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Sustainable Intensification of Agriculture

– Challenges in Soil Science confronting Global Food Security

Exploratory Workshop 30th – 31st of January 2018

Edited by Anke Herrmann & Åsa Larsson

Welcome to the *Sustainable Intensification of Agriculture* Workshop!

Global food security is one of the many pressing challenges currently facing humanity. The rapidly growing world population is putting pressure on food supply, and agriculture needs to adopt practices that minimize impacts on agroeco-systems while making them sustainable in the long-term with respect to provisioning and regulating services. The reform of the EU Common Agricultural Policy acknowledges this challenge and promotes a policy of sustainable intensification of agricultural land. In line with this international trend, the Swedish government launched a Food Strategy in June 2017.

Soils are a fundamental resource for all civilization as they are an important integral component of a sustainable agriculture for global food security. However, in most contemporary societies there is a general lack of awareness of the role and importance of soils. The challenge is that this 'underworld' is obscure, not least because the majority of its key attributes are invisible to the unaided eye – *out of sight is out of mind*. Furthermore, soils are also some of the most complex systems on the planet in terms of their physical structure, chemical constitution and bio-diversity. As such soils present a real challenge in terms of analyzing the mechanisms underlying their functioning. The Department of Soil & Environment at the Swedish University of Agricultural Sciences (SLU) aims to increase our understanding of soil chemical, physical and biological properties and processes - providing knowledge that is important for the sustainable use of soil as a natural resource.

The aim of this two-day exploratory workshop is to gather international and SLU researchers focusing on soil science related questions within the area of sustainable agriculture. We hope that this workshop will act as a think-tank for future common research proposals both on the national as well as the international level including outreach activities to the general public. The workshop is funded through SLUs strategic cross-disciplinary initiative on **Sustainable Multifunctional Land Use** and **SLU Future Food Platform**.

The organizing committee at the Dept. of Soil & Environment, SLU, Uppsala, January 2018

Day 1 – Tuesday, 30th of January 2018
Location: Audhumbla, VHC building

Session 1 Background – Why bother?

Chair: Anke Herrmann, SLU, Sweden

08.30 – 08.45 **Welcome, introduction and opening remarks**
Anke Herrmann, Soil & Environment, SLU, Sweden

08.45 – 09.30 **Sustainable intensification of agriculture – challenges and opportunities**
INVITED: Liesl Wiese, Stellenbosch University, South Africa

09.30 – 09.50 **FIKA**

Session 2 Sustainable Land Use & Water Management in Africa & Asia

Chair: Sigrun Dahlin, SLU, Sweden

09.50 – 10.10 **Small spaces for big change? The role of soil and water management for sustainable intensification of smallholder farming systems**
INVITED: Jennie Barron, Soil & Environment, SLU, Sweden

10.10 – 10.25 **Biochar for long-term food security in smallholder farms in Kenya**
Erik Karltun, Soil & Environment, SLU, Sweden

10.25 – 10.40 **Triple L – Land, Livestock and Livelihood (+soil) dynamics in a transition from pastoralism to livestock based agri-pastoralism**
Gert Nyberg, Forest Ecology & Management, SLU, Sweden

10.40 – 10.55 **Big data and small data: global data for local use**
Kristin Piikki, Soil & Environment, SLU, Sweden

11.00 – 11.20 **Current and future challenges to rice productivity**
INVITED: Kristin Boye, SSRL, Stanford University, USA

11.20 – 11.35 **A single gene helps reduce methane emissions from rice paddies**
Chuanxin Sun, Plant Biology, SLU, Sweden

11.35 – 11.50 **Soils CO_2 venting by rice as a mechanism for tolerating zinc deficiency**
Marie-Cécile Affholder, Soil & Environment, SLU, Sweden

12.00 – 13.00 **LUNCH**

Session 3 Future Potential of Long-Term Field Experiments & Farm Platforms

Chair: Sofia Delin, SLU, Sweden

13.00 – 13.30 **Developing farm platforms to support agri-systems research**
INVITED: Graham Begg, The James Hutton Institute, U.K.

13.30 – 14.00 **The North Wyke farm platform and other national capabilities at Rothamsted Research**
INVITED: Paul Harris, Rothamsted Research, U.K.

14.00 – 14.15 **Infrastructure at SLU's research stations**
Göran Bergkvist, Crop Production Ecology, SLU, Sweden

14.15 – 14.30 **Soil management long-term field experiments**
Ararso Etana, Soil & Environment, SLU, Sweden

14.30 – 14.45 **SITES – a resource for agroecological field research**
David Parsons, Agricultural Research for Northern Sweden, SLU, Sweden

14.45 – 15.00 **Long-term soil structure observatory for monitoring post-compaction evolution of soil structure**
Thomas Keller, Soil & Environment, SLU, Sweden

15.00 – 15.30 **FIKA**

15.30 – 17.00 **Discussion groups including feedback**

19.00 **Workshop Dinner: Lunch room MVM-building**

Word cloud based on submitted SIA abstracts

Session 1

Background – Why bother?

Sustainable intensification of agriculture – Challenges and opportunities

L. WIESE

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Correlation between human population growth and agricultural intensification (increase in agricultural production per unit of inputs) can be traced back to the beginning of the Neolithic Age roughly 12 000 years ago as humans introduced different technological adaptations to sustain growth in agricultural production. However, over time this intensification resulted in the degradation of various natural resources [1], which led to interest in agricultural sustainability [2]. The sometimes-controversial concept of sustainable intensification of agriculture (SIA) thus developed, broadly defined as "producing more food from the same area of land while reducing the environmental impacts" [3]. However, during implementation of SIA, care should be taken to ensure that productivity does not increase at the expense of sustainability. This challenge is especially apparent in industrial agriculture which is often characterised by high use of external inputs that benefits economic resource use efficiency over environmental and social benefits. In this case, implementation of SIA may therefore imply reduced use of inputs and necessitates priority setting, cost-benefit analyses and the weighing of trade-offs to balance economic, environmental and social outputs. Subsistence agriculture on the other hand is generally characterised by low external inputs and therefore presents a different side of the SIA spectrum. In this case, increased inputs are part of the solution to achieve SIA [4]. Ultimately, ensuring the achievement of SIA necessitates the definition of boundary conditions and associated metrics to measure and evaluate its implementation and effect [5]. Although SIA raises various challenges, the need for increased food production without an increase in agricultural land is clear and various research opportunities arise as a result. This presentation will explore the various challenges and opportunities arising, with specific focus on soil research. This includes opportunities to implement and test systems approaches for sustainable intensification in agriculture, addressing sustainable soil management (including aspects of soil quality, nutrient uptake and carbon management), nutrition-sensitive agriculture, maintaining the essential functions of soils under changing agricultural input regimes, the generation and use of soil data and information to monitor soil changes resulting from SIA and more.

