LUND UNIVERSITY

‘Is the Future of Agriculture Perennial?’

LUND, 6-10TH OF MAY 2019

Abstracts

Keynote talks

Tuesday 7/5

Wes Jackson, The Land Institute
Nature Systems Agriculture and the Need for a Creaturely World View

Natural Systems Agriculture began less than a year after our 1976 beginning when my students and I took a field trip to a native Kansas Prairie. Noting the contrast between nature's prairie and annual grain monocultures the reality of nature's wisdom and the failure of human cleverness was clear. Perennial grain polycultures research began, but with full awareness that science is embedded in dominating social organizations which must be well understood if we are to address the countless problems in our climate changing ecosphere. To that end I will give a brief history of our origins and argue for a information rich creaturely world view to replace the industrial mind.

John Head, Kansas University
Is the Future of Agroecological Governance also Perennial?

In addition to the scientific innovations that will allow us to give an affirmative answer to the central question of this conference – "Is the Future of Agriculture Perennial?" – we must also consider and design legal and institutional innovations, especially at the global level, that can facilitate an effective transformation from modern extractive agriculture to agroecological husbandry. These reforms in agroecological governance should give special emphasis to (i) reconceptualizing state sovereignty to reflect 21st-century realities and (ii) introducing new legal entities ("eco-states") with authority to manage agroecological matters in ways that will address the soil and climate crises.

Wednesday 8/5

Michael Palmgren, Copenhagen University
Accelerating the Domestication of New Crops: Feasibility and Approaches

The domestication of new crops would promote agricultural diversity and could provide a solution to many of the problems associated with intensive agriculture. New breeding techniques may be used by breeders as tools to accelerate the domestication of semi-domesticated or even wild plants, in this way building a more varied foundation for the sustainable provision of food and fodder in the future. The feasibility of such plants from biological, social, ethical, economic, and legal perspectives has been examined and will be discussed.

Harriet Friedmann, University of Toronto

Why we need to reinvent agriculture: Lessons from disrupted civilizations about reconnecting soils and diets

Colonial and industrial monocultures began to disconnect agriculture from healthy soils and healthy culinary cultures, which were the foundation of civilizations for 10,000 years. Beginning only 150 years ago, the world's grain supply became concentrated in a few grassland ecosystems, which have since alternated between ecological crisis and temporary technological fixes. Mining soils and waters cannot continue. Human survival depends on consciously reconnecting crops and diets.

Tim Crews, The Land Institute

Is the future of agriculture perennial?—how functional ecosystems will lead the way to a post fossil fuel-intensive agriculture

Energy is a central consideration of why humans began to farm, why early proto-farmers bypassed perennial grasses in favor of annual grasses in the domestication process, and why most people in agricultural societies, before fossil fuel-based technologies were adopted, had to farm. In the last century, agriculture in much of the world has become profoundly dependent on inexpensive fossil fuels to produce grain crops. A promising path forward to a low carbon economy includes mixtures of perennial crops that achieve through ecological intensification what annual monocultures have achieved through fossil fuel-based input intensification.

Lee DeHaan, The Land Institute & Fengyi Hu, Yunnan University

A tale of two grains—Kernza and perennial rice. The different paths to creating a perennial grain, and the social experiments of early commercialization in the West and East

Kernza® perennial grain, which is the seed of intermediate wheatgrass, is marketed at a small scale in some regions. Intermediate wheatgrass has been used as a forage grass in the USA for decades, and in 1990 work was begun to domesticate it for use as a grain for human consumption. Introducing a new crop requires a wide array of agronomic, genetic, food science, marketing, pathology, and entomology research efforts. A new perennial grain additionally has production challenges that are unique to perennials. Future efforts should take the pipeline approach to identifying promising species.

Perennial Rice 23 (PR23), from which derived an interspecific hybrid of RD23/Oryza longistaminata, RD23 is cultivar of O. sativaand wide adaptation in Southeast Asia, was released in 2018 in China. It means the perennial crops could be commercialized first time in China. Here we will report the progress of Perennial Rice and discuss the future not only for Perennial Rice but also for Perennial grains.

Aubrey Streit Krug, The Land Institute & Omar Tesdell, Birzeit University
A Social Perennial Vision

If the ecological future of agriculture is to be perennial and diverse, what is required of us in social terms? The dominant logics that have grown out of the history of agriculture and that shape our economic and energetic relationships to the land and each other are incompatible with the health of the ecosphere. This historical, geographical analysis of the problem of agriculture calls us to understand the deep need for human community behavior to transform along with landscapes. An honest social perennial vision requires new systems of responsibility, sufficiency, mutuality, and curiosity.

Thursday 9/5

Jim Bever, University of Kansas
Microbiome influence on yield of Perennial Polycultures

Components of the microbiome of plants, including beneficial symbionts such as mycorrhizal fungi and N-fixing bacteria, and antagonistic pathogens, can exert large effects on yield. While conventional management of annual agriculture emphasizes disruption of the plant microbiome through tillage, fertilization, pesticide use and breeding, alternative approaches could be taken to maximize the benefits of the microbiome in perennial agriculture. We develop perspectives on microbiome influence on perennial yield based on research on the microbiome of prairie plants and annual agriculture.

Francesca Cotrufo, Colorado State University
Can perennialization and diversification solve the soil C dilemma?

To feed the growing world population we need to regenerate and sustain the health of our agricultural soils. Healthy soils, by definition, are able to support productivity through nutrient recycling, water retention, and increased organic matter content. The accrual of soil carbon (C) while maintaining nutrient recycling is not an easy task, since it requires that crop inputs and other organic amendments are processed by microbes, assuring the mineralization of nutrients, while the C is efficiently stored in persistent organic matter fractions. Henry Janzen elegantly presented this issue as the "soil C dilemma". We propose that increasing and maintaining consistent crop inputs through time in particular via the root system along the soil profile with perennialization will promote C accrual both by the increased addition of crop residues and root exudates, and by maintaining a connected microbial community. This, in conjunction with diversification through the addition of a legume to the cropping system, will maintain a diverse microbial community, promoting co-metabolic activities and the recycling of soil organic matter to provide fertility. We have started testing this hypothesis using dual, 15N and 13C labeled residues to trace their fate in cropping systems with different degree of diversification, perennialization and diversification and will present concepts and preliminary results.

