14. National Research Programme NRP 68: Research for improving soil knowledge and for sustainable use of soils

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14.1

Sustainable management of organic soils in Switzerland – CO_2 emissions from organic soils under agricultural use

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The organic soils of peatlands represent a major global sink for terrestrial carbon. They cover approximately 4.16 x 106 km² of the earth's surface (Joosten et al. 2004) and store between 15-20% of organic soil carbon (Parish et al. 2008). Agricultural use of organic soils requires drainage, changing conditions in these soils from anoxic to oxic. As a consequence, the organic carbon that had been accumulated often over millennia is rapidly mineralized, so that these soils then are no longer a sink but become a source of CO_2. The emission rates of CO_2 from drained organic soils lie between 1 and 11 t C $ha^{-1}a^{-1}$ (Byrne et al. 2004, Couwenberg et al. 2011). In Switzerland, every year approximately 0.69 Mt CO_2 are emitted from 22'000 ha of drained organic soils (FOEN 2012). These rates correspond to 14% of agricultural CO_2 emissions.

The aim of our study is to analyse the amount and origin of CO_2 emitted from organic soils under three land-use types (forest, arable cropland and grassland). Our study area is located in Gals (BE) a community of the Bernese Lakeland. The peatlands of this region were drained in the 1870ies, and the site as well as the surrounding area is now managed by a state prison. Since decades our study sites are under the same land-use. In Mai 2014 we took three soil samples from each land-use site from a depth of 20-30cm. The samples were taken at different distances from a major drainage ditch (Fig.1).

Roots were removed manually, and the moisture content of the samples was equilibrated at a pF-value of 2.To determine the respiration rate 80 g of each sample were incubated for several weeks in a Respicond VII analyser at 20°C. Half of the sub-samples were spiked with 0.2-0.4 g of labelled corn stalk enriched in $\partial^{13}C$ ($\partial^{13}C$=2000‰) in order to mimic plant residue inputs in the field. The addition of fresh plant material resulted in a positive priming effect, and intensified respiration rates by 33, 82 and 88% in the forest, cropland and grassland samples, respectively. Comparing the stable isotopic signals of CO_2 emitted from spiked and control samples as well as the corn itself will reveal the contribution of corn and peat towards soil respiration. Using radiocarbon information from the peat samples, emitted CO_2 and corn, we also evaluate the contributions of old peat or young organic matter other than corn in the samples to the CO_2 emissions.

The samples are also analysed for their chemical composition, in particular the amounts of C, H, N and O. Infrared spectra will be recorded to determine the relative abundance of easily degradable polysaccharides.

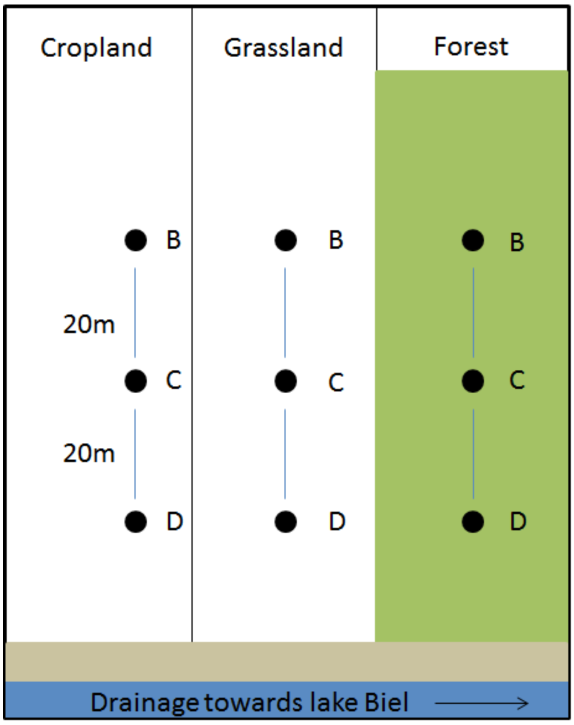

Figure 1: Study site in Gals (BE)

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14.2

Assessment of the Natural Occurrence of Entomopathogenic Nematodes in Swiss Agricultural Soils

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As part of a research consortium that explores how soil health can be improved by applying ecological and rational approaches (NRP68: Biology), we study how entomopathogenic nematodes (EPNs) can be better exploited for the biological control of soil-dwelling insect pests in annual crops. We hypothesized that the frequent disturbance of soils in annual crops will compromise the natural occurrence and activity of EPN due to frequent exposure to harsh abiotic conditions and limited availability of insect host. These factors are expected to also negatively affect other members of the soil food web, such as free-living nematodes (FLN) that compete for insect cadavers, ectoparasitic bacteria that limit the nematodes movement in the soil, and nematophagous fungi (NF), all of which have previously been shown to be spatially associated and distributed with EPN.

We combined traditional and new molecular methods to evaluate how below ground multitrophic interactions affect EPN activity and occurrence in three long term running Swiss field trials. Two of the experiments, both located in Nyon, focused on tillage soils: one experiment compared tillage *versus* light-tillage, as well as monoculture (continuous wheat) *versus* crop rotation (maize alternated with other crops) (P20), whereas the second experiment studied four levels of tillage in two soil types planted with wheat (P29). In the DOK trial based in Therwil we evaluated the impact of crop type (maize, wheat and grass) and fertilization program (conventional with manure, organic and biodynamic, each performed at two fertilizer levels, as well as a conventional system without manure and a unfertilized control).

We obtained composite soil samples (20 cores of 2.5 diam. X 20 cm depth per sample; Fig. 1A) from each plot during two sampling periods: April and in October 2013. To analyse the samples we employed previously published molecular probes for six EPN species (*Heterorhabditis bacteriophora, H. zealandica, Steinernema affine, S. carpocapsae, S. feltiae,* and *S. glaseri*) and designed and optimized the system for seven additional EPN species that might co-occur in Swiss soils (*H. megidis, S. bicornutum, S. intermedium, S. intermedium*-group, *S. kraussei-silvaticum, S. poinari* and *S. weiseri*). Other members of the EPN soil food web (six NF, one ectoparasitic bacterium, and the FLN *Acrobeloides*-group) were also quantified after sucrose centrifugation protocols (Fig. 1B) to assess how the soil food web is assembled under the mentioned practices.

In the tillage soils (P20 and P29), real time qPCR analysis detected only trace levels of six EPN species (*H. megidis, H. bacteriophora, S. affine, S. carpocapsae, S. kraussei-silvaticum* and *S. feltiae*), which was in agreement with the low mortalities observed when we baited soil samples with larvae of *Galleria mellonella* (<5%). Overall, tillage did not affect the natural EPN occurrence in either experiments. Monoculture favored EPN activity as measured by bait larvae mortality, but it also favored their FLN competitors ($P < 0.01$), whereas it reduced NF richness ($P < 0.05$). Heavy soil harbored larger quantities of the natural enemies of EPN.

In the DOK trial, the same EPN species were detected, except *S. kraussei-silvaticum*. Soil management systems had no impact on the presence of these organisms ($P > 0.05$). However, crop type significantly shaped the activity ($P = 0.01$) and abundance ($P = 0.007$) of nematodes (EPN + FLN), which all were found to be more abundant and active in wheat plots ($P = 0.01$) (Fig. 1C and D). As in the tillage soils, the total numbers of EPN were very low, implying that their natural presence is not sufficient to have a suppressive effect on soil-dwelling insect pest.

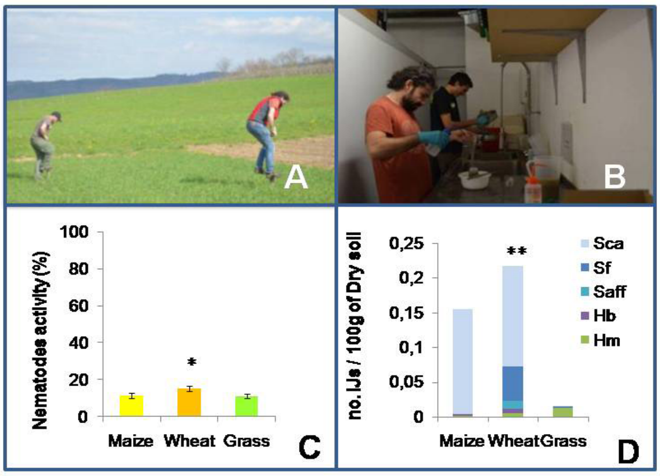

Figure 1. Nematode sampling (A), nematode soil food web extraction from soil samples by sucrose centrifugation (B) and effect of the crop type in the nematode activity (EPN + FLN) (C) and abundance (D). Entomopathogenic nematodes species: *Steinernema carpocapsae* (Sca), *S. feltiae* (Sf), *S. affine* (Saff), *Heterorhabditis bacteriophora* (Hb) and *H. megidis* (Hm); infective juveniles (IJs).