[1] FAO. 2004. The ethics of sustainable agricultural intensification. [2] Godfray et al. 2010. Science. (80)327,812–818. [3] Pretty & Bharucha. 2014. Ann. Bot. 114,1571–1596. [4] Smith et al. 2017. Glob. Food Sec. 12,127–138. [5] Struik & Kuyper. 2017. Agron. Sustain. Dev. 37,39.

Session 2

Sustainable Land Use & Water Management in Africa & Asia

Small spaces for big change? The role of soil and water management for sustainable intensification of smallholder farming systems

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Often the concept of 'sustainable intensification' focusses on crop and agronomy aspects closing yield gaps in smallholder farming systems, which dominates Sub Sahara Africa (SSA) and many parts of Asia. Yet, in degraded landscapes and agro-ecological areas with temporal and spatial water limitations, none of these will be effective without also addressing fundamental soil physical conditions, soil water characteristics and water management. In this talk, we discuss how soil and water management research are fundamental to attain and leverage scaling of other aspects of sustainable intensification, such as crop rotation, integrated nutrient and pest management, and improved seeds. We start with a presentation providing insights on the context of smallholder farming systems, i.e. the 470 million farms with 2 ha or less of crop land, mostly situated in the developing and emerging economies. Two examples of transformative change through technology adoption for sustainable intensification is shared from recent research of the CG research program 'Water, Land, Ecosystems' (www.wle.cgiar.org). Firstly, we share findings on the small scale individual irrigation trend occurring in SSA smallholder farming systems. It has increased exponentially in several SSA countries in the last 10-15 years, and contributed to intensification and productivity gains, albeit not always sustainably, nor equitably so in all aspects. The second substantial effort in sustainable intensification is around rehabilitation of largely degraded land though various soil and water management efforts in South Asia and parts of SSA. These efforts focusing on rain fed cropping and have often been supported heavily by donors and governments in implementation. Whereas these technologies has aided intensification, increasing variability in rainfall require new approaches to be effective for productivity and for ecosystem services. Based on these two examples, we discuss the implications on need for new research to support further efforts in sustainable intensification, with specific reference to soil and water management in the development context. We propose three key topics are critical 1) issues on data and management of soil physics characteristics to enhance water availability and soil health, 2) the time-space dimensions of water management and 3) the critical importance of new knowledge among farmers, and other practitioners, policy and investment players, alongside researchers.

Biochar for long-term food security in smallholder farms in Kenya

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Application of biochar (BC) has been shown to increase soil fertility and mitigate climate change through soil carbon sequestration. However, little is known about the persistence of crop yield responses reported in the literature. To investigate the long-term effect of BC application, we laid out meta-replicated field experiments in 2006 in Kenya. During 20 growing seasons (10 years) the positive effect on crop yield has been persistent after application of 10 kg BC m^{-2} during the first year of the experiment, both in treatments with and without mineral fertilization. In 2015, new experiments were started for testing the effect of much lower application rates of BC on crop performance. Crop yields increased with rates of BC application at all sites. The results from our controlled field experiments are supported by preliminary results from an ongoing participatory project involving paired on-farm plots with and without BC application on 152 smallholder farms in Kenya. In conclusion, the yield enhancing effect of BC is long-lasting at all studied sites. BC, which can be locally produced in small-holder farms in Kenya from different region-specific organics resources has the potential to increase food security and reduce poverty in many rural areas.

Triple L – Land, Livestock and Livelihood (+soil) dynamics in a transition from pastoralism to livestock based agri-pastoralism

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The Triple L research initiative is a multidisciplinary research initiative taking its base in the land-use and livelihood transformations that has taken place in West Pokot, Kenya, during the last three decades. These transformations are relevant and common to vast areas of drylands in Sub-Saharan. Population increase and the commodification of agriculture are strong drivers in this transition. In enclosures where grazing is controlled there is higher vegetation ground cover and higher proportion of perennial grasses as compared with surrounding areas with open access grazing. Also soil parameters as SOC (+30%), TN (+30%), microbial respiration (+100%) and soil moisture (30-70%) increase inside enclosures. Although not immediate, soil effects are not directly related to age of enclosures (0- >20 years). Livelihoods have improved and

agriculture is more productive and diversified than before. However, livelihoods and culture remains strongly livestock passed. Some 70% of household incomes derives from livestock.

[1] Nyberg et al 2015. Pastoralism: Research, Policy and Practice. 5:25. [2] Wairore et al 2016. Land Degradation & Development 27:532.

Big data and small data: global data for local use

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Development of global and continental soil databases will change the manner in which soil data can be included in the decision-making processes in society, both at the policy level but also locally in villages and individual farms. Recently developed digital soil mapping products are detailed enough to give the impression that no further soil sampling is required, and it can be expected that such soil databases will be used as a quick and low-cost alternative to new soil sampling campaigns. However, even if global validations indicate precise and accurate predictions, comparisons with local data reveal that even when used for estimates of average statistics for agricultural land across relatively large regions there might be considerable discrepancies. Nonetheless, by combining the global database with a relatively small number of local soil observations it is possible to locally adapt (i.e. downscale) the global data and significantly improve the accuracy within an area of interest. This methodology was evaluated at five locations (in Europe and Africa) [1], and has been implemented in a decision support system in Sweden [2]. In conclusion – big data alone will not be the solution for sustainable intensification.

[1] Söderström, Piikki 2017, http://bit.ly/2r956AR. [2] Piikki et al. 2017, DOI10.1017/S2040470017000966

Current and future challenges for rice production

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Rice is a daily staple for more than 35 million people, providing >19% of the daily global dietary energy. Estimates state that rice yields need to increase by 25% in the next 25 years in order to meet the demands of the growing population. At the same time, climate change, nutrient deficiencies, land degradation, and contaminants pose major threats to rice quality and yields. Worldwide research efforts are directed at predicting and mitigating these challenges, ranging from understanding the mechanisms underlying the responses of rice to change, breeding and engineering new crop varieties, to educating and developing tools for farmers to optimize fertilizer and management strategies. This presentation will provide an overview of challenges to rice production and mitigating efforts being developed to meet them, with the focus being on research conducted within the Fendorf group at Stanford University. Our research is aimed at understanding the effects of climate change and amendments on rice uptake of arsenic, a major concern for rice productivity and consumption. Through developing a mechanistic understanding of the biogeochemical processes in the soil-root-water interface of paddy rice, we provide knowledge that helps improve predictions and tailored mitigation methods to meet current and future challenges for sustainable and intensified rice productivity.