Parallel session talks

James Anderson, University of Minnesota
Kernza Breeding and Genomics at the University of Minnesota
(co-authored with Prabin Bajgain)

The University of Minnesota has been domesticating Intermediate wheatgrass (Thinopyrum intermedium, Kernza) as a perennial grain crop since 2011. After 3 cycles of selection we have improved seed mass by 60%, free threshing by 34%, and shatter resistance by more than 15%. Our first synthetic variety was released in 2019. Genomic selection (GS) is integral to our breeding strategy and we discovered that incorporating genotype by environment and dominance effects increases prediction accuracy by up to 23%. In addition, we routinely conduct genome-wide association mapping and use discovered significant markers in GS models as fixed effects to increase predictive ability.

Dorte Bodin Dresbøll, University of Copenhagen
Root growth and deep water uptake of 3 perennial crops
(co-authored with Kristian Thorup-Kristensen)

Including perennial crops in cropping systems is expected to increase the use of resources in the soil, as time will allow perennials to develop deep roots exploiting soil layers otherwise inaccessible to crops. However, little knowledge exists on the uptake of water from deep soil layers. Three perennial crops, lucerne, silphium and kernza, were grown in large rhizoboxes (4×1.2×0.3 m). Root growth and water uptake was determined and all species were found to be able to take up water from around 3 m depth, however during dry conditions only lucerne was found to take up significant amounts of deep water.

Douglas J. Cattani, University of Manitoba
Initial studies into seed size and viability of Linum lewisii

Lewis perennial blue flax (Linum lewisii) is native to North America. Southern Manitoba collections were evaluated under nursery conditions. Seed was separated into groups based on density with germination (2016, 2019) and emergence (2016) evaluated under greenhouse conditions. Accession seed density was correlated to thousand seed weight. Seed size was not related. Thousand seed weight was related to germination and emergence, however, not between accessions. Seed yield across the tested accessions indicated that there is sufficient variability within the accessions for selection, however, materials from other regions would be required for an effective breeding program.

Yann Clough, Lund University

Perennial habitats, biodiversity and ecosystem services and disservices in farmland

Land-use intensification through increased input use, the spatial separation of animal and arable crop production, mechanisation and the concurrent increases in the size of fields have reduced the diversity and abundance of non-crop plants, invertebrates and vertebrates in agricultural landscapes. Ecosystem services such as pollination, pest control and decomposition are key to support a sustainable intensification of agriculture. Perennial crops are associated with reduced disturbance in the field, and thus offer resources for biodiversity that annually tilled fields do not. Here, I draw upon the existing literature to assess how the uptake of perennial crops at the landscape scale may change the availability of resources for pests and beneficial insects, and wider biodiversity, setting up several hypothesis suitable for testing in field- and landscape-scale implementations of perennial crops.

Stan Cox, The Land Institute

Ploidy and perenniality in Sorghum bicolor x S. halepense populations
(co-authored with Pheonah Nabukalu)

All populations derived from crosses between the annual diploid species Sorghum bicolor and the tetraploid perennial S. halepense have until now been tetraploid. This complicates and slows their use in developing perennial grain sorghum. We recently found two routes to producing diploid breeding populations from crosses between these species. Relative rates of diploid, triploid, and tetraploid F1 hybrid production from diploid x tetraploid crosses may be influenced by choice of maternal parent and ambient temperature on the day before pollination. Availability of diploid lines with S. halepense-derived capacity for rhizome development will accelerate development of perennial sorghum.

Jared Crain, Kansas State University

Genomic Selection in Intermediate Wheatgrass

For perennial crops to be viable, they must provide proportionate benefits as annual crops. Most perennial crops have low yield and other negative traits such as shattering and non-free threshing seeds that must be improved. Genomic selection (GS) is a powerful breeding technique that can be used to identify superior plants and increase the rate of genetic gain. In an intermediate wheatgrass breeding program, GS has reduced the breeding cycle by half, potentially doubling genetic gains. Application of GS can be used to more rapidly close the gap between perennial crops and their annual counterparts.

Steve Culman, Ohio State University

Harvesting Forage Stimulates Grain Production in Kernza

Kernza is an emerging perennial grain that produces a large amount of forage with modest grain yields. A dual-use strategy (harvesting both forage and grain) represents a significant opportunity to increase farmer adoption and profitability of Kernza. We conducted a pilot study at nine total sites across the US with the following objectives: 1) evaluate Kernza grain and forage yields across a wide range of environments and ii) determine how harvesting Kernza forage biomass impacted grain and forage yields. Across all sites, grain yields averaged 768, 294 and 225 kg/ha and forage yields averaged 6.33, 4.64 and 5.85 Mg/ha for the first, second and third year respectively. Across all sites, harvesting forage positively impacted grain and forage yields. Our data collectively suggest that harvesting Kernza forage over a broad range of environments improves grain and forage yields. In addition, at one site harvesting Kernza increased root biomass and stimulated soil nitrogen cycling, suggesting that a dual use strategy can increase soil and water conservation outcomes.

Christophe David & Olivier Duchene, ISARA

Development of intermediate wheat grass in France

Perennial grains have been suggested to mitigate the impact of global change and exploitation of natural resources in intensively managed agricultural landscapes dominated by annual crops. In the European context, limited scientific references on perennial grains exist. In 2017, ISARA (www.isara.fr) set up a research program on intermediate wheatgrass. The aim was to identify environmental gains and tangible benefits of intermediate wheatgrass in relation to plant age and practices. Under various conditions in European arable systems, intermediate wheatgrass research is being conducted comparing production systems (organic vs conventional), crop architecture (with or without clover), fertilization regimes, and mowing practices to evaluate agronomic and ecological performance over time.

