11. Soil: Formation, Processes, and Conservation

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11.1

Field Verification of Remote Sensing-based UN Land Degradation Neutrality baseline produced using Geospatial cloud computing and machine learning

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Achieving land degradation neutrality (LDN) has been proposed as a way to stem the continued loss of land resources globally. LDN baselines are being set and the corresponding UN Sustainable Development Goal 15.3.1 indicator to estimate the proportion of degraded land over total land area between 2000 and 2015. LDN baseline is based on estimate of these three sub-indicators, i) land cover (LC) change computed as a proxy for land use change, ii) land productivity dynamics (LPD) in vegetation productivity, iii) soil organic carbon stocks (SOCs). United Nations Convention to Combat Desertification (UNCCD) recommended the use of Remote Sensing-based (RS) global datasets (DD), particularly in data scarce contexts. For the first round of LDN reporting in 2018, many countries estimated the LDN and SDG 15.3.1 but reported with low levels of confidence because estimates were made with global datasets in the absence of national and/or local datasets without field verification.

Contributing to the scientific basis for operationalizing LDN and leveraging the availability of freely available satellite images, we developed procedures for generating national level metrics (NM) using geospatial cloud computing and machine learning (Fig. 1) [1]. Landsat 30m images were processed for land cover classification (2015) in Google Earth Engine using Random Forest. LPD was measured in terms of the state, trend, and performance of vegetation productivity using MODIS vegetation time series (250m). State captures recent changes to vegetation productivity and is computed by comparing the initial biomass (2000-2012 mean) to the final biomass (2013-2015 mean) in the time series. For trends in vegetation conditions, we used the Mann-Kendall test in R. Performance compares local levels of productivity with that of similar areas in the region [2]. SoilGrid250m data (~2000) was used for computing SOCs (t/ha), whereas SOCs (2015) uses the carbon conversion coefficients (tropical dry) in relation to LC transitions.

We validated LDN and SDG 15.3.1 estimates based on field datasets over Palapye, eastern Botswana using the Composite Land Degradation Index (CLDI). CLDI incorporates physical, chemical, biological degradation indicators [2]. Differences in the NM, DD and CLDI classes do not permit direct matching. Instead, based on the spatial intersection of land degradation classes, the modal class (most frequently occurring class) was adopted per unit (Fig 2a). A matching scheme of the possible combinations of classes between the maps was then developed using the one-in-one-out rule ([3], Fig 2b). NM and DD underestimated the ‘Improved’ class by 12% and 88% respectively (Fig 2c).

Fig. 1 The workflow followed in this study
NM overestimated the ‘Stable’ class by 17%, whereas DD underestimated ‘Stable’ by 75%. NM and DD overestimated the “Degraded” class by 21% and 267% respectively. Thus, NM estimates better match the CLDI than does the DD. Overall, SDG 15.3.1 estimate using the DD (51.4%, 296,717 sq/km) improved with the use of the NM (32.6%, 182,985 sq/km). The study demonstrates conducting LDN validation with field-based data.

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Fig. 2 Validating land degradation with CLDI data in Palapye (a) SDG 15.3.1 (NM) map with the CLDI unit boundaries superimposed
11.2
Global phosphorus shortage will be aggravated by soil erosion

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Soil phosphorus (P) loss from agricultural systems will limit food and feed production in the future. Here, we combine spatially distributed global soil erosion estimates (only considering sheet and rill erosion by water) with spatially distributed global P content for cropland soils to assess global soil P loss. The world’s soils are currently being depleted in P in spite of high chemical fertilizer input. Africa (not being able to afford the high costs of chemical fertilizer) as well as South America (due to non-efficient organic P management) and Eastern Europe (for a combination of the two previous reasons) have the highest P depletion rates. In a future world, with an assumed absolute shortage of mineral P fertilizer, agricultural soils worldwide will be depleted by between 4 – 19 kg ha⁻¹ yr⁻¹, with average losses of P due to erosion by water contributing over 50% of total P losses.