Our main conclusion is that under the ecological scenarios that we sampled, the most effective biological control strategy with EPN would be an augmentation rather than a conservation approach. Optimizing the timing and method of EPN application might provide effective alternatives to repeated convential applications. Ongoing collaborative experiments in Swiss annual crops will provide further insights into the natural occurrence, survival and persistence of EPN. This information will be used to develop new strategies for the general application of beneficial organisms to enhance soil health.

14.3

Above and below ground indicators for stress induced by compacted soils of small grain cereals and soybean

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Soil compaction due to heavy agricultural machinery is a major environmental threat to arable soils, which is still difficult to detect and to quantify at the crop level. Increased mechanical impedance and disturbed water, solute and gas flows in compacted soils reduce root growth and crop productivity. A precise quantification of the above- and below-ground reaction of crops to this stress will help to identify indicators for compaction and suitable species, genotypes and management opportunities to mitigate compaction.

Soybean and small grain cereals were chosen to cover the variation between some of the globally most relevant crops in terms of plant development and root system architecture. To account for different plant developmental stages experiments were conducted under controlled conditions and in the field with the same soil.

In growth chamber experiments early responses of roots to two different soil bulk densities (1.34 and 1.60 g cm^{-3}) were evaluated using X-ray computed tomography periodically throughout 14 days. Five days after sowing soil compaction caused increased root diameters and decreased lateral root numbers in both species. Plant height and shoot dry weight decreased due to compaction in wheat, whereas no such responses occurred in soybean.

In the field the soil was compacted by multiple track-by-track passing with a heavy vehicle. In the case of triticale the topsoil was either ploughed or remained undisturbed, whereas for soybean the top five centimeters were tilled after compaction. Leaf growth rates and shoot biomass of both species decreased due to compaction. For triticale very similar root architectural responses to compaction were observed as under controlled conditions. Even if the topsoil was ploughed, numbers of nodal and lateral roots decreased, while their diameters increased under compaction. In soybean the lateral root number also decreased, while root diameters also decreased as a result of compaction.

These results showed that the reaction of root systems to soil compaction might differ substantially between different plant species and developmental stages. This points out the necessity to look at the entire growth cycle of crops, when identifying root traits that have the potential to mitigate soil compaction and maintain crop productivity under soil compaction.

14.4

An integrated Modelling framework to monitor and predict trends of agricultural management (iMSoil). The Land Management Model (LMM).

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Agricultural systems are subject to various pressures induced by a number of socio-economic drivers, leading to changes in farming practice. These changes can result in the intensification of agricultural land management, with implications on crop and livestock production, fertilization practices, pest management, tillage, and ultimately can adversely affect important soil functions. In order to steer the development into desired directions, tools are required by which the effects of these pressures on agricultural management and the resulting impacts on soil functions can be predicted or detected as early as possible. The use of integrated models, combining different scientific disciplines within a common framework, can be very helpful in this context. Significant progress has been made in this field over the last decades. However, the development of such modeling frameworks has been hampered in the past by a lack of spatially explicit soil and land management information at regional scale. Moreover, the inherent characteristics and processes of the soil system have been often oversimplified.

The iMSoil project, funded by the Swiss National Science Foundation in the national research programme NRP68 “soil as a resource” (www.nrp68.ch) aims at developing and implementing an integrated modeling framework (IMF) which can overcome the limitations mentioned above, by combining socio-economic, agricultural land management, and biophysical models, in order to predict the long-term impacts of different socio-economic scenarios on the soil quality.

This presentation focus on the Land Management Model (LMM) that is one of the main component of the IMF. The LMM estimates fertiliser and pesticide application rates and calculates surface balances (input and output at the soil surface) of various elements such as N, P, Cu, Zn for each land management unit (i.e. a field or block of fields). These estimates are obtained through a downscaling approach which makes use of available geo-referenced farm census data, national fertilization guidelines and various concentration datasets combined with land use information derived from remote sensing data (the poster presented by Gómez Giménez et al. shows how remote sensing thecniques were used to distinguish the main land use types). Farm census data (essentially the area covered by each crop and the livestock number), together with compiled datasets and measurements of element concentrations in manure and element crop uptake, is used to estimate the crop spatial pattern and the element input to each land management unit. For this purpose an algorithm was developed that takes into account land use type, terrain attributes and the distance of the management units from the farm. Manure trading between farms is also simulated, based on a number of rules derived from Swiss legislation and interviews with agronomic consultants. Firstly, nutrient surplus or deficit at farm level is calculated. Then, the algorithm try to match manure offer and demand considering manure quantity, number of possible treatments and distance between farms. The LMM results are spatially explicit and can be displayed as maps representing, for example, annual phosphorus inputs (Figure 1).

The iMSoil project is currently testing the IMF on a case study region located in canton Zurich. Given the availability of Swiss farm census data, spatially explicit annual element balances can potentially be calculated since 1998 for the whole country. Thus, the changes occurred in the agricultural system over the last 16 years, as well as their impact on nutrient and trace element fluxes and on soil functions, can be quantified.

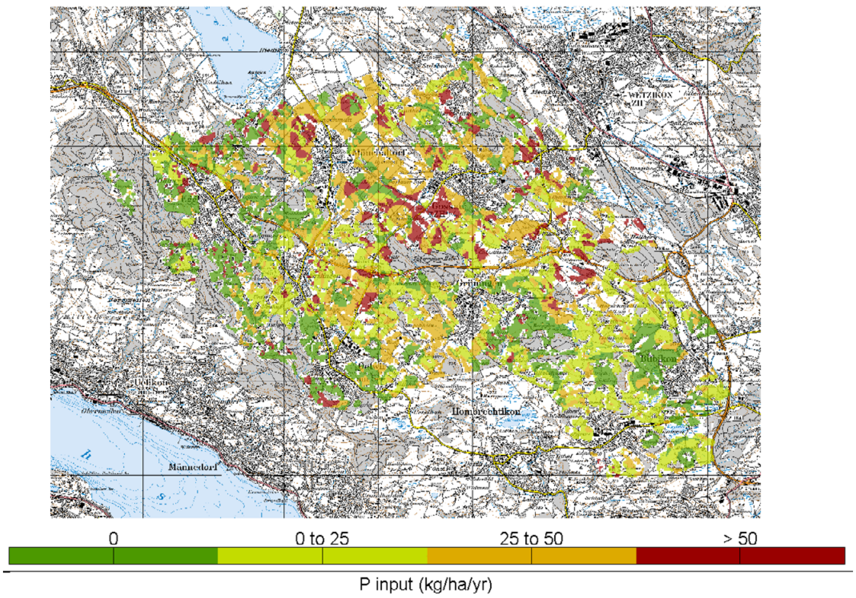

Figure 1. Phosphorus inputs for the year 2011 (kg P ha^{-1} yr^{-1}) over one of the iMSoil study areas (located in Canton Zurich), estimated using the land management downscaling approach (LMM).

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14.5

Sustainable management of organic soils in Switzerland – economic and policy analysis

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Agricultural production activities on peat soils lead to severe forms of degradation of this natural resource. This is mainly due to the intensive soil drainage, necessary to enable production. The current non-sustainable farming practices (from the perspective of the peat soil resource) combined with the effect of climate change increasingly contribute to the conversion of peat soils from carbon sinks to carbon sources with accompanying losses of soil fertility and of ecosystem values such as biodiversity (Xintu, 2009). These impacts are not restricted to the field but also concern the surrounding ecosystem. Besides, the continuing degradation of former peatland challenges the future of production activities at these places. This study aims at analyzing, from both production system and policy angles, the mechanisms which could prevent long-term disappearance of agriculturally utilized peat soils in Switzerland.