Lee DeHaan, The Land Institute

Breeding Kernza Perennial Grain for the Great Plains, USA

Intermediate wheatgrass (IWG, marketed as Kernza® perennial grain) is being developed for diverse temperate agricultural systems. Since 2003, we have been breeding this species for increased harvestable grain yield in a region that regularly experiences heat and drought stress during the growing season. Increases in yield per head are derived from a combination of mass per seed, percent seed set, and florets per head. Despite attempts to select for reduced height and early maturity, these traits are largely unchanged. Early maturity could help avoid heat stress, but this trait may require a new approach.

Marcia DeLonge, Union of Concerned Scientists
Impact of perennial cover on soil hydrologic properties

Agricultural practices that enhance water cycling are critical, especially in a climate with increasing risks of droughts and floods. To better understand the hydrologic impacts of practices such as introducing perennials (grasses, agroforestry, managed forestry), cover crops, no till, or grazing management, we conducted global meta-analyses. We found large increase in infiltration rates from perennials (59.2 ± 20.9%) and covers crops (34.8 ± 7.7%). In another analysis, continuous living cover (perennials, cover crops) improved total porosity (8.0 ± 2.2%) and field capacity (9.3 ± 2.7%). Despite these benefits, public investments in such practices are limited in the US.

Gabriel de Oliveira, University of Kansas
Carbon and water relations in perennial Kernza plants
(co-authored with Nathaniel A. Brunsell, Timothy E. Crews, Lee R. DeHaan & Giulia Vico)

Perennial grain/forage crops can sustain high yields without replanting for 3-10 years or more, with potentially important environmental benefits. Although previous research has been conducted in perennial food crops, the coupling between these ecosystems and the atmosphere is not well understood. The objective of this study was to evaluate the magnitude and temporal variability of the water-use relationships in a perennial Kernza wheatgrass crop in Salina, north-central region of Kansas (KS), USA. The study period comprised approximately 6 years (2012-2018) of eddy covariance observations collected at the US-KLS AmeriFlux tower. In particular, we examine the water-use efficiency, carbon and water fluxes in relation to the local environmental factors, such as vapor pressure deficit, soil moisture, air temperature, etc. An analysis of the correspondence between accumulated precipitation (PPT) and ET in the perennial crop indicated a most likely low surface runoff and that there were other sources of water for plant intake in addition to the annual PPT, i.e., deep water. In this sense, we highlight that the long roots observed in perennial crops may facilitate the water uptake in the deeper soil layers, providing extra resources for the plant growth especially when the rainfall indices are low. The results obtained in this work are important in order to better understand the hydrologic cycle of perennial agroecosystems as well as to understand the benefits and disadvantages in relation to annual crops particularly under changing climatic conditions.

Linda-Maria Dimitrova Mårtensson, Swedish University of Agricultural Sciences
Kernza as a model for perennial cereal production in Sweden – with focus on nitrogen
(co-authored with Shoujiao Li, Erik Steen Jensen and Ana Barreiro)

Including perennial grain crops in annual crop rotation systems are likely to reduce the negative consequences of inverting soil tillage and add more root dry matter for building SOM, when applying agroecological principles of ecological intensification to support future food production (Crews and Dehaan 2015; Crews et al 2016). The Land

Institute has domesticated intermediate wheatgrass (Thinopyrum intermedium), which may grow vigorous and deep root system expected to deliver ecosystem services, such as reduced erosion and nitrate leaching compared to annual cereals (Culman et al 2013; Crews and Dehaan 2015). The SITES Agroecological Field Experiment (SAFE), Lönnstorp Research Station at the Swedish University of Agricultural Sciences, includes a perennial agroecosystem with intermediate wheat grass grown with and without the legume Medicago sativa (lucerne) as intercrop. The aim of our research is to evaluate the environmental benefits hypothesised for perennial herbaceous production Crews et al (2016). A greenhouse experiment in large pots showed the importance of plant available N to maintain the competitive ability of Kernza during the establishment when intercropped with Lucerne. Lucerne increased the fixation of atmospheric N2 without no- N-fertilizer and was highly competitive in mixtures with Kernza. Biological soil functions are also important in ecological intensification. Preliminary data indicate higher abundance of arbuscular mycorrhizal fungi as well as bacterial biomass in Kernza plots as compared to wheat plots. A vital soil microbiome may prove to be beneficial for the Kernza production as well as subsequent crops. Continued research will focus on finding the most suitable legume intercrop, identifying appropriate establishment and management practices, investigate crop rotational aspects and the soil development in Kernza and Kernza-legume crops.

Martin Entz, University of Manitoba
Perennializing "Conservation agriculture"
(co-authored with April Stainsby, Michael Salomons and Myra Van Die)

.Conservation Agriculture (CA) is a farming system that "promotes maintenance of a permanent soil cover, minimum soil disturbance and diversification of plant species" (FAO). We are testing polyculture systems in annual grain CA. A high degree of "perennial mimicry" was achieved when a self-regenerating legume cover crop (Medicago lupulina) was added to an already diverse no-till farming system. In a second Canadian study, a seeded cover crop allowed an annual grain no-till system to mimic a native grass planting in terms of water infiltration, soil moisture redistribution, and, interestingly, soil freezing and thawing over winter. Our on-farm research in Southern Africa demonstrated that including semi-perennial legumes, lablab (Lablab purpureus) and pigeon pea (Cajanus cajan), in hoe-based maize CA systems increased plant net primary production during maize growth and during the following dry season – when ratooned legumes regrew. Our second objective is to advance the successional state of CA systems through strategic livestock integration.

Richard C. Hayes, New South Wales Department of Primary Industries
Novel dual purpose perennial wheat for grazing

The first commercial use of perennial wheat in Australia will be a multifunctional grain and graze crop. Whereas annual winter wheat herbage is grazed by livestock during autumn -winter before being rested for grain harvest, perennial wheat will be sown in a mixture with legumes, offering substantial benefits for high-producing classes

of livestock grazing a more diverse diet. A new research project aims to establish the suitability of perennial wheat as a novel source of forage for sheep, and tests the hypothesis that a more diverse perennial cereal-based diet leads to a more balanced mineral profile in the animal, resulting in higher livestock productivity and improved meat quality.