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11.3
Geochemistry and Paleopedology of a Paleosol Carbonate Sequence from the Okavango Delta, Northern Botswana: Implications for Environmental Change

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The Okavango delta is home to the biggest wetland ecosystem in southern Africa. Characterised by hot semi-arid climates, evapotranspiration exceeds precipitation in the Okavango and this leads to the deposition of soluble salts, mainly alkali carbonates, as surface crusts which are subsequently leached into the subsoil during rainy season (McCarthy and Metcalfe, 1990). In consequence, the area has active carbonate and silica accumulation. Paleosol carbonates are important source of information on terrestrial environmental and climate variations over a long temporal scale (Sheldon and Tabor, 2009; Eze and Meadows 2014, 2015). Our study seeks, for the first time, to: (i) delineate and characterise the soils and paleosol carbonates from an Okavango palustrine sequence using their morphological, physico-chemical, geochemical composition and clay mineral content; and (ii) interpret the paleoenvironments and paleoclimates of the area using geochemical indicators of weathering and pedogenesis

Standard pedological parameters including structure, colour, pH, electrical conductivity and carbonate contents were determined using routine laboratory procedures. Mineralogical composition of the fine-earth fractions (<2 mm) were determined by x-ray diffraction. Total elemental composition of the soils were determined using XRF. Weathering and pedogenic intensities were assessed using selected geochemical molecular ratios.

Results of the study shows the palustrine carbonate sequence (Fig. 1) consists of two distinct units: an older paleosol unit and recent alluvial topsoil unit. An abrupt and irregular soil horizon boundary separates the two units. Horizons “A” and “Bkm” developed weak granular and hard sub-angular blocky structures respectively. Based on paleosol maturity and drainage classification indices, the paleosol carbonates of the Okavango Delta are moderately developed and poorly drained. Soil pH ranged from 8.1 to 10.0 in the sequence. Electrical conductivity also increased consistently from 10 dS/cm in the topsoil to 55 dS/cm in the 2Bkm3. The total elemental compositions of the units show SiO₂ as the dominant major oxide (56.6 – 94.1 wt. %) followed by CaO (0.19 – 16 wt. %), Al₂O₃ (1.76 – 4.20 wt. %), Fe₂O₃ (1.02 – 3.09 wt. %), and MgO (0.44 – 2.98 wt. %). Loss on ignition was lowest (1.9 wt. %) for A horizon and highest (17.36 wt. %) for the 2Bkm3 horizon. Molecular weathering and pedogenic ratios derived from geochemical signatures of the samples varied across the section.

Figure 1. The studied sequence from the Okavango delta.
The index of chemical variability (ICV) ranges from 1.39 to 5.26, while chemical index of alteration (CIA) of the samples falls between 19.04 and 72.43. In the paleosol unit, the 2C horizon is quite outstanding for having the highest ICV and the lowest CIA values. On the contrary, the topsoil (A horizon) has the lowest ICV and the highest CIA values. Quartz and calcite are the dominant minerals in the <2 microns fractions. With the exception of hydrolysis, i.e. the loss of common rock forming alkaline and alkaline earth elements relative to Al during pedogenesis, other pedogenic processes (leaching, clayeyness, calcification and acidification) were quantitatively below the threshold.

A combination of evidence from the geochemistry and pedological properties points to incipient (weak) weathering and pedogenesis under cool and dry arid climates in the Okavango Delta. Calcification, a medium term pedogenic process, is predominant in the area. The paleoenvironments have been predominantly alkaline, had intermittent wetting and drying soil conditions and low leaching intensity. This study validates the efficacy of paleosols in understanding climate change in depositional settings, and gives the possibilities of connecting the paleosols to regional stratigraphic markers.

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A novel in-situ sensor for soil enzymatic activity

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Sustainable soil management requires good indicators for soil health and ways to monitor them. Microbial activity is a particularly good indicator for healthy, non-degraded, and resilient soils and reacts sensitively to management practices. A good proxy for microbial activity in the soil is the activity of extracellular enzymes, which reflects both the long-term microbial activity and the activity of the currently viable microbial population. As such, it directly affects the ability of soil to fulfill its numerous functions.

Most commonly, soil enzyme activities are assessed using destructive biochemical laboratory incubations that involve the dispersion of soil in an aqueous solution of a suitable chromogenic or fluorogenic substrate at a relatively high solution to soil ratio. However, due to these artificial measurement conditions and the influence of transportation and storage on the samples, such assays might not represent the true in-situ activity at the time of sampling but rather a "maximum potential activity". A recent alternative, operating at more natural conditions, is zymography. Here, enzyme-specific fluorogenic substrates are attached to membranes, which are then applied directly to soil surfaces. The method is particularly suited to map the distribution of enzyme activities around roots or earthworm burrows exposed on the surface of mesocosms in the laboratory. However, the potential application of substrate loaded membranes to assess enzyme activities as an indicator of soil health in-situ in the field has been prevented so far by difficulties in preparing and employ all the materials under field conditions.