This study is composed of three interdependent parts. The first part consists of the selection of an indicator or a set of indicators able to capture the farming system performance on managed peat soils in an encompassing way, by accounting for "traditional" agricultural inputs (including factors of production characteristic to peatlands and differentiating pollution-causing inputs from non-pollution causing inputs) and outputs, as well as undesirable outputs (e.g. greenhouse gas emissions) and ecosystem services provision (e.g. soil water retention capacity). This indicator or set of indicators will be based on a productivity and efficiency analysis of farms operating on peat soils using a multiple-inputs multiple-outputs model and will enable assessment and comparison of land management options (e.g. intensive versus extensive land uses). Two complementary methods will be used for this analysis: data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Economic data concerning the farming production system will be obtained from secondary data. Data relative to undesirable outputs, positive externalities provision, and some of the pollution-causing inputs will be obtained from the analysis of primary data collected in the companion NRP68's PhD project. At a broader level, the objective of this part is to build a conceptual framework in farm performance analysis applied to specific natural resource management (here peat soils) that considers the complete farming system, enables accounting for farm factors which are relevant at a landscape or regional level, are inter-dependent between farms, and allows the design of an indicator facilitating the comparison between different land uses.

The second part develops policy instruments orienting the farming system towards the adoption of more sustainable management practices, as identified in the NRP 68' companion research project. In the context of peat soil management, and considering the management of drainage systems, cooperation among farmers is hypothesized as a promising possibility to the adoption of alternative soil practices. Nevertheless, the study assumes that a wise combination of self-organization and external incentives is likely to perform optimally (Stallman, 2011). In this context, the field investigation will study the potential for market-incentive based policies and collective action around peat soil resource management. An experimental computerized game will be designed to study farmers' reactions and behaviors to different policy options and institutional features targeting the management of peat soil resource. The two main purposes of the game are 1) to study how farmers are willing to and interested in cooperating around the implementation of alternative peat soil management strategies and thus towards maintaining productivity on these soils on the long run, and 2) to study the types of incentives which could complement and strengthen such cooperation, through studying their effects on farmers' behaviors.

The last part focuses on analyzing and predicting the acceptance and effects of the implementation of the selected policy instruments. As compared to the previous part on design of policy options from the perspective of the conservation of peat soil's natural resource, this part will adopt the farmer's perspective, also using the results of the experimental game. It will be about studying the acceptance by farmers of the selected policy options as well as the potential effects and impacts of the associated measures on farmers' profession, farmers' territorial roles, positions and perceptions etc. After identifying eventual challenges and obstacles in the implementation of the selected policy instrument, the research will focus on ways to overcome them. Complementarily to the experimental game's results, the study may use assessment methods such as focus groups and interviews with different actors of the territory.

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14.6

Metagenomic analysis of long-term land-use effects on soil microbial communities in 600-year Alpine pasture system

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This study aimed to obtain a comprehensive profile of microbial communities and antimicrobial resistance (AMR) determinants in two proximal soil systems with a different treatment history, located at the alpine Glaspass (Switzerland). One of the sampling fields has been amended with manure for the past centuries (termed intensive), whereas the other corresponds to a free-range grazing area free of manure applications (extensive).

DNA was extracted from one pooled sample [10 equidistant pooled (5 replicates) samples] per soil system. Two metagenomic approaches were undertaken to estimate microbial diversity: (i) DNA was directly sequenced using a single run Illumina MiSeq (300 bp paired-end reads) per soil sample, yielding around 12 and 17 million reads, respectively; and (ii) 16S rRNA amplicon sequencing was performed yielding around 88,000 and 130,000 reads, respectively.

Both sequencing approaches showed similar trends in microbial communities. The five most abundant Bergey's classes detected were Betaproteobacteria, Actinobacteria, Alphaproteobacteria (all predominant in the dataset termed intensive), Acidobacteria Gp1 and Gammaproteobacteria (both predominant in extensive). Chitinophagaceae and Xanthomonadaceae were the predominant Bergey's families detected in the intensive and extensive dataset, respectively. Gp5 (Gp3 based on 16S rRNA profiling) and Gp6 were the most abundant Bergey's genera in intensive, while Gp1 and Gp2 were prominent in extensive.

The MvirDB database was used to search for AMR determinants. Entries retrieved from both soil systems included numerous (multi)drug efflux pumps (for tetracyclines, macrolides, phenicols); antibiotic target protection proteins (macrolides-lincosamides-streptogramins, tetracyclines, fluoroquinolones); antibiotic modifying (aminoglycosides, lincosamides, phenicols, tetracycline) or degradation enzymes (betalactams); and antimicrobial target replacement proteins (diaminopyrimidines, sulfonamides, glycopeptides, betalactams). A set of reads was also assigned to integrases (IntI3, IntI1) and transposases, which were also detected in the Enzyme Commision (EC) and COG number category annotations. An ongoing functional metagenomics approach of both soils systems is devoted to the characterization of novel AMR determinants.

Keywords: comparative metagenomics, 16S rRNA profiling, soil systems, manure, antimicrobial resistance

14.7

Are Swiss forest soil carbon stocks resilient to historical land-use?

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Forest cover in Switzerland has increased by approximately 22% in the last century (Ginzler et al. 2011). Since soils store the highest amounts of carbon in the terrestrial ecosystems, it is important to understand if and how these forest cover changes have affected soil carbon stocks. However, our knowledge is currently still very limited due to the lack of historical soil samples and the lack of soil studies on historical land-use.

Our approach was to reconstruct past forest cover changes and to estimate how these changes have affected current soil C storage. Using the coordinates of 1000 soil profiles from the soil data base of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), we reconstructed forest cover changes for the last 150 years. For that goal, we evaluated historical and modern topographic maps using ArcGIS, classifying forest cover into forest, no-forest, forest edge, and open forest. The oldest nationwide maps containing forest cover for the territory of Switzerland are the Dufour original surveys, dating back to 1850. For the period around 1900 and 1950, we used Siegfried maps, and between 1950 until 2011 – modern topographic maps. This allowed us to estimate the time since afforestation, the minimal forest age, and the forest cover continuity for all currently forested sites. Moreover, we examined the effect of tree species composition on soil carbon to further improve our knowledge of the interactions between above-ground vegetation and soil.

Our analysis shows that approx. 75% of the current forest soil profiles have been located in forest areas already in 1850, whereas 12% sites have been located outside a forest at the time. Further 12% have been located at a forest edge and 1% - in an open forest. Surprisingly, our results indicate slightly higher SOC stocks in younger forest sites compared to sites that have permanently been forested. This result could be seen in both the organic layer and the mineral soil (Figures 1 and 2, respectively). Moreover, we observed higher SOC stocks under coniferous than under decidous or mixed forests – however, this was only evident in the organic layer, but not in the mineral soil.

We tested a number of potential explanations for the higher C-stocks in new forests such as altitude, temperature, pH, soil structure. However, none of these drivers differed significantly between the permanent and the new forest sites. Probably, the younger forests have been growing on soils with inherently higher C-stocks, such as favorable land previously used for grassland. Thus, we come to the conclusion that forest cover has a neglible effect on carbon stocks in Swiss forest soils.

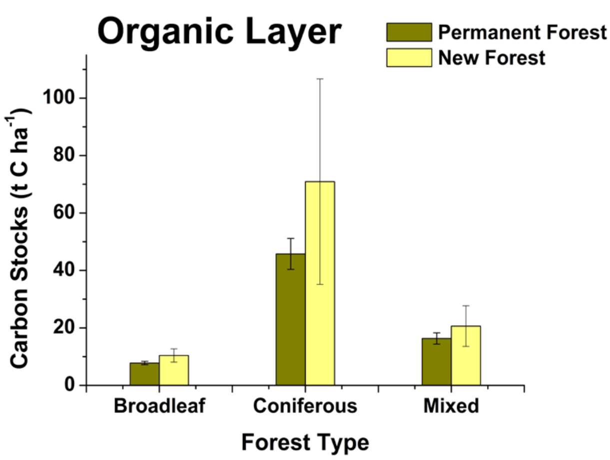

Figure 1. Forest type and cover effect on C-stocks in organic layer

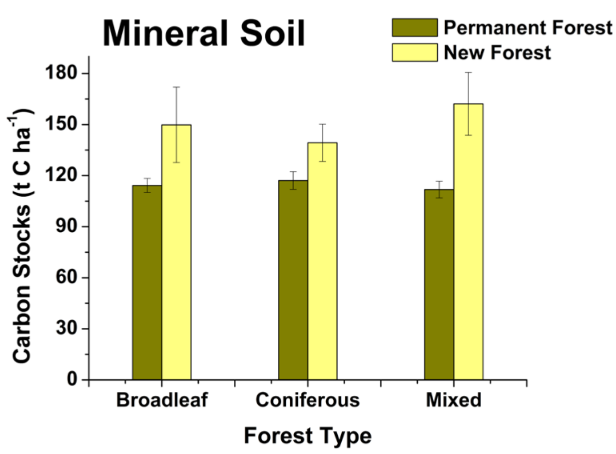

Figure 2. Forest type and cover effect on C-stocks in mineral soil.