John Hill Price, University of Minnesota

Assessment of Phenotypic Diversity in a Silphium integrifolium Breeding Population

To help inform domestication efforts in Silphium integrifolium, we have evaluated a population of breeding germplasm over three years in six diverse locations, collecting data on a range of architecture and yield traits. This talk will summarize some of the findings of the study, and will illustrate two ways in which the data may be used to answer key breeding questions and make selections.

Brent Hulke, USDA Agriculture Research Service

Breeding and genetics research at USDA and University of Colorado on perennial oilseeds Silphium & Lewis flax

The perennial crop breeding community has made great progress in the domestication of grain crops, but is far behind in domestication of oilseeds. Fats and oils are underappreciated as nutrients: some are critical for human health and cardiovascular function, while others are detrimental. I describe, in general terms, progress the USDA and University of Colorado group has made in understanding the basic biology of Silphium in order to develop sane methods for crop improvement that minimize goal conflict and strategy bias on populations under domestication. Similar work on Lewis flax, another perennial oilseed, will also be discussed.

Ellinor Isgren, Lund University

New perennial grains in African smallholder agriculture: A farming systems perspective

(co-authored with Wim Carton & Elina Andersson)

In the African context, perennial varieties of crops such as sorghum, pigeon peas and rice appear to have potential to contribute to sustainable intensification in smallholder agriculture. However, introduction new crops and practices in smallholder agriculture is a complex process, which need to be approached from an interdisciplinary perspective. In this study, we seek to inform the emerging research agenda around perennial grains in African smallholder agriculture with insights from recent decades' research on farming systems. We use literature on smallholder farming systems to outline key considerations for developing and studying new perennial grains in smallholder contexts, emphasizing aspects such as agroecosystem diversity, varied resource endowments and risk aversion. But important critiques have been aimed at farming systems research, highlighting the importance of embedding analyses

of farmers' production systems and livelihood strategies within a broader political-economic context. While farming systems perspective offers a fruitful theoretical and methodological entry point for research on new perennial grains in African smallholder agriculture, comprehensive understanding of their potential and challenges therefore requires cross-scalar analysis capable of looking beyond the farming system.

Robert Jensen, The Land Institute/Ecosphere Studies
Theological Metaphors: From the Royal to the Prophetic to the Apocalyptic, and the Case for a Saving Remnant

Robert Jensen will borrow terminology—royal, prophetic, and apocalyptic—from the Hebrew and Christian bibles (leaving behind the underlying theology) to suggest a framework for approaching our intellectual and political work. Jensen will argue that our task is not only to continue to struggle to create a just and sustainable world today but also to begin to imagine a saving remnant that will negotiate a radically different future in which new skills, stories, and spaces will be necessary.

Jacob Jungers, University of Minnesota
Nitrate leaching reductions to groundwater beneath a new perennial grain crop
(co-authored with Lee DeHaan, David Mulla, Craig Sheaffer & Don Wyse)

Nitrate nitrogen (NO3-N) leaching from fertilized annual crops can contaminate groundwater and pollute natural aquatic ecosystems and rural drinking water sources. We measured water quality variables and crop yields beneath the perennial grain crop intermediate wheatgrass (IWG), maize, and switchgrass under three N fertilizer treatments. Average annual NO3-N leaching estimates in the high N treatments was one and two orders of magnitude lower below IWG compared to switchgrass and maize, respectively. Intermediate wheatgrass has great potential to provide food-quality grain and biomass while preventing NO3-N leaching.

Wenqian Kong, University of Georgia
Unraveling the genetic components of perenniality toward breeding for perennial sorghum

Sorghum, one of the few multi-purpose crops that provide both grain and biomass in some of the world's most adverse conditions, has two perennial relatives as well as rich morphological diversity occurring during divergent evolution both in the wild and under domestication, making it a good candidate for breeding for perenniality. We conducted a quantitative study to elucidate the genetic components conferring perenniality-related traits, mainly rhizomatousness and winter survival, in two novel BC1F2 populations totaling 246 genotypes derived from backcrossing two Sorghum bicolor x S. halepense F1 plants to a tetraploidized S. bicolor.

Jimmy Lamo, National Agricultural Research Organization (NARO) Uganda
Evaluation of perennial rice introductions for Rice Yellow Mottle Virus diseases resistance in Uganda
(co-authored with Alibu Simon, Otim Michael, & Fengyi Hu)

Rice varieties, PR 23, PR 26 and PR 107 developed by Yunnan University were screened for tolerance to Rice Yellow Mottle Virus (RYMV), a serious disease problem in Uganda. Results showed that days to symptom appearance varied among the accessions. The susceptible check IR-64 was the first to express symptoms of the disease at 9 days after inoculation, while the resistant check Namche-2 did not express disease symptoms. The duration of symptom expression varied among the perennial rice introductions, with PR26 expressing symptoms first (13 DPI), while PR-107 expressed symptoms last (20 DPI). Genotype PR-107 was selected for further evaluation.

Steve Larson, USDA Agriculture Research Service
Intermediate wheatgrass breeding and genetics for the western U.S.

The USDA Agriculture Research Service (ARS) Forage and Range Research unit in Logan, Utah, has conducted over six decades of breeding and genetic research that has resulted in successful releases of perennial forbs, legumes and grasses for a wide array of agricultural and conservation uses in the western U.S. Intermediate wheatgrass ranks among the most productive and versatile grasses tested in this region. This presentation will briefly describe cooperative research that aims to domesticate and improve intermediate wheatgrass as a perennial forage and grain crop.