A single gene helps reduce methane emissions from rice paddies

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Climate change and food security require future crops with higher production and less environmental drawbacks. Paddy rice is a major staple food for human race. Global average consumption of rice per person is 100 kg. Production of every 100 kg of rice generates 14 kg methane. Annually, the global rice agriculture produces up to 100 million tonnes of methane, an equivalent of CO_2 emission from 250 million cars in terms of greenhouse gas effects. As the human population is growing, demand for rice will certainly increase, which leads to even more methane emissions. The issue of mitigating methane emissions from paddies must be addressed. We have invented a low-methane and high-starch rice variety, *SUSIBA2* rice previously[1]. *SUSIBA2* rice was engineered by adding a single barley gene to a conventional rice variety and has 90% less methane emissions and 10% higher yield than the conventional variety. A

theoretical calculation indicates that if the world adopts *SUSIBA2* rice in rice agriculture, a global environmental improvement of an equivalent of removing 125 million cars from the road can be generated and additional 700 million people´s food can be provided. I will present how we developed *SUSIBA2* rice for the global rice agriculture.

[1] Su et al. 2015, *Nature* 523, 602-606

Soil CO_2 venting by rice as a mechanism for tolerating zinc deficiency

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Zinc (Zn) deficiency often limits paddy rice yields, and it causes serious health problems in human populations with rice-based diets. Deficiency tolerance and ability to concentrate Zn in grains are priorities in rice-breeding programmes. However, progress is impeded by poor understanding of underlying mechanisms. We sought to explain rice genotype differences in Zn deficiency tolerance and also the counter-intuitive observation that Zn uptake per plant increases with increasing planting density [1]. This observation can only be explained by some interaction between neighbouring roots resulting in greater Zn solubility or neutralization of a toxin (e.g., HCO_3) or both. A potential mechanism, which has not received attention, is the venting of soil CO_2 through the roots. We grew tolerant and intolerant rice genotypes in a Zn deficient flooded soil and measured plant growth, Zn uptake and changes in the composition of the rhizosphere soil solution [2]. We also measured depletion of CO_2 bubbles around rice roots using X-Ray Computed-aided Tomography images. We concluded that differences in venting of soil CO_2 through root aerenchyma were responsible for the genotype and planting density differences.

[1] Mori et al. 2016. Front. Plant Sci. 6, 1160. [2] Affholder et al. 2017. Plant Cell Environ. 40, 3018-3030.

Notes

Lanna Research Station © Mats Söderström, SLU.

Session 3

Future Potential of Long-Term Field Experiments & Farm Platforms

Developing farm platforms to support agri-systems research

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The James Hutton Institute formed in 2011 from the merger of the Macaulay Land Use Research Institute and the Scottish Crop Research Institute. The development of the James Hutton Institute with its combined strengths in crops, soils, land use and environmental research, has been driven by the need to tackle key global issues, such as food, energy and environmental security. The importance of agricultural sustainability in addressing these challenges is widely recognized and is central to much of the work of the Institute. The move away from a production only focus to one that seeks to balance the economic, environmental, and social performance of farming demands new approaches to agricultural research and new requirements of the facilities on which this research relies. The James Hutton Institute runs four research farms which include a range of production systems and environmental conditions, together representing much of Scotland's agriculture. Like many research farms, their primary goal has been to support field-based experiments with the commercial production of livestock and crops fitting within this framework. The balance between field-experiments and commercial production, and the nature of the experimental work, is driven by the needs of the Institute's scientists in fulfilling the requirements of short-term projects rather than following a strategic research program. There are exceptions to this, most notably the Centre for Sustainable Cropping, located on the Balruddery Research Farm, is a 46 ha long-term experimental platform comparing an arable rotation under conventional versus integrated management. This experiment is indicative of the whole-systems approach to agricultural research that is needed to fully understand how to farm sustainably, optimizing social, economic and environmental outcomes. There is a need to extend this approach and to reconsider the way in which research farms are used and operate. Driven by this challenge and drawing on our experience in agroecology research and sustainable agricultural systems we have proposed a new approach, integrating experimental research and commercial production within a farm-systems framework. A shift in the priorities and focus of research farms in this way could provide a clearer route to application for small-scale experimental studies, increase the research and innovation potential of the commercial operations, and provide a new basis for farm systems research.

The North Wyke farm platform and other national capabilities at Rothamsted Research

P. HARRIS

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The North Wyke Farm Platform (NWFP) was established in 2010 as a UK national capability for collaborative research, training and knowledge exchange in agro-environmental sciences looking at agricultural productivity and ecosystem responses to different management practices for beef and sheep production in lowland grasslands. A systems-based experiment on permanent pasture was implemented in 2011 on three 21 ha farmlets in order to obtain baseline data in hydrology, nutrient cycling and productivity for 2 years. In 2013, two farmlets were progressively modified over a 2-year period through either: (i) planned reseeding with grasses which have been bred for high water soluble carbohydrate or deep rooting traits; or (ii) sowing grass and clover-legume mixtures to reduce nitrogen fertiliser inputs. This forms the *first* post-baseline phase of the NWFP which is due to end in 2019. Each farmlet currently supports 30 weaned beef cattle and 75 ewes and their lambs, that graze 5 hydrologically-isolated catchments instrumented to measure rainfall, soil moisture/temperature, water discharge and physical/chemical properties. Some catchments consist of multiple fields. Inputs of fertilisers, herbicides and farmyard manure are recorded and field surveys for soils, plants and fauna are conducted periodically. The NWFP Data Portal https://nwfp.rothamsted.ac.uk/ provides the ability to freely-download the data for specified time periods and catchments; and has been populated with time series, livestock, field event and field survey data. Many campaign data sets also exist, where to date, 90+ such collections have been conducted across a variety of topics (http://resources.rothamsted.ac.uk/farmplatform). Research teams mesh campaign data with the freely-available core data (from the data portal) to robustly test study hypotheses. Covering many campaigns has been the measurement of greenhouse gas (GHG) emissions, where the importance of this data has entailed that GHG data has been re-assigned as core data and will eventually be made freely-available via the data portal. Other notable data sets include animal movement data and remotely sensed data. The promotion of the NWFP as a sensor testbed is also on-going, where the value of both GHG and phosphorous low cost sensors are currently being evaluated. Agri-model development and evaluation is also a key component of the NWFP, where its core high-resolution data sets are vital to such assessments. Rothamsted also hosts two other National Capabilities: (a) the Long-term Experiments (LTEs - started 1843) and (b) the Rothamsted Insect Survey (RIS - started 1964 and is UK-wide).