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14.8

Influence of soil management on N_2O producing and reducing microbial communities

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N_2O is a potent greenhouse gas, with an atmospheric half lifetime of 113 years, which also contributes to ozone layer destruction. Agriculturally managed soils hold for the gross of anthropogenic N_2O release. In order to develop effective mitigation strategies a detailed understanding of processes and mechanisms leading to N_2O formation and reduction in croplands is urgently needed. Although the influence of single parameters on N_2O emission is quite well understood, knowledge on the underlying mechanisms especially under complex farming systems is still sparse. Different farming strategies like reduced tillage, organic soil management and biochar addition have the potential to influence extend of N_2O emissions from croplands.

As cycling of fixed N in soils is almost entirely controlled by microbial activities it is crucial to understand the impact of soil management on N cycling microbial communities. Generally, N_2O is produced by nitrifying and denitrifying microbial communities. However, when assessing impact of microbial communities on N_2O emissions special emphasis must be put on N_2O reducing microbial communities. This functional guild can perform the last step of denitrification, the reduction from N_2O to N_2, and thus reduces N_2O emissions from soils.

In order to assess impact of reduced tillage, biochar addition and organic soil management on N_2O emissions individual field and incubation experiments under controlled conditions were conducted. Here we present the first results of an incubation study in which the impact of organic and mineral fertilization history on potential N_2O emissions was assessed. Therefore, soil was taken from the DOK trial in Therwil/BL and incubated for 17 days under controlled conditions optimal for denitrification processes.

Apart from monitoring N_2O emissions qPCR analysis of functional genes was employed to quantify archaeal and bacterial *amoA*, *nirK* and *nirS* as proxy for nitrifying and denitrifying communities. N_2O reducing bacteria were assessed by quantifying the functional gene *nosZ*. Additionally mRNA analysis was used to measure expression of these functional genes. In order to verify molecular biological data ^{15}N tracing technique was used to determine N_2O/N_2 product ratio and fertilizer derived sources of N_2O emissions.

First results show increased N_2O emission potential of organic fertilization history. Higher N_2O/N_2 product ratios indicate less complete denitrification in this treatment. Increased C_{org} contents seem to provide excess electrons for all denitrification processes, which leads to a decrease of the kinetically unfavorable process of N_2O reduction.

These results emphasize the need for appropriate soil management to minimize N_2O emissions especially for soils with organic fertilization history.

14.9

A Soil Structure Observatory (SSO) to study structural recovery of compacted soil by natural processes

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Agricultural soil compaction adversely impacts the soil's structure, productivity and ecological processes thereby affecting crop growth and other ecosystem services. Most soil compaction studies focus on quantifying compaction and immediate impacts on soil hydrology and productivity. Little is known about mechanisms and rates of natural soil structure recovery after compaction. However, knowledge of soil structural regeneration is required for quantification of the real costs of soil compaction. The primary objective of the newly-launched long-term soil structure observatory (SSO) is to quantify post-compaction structural restoration at years to decade time scales. The SSO was established on a loamy soil in Zurich, Switzerland, and monitors key biophysical properties affecting soil structure restoration such as root growth, shrink-swell of soils and earthworms bioturbation. We implemented three compaction treatments: uncompacted surface, full surface compaction and wheel-track compaction. On each of these treatments we apply four cropping systems (bare soil; permanent grass; crop rotation - no till; and crop rotation - conventional tillage) replicated in three blocks. The site was characterized pre- and post-compaction, and sensor banks were installed for continuous monitoring of soil water content and matric potential, temperature, CO_2 and O_2 concentrations, redox potential and oxygen diffusion rates. Soil sampling and measurements are done periodically, including soil surface elevation, soil physical properties, earthworm abundance and burrows, below and above ground crop measurements, as well as electrical resistivity tomography (ERT) and ground penetrating radar (GPR) imaging to observe structural changes over time at the plot scale. Comparison of soil properties before and after compaction show a significant decrease in soil porosity and infiltration rates (2 orders of magnitude), a decrease in O_2 and increase in CO_2 soil air concentrations in compacted plots. GPR and ERT images show differences in electrical permittivity and resistivity in compacted relative to uncompacted plots. This SSO study aims to monitor the evolution of soil structure and the soil functions associated with it, under different treatments during the next 10 years.

14.10

Restoration of soil functions and improving plant yield with the help of arbuscular mycorrhizal fungi

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Soils are the basis for nutrient production and a main component for maintaining biological diversity. Arbuscular mycorrhiza fungi (AMF), a common group of soil fungi, play a crucial role for various important soil ecosystem services. They form symbiotic relationships with most terrestrial plants, including most crop plants. They can improve plant growth and promote plant diversity (van der Heijden et al. 2008). In this project we used molecular tools (single molecule real-time (SMRT) sequencing and 454 sequencing) to characterise fungal communities in a wide range of fields with different land use intensity. We present first insights into AMF communities in roots of wheat plants and we show that one particular group of soil fungi (Sebacinales) are characteristic for organically managed arable fields (Figure 1, Verbruggen et al. 2014). Using this information we aim to characterise fungi as bioindicator species for different land management practices (Oehl et al. 2011). Secondly, we have performed inoculation trials to test whether introduction of AMF in field soil can enhance plant yield, nutrient uptake and nutrient use efficiency (Bender & van der Heijden 2014). First results indicate that inoculation of AMF can enhance plant yield and nutrient use efficiency in some soils, but results are variable and dependent on soil type and crop species. Moreover, in ongoing work, the obtained AMF community profiles will be used as a basis for the targeted inoculation of AMF species in field soils. We examine if the taxonomy-based application of AMF inoculum enhances plant productivity.

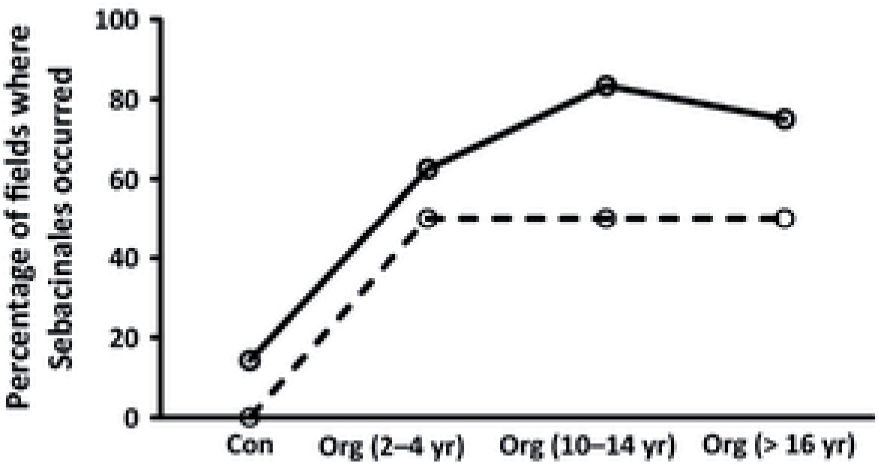

Figure 1. The percentage of fields within each management group (Con, conventional; Org, under organic management) in which members of Sebacinales were detected in wheat roots. NGS (open circles, dashed line), represents fields where Sebacinales were detected using Next Generation Sequencing; Total (open circles, solid line) represents the number of fields including both NGS and Sebacinales specific PCR (effect of management NGS: $\chi2=5.64$, $P=0.027$; Total: $\chi2=7.48$, $P< 0.01$) (see Verbruggen et al. 2014).