Sonali McDermid, New York University
An Integrated Assessment of the System of Rice Intensification: Can perennial rice advance food security and climate change goals?
(co-authored with Roberto Valdivia, Geethalakshmi Vellingiri, Lakshman Arunachalam & Kelly Witkowski)

Rice is a critical staple crop that directly feeds ~2 billion people, and supports ~150 million households globally. However, rice-based farming systems also constitute a substantial fraction of anthropogenic GHG emissions, particularly. Furthermore, many rice-growing nations face critical water resources shortages and changing climate conditions. There is thus an urgent need to identify high-yielding rice-growing methods that build climate resilience while reducing water and input consumption. Such practices may also help rice-growing countries to achieve their Nationally Determined Contributions towards reducing GHG emissions, as provisioned by the 2015 Paris Climate Agreement. Alternative rice water management regimes that reduce flooding can abate rice CH4 emissions, and when coupled with practices that foster strong plant establishment, such as the System of Rice Intensification (SRI), small-holder farmers may experience yield gains. However, there are potentially trade-offs between CH4 and N2O emissions with reduced flooding, and SRI management practices are often cited as increasing labor costs and social inequity. SRI has also not yet been evaluated

for its resilience under projected future climate changes. I will present nascent work to quantify these potential SRI benefits and trade-offs, which combines the results of on-going, factorial SRI field trials across varying agro-climatic zones in southern India with an innovative, integrated modeling approach to assess climate change impacts on food security. Furthermore, I will consider the ways in which incorporating perennial rice could address these outstanding SRI limitations and uncertainties, and provide an improved means to secure rice production while alleviating environmental pressures under future climate conditions.

Allison Miller, Saint Louis University/Danforth Plant Science Center

(1) Building a botanical foundation for perennial agriculture: Global inventory of wild, perennial herbaceous Fabaceae species

To facilitate development of edible, perennial, herbaceous crops, we constructed an online resource of wild, perennial, herbaceous species - the Perennial Agriculture Project Global Inventory (PAPGI; http://www.tropicos.org/Project/PAPGI). The first component focuses on Fabaceae. We extracted taxonomic names and descriptors from the International Legume Database and Information Service. Names were added to PAPGI, a special project within the botanical database TROPICOS, where they link to specimen records and ethnobotanical and toxicological data. PAPGI includes 6,644 perennial, herbaceous Fabaceae species. We are adding data for more than 60 agriculturally important traits; here we highlight food uses and toxicological data.

(2) Growing the botanical foundation for perennial agriculture: accelerating pre-breeding of diverse perennial, herbaceous species to enhance agricultural resilience

The process of crop domestication has dramatic phenotypic effects on both the direct targets of artificial selection and off-target traits. Here I share some recent work characterizing vegetative and reproductive traits of perennial legumes. Then, I introduce a developing project aimed at understanding variation and correlations among traits expressed in early life stages, and, their associations with single and multi-year plant vigor and reproductive output. Our goal is to develop a predictive framework based on comprehensive trait observations that will expedite selection and pre-breeding in a diversity of emerging perennial, herbaceous crops.

Baloua Nebie, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

Development of drought tolerant sorghum to enhance farmers' resilience to climate variability in the Sahel of West Africa

(co-authored with Ouedraogo O. C., Diancoumba M., Toure A., Weltzien E., Sissoko I., Boubacar A., Deshpande S. & Paterson, A.)

Sorghum and Pearl millet are staple-food crops for millions people in the sahelian zone of West Africa where drought is the most important abiotic stress limiting crop production. To contributing to food security in this zone, 669 BC1F5 sorghum

progenies were developed from 7 drought tolerant donors and a recurrent parent preferred by farmers. The performance of these progenies under terminal drought conditions was also assessed. An important diversity was obtained for grain yield, flowering time, stay-green, chlorophyll content, survival rate and farmers' preference in two environments differing in annual rainfall, 881 mm and 418 mm respectively.

Elena Pestsova, Institute of Bio- and Geosciences - Plant Sciences, Forschungszentrum Jülich
Exploiting genetic diversity for breeding of high-biomass yielding perennial crop Silphium perfoliatum

Cup plant (Silphium perfoliatum L.) represents a promising alternative to silage maize as an energy crop for biogas production. So far, there have been almost no breeding attempts for the cup plant, and all field experiments showing its high biomass yield were conducted by using only a few cultivated populations of unclear ancestry. Comprehensive assessment of five such populations for their biomass and methane yield parameters revealed substantial genetic variations indicating the possibility of improving these traits through selection and breeding. Higher biomass yield is likely to be achieved by breeding for secondary traits such as plant height, shoot diameter and internode number as well as photoperiod response. For increasing the methane production, reduced lignin or fibre content in the biomass seems to be important. Genetic relationships among the populations were estimated using tunable genotyping by sequencing (tGBS) technology. Genetic structure and phylogeny analyses revealed that all the plants belong to the same gene pool and share a common ancestry. To achieve a successful domestication and breeding of this new high-yielding perennial crop, a broader base of genetic diversity needs to be ensured and complemented by innovative breeding strategies driven by molecular genetic and modern genomics approaches.

Andrew Paterson, University of Georgia
The evolution of a perennial crop relative, Sorghum halepense

From noble beginnings as a prospective forage, polyploid Sorghum halepense ('Johnsongrass') is both an invasive species and one of the world's worst agricultural weeds. Formed by S. bicolor x S. propinquum hybridization, we show S. halepense to have S. bicolor-enriched allele composition, and be rich in novel alleles. Rhizomes of S. halepense are more extensive than those of its rhizomatous progenitor S. propinquum, have growth correlated with reproductive rather than other vegetative tissues, and increase survival of both temperate cold seasons and tropical dry seasons. The spread of S. halepense may have been facilitated by introgression from closely-related cultivated sorghum.

Kelsey Peterson, University of Minnesota

Interrogating the Genomic Variation available for de novo domestication of Silphium integrifolium

Silphium integrifolium is a deep-rooted perennial plant that is being domesticated as an oilseed and forage crop. Due to Silphium's large repetitive genome, we utilized a transcriptomic approach to characterize functional genetic variation found in wild populations across the species range. To do so we quantified genetic diversity within and divergence among populations and discuss these results within the context of identifying genetic variation that is available to improve the existing domestication breeding program.