Infrastructure at SLU's research stations

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Agricultural field experiments at SLU are mainly carried out at four research stations situated at Lövsta, Lanna, Röbäcksdalen and Lönnstorp in east, west, north and south Sweden, respectively. The stations at Röbäcksdalen and Lönnstorp are part of the Swedish Infrastructure for Ecosystem Science – SITES – partly funded by Vetenskapsrådet. The NJ-faculty at SLU has in later years also made investments at Lövsta and Lanna with the aim to improve the capacity also at those stations. The most important infrastructure at the research stations are probably the Long-term field experiments (LTEs) that are a useful resource when assessing impact of management practices on soil, water and production. There are about 40 LTEs at almost 80 sites, of which a majority is situated at the four research stations, but quite many also in farmer fields and managed by other operators than SLU. The LTEs older than about 50 years typically investigate the effect of cropping systems, crop rotations and fertiliser doses on yield and soil fertility. More recent LTEs tend to focus on efficiency in use of soil resources and on environmental effects. A Management Board was formed in 2007 to encourage Departments to re-evaluate their existing LTEs and even start new LTEs.

Soil management long-term field experiments

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Soil management plays a key role for soil organic matter turnover and in shaping soil structure, and therefore has a large impact on ecosystem services provided by arable soil including productivity. Since many soil processes are slow, effects of soil management on soil properties and functions become measurable only after years to decades. Long-term field experiments provide a platform for monitoring impacts of soil management on soil functions. Eleven long-term field experiments with focus on soil management aspects are currently run by the Department of Soil and Environment at the Swedish University of Agricultural Sciences (SLU), funded by the Faculty of Natural Resources and Agricultural Sciences at SLU. The experiments address various research questions and include different soil tillage systems in combination with either crop rotation, compaction level, straw residue management or fertilizer placement. About half of the experiments are located in Uppsala. This presentation will describe the objectives and designs of the soil management long-term field experiments, present selected results, and discuss ways to better diffuse and use these valuable resources.

SITES – a resource for agroecological field research

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SITES (Swedish Infrastructure for Ecosystem Sciences) is a nationally co-ordinated infrastructure for terrestrial and limnological field research, extending through different ecosystems and climatic zones. Two of the nine stations, are on agricultural lands: Lönnstorp in Skåne and Röbäcksdalen in Västerbotten. Activities on the agricultural stations include climate monitoring, measurement of hydrological parameters from waterways, chemical and physical monitoring of soils, phenological data collection, collection of spectral data, long term field experiments, and future cropping systems. SITES is accessible for all researchers, regardless of their institution. A researcher may use existing data or archived samples, stay at the station to take measurements using that station's infrastructure, or outsource tasks which are managed by the station. Through utilising the SITES infrastructure we aim to enable collaboration between scientists, facilitate research opportunities, and promote agroecological research, leading to more sustainable production systems.

Long-term soil structure observatory for monitoring post-compaction evolution of soil structure

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The projected intensification of agriculture to meet food targets of a rapidly growing world population is likely to accentuate already acute problems of soil compaction. Compaction caused by farming traffic alters soil structure, thereby negatively affecting soil hydro-ecological functions. The ecological and economic costs of compaction are given by the cumulative loss of soil functions following a compaction event, integrated over time until a soil has recovered to its pre-compaction state, and hence directely related to the recovery time. The lack of reliable observations and metrics for post-compaction soil structure recovery rates and times motivated the establishment of a long-term soil structure observatory (SSO). The SSO was launched in 2014 on a loamy soil in Zürich, and designed to provide information on recovery of compacted soil under different post-compaction soil management and cropping systems, including natural recovery of bare and vegetated soil as well as recovery with and without soil tillage. This presentation will describe the objectives, the design, the implementation, and monitoring concept of our soil structure observatory and present selected results of the initial compaction effects and the short-term recovery.

Notes

Day 2 – Wednesday, 31st of January 2018
Location: Lecture hall W, Ulls hus building

Session 4 Developing Novel Farming Systems

Session 4a Soil Management & Soil Structure Dynamics

Chair: Thomas Keller, SLU, Sweden

08.30 – 09.00 **The roots of soil structure**
INVITED: Paul Hallett, Aberdeen University, U.K.

09.00 – 09.15 **An interdisciplinary research framework to improve crop productivity on soils of high penetration resistance**
Tino Colombi, Soil & Environment, SLU, Sweden

09.15 – 09.30 **Using X-ray tomography to quantify the impacts of soil management and soil organic carbon on soil structure and functions**
Nick Jarvis, Soil & Environment, SLU, Sweden

09.30 – 09.45 **Quantification of soil structure dynamics after tillage**
Reza Hosseinpour Ashenaabad, Soil & Environment, SLU, Sweden

09.45 – 10.00 **Influence of soil structure and drainage on water transport in soils close to saturation**
Annette Dathe, Norwegian Institute of Bioeconomy Research, Norway

10.00 – 10.20 **FIKA**

Session 4b Precision Agriculture & Soil Fertility

Chair: Bo Stenberg, SLU, Sweden

10.20 – 10.50 **Sustainability through precision agriculture**
INVITED: Ken Sudduth, USDA Agricultural Research Service, USA

10.50 – 11.05 **Precision agriculture for everyone through intelligent decision support systems**
Mats Söderström, Soil & Environment, SLU, Sweden

11.05 – 11.20 **Near infrared spectroscopy in soil science**
Bo Stenberg, Soil & Environment, SLU, Sweden

11.20 – 11.35 **Potential for NIR and MIR spectroscopy to estimate soil carbon fractions identified by solid state ^{13}C NMR spectroscopy**
Johanna Wetterlind, Soil & Environment, SLU, Sweden

11.35 – 11.50 **Towards the optimal nitrogen fertilization in wheat production**
Karin Hamnér, Soil & Environment, SLU, Sweden

12.00 – 13.00 **LUNCH**

Session 4c **Soil Functioning – Biology Matters**

Chair: Björn Lindahl, SLU, Sweden

13.00 – 13.30 **An underground revolution: Biodiversity & soil ecological engineering for agricultural sustainability**
INVITED: Marcel van der Heijden, Agroscope, Switzerland