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14.11

Scales of spatial & temporal variability in radiocarbon contents of organic carbon across different regions in Swiss soils

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Soil organic matter (SOM) forms the largest terrestrial pool of carbon outside of sedimentary rocks, and it provides the fundamental reservoir for nutrients that sustains vegetation and associated microbial communities. With ongoing changes in land-use and climate, SOM is subject to change, with potentially major consequences for soil as a resource and for global biogeochemical cycles. Radiocarbon is a powerful tool for assessing OM dynamics and is increasingly used in studies of carbon turnover in soils. However, due to the nature of the measurement, comprehensive ^{14}C studies of soils systems remain relatively rare. In particular, information on spatial variability in the radiocarbon contents of soils is limited, yet this information is crucial for establishing the range of baseline properties and for detecting potential modifications to the SOM pool.

The present study aims to develop and apply a comprehensive four-dimensional approach to explore heterogeneity in bulk SOM ^{14}C, with a broader goal of assessing controls on organic matter stability and vulnerability in soils across Switzerland. Focusing on range of Swiss soil types, we examine spatial variability in ^{14}C as well as ^{13}C and C:N ratios over plot (decimeter to meter) to regional scales, vertical variability from surface to deeper soil horizons, and temporal variability by comparing present-day with archived (legacy) samples.

Preliminary results show that differences in SOM ^{14}C age across small lateral and vertical distances within soil systems can be as large as those between regions, underlining the importance of considering compositional heterogeneity in assessing SOM dynamics. These studies of bulk variability are being followed up with analyses of SOM sub-fractions, including ^{14}C measurements at the molecular level in order to SOM components that are most sensitive to climate change and anthropogenic pressures. Such investigations of ^{14}C variability over various space and time domains will shed light on the scales of processes that drive the composition and vulnerability of SOM, and provide valuable constraints on models of SOM turnover.

14.12
Quantification of Vegetation Effects on the Stress-Strain Behaviour of Soil

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The effects of vegetation on the stability of soil has been widely investigated and well recognized in the last decades. Root reinforcement has been investigated based on different approaches including laboratory or in-situ shear tests of rooted soil, employing analytical models of soil-root interaction or by the use of relatively novel methods such as the Fibre Bundle Model (FBM). Traditional methods, generally, consider roots passing through the shear surface and full development of tensile strength of the roots (Wu *et al*. 1979). However it has been shown that lateral roots contribute to strength as well, and roots and soil do not necessarily fail simultaneously (Sakals & Sidle 2004; Potten *et al*. 2004). A robust inclinable large-scale direct shear apparatus was constructed in order to evaluate the effect of a soil-root system on the shear behaviour of soil. It is intended to present the design and mechanical aspects of the apparatus, as well as the results of the ongoing initial tests in this study.

Direct shear tests have been conducted on unplanted and planted soil samples at a constant rate of horizontal displacement of 1 mm/min to a maximum horizontal displacement of 200 mm. Three different normal stress levels, namely 6 kPa, 11 kPa and 18 kPa, are chosen to be comparable to the average depth of shallow landslides. Planted samples consisting of combinations of a tree (*Alnus incana*), legume (*Trifolium pratense*), and grass (*Poa pratensis*) have been prepared using moraine (SP-SM) from a recent landslide area in Central Switzerland. Planted samples are maintained in shear boxes (500x500x400 mm) inclined at 30° simulating a slope and corresponding natural growth of roots on it. Both unplanted and planted samples are saturated prior to testing by applying rainfall at a constant intensity (100 mm/h) in order to simulate the loss of strength after a heavy rainfall period. Analyses of the test data will not only be based on increased shear strength due to root reinforcement, but also the general stress-strain behaviour of root-permeated soil and the dilatancy.

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P 14.1

Remote sensing sources for land cover differentiation of arable land and grassland to improve a Land Management Model

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INTRODUCTION:
Agriculture plays an important role as service provider to human activities. This sector is characterized by sustainability and market-oriented principles, which have been well established through different actions e.g. laws, constitution articles and subsidies (Conseil 1998); (OECD 1998); (Confédération 1999). About one third of Switzerland with an extention of 41,285 km^2 is occupied by Utilised Agricultural Area (UAA). The total UAA is classified by the Federal Statistics Office (FSO) in 7 classes: grassland (70.9%), cereals (maize, oats, barley, wheat and other cereals), potatoes, sugar and fodder beet, oilseeds, permanent crops, other arable land and other UAA (FSO 2011). Monitoring the state and the dynamics of the UAA and knowledge of the land managament of this area is essential for many environmental models that deal with agricultural systems. For instance, to foster sustainable land management and ensure fluxes of natural resources without jeopardising biodiversity and conservation goals stated in the Swiss Agricultural Policy.

OBJECTIVE:
The objective of this study is to improve a Land Management Model (LMM) within an Integrated Modelling framework to monitor and predict trends of agricultural management (NRP68 iMSoil project). Remote sensing (RS) sources are used to improve the differentiation between arable land and grassland in space and time compared to the often-used areal statistics. Based on the spatial units provided by RS and geo-referenced farm census data, the LMM estimates fertiliser and pesticide application rates and calculates surface balances (input and output at the soil surface) for various elements such as N, P, Cu, Zn for each land management unit. In order to link RS sources with the LMM we follow a tiered approach: I) Land cover classification, II) Land use classification and III) Land management classification. This study is focused on the first stage with a land cover differentiation of arable land and grassland in an agro-ecosystem located in the Canton Zurich.

DATA AND METHODS:
Two Landsat 8 images from summer and winter were used. Atmospheric corrections were applied and topographic corrections were avoided due to the smooth orography with most of the slopes around 3%. A pixel-based classification approach was carried out in the northern part of the study site leaving the southern part for validation. Maximum likelihood classification was chosen for its robustness and sufficient training areas were collected to meet statistical criteria. Ancillary data and one spectral index were used to mask out images, to avoid misclassification and to validate the results. The final product with 30m spatial resolution was aggregated into cells of 1 ha to assess the LMM's spatial resolution sensitivity.
RESULTS: The classification assessment reported an overall accuracy of 88.4% and 82.7% for the summer and winter images respectively. Combining both classifications improved the arable land and grassland estimation. Nevertheless, the comparison with a farm census showed that arable land was underestimated for 9%, as well as the total agricultural area, i.e. 285 ha less than the proportion reported by farmers. The use of ancillary data e.g. vector layers validated in the field and a spectral index are useful to avoid misclassifications and contribute to maintain a coherent amount of agricultural area between classifications. However, it might be generalizing some land covers classes (e.g. urban areas) and underestimating the total agricultural area, further analyses are needed to determine this issue. In addition, low spectral separability between classes such as crops and grassland and the impossibility of differentiating temporary grassland (as part of arable land) with only two images and without *a priori* land cover knowledge produce the overestimation of the grassland area. The first test run with the LMM showed that spatial resolution is a key point for land allocation to the farms. Increasing the spatial resolution (from 100m to 30 m) decreased the amount of non-allocated farmland by 860.5 ha.

CONCLUSIONS:
The combination of two Landsat 8 images from different seasons improves the discrimination of arable land and grassland. However, a longer multi-temporal analysis of images is required to estimate the agricultural extent more accurately and improve the differentiation between the land use types. Higher spatial resolution sources would be needed to improve the overall classification accuracy as well as a field campaign to train the classifier and validate the results. Thus, the use of a non-parametric classifer, for which less number of training samples do not lead to worse results (Pal and Mather 2003); will be more suitable for futher analysis. The LMM sensitity to spatial resolution makes appropriate change the methodology approach to a object oriented classification. These recommendations will be implemented in the next project stage.

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P 14.2

NRP68 project PMSoil: Spatial prediction of soil properties and soil function potentials from legacy soil data and environmental covariates

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Soils play an essential role in ecosystems and provide important services for humans. Soils are the dominant basis for food and fodder production and are also needed for housing and infrastructure. But soils provide many more functions, for example, by retaining water after heavy rainfall and supplying water to plants from this storage during drought periods, providing habitats to organisms, storing carbon, preventing nutrients and pollutants from leaking into ground- and freshwaters, etc. Soil functions are often not noticed, let alone valued, except when soils fail to provide them.