Valentin D. Picasso, University of Wisconsin – Madison

Optimizing agronomic management of Kernza intermediate wheatgrass as perennial grain and forage crop

Kernza Intermediate wheatgrass is the first perennial grain crop. Our research aims to develop a Kernza dual-use, grain and forage system, which will increase profitability, reduce adoption risks for farmers, and facilitate a landscape-scale transition to perennial agriculture in the US and the world. We evaluated forage yield and nutritive value of dual-use Kernza systems, identifying agronomic management practices that optimize grain and forage yield, and identifying legume-Kernza polycultures for increased benefits. We started by identifying farmers perspectives and research needs. We are evaluating a wide range of agronomic management treatments including timing and frequency of forage harvest, direct grazing, species and seeding time of companion legumes in polycultures, nitrogen fertilization, weed management, planting and harvesting timing, and post-grain harvest practices on Kernza grain yield and forage quality over time. We have documented high forage yield and nutritive value of Kernza dual use systems, the beneficial effect of harvesting forage on grain production, great weed suppression of annual weeds over time, low Nitrogen requirements and compatibility with legumes, and determined the role of non-structural carbohydrates in roots and rhizomes on next spring regrowth. International expansion of perennial grains is also a major focus, and we have collaborations with Argentina, Chile, China, Italy, Japan, Mali, Sweden, Switzerland, Ukraine, and Uruguay. Understanding vernalization and photoperiod requirements is a critical point towards this goal, and we have evaluated optimal conditions and variability in germplasm to these factors.

Damián Ravetta, Museo Egidio Feruglio-CONICET

Why has it been difficult to define the ideotype for a perennial oil-seed plant?
(co-authored with David Van Tassel, Luciana González-Paleo & Alejandra Vilela)

The ideotypes for the wild perennial candidate and the following cultivated plant are difficult to define. There is no consensus on which traits are more important and should be used. In part, this lack of a clear definition is due to scarce knowledge

and poor understanding of the consequences of different plant traits, at different scales. Also, their relevance for the plant's resource acquisition and use-efficiency, yield performance and its variability, and overall system sustainability, need to be determined. The same trait may have a positive or negative effect depending on the intended service. Drawing from knowledge on Silphium, Physaria, and other perennial oil-seed crops, we discuss structural and functional characters and their relevance to define future ideotypes for Silphium integrifolium.

Stephan Reinert, University of Colorado
Phenotypic evaluation of important traits for Silphium domestication

Silphium spp. have garnered interest in Europe as a bioenergy crop and in North America as a perennial oilseed crop. However, little has been done to characterize key characteristics, including self-compatibility and important oilseed traits. The objective of this work was 1) to develop an understanding of how biogeography and associated population genetic forces have shaped seed phenotypes in plant collections across the native range of Silphium integrifolium Michx., the primary domestication candidate for oilseed use, 2) how sever is self-incompatibility in Silphium integrifolium Michx., Silphium perfoliatum L., and interspecific hybrids, and 3) how does interspecific hybrids perform yield-wise compared to Silphium integrifolium Michx. and Silphium perfoliatum L.

Matthew Ryan, Cornell University
Gaining Ground with Perennial Grains in the Northeast

Interdisciplinary research is needed in order to advance perennial grains and facilitate adoption among farmers. Working with a team of four prominent organic farmers in New York, we evaluated intermediate wheatgrass and perennial cereal rye in a series of on-farm strip trials. Additional field experiments at our research station have focused on intercropping perennial grains with legumes and renovating old stands of intermediate wheatgrass. We also conducted a survey to gauge farmer interest in growing perennial grains, and we are in the process of conducting a willingness to pay experiment to quantify consumer preference for Kernza.

Nir Sade, Tel Aviv University
Dissecting the physiological mechanism of perennial grain behavior under climate change

Perennial grain cropping systems provide many beneficial attributes for the environment as compared to their annual analogues. Perennial crops are more resource-use efficiency and contribute less to soil erosion. Development of perennial grain for agriculture is done using domestication and hybridization strategies. Nevertheless, the effect of those strategies on the physiological behavior of the plants is an important milestone for the global use of perennial grain. Moreover, the effect(s) of domestication/hybridization on the response(s) to abiotic stress is not yet fully

understood. Thus, our overall objective is to use a cutting-edge phenotyping system to physiologically characterize selected perennial lines for their water use efficiency and resource assimilation and allocation under optimized and water deficit conditions. We aim to identify genes and pathways that will define useful traits to crop breeders under changing environments. In addition, we will functionally characterized key traits using forward- and reverse-genetics in a perennial grass model plant.

Brandon Schlautman, The Land Insitute
Perennial legume breeding at The Land Institute: new species in the domestication pipeline

We are in the early stages of candidate species selection and exploring two potential uses for perennial legumes: 1) as high protein perennial pulses and 2) as nitrogen fixing companion legumes interseeded between grain crops. We are establishing breeding trials for existing perennial forage legumes (e.g. alfalfa and sainfoin), which have many existing genetic resources. The trials are being designed in unique ways we hope will generate agronomic knowledge about our proposed cropping systems and help revise our current perennial grain & companion legume ideotypes. This is as important – if not more important – as the genetic improvement of these proto-crops.

Aubrey Streit Krug, The Land Institute
Care Work in the Field

Drawing on scholarship from across the humanities and social sciences, this talk identifies the importance of emotional labor in learning processes and explores why skillful "care work" matters for future collaborative agroecological research and education. How might more equitable networks of care and new forms of emotional attachment—to diverse crops-in-process, to human communities, to the ecosphere—help build the capacity, conditions, and cultural institutions for the transformation to perennial agriculture?