13.30 – 13.45 **Agro-ecosystem diversification: Digging deeper**
Aurélien Saghai, Forest Mycology & Pathology, SLU, Sweden

13.45 – 14.00 **Nitrogen retention or loss relies on the relative abundance of denitrifying and DNRA bacteria and their activity in agricultural soil**
Martina Putz, Forest Mycology & Pathology, SLU, Sweden

14.00 – 14.15 **Bioenergetics of microbial communities in soil systems**
Tobias Bölscher, Soil & Environment, SLU, Sweden

14.15 – 14.30 **Crop residue addition in the upper subsoil increases crop yield and alters soil chemical and biological properties – a short term investigation**
Masud Parvage, Soil & Environment, SLU, Sweden

14.30 – 15.00 **FIKA**

Final Session Workshop Wrap Up

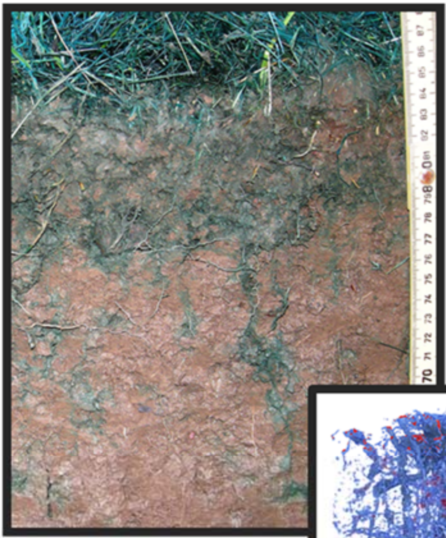
Chair: Anke Herrmann, SLU, Sweden

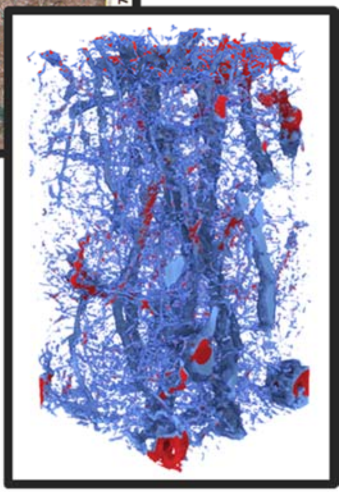
15.00 – 15.40 **Discussion groups**

15.40 – 16.00 **Reconciliation:**
S.O.S. – Save Our Soils. The most valuable yet least appreciated resource
Peter Sylwan, Science Writer & Agronomist, Sweden

16.00 – 16.30 **A common "ground" for sustainable development?**
Panel discussion with invited speakers

16.30 – 17.00 **Workshop summary & outlook**





Session 4a

Developing Novel Farming Systems

Soil Management & Soil Structure Dynamics

The roots of soil structure dynamics

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One way to use less resources for sustainable intensification in agriculture is to get plant roots to do the work. Roots are a major source of easily decomposed organic matter into soil, and the combination of the hydraulic and mechanical stresses they impart to soil provides a major physical nucleus of soil structure development. Using rheological tests, we have found that root mucilage exuded into soil disperses soil particles if produced by barley, but gels particles if produced by maize [1]. After microbial decomposition, dispersion caused by barley exudates changes to gelling, suggesting that roots may ease penetration and expose new mineral surfaces for nutrient capture when they first grow, followed by stabilised aggregation over time to create the rhizosphere. Root exudates may also decrease the risk of compaction stress and improve the capacity of roots to penetrate strong soils [2]. We found that amending soil with root exudates increased compressibility (compression index) by 16% and a modelled root elongation rate by 40%. Root exudates influence water dynamics considerably, with effects varying between species. Whereas maize root or a model root exudate consisting of chia seed exudate holds onto water as a hydrogel, barley root exudates with their low surface tension act as a surfactant. A hydrogel holds more water to improve drought resistance, whereas a surfactant makes it easier for a root to capture water from soil, so both offer a physiological advantage to the plant. As the root-soil interface matures, the rhizosphere forms. Using very high-resolution Synchrotron tomography, we have found that this small physical volume, in most agricultural soils, restructures to recreate macropore volumes lost due to compression induced by roots during growth [3]. Vital to this restructuring of soil is the presence of root hairs that are small appendages that increase the zone of influence of the root and anchor it into surrounding soil. At larger-scale, roots provide mechanical reinforcement that holds together soil [4] and the hydraulic stresses they generate through transpiration may be one of the most important, yet widely ignored, underpinning processes in soil structure genesis [5]. The influence of roots on soil structure dynamics varies between species and the initial conditions of soil. There is considerable scope to alter the traits of roots and the selection of crops in a rotation to help drive soil structure at the same time as increasing yields.

[1] Naveed et al. 2017. Eur. J. Soil Sci. 68, 806-816. [2] Oleghe et al. 2017. Plant Soil 421, 19-30. [3] Koebernick et al. 2017. New Phyt. 216, 124-135. [4] Loades et al. 2013. [In] Advances in Agricultural Systems Modeling 4. Enhancing Understanding and Quantification of Soil–Root Growth Interactions, 197-228. [5] Hallett et al. 2009. Plant Soil 314,183-196.

An interdisciplinary research framework to improve crop productivity on soils of high penetration resistance

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High penetration resistance characterizes both compacted and dry soils and reduces root growth and crop productivity. When exploring soils of increased penetration resistance, plant roots need to exert higher penetration stresses. This results in increased energy and carbon costs of root growth, which in turn reduces the carbon readily available for shoot growth and grain formation. The development of crop varieties that may exploit soil at lower carbon costs is a promising approach to increase crop yields in compacted and dry soils. We therefore aim to identify functional root traits, which reduce the energy requirements of root growth in soils of increased penetration resistance. To achieve this an interdisciplinary framework is needed, which will be presented. We use isothermal calorimetry to quantify the energy turnover of growing roots and biomechanical models to calculate root penetration stresses. In combination with plant phenomics, i.e. the assessment of multiple root phenotypic properties, we can then identify root traits that govern the energy requirements of root growth. Based on such information, crop breeders can define selection criteria to develop varieties with superior performance on soils with high penetration resistance.

Using X-ray tomography to quantify the impacts of soil management and soil organic carbon on soil structure and functions

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Sustainable agricultural production is dependent on the structure of the soil pore space, because it influences almost all important functions and processes in soil. In turn, soil structure is affected by land use and management practices through a complex web of interacting physical (i.e. tillage, traffic) and biological (i.e. organic carbon storage, soil macro-fauna) factors and processes. The study of these feedbacks and interactions has been hampered in the past by a lack of measurement techniques to non-destructively quantify soil structure. In this talk, we will present the results of some recent [1, 2, 3] and on-going studies carried out to investigate and quantify the complex links between soil and crop management practices, soil organic carbon storage and soil functions and processes, making use of X-ray tomography to non-destructively image the characteristics of soil structural pore networks.