A sustainable use of the soil resources needs to balance human requirements with the capacity of the soils to provide the various services. Currently, land use decisions in spatial planning are largely taken without consideration of the potentials of the soils for the various functions. One important reason for this unfortunate situation in Switzerland is the widespread lack of accurate large-scale spatial information on soils. Spatial information on soil properties is available only for less than 30 % of the agricultural land in Switzerland. In addition, standardised evaluation methods for assessing soil functions in Switzerland are still lacking. Most soil functions cannot be measured directly but must be deduced from basic soil properties, site characteristics and pedotransfer functions by modelling.

The project PMSoil aims (i) to develop digital soil mapping procedures for generating spatial soil information from legacy soil data and comprehensive environmental covariate information on pedogenetic conditions and land management, (ii) to establish an inference system of pedotransfer functions to derive soil function potentials from basic soil properties and (iii) to map basic soil properties and the potentials for selected soil functions in three study regions in the Cantons of Zurich and Berne (Figure 1).

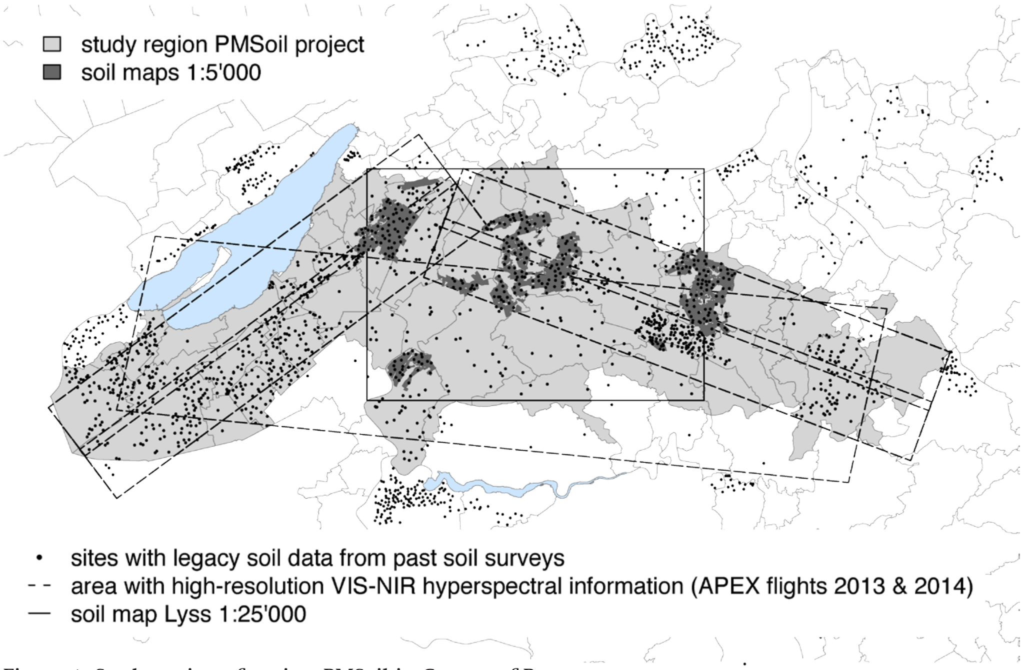

Figure 1. Study region of project PMSoil in Canton of Berne.

In more detail, the work of the PMSoil research team focuses on

- development of procedures for harmonizing legacy soil data stemming from various sources, which is a prerequisite for using such data for spatial analyses (workpackage WP A),
- modelling terrain attributes, which are important environmental covariates for spatial prediction of soil properties (WP B),
- optimized use of remotely sensed hyperspectral information on soils for predicting soil properties in a mosaic of partly vegetation-covered land (WP B),
- use of machine learning methods (boosted geo-additive models) for predicting soil properties parsimoniously from a possibly large set of environmental covariates (WP C),
- development and validation of soil function assessment methods for Swiss soils (WP D)
- and applying jointly the results of these research envdeavours in the study regions to create soil property maps and to map the potentials for particular soil functions which are of interest to the stakeholders.

The work of PMSoil is closely linked to the NRP68 projects OPSOL (A. Grêt-Regamey et al.) and iMSoil (A. Keller et al.) . The three projects jointly strive to provide answers to the pressing question how the scarce resource “soil”, which is currently still lost at a very fast pace in Switzerland (about 3’000 ha each year), can be better preserved and more sustainably managed in the future.

The presentation will introduce the objectives and the approach adopted in the project PMSoil with the aim to give some complementary to the more specific presentations about environmental covariate generation (WP B, presentations by S. Diek et al. and M. Fraefel et al.), statistical modelling (WP C, presentation by M. Nussbaum et al.) and soil function assessment (WP D, presentation by L. Greiner et al.).

P 14.3

Exploring the use of imaging spectroscopy in order to derive soil properties for agricultural areas in Zürich Oberland.

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Soil is a resource in Switzerland that is both essential and under pressure. An efficient system for soil management is therefore highly needed. In the framework of NRP68 the project PMSoil is aiming to provide contiguous spatial soil information and to establish an evaluation system for assessing soil functions for Swiss soils. Within this framework remote sensing serves as secondary information source for digital soil mapping. The use of remote sensing has the potential of providing quantitative spatial and temporal information of extended areas (Ben-Dor et al., 2009), while ist acquisition requires only a limited amount of fieldwork.

The use of soil spectroscopy is promising, however most research is based on laboratory-derived reflectance spectra and field studies were mainly executed in semi-arid areas (Mulder et al., 2011). Difficulties with vegetation cover, differences in soil moisture and management are eluded in this way. Therefore, we explored the use of soil spectroscopy for agricultural areas in Zurich Oberland. Fully processed airborne imaging spectrometer data from the Airborne Prism Experiment (APEX) sensor was available (September 2013 and May 2014) as well as harmonized soil data from the kanton of Zurich (canton ZH soil mapping 1:5.000, canton ZH soil monitoring, and canton ZH soil pollution surveys; data from 1960 to 2012). Field spectroscopy measurements and soil samples were taken at the same time APEX was flown. Based on existing algorithms (HYSOMA (Chabrillat et al., 2011)), soil properties, including soil organic matter, soil texture (clay and sand), and soil moisture were derived. The variables were retrieved using a combination of index-based and physically-based retrievals. The performance of the existing algorithms for deriving properties like clay, soil moisture and organic matter was tested with the harmonized soil data. Furhermore we explored the use of several interpolation methods in order to create full coverage soil property maps.

We discuss the challenges that need to be dealt with in order to use soil spectroscopy in an area like Switzerland. The neccessity of using in field measurements is discussed, as well as suggestions for improvement of existing algorithms.

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P 14.4

Multi-Scale Terrain Modelling for Predictive Soil Mapping in Switzerland

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Spatial information on soil properties in Switzerland is fragmentary and does not meet the increasing demand. In order to establish a validated and cost-effective procedure for creating soil property and soil function maps in Switzerland, the project PMSoil applies digital soil mapping (DSM) using geostatistical models based on a) harmonised legacy soil data, b) terrain characteristics, and c) remote-sensing data. Digital soil mapping has evolved considerably in recent years and has the potential to create soil maps at affordable cost, but has hardly been used in Switzerland so far.

Because topography is one of the main influencing factors on soil formation, and because high-resolution digital terrain models have become available in many regions, terrain attributes play a leading role as predictors in digital soil mapping (McBratney et al. 2003). However, the choice of relevant terrain attributes and, in particular, the spatial scale on which these should be computed has been a matter of debate in the past years (Behrens et al. 2010b, Lagacherie et al. 2006).

Within the framework of the PMSoil project, we compiled a large set of local and regional terrain attributes in three study regions in the cantons of Zurich and Berne. In the canton of Zurich, we relied on the swissALTI3D digital terrain model (2m resolution). For the study regions in the canton of Berne, cantonal LiDAR data was used (where available) and different filtering and interpolation methods and tools were compared to create a very precise, high-resolution DTM. To address the scale issue, various terrain attributes were calculated on different spatial scales by applying averaging windows of varying sizes. In addition, selected terrain attributes were calculated based on resampled versions of the DTM as well as using computation windows of different sizes.

In contrast to this set of terrain attributes, the contextual mapping approach (Behrens et al. 2010a) integrates a range of spatial scales and allows to consider directional components without referring to terrain attributes as calculated in "conventional" terrain analyses. This approach is implemented in the same study areas and will be compared to the terrain-attribute approach by studying the effect on the predictive soil maps, allowing us to define the best set of terrain characteristics and scales for the compilation of digital soil maps in each study region.