Kathryn Turner, The Land Institute
Perennial Grain Polyculture Under Attack: Pathogens

Our perennial grain crops have many defenses to protect them from disease. Growing these crops in a perennial system has the potential to increase some pathogen pressures while limiting others. We are currently identifying significant diseases and selecting for defenses as our crops are domesticated to avoid severe disease outbreaks due to loss of genetic diversity.

Geoffrey Tusiime, Makerere University

Adaptability of temperate Sorghum bicolor x Sorghum halepense hybrids to tropical environments in Uganda

(co-authored with Nakasagga, S., Biruma, M., Nabukalu, P. and Cox, S.)

Sorghum bicolor x Sorghum halepense hybrid lines of temperate origin were evaluated for adaptability to 2 environments in Uganda, Serere and Kabanyolo. One hundred ninety six backcross tetraploid hybrids and four locally adapted sorghum varieties were evaluated over two growing seasons. Rhizomes were produced in both locations, though production at Serere was higher than at Kabanyolo. Rhizome production ranged from zero to above 10 in different lines, with majority ranging from 7-10 rhizomes. The variation in performance between MUARIK and NaSARRI was attributed to weather and soil differences between the two locations. Production of rhizomes in the tropical environment makes these temperate potentially useful in improving the non-rhizomatous cultivated Ugandan varieties. Evaluation of agronomic traits (days to 50% flowering, head count, tiller number, plant height and panicle characteristics) showed that the lines were adaptable Ugandan conditions, although many still contained wild traits from Sorghum halepense. Genotypes with agronomic traits close to those of cultivated sorghum can be selected for further evaluation and possibly use in introgressing the rhizome production trait in local varieties.

David van Tassel, The Land Institute

Domestication of domestication: the homely side of an exciting science

Drawing on 20 years of domestication trials and errors, I reconsider the classic domestication syndrome concept as it applies to perennials. I will also contrast the notion of rapid de novo domestication (e.g., via genome editing) with the previously successful formula of public investment in organismal biology (entomology, microbiology, crop physiology), dispersed, local agronomic trials and social science research and outreach. I invite audience brainstorming on how our community can sustain these vital yet homely arts despite a public research investment model increasingly using national/international competition to prioritize advances in theory and technological innovation.

Maria von Korff, Heinrich Heine University

Physiology and genetics of longevity in barley and its wild perennial relatives

(co-authored with Walla A and Zhong J)

We present the Hordeum genus with closely related annual and perennial species, including the annual cereal crop barley, Hordeum vulgare as a unique system to dissect the physiology and genetics of different life history strategies. The perennial Hordeum species revealed unique features in reproductive development compared to those found in perennial model plants, such as a lack of a juvenile phase, perpetual flowering and photoperiod-controlled cycling between vegetative and reproductive growth. Consequently, annual and perennial Hordeum species differed essentially in longevity.

We have also identified and characterized a barley mutant which tillers perpetually and survived for more than two years in the greenhouse. NGS mapping of a mutant derived backcross line demonstrated that this drastic change in plant longevity was controlled by a single gene that is involved in histone deacetylation, is exclusively expressed in axillary meristems and causes the misexpression of a handful of genes involved in cell proliferation and differentiation.

Giulia Vico, Swedish University of Agricultural Sciences
Water requirements and yield stability in annual vs. perennial crops
(co-authored with Nathaniel A. Brunsell)

An extensive dataset of traits of congeneric annual and perennial species is used to parameterize a probabilistic description of the soil water balance and crop development in the face of unpredictable precipitation. This modelling tool is used to identify the conditions under which perennial crops are more suitable than annuals with reference to yield, yield stability and efficient use of water. Perennials may better exploit available soil water and lead to more stable yields, but may have lower water productivity and, in some cases, final seed yields.

Alejandra Elena Vilela, Museo Egidio Feruglio-CONICET
The domino effect of selection for yield in perennial sunflower: from conservative to acquisitive
(co-authored with Luciana González-Paleo, David Van Tassel and Damián Ravetta)

Domestication and crop improvement have been largely focused on increasing yield of plants from wild germoplasm. While choosing wild candidates for grain production and ecosystem services provision, selection for high-yield inadvertently provoked a cascade of changes at different scales and levels, from crop to anatomy, altering the very same desirable traits for which wild plants were originally preferred. We present a hierarchical model and describe the changes observed in Silphium integrifolium after five generations of breeding for yield. The potential consequences of those changes on plant survival, stress tolerance, pest resistance, resource-use efficiency, nutrients cycling and profitability are discussed.

Bill Vitek, Middlebury College & New Perennials Project, Rockefeller Family Fund
Grains and Brains: A 10,000-Year Love Affair

This presentation explores the hypothesis that food systems and thought systems are co-emergent. Annual disturbance surplus agriculture (ADSA), for example, developed in many places around the globe 10-12,000 years ago, requiring and influencing 1) accounting systems: alphabets and numbers; 2) external storage systems: granaries, libraries, and schools; and 3) experts who maintain and manage material and cultural surplus: farmers, soldiers, accountants, teacher-scholars, and a ruling class. Like ADSA, annual thought systems focus on reduction, hierarchy, abstraction, efficiency, and short-term/high-yield productivity. Can a perennial agriculture, along with ancient

and contemporary notions of perenniality in wisdom traditions, the arts and sciences co-emerge to foster a regenerative future? The presentation concludes with a brief discussion of food-and-thought curricular experiments underway at Middlebury College in Vermont USA.

Len Wade, University of Queensland
Research Needs in Perennial Grains, with Reference to Perennial Rice

Since the FAO Experts Workshop in Rome on "Perennial Crops for Food Security" in Aug 2014, there has been much progress in developing perennial grains, including domestication (e.g. Kernza), and hybridization (e.g. release of PR23 perennial rice). Evidence of perennial crop performance is being published, and even data on root depth, water use, soil changes, and systems implications. But fundamental challenges to perennial crop philosophy remain, especially in physiology, resource balance and practicality. This paper draws attention to concerns about trade-offs, whether they are real, if they can be compensated by resource capture or ecosystem health, and implications for practical systems and end-products suitable for market. A research approach is briefly indicated, using perennial rice as the example.