[1] Larsbo, M., et al. 2016. Vadose Zone Journal, doi:10.2136/vzj2016.03.0021. [2] Jarvis, N.J., et al. 2017. Agric., Ecosyst., Environ., 247, 319-328. [3] Jarvis, N.J., et al. 2017. Geoderma, 287, 71-79.

Quantification of soil structure dynamics after tillage

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Tillage aims at optimizing the soil environment for crop growth and involves alteration of the structure of the topsoil by mechanical agitation. However, freshly tilled soil is unstable. The tilled soil therefore undergoes slumping, largely caused by climatic forces (wetting-drying). Slumping is associated with changes in soil structure and associated functions, e.g. fluid transport. Although the processes involved in post-tillage soil structure dynamics are generally well established, their quantitative and predictive representation remain limited. The current doctoral research project aims at advancing the quantitative description of post-tillage soil structure evolution. We will combine monitoring of soil structure evolution in long-term field experiments, targeted small-scale experiments in the laboratory to better understand the slumping mechanisms (such as coalescence, slaking due to compression of entrapped air, and micro-cracking due to differential swelling) and their relative importance, and modelling approaches at the aggregate scale that consider geometrical representation of aggregates, hydraulic stresses and physical properties of soil. We will present the framework of the PhD project and the experimental set-up of the first series of small scale mechanistic studies.

Influence of soil structure and drainage on water transport in soils close to saturation

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Agriculture in Scandinavia could benefit from a changing climate because of raising temperatures, but soils tend to be too wet for early spring cultivation and a timely harvest of grain crops during late summer and early fall. For the future even higher amounts of rainfall and higher intensities and more erratic precipitation patterns can be expected. To provide guidelines on improved cultivation methods we first have to understand the underlying soil physical principals which govern water transport in these soils. Soil macropores and the drainage system are the main pathways for subsurface water transport close to saturation. Insufficient drainage could increase surface runoff and therefore the risk of soil erosion. We will present ongoing basic research on the relationship between soil structure and water transport properties, conducted in a joined project of NIBIO and SLU, and applied research conducted by NIBIO at different locations in Norway to obtain increased knowledge about the interaction between drainage intensity, groundwater level, soil moisture content and the impact on trafficability, yield and nutrient losses.

Notes

Session 4b

Developing Novel Farming Systems

Precision Agriculture & Soil Fertility

Sustainability through precision agriculture

K. SUDDUTH

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As population and standard of living increase in many parts of the world, so will the need for food and other agriculturally-based products. To be sustainable, these increases in production must occur with minimum impact on the environment and with efficient use of production resources, including land, water, energy, and other inputs. This sustainable intensification will require farmers and their advisors to better understand and optimize production systems under the constraints of varying soils, weather, and the host of biotic and abiotic stresses that can affect production. This process is enabled by precision agriculture, using electronic and computer systems to collect, manage, and extract information about the farming enterprise both spatially within fields and temporally through the growing season. Precision agriculture then uses this information to automatically control the machines that implement field operations. By recognizing and building on the value of information in agricultural decision-making, precision agriculture allows farmers to "do the right thing, at the right place, at the right time." By targeting management operations and inputs according to crop needs, precision agriculture increases the economic and environmental sustainability of crop production, thus enabling progress toward the goal of sustainable intensification.

Precision agriculture for everyone through intelligent decision support systems

M. SÖDERSTRÖM*, K. PIIKKI, L. ENGSTRÖM, J. WETTERLIND, B. STENBERG

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Precision agriculture has been recognised as one important component in sustainable, intensified agricultural production. Achieving a broad adoption requires new tools to support advisors and farmers. Moreover, adequate and detailed data must also be available. Recently, two decision support systems (DSS; CropSAT.se [1] and Markdata.se [2]) have been developed that cover most of Sweden's arable land, and in addition provide data detailed enough to be used for within-field applications. Both systems were designed for farmers, and have interactive functions in order to include the users' data, expertise and knowledge. The first system focuses on crop status and nitrogen uptake and is based on semi-real time satellite data, whereas the latter is created on top of a new digital soil mapping database of arable land. So far the systems have been free to use, and they have been implemented in a national programme for improved nutrient efficiency [3]. The systems have had several thousand users yearly, and we believe they are the first step into a new type of DSS that is needed in the challenging endeavour of increasing yields whilst reducing environmental impact.

[1] Söderström et al. 2017, DOI10.1080/09064710.2017.1324044. [2] Piikki, Söderström 2018, DOI10.1016/j.geoderma.2017.10.049. [3] Focus-on-Nutrients (http://www.greppa.nu)

Near infrared spectroscopy in soil science

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This presentation is based on a review article in Advances in Agronomy [1]. A review of the past and current role of vis–NIR spectroscopy in soil analysis is provided, focusing on important soil attributes such as soil organic matter (SOM), minerals, texture, nutrients, water, pH, and heavy metals. We then discuss the performance and generalization capacity of vis–NIR calibrations, with particular attention on sample pre-treatments, co-variations in data sets, and mathematical data preprocessing. Field analyses and strategies for the practical use of vis–NIR are considered.

[1] Stenberg B., Viscarra Rossel R.A., Mouazen A.M. and Wetterlind J., 2010. Visible and near infrared spectroscopy in soil science. Advances in Agronomy, 107: 163-215.

Potential for NIR and MIR spectroscopy to estimate soil carbon fractions identified by solid state ^{13}C NMR spectroscopy

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The turnover of soil organic matter is a key function in the terrestrial ecosystem. Soil organic matter (SOM) consists of a wide range of heterogeneous material and total amounts are often not enough when describing carbon pools. There is also a need to further our understanding of the chemical composition of SOM in order to better understand the mechanisms governing terrestrial carbon cycling. Solid-state ^{13}C Nuclear Magnetic Resonance (NMR) spectroscopy is a powerful technique for determining the structure of SOM. But the technique is time consuming and expensive which strongly limits the number of samples that can be analysed. In comparison, reflectance spectroscopy in the near infrared (NIR; 780-2500 nm) and mid infrared (MIR; 2500-25000 nm) wavelength ranges are fast, easy-to-use and the techniques are comparably cheap per measurement. In a study on Swedish agricultural soils, NIR and MIR spectroscopy were used to predict ^{13}C NMR derived C-groups with promising results. The Alkyl/O-alkyl ratio has been suggested as a good indicator of the degree of decomposition of the organic matter and was estimated with good predictions especially using the MIR region. The spectroscopic techniques have the potential for *in-situ* estimates and this will be further studied in a newly funded project.