Here, we present the design of a novel easy-to-use tool (Digit Soil; www.digit-soil.com) based on zymography methodology that allows both researchers and practitioners to reliably, reproducibly and comparably measure a suite of soil enzyme activities to assess soil health and better understand enzyme-driven ecosystem processes. It combines soil incubation unit and camera detection in one small hand-held device capable of measuring the activity of main soil enzymes in-situ in a wide variety of soils within minutes. Apart from time-saving, this also minimizes the problem of changes in conditions, in particular moisture, during membrane application. Data can be transferred to a hand-held device such as a tablet computer and be analyzed, thus allowing immediate management decisions based on the measured enzymatic activities.
Soil carbon sequestration potential in Swiss agricultural mineral topsoils

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Soil carbon sequestration is one of the cheapest and technically least demanding carbon dioxide removal (CDR) technologies. Several recent studies have estimated the potential to sequester carbon (C) in soils, incorporating the concept of soil organic carbon (SOC) saturation as a limiting factor. In Switzerland, biomass availability is most likely limiting rather than the soil’s capacity to store C. We therefore use an opposite approach and ask the question: How much C could additionally be stored in Swiss agricultural soils, given the organic material sustainably available within the country? More specifically, we determine how much additional C can be sequestered by, e.g. maximising the use of cover crops, maximising residue retention, increasing organic amendments (fertilizer, compost), and applying biochar produced with domestic material, without compromising food production and soil fertility.

To estimate SOC stocks in mineral topsoils for Switzerland under these different management options, we use a modelling system that we have developed for national greenhouse gas reporting. It is based on the soil-C model RothC. For the present study, we modified RothC to dynamically simulate biochar applications. Simulations are run until 2100 using regionally downscaled climate change scenarios. A critical requirement for the simulations is that agricultural productivity of Switzerland should be sustained and that shares under different land-use types such as cropland, grassland and forest will remain the same. We estimate the C sequestration potential as the difference to a baseline scenario, where current practices are maintained.
11.6
Quantitative soil erosion assessment based on imagery acquired by Unmanned Aerial Vehicles

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Measuring and mapping actual erosion across agricultural land remains a challenging task even after more than 100 years of research in the topic. While the occurrence of erosion is easy to spot and mark on a map, assessing the actual amount of soil lost on cropland affected by erosion is more difficult. There are several reasons for this difficulty of measuring soil loss. Soil erosion by sheetwash and shallow raindrop-impacted flow is widespread, but moves only a millimetre-thin layer of soil. In addition, rainfall and wetting smoothen and compact the surface soil, so a lowering of the soil surface does not necessarily translate into an equivalent loss of soil. For rill erosion, the change in surface features is more prominent, but the shape of the rills is complex so that simple measurements of width and depth offer only a rough estimate of the volume of soil that is lost. Furthermore, the mapping of rills in the field is time consuming. To a certain extent these problems have been overcome in an indirect way by establishing erosion monitoring plots where a qualitative assessment of rills being present or not can be combined with the amount of sediment caught at the plot outlet. However, plot data are associated with several problems, most notably their size and artifical boundaries, which often interfere with the actual surface hydrology and erosion and deposition patterns on an agricultural landscape (Fig. 1). Furthermore, in the case of the standard plot size introduced for the Universal Soil Loss Equation in the 1950s (22.13 m long, 1.83 m wide, 9% slope) modern farm machinery does not fit on a plot anymore. Finally, plots are expensive to install and deliver erosion only for the site where they are built, which may not correspond to the sites with the greatest erosion problem in a particular agro-ecosystem.