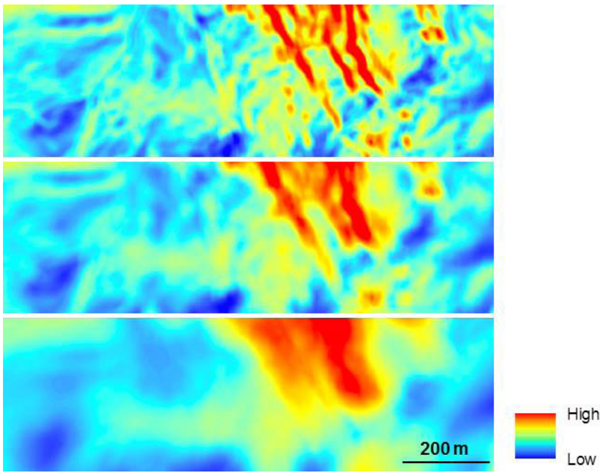

Figure 1. Slope raster smoothed with moving windows of different sizes (5x5, 10x10, and 25x25 cells).

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P 14.5

Predictive mapping of soil pH in forests of Zurich by component wise gradient boosting

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Acidification of forested soils is, judged on the size of the affected area, one of the biggest problems that soil protection agencies are currently facing in Switzerland. Deposition of nitrogen, emitted into the atmosphere by agriculture and road traffic and subsequently deposited onto forests, is the main cause for accelerated acidification of forest soils. Delineation of strongly acidified soils on maps has become important for successful mitigation. For many regions precise maps are missing. Hence, digital maps of soil properties characterizing acidification are needed.

A wide range of statistical approaches has been used for soil property mapping. However, no method clearly outperforms the others. When many environmental covariates are available (e. g. with hyperspectral remote sensing data) the selection of the model with best predictive power becomes even more difficult. Besides the issue of covariate selection, methods such as regression or external-drift kriging models are limited to model linear relations between a response variable and environmental covariates. On the other hand, some machine learning tools as Random Forest that model non-linear relations result in black-box models. To overcome some of these drawbacks we used a gradient boosting approach that included as base learners linear and smooth non-linear terms. Non-stationary relationships were predicted by a smooth spatial surface.

To investigate the feasibility of the gradient boosting approach for digital soil mapping we mapped the topsoil pH for the forest area of the Canton of Zurich, Switzerland. The mapping included legacy data of 1'200 soil profiles. Model performance was evaluated by a data set of 170 soil profiles not used for model calibration.

P 14.6

Towards Soil Function Assessment for Switzerland

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Soil fulfils important functions for humans and the environment. Rather visible for human society, soils function as the dominant basis for food and fodder production and with increasing demand as carrier for housing and infrastructure. In addition, soils provide many more functions, as retaining water after heavy rainfall or supplying plant available water during dry periods, providing habitats to organisms, storing carbon, preventing nutrients and pollutants from leaking into ground- and freshwaters. In principle, most soil functions are hardly noticed and at the same time taken for granted from human perspective.

As a consequence, a crucial aspect towards a sustainable use of soil resources is to foster the awareness about the soils importance, not only in fulfilling carrier and production function but also about its' regulation and habitat function. Likewise knowledge about the state of the soil is fundamental (Bouma et al. 2012). Hence, a tool is needed to increase the awareness about soils and to communicate relevant soil information to stakeholders and policy in spatial planning procedures. Based on the experience in some other European countries a transparent and soil-science based soil function assessment (SFA) providing spatial information with maps for soil function fulfillment is a promising tool to include soil in spatial planning processes.

However, soil functions are not directly measureable, but can be derived from soil properties such as texture, organic matter content, soil depth, bulk density, for instance. To assess soil functions for sustainable use of soils, one requires spatial information about soil properties and an inference system to derive soil functions from soil properties, i.e. scientific sound assessment methods to quantify soil functions.

Soil is important for several ecosystem services, but currently there are more general frameworks and related studies that provide hardly any concepts and detailed methods how soil functions can be assessed (Dominati et al. 2010). In contrast, geological survey institutions that are responsible for soil mapping in their countries, developed simplified assessment methods for various soil functions (see for a compilation of German methods Ad-ho-AG Boden 2007, and ÖNORM 2013 for Austrian methods).

In Switzerland - despite the efforts made by some Cantons such as Basel-Land, Solothurn or Zürich - a common Swiss national framework for soil function assessment and a method catalogue for potentially applicable SFA-methods is still missing yet.

In order to fill this gap the National Research Programme (NRP) 68 project PMSoil 'Predictive mapping of soil properties for the evaluation of soil functions at regional scale' aims to assess soil functions for two regional case studies in Switzerland. Applicable SFA-methods that were mainly developed in Germany will be compiled and tested for Swiss soil data classification and soil function maps generated. The SFA methods will be evaluated for two case study regions based on a large number of soil profiles originating from conventional soil mapping surveys and on soil property maps generated by the digital soil mapping approach in PMSoil. We focus mainly on the following three soil functions: regulation (water cycle, nutrient cycle, acidity buffering), agricultural production and habitat function. The generated soil function maps will serve then as the soil information layers for the land-use-decision model in the NRP 68 OPSOL project.

The poster shows how some soil sub-functions can be assessed for soil legacy data in Switzerland (soil profiles) and points out the differences in existing SFA methods from various countries and their potential to be adapted to Swiss conditions.

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P 14.7

Soil bioturbation by earthworms and plant roots- mechanical and energetic considerations for plastic deformation

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Soil structure is a critical factor in agriculture for determining hydrological and ecological functions including water storage, deep recharge and plant growth. Compaction is known to adversely impact the resulting hydrology and crop productivity as well as other ecological functions of this habitat. An important class of soil structural restoration processes are related to biomechanical activity associated with borrowing of earthworms and root proliferation in impacted soil volumes. This study utilizes mechanical processes in order to simulate earthworm and plant root bioturbation in order to determine the mechanical energy investments into the system. As a model process, we consider steady state plastic cavity expansion to determine the burrowing pressures of earthworms and plant roots under various soil conditions. Cavity expansion models are then linked with cone penetration in order to quantify the burrowing process of plant root growth or earthworm locomotion related to different penetration angles. The associated cavity pressures and expanded radii determined the amount of mechanical energy invested for bioturbation under different hydration conditions and root/earthworm geometries. By considering earthworm physical and ecological parameter such as population density, burrowing rate, and burrowing behavior, we use the mechanical energy to infer estimations of necessary soil organic matter requirements for earthworm populations. Results illustrate a reduction in strain energy with increasing water content and trade-offs between pressure and energy investment for various root and earthworm geometries and soil hydrological statuses. This study also provides a quantitative framework for estimating the associated energy requirements (soil organic matter, plant assimilates) needed to sustain structure regeneration by earthworms and plant roots, and highlights the potential mechanical limits of such activities.

P 14.8

Are Soils Systematically Influenced By Their Soil Ecosystem Properties?

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Organic matter in forest soils is of increasing interest due to its connection to the atmosphere and potential role as a source and sink of CO_2.

When fresh organic matter is incorporated into the soil it becomes stabilized within the matrix through biologically mediated physico-chemical processes. It is well known that microbes are the main agents mineralising soil organic matter (SOM); however, the answer to what are the drivers with the greatest influence on SOM vulnerability is still unclear.

In Schmidt et al., 2011 soil ecosystem properties are described as the environment that has a direct influence of soil carbon dynamics. Based on this concept, it is hypothesised in this project that the main variables influencing soil ecosystem properties, and therefore the vulnerability of SOM, are, firstly, climate (i.e. temperature and soil moisture) and, secondly, soil (i.e. pH and clay content) and terrain properties (i.e. slope and aspect).

Based on these hypotheses, 54 study sites, all part of the Swiss Federal Institute for Forest, Snow and Landscape Research network, were selected to represent different combinations of the variables of interest for testing. The methodology followed was in line with the one applied in Barrufol et al., 2013.

Infrared spectroscopy has already been used as a quick method to gain information on the bulk soil (Haaland & Thomas, 1988; Zimmermann, Leifeld, & Fuhrer, 2007).

In the proposed poster, the results from relating soil ecosystems properties and middle infrared spectrometry data will be shown and explained in detail.