Towards the optimal nitrogen fertilization in wheat production

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Nitrogen (N) plays an important role in wheat production with major impact on both yields and grain quality. Since N input is associated with both high costs for the farmer and risk of losses to the surounding environment it is of utmost importance to optimize N fertilization. Efficient N fertilization is possible through split N applications and sensor techniques, where N input during late developmental stages has been shown to be an efficient way to improve yield and protein content in wheat grains. However, systematic studies on N accumulation and retranslocation in wheat during late developmental stages are currently lacking. The overall aim of this project is to further optimize N use efficiency in wheat crop production and increase yield and protein content in wheat grains. In pot- and field trials, the potential of different wheat genotypes to acculumlate N around and after flowering will be examined. Together with increased knowledge on dissolution rates of mineral N fertilizers, results will help farmers to make imformed decisions about application timing for optimal N use during the cropping season. This will contribute to a sustainable crop production by increasing the profitability for the farmer and decreasing negative environmental impact.

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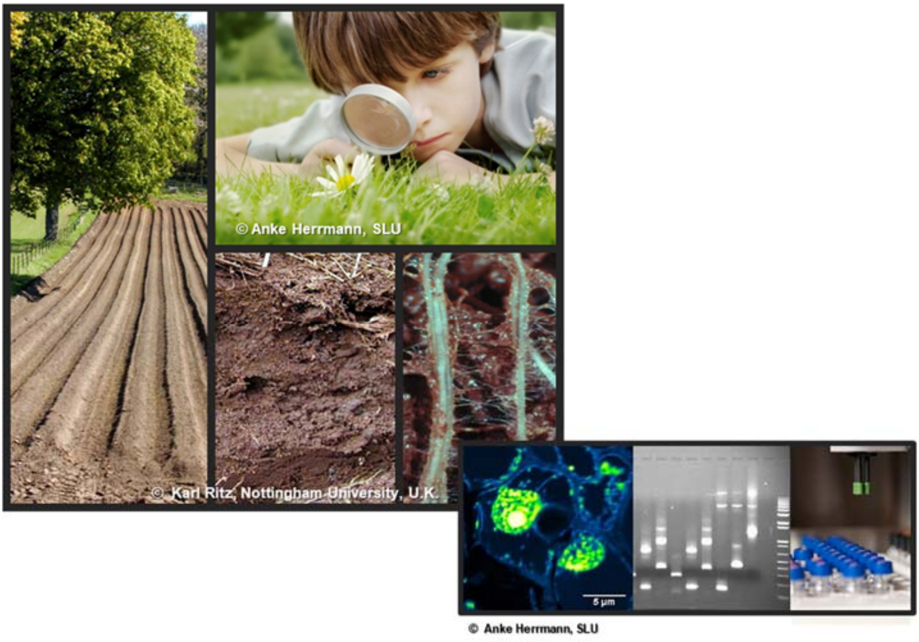

Session 4c

Developing Novel Farming Systems

Soil Functioning – Biology Matters

An underground revolution: Biodiversity & soil ecological engineering for agricultural sustainability

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One of the primary challenges of our time is to develop sustainable farming systems that can feed the world with minimal environmental impacts. There is an increased awareness that agricultural sustainability starts below ground in the soil. Here I discuss the potential of soil organisms to enhance ecosystem service delivery and demonstrate that below ground biological diversity promotes multiple ecosystem functions simultaneously (i.e., ecosystem multifunctionality). Then results will be presented that demonstrate how soil management and various land use practices including organic, conventional and conservation agriculture influence soil life and how these practices influence short term economic benefits (e.g. yield) and long term environmental costs (e.g. soil erosion, soil carbon sequestration and global warming potential). Soil ecological engineering [1] is presented as a concept to generate human land-use systems, which can serve immediate human needs while minimizing environmental impacts. Next, a number of direct (e.g. field inoculation with beneficial soil biota) and indirect measures (altered agricultural management) will be discussed that may help to enhance the sustainability of agro-ecosystems.

[1] Bender et al. 2016. Trends in Ecology & Evolution 31: 440-444.

Agro-ecosystem diversification: Digging deeper

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Biodiversity loss has become a global concern as evidence accumulates that it weakens ecosystem services on which society depends. While most studies have targeted aboveground communities, a large part of biodiversity remains hidden below ground. Whether reduction of soil biodiversity has consequences for the overall performance of an ecosystem is still poorly understood, but several studies indicate that soil biodiversity is decreasing upon land-use intensification in agro-ecosystems. This loss is of particular concern due to the importance of agricultural systems for food production and water quality, which directly depend on inherent supporting and regulating biotic processes occurring in soil. Simplified model systems have shown that soil biota play essential roles in regulating services (e.g. nutrient cycling), but we lack a conceptual and applied framework at larger scales and in complex systems. The next frontier is therefore to understand whether and how changes in aboveground biodiversity alter the relationship between soil biodiversity and ecosystem multifunctionality. We will combine a pan-European sampling campaign with various greenhouse trials in order to unravel whether innovative farming practices that increase plant diversity are a vehicle for optimizing the simultaneous delivery of multiple beneficial soil ecosystem services.

Nitrogen retention or loss relies on the relative abundance of denitrifying and DNRA bacteria and their activity in agricultural soil

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A challenges in agriculture is the mitigation of the fertilizer caused greenhouse gas N_2O while ensuring high crop yields. A higher degree of nitrogen retention is desired for sustainable intensification of agriculture. Nitrate (NO_3^-) is reduced by microorganisms either by the process dissimilatory nitrate reduction to ammonium (DNRA) and thus N is retained in the soil, or by denitrification to gaseous nitrogen compounds and thereby lost. Denitrification is also a main source of N_2O [1]. The relative importance of these processes is controlled by the C/NO_3^- ratio [2-3]. The aim was to determine if cropping systems resulting in increased soil C/NO_3 ratios promote DNRA and consequently emit less N_2O. A field experiment with a cereal rotation was compared to one including ley, both with and without nitrogen fertilization. By quantifying marker genes for denitrification, DNRA and N_2O reduction and conducting a ^{15}N tracing experiment, we show that the ley rotation increased the relative abundance of DNRA bacteria, resulting in higher DNRA rates and lower N_2O production.