Erosion mapping using Unmanned Aerial Vehicles has been explored for some time, but only during the last decade the fast development of both, drones capturing images and their processing into Digital Elevation Models (DEMs) has opened their use for widespread application. In most studies and applications, imagery of eroding sites was captured either just after the erosion event, or at some point before and after. In the former case, erosion features, mostly rills, have been separated by an algorithm from the surrounding soil surface. The volume of soil below the perimeter of the rill has been calculated from the DEM. When before and after erosion imagery is available, the net reduction in surface height between two DEMs has been considered as corresponding to the actual soil loss. The accuracy of these approaches has been tested by comparing DEM derived from UAV imagery and independently constructed DEMs using a terrestrial laser scanner. The results show that UAVs can offer a good approximation of the actual amount of soil eroded by rill erosion. However, it became also clear that each soil management and tillage system requires a specific quality of the imagery in terms of resolution and time of acquisition. In addition, the DEM generated by laser scanning for comparison has inaccuracies itself, e.g. as a result of the shadowing by steep and overhanging rill walls or deep furrows from tillage. In this study we therefore aimed at comparing a direct measurement of rill volume with the change of volume estimated from UAV imagery, both through a before and after comparison, as well as the mapping of rills from an after event image. The rill erosion mapping was carried out on a cropfield on the Heshan Farm (125° 20’ 10.5″ E, 49° 00’ 23.1″ N) in Nenjiang County, Heilongjiang Province, Northeast China. The field experiences rill erosion regularly, often due to snowmelt in spring. For this study, rills were created artificially by generating runoff in furrows with a downslope orientation. UAV imagery was captured using a DJI Mavic 2 pro. Rill volume was measured by filling 29 one-metre sections of rills with sand. The volume of the sand filled into the rills was assumed to correspond to the amount of soil that had been washed away by erosion. UAV images were taken before rill erosion was initiated, after the erosion, and after the rill sections had been filled with sand. From the DEMs, the rill volume was calculated in two ways: first by the volume of soil below the rill edge delineated by the sand, and second by calculating the difference between the DEMs for the test sections captured before and after the rill erosion.

The results show that the commonly used difference between DEMs capturing the soil surface before and after an erosion event are within 20% of the volume of sand filled into the rills. Matching the sand volume with the DEM generated after filling proved difficult because of the limited quality of the elevation of the sand surface. This is attributed to their uniform colour, lacking matching points for constructing a DEM. Overall, the comparison between the direct measurement of the volume of eroded soil with the DEM showed that the imagery has the potential to improve and replace current approaches to quantitative erosion measurements. Apart from an acceptable variability, UAVs can measure erosion where it happens rather than on plots with disturbed hydrology and erosion and deposition patterns. They can also be applied in a far more widespread way by capturing images of sites where erosion actually happened which enables an improved quantitative identification of the boundary conditions that cause erosion compared to just qualitative mapping or few plot studies.
Figure 1. Erosion and deposition caused by runon slope and tillage direction
Rapid decrease of soil erosion rates with soil formation and vegetation development in periglacial areas

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High mountainous areas are strongly shaped by redistribution processes of sediments and soils. Due to the projected climate warming and the continued retreat of glaciers in the 21st century, we can expect the area of newly exposed, highly erodible sediments and soils to increase. It is therefore important that we improve our understanding of erosion processes in young, mountainous soils and that we quantify them. An increase in soil erodibility could threaten human infrastructure (i.e. hydroelectric power, touristic installations and settlements) as well as the livelihood of mountain farmers due to the resulting soil degradation.

While soil development is increasingly well understood and quantified, it has rarely been coupled to soil erosion. The aim of this study was, therefore, to assess how soil erosion rates change with surface age. We investigated two moraine chronosequences in the Swiss Alps: Firstly, the periglacial area of Steingletscher (Sustenpass), with siliceous soils ranging from 30 a to 10 ka, and secondly, in the periglacial area of Griessgletscher (Klausenpass) with calcareous soils ranging from an age of 110 a to 13.5 ka. We used ²³⁹+²⁴⁰Pu fallout radionuclides to quantify erosion rates and compared them to physical and chemical soil properties and the vegetation coverage. At both chronosequences, the erosion rates were highest in the young soils (on average 5–10 t ha⁻¹a⁻¹ soil loss). Erosion rates decreased markedly after 3–5 ka of soil development (on average 1–2.5 t ha⁻¹a⁻¹ soil loss) to reach a more or less stable situation after 10–14 ka (on average 0.3–2 t ha⁻¹a⁻¹). We conclude that climate change does not only cause glacier retreat, but also increases sediment dynamics. Depending on the relief and vegetational development, it seems to take up to at least 10 ka to reach soil stability. The establishment of a closed vegetation cover with dense root networks seems to be the controlling factor in the reduction of soil erodibility.
11.8
Effects of shallow incorporation of cover crop mixtures on short-term soil organic matter cycling in agricultural soils – An on-farm field trial