Håkan Wallander, Lund University
Phosphorus efficient agriculture with arbuscular mycorrhizal fungi

In natural ecosystems plants live in symbiosis with arbuscular mycorrhizal fungi (AMF) that are efficient in taking up P from the soil. This symbiosis is poorly developed in modern agriculture since high levels of P downregulate the symbiosis. Most crops depend on easily available P sources but a large portion of soil P is poorly available. The aim of this project is to improve uptake of poorly available P sources in agricultural soils by creating better conditions for AMF. Preliminary results suggest significant P uptake by AMF from organic matter (maize compost) in a grassland in Iceland. In addition, ectomycorrhizal fungi utilized significant amounts of P adsorbed on iron oxide (goethite) in a Larix decidua forest growing on serpentine soils in Italy.

Anna Westerbergh, Swedish University of Agricultural Sciences
Domestication and wide-hybridization for development of perennial barley, and adaptive breeding of intermediate wheatgrass for cold temperate climates.

We have initiated the development of new cereal grain crops that are perennial for cultivation in Sweden and other cold temperate climates. Our evaluation of several candidate species and related plant material showed that wild perennial relatives of barley and wheat are valuable genetic resources. Applying different approaches adapted to the plant material used in our breeding, a diversity of perennial grains may be developed. This will contribute to sustainable agriculture in cold temperate climates by giving resilience to climate changes and a reduced negative environmental impact.

Christian Wever, University of Bonn

Creating a new crop—genetic evaluation and collection of Silphium perfoliatum L.

(co-authored with Lukas Becker, Martin Höller, Peter Westoff, Elena Pestsova and Ralf Pude)

The cup plant (Silphium perfoliatum L.) is like sunflower a member of the Asteraceae and native to the US. Due to its high biomass yield, Silphium is a promising alternative for energy maize. Silphium perfoliatum is a perennial plant with a broad range of ecological benefits: a long flowering period, an efficient growing under low-input agriculture, less weed killers and soil erosion. Until today almost no breeding attempts have been made for domestication of the cup plant and all field trials in Europe were done with the few available European genotypes of unknown origin. For making sure that future breeding will be based on sufficent germplasm diversity, a plant hunting trip to the US has been performed. Based on herbarium data over 40 accessions of Silphium were collected, which are covering its hole native distribution. These new genotypes were analysed via Tunable Genotyping By Sequencing (tGBS) technology and compared with the European genotypes on two levels, genetically via tGBS and phenotypically via field trials. Our study is illuminating the origin and history of the European accessions. First field data of the new Silphium perfoliatum accessions will be shown as well as results of crossbreeding with related species aiming for new agronomically traits.

Shilai Zhang, Yunnan University

Perennial Rice Breeding, Evaluation and Release

(co-authored with Jing Zhang, Guangfu Huang & Fengyi Hu)

Oryza longistaminata, is a perennial wild rice species from the same genus as cultivated rice, such as O. sativa. In 1997, RD23 and O. longistaminata were crossed, resulting in an F1 individual with strong rhizomes. Breeding and selection were carried out for many years. Several lines have been bred so far.Genotype by environment (GxE) interactions for grain yield were investigated in 22 perennial rice derivatives over four successive growing seasons at three sites in Yunnan in southern China and one site in Lao PDR. The result simply that regrowth success and maintenance of spikelet fertility over regrowth cycles are important for adaptation of perennial rice, especially to low minimum temperature at higher altitude and rainfall deficit at lower altitude, and future breeding programmer in perennial rice should address these environmental stresses. By (1) comparing its survival, regrowth, performance with preferred annual rices across nine ecological regions in southern Yunnan; (2) examining the economic costs and benefits of perennial versus annual rice there; and (3) discussing the evidence for the release of PR23 as a broadly adapted and acceptable cultivar for farmers. Overall, PR23 was proposed for release to farmers because of its comparable grain yields to annual rices, its acceptable grain and milling quality, its cost and labor savings, and the likely benefits to soil stability and ecological sustainability. And PR23 was got the release permit in 2018 issued by Yunnan government.

Yujiao Zhang, Yunnan University

Long term experiment of perennial rice

Perennial rice, which once planting can harvest more than 3-5 years reduced the links including plowing, seeds, seedling and transplanting etc. since the second year or season. The previous experiment in Yunnan Province showed that since the second year or season we can save 7500-9000 CNY for labor per hectare when we planted perennial rice. Now, the perennial rice has been tested in China, Laos, Vietnam, Cambodia, Myanmar, Uganda, Sierra Leone etc. "one belt one road" countries. In China, the perennial rice has been tested in Zhejiang, Jiangxi, Henan, Hubei, Hunan, Fujian, Guangdong, Guangxi, Guizhou, Yunnan etc. 10 Provinces, and the total cultivated area is more than 105 ha (76 sites) in Yunnan Province. However, the life span of perennial rice was not clear since now, and the soil properties and environment changes in long-term perennial rice field need to be clarified. Therefore, we set two long-term experiments to explore the characteristics of perennial rice, soil and environment dynamics in Manla Village, Menghai County, Yunnan Province, China since January 2019. The first experiment is different growth years of perennial rice (from 1 to 6 years) that to explore the optimal planting years of perennial rice and soil properties dynamics in field. The second experiment is straw return or not as the main plot, different perennial rice varieties as the sub-plot that to explore the characteristics of perennial rice and the soil and environment dynamics in field.

Hosts

The Pufendorf IAS is an interdisciplinary institute at Lund University. The institute is a place where researchers from all faculties at Lund University – from science and medicine to the humanities and arts – are invited to work together. The aim is to be a creative forum, an incubator for new ideas and a springboard for new research initiatives.

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The Land Institute, founded by Wes Jackson (Right Livelihood Laureate 2010), as a nonprofit organization in 1976, is committed to researching and developing food production methods that sustain the soil, the land, and rural societies.

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