[1] Butterbach-Bahl et al. 2013. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 368. [2] Tiedje et al. 1982. Antonie Leeuwenhoek 48, 569. [3] Van Den Berg et al. 2015. ISME J. 9, 2453.

Bioenergetics of microbial communities in soil systems

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Energy is continuously transformed in soils through the metabolic activities of microorganisms, and microbial energy demands regulate terrestrial element cycles. The transformation of energy in living systems, i.e. bioenergetics, is therefore fundamental for soil functioning. We advanced thermodynamic approaches to evaluate microbial bioenergetics and carbon turnover in soil systems [1-2]. Among various soil management systems, we quantified thermodynamic efficiencies of microbial communities which is defined as resource allocation between respiratory energy losses and biosynthetic stabilization. This property is important in governing for example soil fertility and carbon sequestration. We found that thermodynamic efficiency was related to microbial community composition with fungi and gram-negative bacteria tending towards higher efficiencies [2]. However, short term variation in efficiency across soil systems can result from altered microbial physiology without changes in community composition [3]. Our aim is to further develop this approach into a bioenergetics framework, contributing to define soil management practices which support efficient microbial communities for sustaining soil fertility and carbon sequestration.

[1] Herrmann et al. 2014. Environ. Sci. Technol. 48, 4344-4352. [2] Bölscher et al. 2016. Biol. Fertil. Soils 52, 547-559. [3] Bölscher et al. 2017. Soil Biol. Biochem. 109, 59-69.

Crop residue addition in the upper subsoil increases crop yield and alters soil chemical and biological properties – a short term investigation

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Subsoils are often equally fertile as the topsoil, however, the root growth into the subsoil and uptake of water and nutrients from there is hindered due to compaction. Therefore, creating soil conditions that allow extensive root growth into the subsoil is crucial for yield increase without further increase of fertilizer input. In this project, we have tested the feasibility of crop residue addition in the subsoil by adding straw channels (8 cm thick and wide, 68 cm apart) and evaluated its impact on crop yield, soil microbial community and some chemical parameters (e.g., pH, water soluble P, total organic C, total N, C/N ratio). Results of the chemical analysis showed that all the parameters significantly increased due to straw addition. However, the temporal effect is different for different parameters. The treatment effect was noticed up to 10 cm lateral distance and 5 cm above and below to the residue layer. In addition, the crop yield was 5-10% higher than the traditionally managed soil (control soil). The microbial analysis is ongoing. The preliminary conclusion from this short term investigation is that crop residue addition in the upper subsoil has a potential to improve crop yield by improving nutrient availability.

Notes

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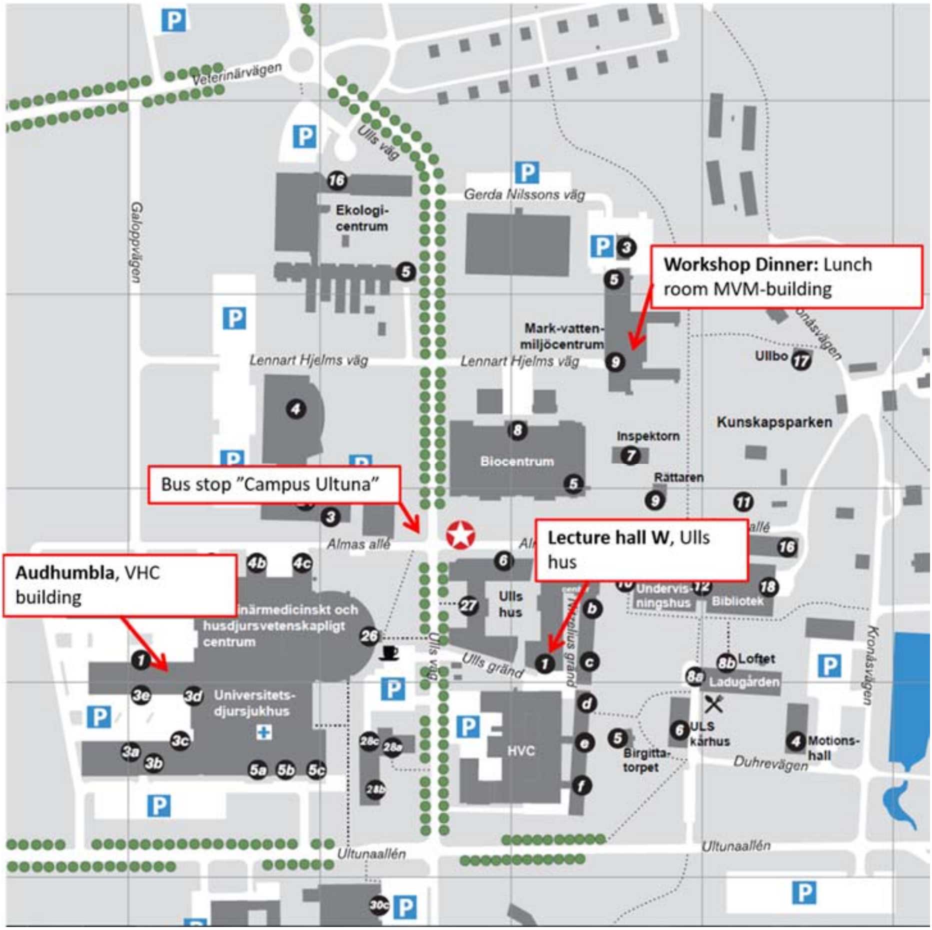
Locations

Sustainable Intensification of Agriculture 2018



Sustainable Intensification of Agriculture
– Challenges in Soil Science confronting Global Food Security

Tuesday, 30th of January

08.30 – 09.30 ***Background– Why bother?***

09.30 – 09.50 FIKA

09.50 – 11.50 ***Sustainable Land Use & Water Management in Africa & Asia***

12.00 – 13.00 LUNCH

13.00 – 15.00 ***Future Potential of Long-Term Field Experiments & Farm Platforms***

15.00 – 15.30 FIKA

15.30 – 17.00 ***Discussion Groups including Feedback***

19.00 Workshop Dinner:
Lunch room MVM-building

Wednesday, 31st of January

08.30 – 10.00 ***Soil Management & Soil Structure Dynamics***

10.00 – 10.20 FIKA

10.20 – 11.50 ***Precision Agriculture & Soil Fertility***

12.00 – 13.00 LUNCH

13.00 – 14.30 ***Soil Functioning – Biology Matters***

14.30 – 15.00 FIKA

15.00 – 17.00 ***Workshop Wrap Up***