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P 14.9

Exploiting dissolved lignin as sentinels of soil organic matter vulnerability

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Dissolved organic carbon (DOC) is the most biologically available and mobile fraction of soil organic matter (SOM). Its central role in nutrient cycling and sensitivity to environmental changes make it a promising candidate to monitor changes in SOM quality during land use and climatic changes. As the second most abundant biopolymer of terrestrial vascular plants, lignin-derived aromatic moieties are considered to be a main component of soil DOC and play a central role in regulating DOC production in forest litter layers (Kalbitz et al. 2006). Hence dissolved lignin is especially worthy of investigation in terms of its fate, stability and applicability as a sentinel of SOM vulnerability.

While the distribution and degradation of dissolved lignin have been extensively investigated, little is known about its radiocarbon age, which carries information on its source as well as residence time within the system. The recent development of high pressure liquid chromatography (HPLC)-based method has made it possible to isolate lignin-derived phenols from soil DOC for radiocarbon dating. The purpose of this study is to exploit the molecular composition and ^{14}C age of dissolved lignin as “early signs” of changes in soil carbon cycling (such as inputs of fresh litter and leaching of pre-aged soil components, etc.).

Towards this end, we utilize the Long-term Forest Ecosystem Research (LWF) station operated by WSL and employed compound-specific radiocarbon analysis to examine the ^{14}C age of lignin phenols in soil solutions as compared with that of bulk DOC and SOM. In a Norway spruce forest (Beatenberg), while SOM exhibited decreasing ^{14}C contents with depths, soil DOC and dissolved lignin showed predominantly modern ^{14}C ages down to 80 cm in the soil profile in May 2012, suggesting a dominant input of recent carbon probably due to the flush of surface DOC after snow melt. We further examine seasonal variations of ^{14}C ages in soil DOC and lignin across the LWF sites and estimate the contribution of fresh litter and pre-aged SOM to the soil DOC pool using two-end-member mixing model. This study provides the first set of ^{14}C data on dissolved lignin in soils and sheds new insights on soil carbon dynamics and fate of DOC in forest soils.

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P 14.10

Molecular and radiocarbon sentinels of soil organic matter vulnerability: a project introduction

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Investigation of soil organic matter (SOM) vulnerability constitutes an important and pressing challenge due to its value as a resource, its role in the carbon cycle and increasing pressures that soils are experiencing. Particular concerns exist regarding how the large pool of OM that is currently stabilized in soils will respond to the influence of climate change and increasing anthropogenic pressures. Causative factors and underlying processes that may change SOM stability are not yet well understood. In this project, we seek to utilize molecular and radiocarbon signatures as powerful and sensitive tools for assessing sources and dynamics of SOM pools. The overall goal of the project, which is part of the national research program NRP 68 “Soil as a Resource”, is to provide more insights into the stability of SOM matter over different temporal and spatial scales. The project, which also forms part of the “SwissSOM” carbon cluster within the NRP68 program, encompasses a wide range of forest soils that are also part of the Long-Term Forest Ecosystem Monitoring program (LWF) of the Swiss Federal Institute for Forest, Snow and Landscape research (WSL). In addition, agricultural soils are investigated in collaboration with Agroscope. The comparison of contemporary and legacy (aged) samples enable insights into the changes that soils have undergone during recent years.

This research activities follow two main strategies: (1) Assessment of ^{14}C variations in bulk soils and soil fractions over a range of spatial scales (plot to regional scales), with a goal is to create a database that will serve as a benchmark against which to gauge future change; (2) Isotopic characterization of lignin and plant wax biomarkers as molecular proxies to trace organic matter dynamics within different soil fractions. We will show preliminary results, including plant wax concentrations in different soil types.

P 14.11

Long-term management effects on root biomass and carbon rhizodeposition of field grown maize

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Below ground carbon (BGC) inputs by agricultural plants into the soil are an important variable in soil carbon (C) modelling (Bolinder et al. 1997). The sources for BGC inputs are dead root biomass and C release by living roots, a process termed C rhizodeposition. Although drivers of BGC inputs have been studied in different contexts there is no consistent information about the effect of the agricultural management system on BGC inputs. Root biomass can increase or decrease with intensification depending on the nutritional state of the “reference system” (e.g. no or optimal fertilization; Costa et al. 2002) while C rhizodeposition may more strongly be affected by environmental factors than by management (Jones et al. 2009). In this research project, as part of the National Research Program 68 “Sustainable use of soil as a resource”, we therefore address the following research questions:
(i) What are the proportions of root biomass and C rhizodeposition of the total BGC input in the surface- and subsoil under maize cultivation at different sites?
(ii) Does long-term fertilization practice affect total root biomass, root distribution, shoot/root ratios, and C rhizodeposition of maize?

In the growing season of 2013, we conducted field experiments with maize on two long-term experimental sites (“DOK”, Therwil BL and “ZOFE”, Zurich) including seven different managment system- and/or fertilization intensity treatments. Four plants per treatment (= 4 field replications) were grown in microplots and were multiple pulse-labelled with ^{13}C-CO_2 in weekly intervals until physiological maturity. The microplot soil was sampled in three layers to 0.75 m depth, coarse- and fine root biomasses were determined by picking and wet sieving, respectively, and the soil and all plant parts were analysed for their $\delta^{13}C$ values.

First results reveal no significant differences between total root biomasses of the 3 “DOK” treatments. Further results will be presented for
total root biomass, root distribution, shoot/root ratios, and C rhizodeposition of maize from both sites.

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P 14.12

Breeding and drought influence root biomass and rooting depth: lessons learned from the Swiss Era wheats.

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Improving root architecture is an important aim to adapt plants to reduced water and nutrient availability as well as to enhance carbon sequestration. Specifically, deep rooting is discussed as a promising strategy to improve plant growth and to enhance soil organic matter in deep soil layers (e.g. Manschadi et al. 2008, Wasson et al. 2012). Soils are the largest repository of organic carbon in terrestrial ecosystems, but it stocks vary depending on year, crop rotation, management practice and, possibly, crop evolution due to breeding. SOC is primarily plant-derived and the sources can originate from (i) root and shoot remains or (ii) root exudates and other root-borne organic substances (Rasse et al. 2005). Therefore, breeding for deeper roots could be one way to mitigate plant limitations and climate change.

However, during the last century, wheat breeders have dramatically reduced plant height by introducing dwarfing genes into their material. This led to increased yield, as the crop could be managed with greater inputs without the risk of lodging. In addition, relatively more biomass was allocated to the harvested grains which increased the so-called harvest index. Thus, while grain yield rose with increasing inputs and harvest index, the increase in biomass was not in the focus of breeders. What about the roots? There is limited information about how rooting depth and root biomass was affected by breeders (e.g. Waines & Ehdaie 2007) and no studies which investigated root architecture of Swiss wheat. Yet, a deeper understanding of this process is urgently necessary to understand future trends and options for nutrient capture and carbon input to the soil. Most of the agricultural area of Switzerland was and still is planted with wheat varieties derived from the Swiss federal breeding programme, now operated by Agroscope (Fossati). Thus, knowing about the trends in root biomass and root distribution of these varieties may enhance our understanding of historic and future trends of carbon inputs of one of the most important Swiss crops covering an area of 83000 ha.

The objective of our study were to elucidate i) how root architecture of winter wheat changed over 90 years of breeding and ii) how root architecture of winter wheat is influenced by emerging drought during early vegetative and/or during late reproductive development. To achieve this, we identified the 14 most important Swiss bread wheat varieties, dominating the landscape during 90 years between 1920 and 2010. We call this selection “Swiss Era Wheats”.

All 14 era varieties were grown in our Deep Root Observation Platform (DROP) at Eschikon Field Station. The platform consist of 144 Plexiglas© columns (1.60 m length, 0.10 m in diameter), which can be weighed to determine water uptake by the plant. Two water stress treatments were established: early water stressed until flowering and water stressed from flowering until maturity. Both water stress treatments were established starting at complete field capacity. Thus, water stress in the root zones developed gradually starting from the upper part of the soil column with most intensive rooting. Plants were harvested at flowering and maturity, and root biomass distribution in the columns was determined in 250 mm intervals.

Our preliminary results indicate that reduction in plant height led to a severe reduction in rooting depth under well watered conditions. However, under early water stress, short, modern varieties could cope with their tall, old ancestors. The implication of the observed trend for carbon input will be discussed.

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