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Short term soil organic matter (SOM) cycling is an important part of soil fertility, soil health and crop performance. In an agricultural system the habitat for soil microbiology is constantly altered by farmer’s management. Within a single crop rotation there are periods of SOM formation and periods of SOM mineralization. Compared to the total amount of SOM, the quantities of these short-term changes are rather small. Therefore, it is challenging to measure these short-term SOM dynamics and accordingly current knowledge is quite limited. However, according to the state of research, cover crops are considered to play a major role in short-term SOM formation. The standard treatment to terminate green cover crops is either ploughing or herbicide application. A new and spreading method in agricultural praxis is to incorporate green cover crops into the first 0-5 cm of topsoil. Thereby, plant biomass is brought into the biologically most active soil layer and can serve as high quality energy source for soil microbiology which leads to a rapid decomposition. By this method farmers expect i) stimulation of soil microbiology ii) efficient formation of soil organic matter, iii) improvement of soil structure and iv) constant nutrient supply for the following crop. In this on-farm trial the direct influence of shallow incorporation of green plant biomass is assessed by taking soil samples in high density. The trial comprises the period of nine months between cereal harvest and sowing of spring crop. In this period two cover crops are sown and shallowly incorporated. The summer cover crop mixture consists of 12 species and the winter cover crop mixture of four species. Soil samples are taken right before cover crop incorporation and about one month after which leads to four sampling time points. At each time point samples are taken at 39 GPS referenced points and three soil depths (0-5, 5-10, 10-20 cm) resulting in 117 samples per time point. The trial is conducted on six fields in Eastern Switzerland. All samples are analyzed for total C, total N and permanganate oxidizable carbon (POXC, also referred to as active C). Additionally, soil microbial biomass is measured per field in a mixed sample with four replications. To analyze the 2600 GPS-referenced samples near infrared spectroscopy is used. The calibration of the spectral models is done for each field separately to achieve a high prediction accuracy. The presentation in the session will discuss the first results of the trial and the suitability of spectral measurements for high density sampling to detect small changes in SOM.
11.9

Aeolian soil erosion assessment ($^{239+240}$Pu) within a dry-oceanic area (Otago, New Zealand)

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New Zealand is characterised by high uplift rates and strong erosion. Currently only a few studies have investigated the local soil redistribution and degradation processes at the largest semi-arid area in New Zealand. Here we present the elemental redistributions results of our comparative study between small hills at an intraterrain valley and an adjacent ridge. On average the Plutonium based soil erosion rates in the valley are typically lower ($86–435$ [t km$^{-2}$ yr$^{-1}$], PDM), compared to the ridge ($193–1,108$ [t km$^{-2}$ yr$^{-1}$], PDM), confirming past $^{137}$Cs-based rates. We estimated that about 400 to 660 [t km$^{-2}$ yr$^{-1}$] are eroded by wind in the Otago upland through mass balances with local river sediment yields.

We found, that higher wind erosion is attributed to the exposed ridge which contains as much as 31% aeolian dust. In addition, the wind erosion effect on the landscape is evident in deep abrasion of the rock tors (large residual rocks). A variety of chemical weathering indices of the local soils have shown a faster mineral removal on the ridge and lesser degree of soil weathering in the valley. Further, a continuous soil surface rejuvenation is found to be present at the ridge, as the mineral decomposition is up to 25 % lower compared to the valley. Soils at both hilltops have the lowest weathering degree. We consider that fresh rock material from adjacent tors (large residual rocks) is causing a rejuvenated chemical weathering signature. The Otago upland is therefore characterised by strongly active geomorphodynamics (soil denudation and subsequently soil production), which are amongst the most intense and fastest in New Zealand.

Figure 1: Graphical Abstract by Raab et al. (submitted).

REFERENCE
11.10
European Joint Programme ‘Soil’ (H2020 EJP Soil): Stocktaking on estimates of achievable soil carbon sequestration on agricultural land in Europe

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Soils are the largest terrestrial pool of organic carbon and can act both as a source and a sink for CO₂. Since agricultural practices have been endorsed as an option to remove CO₂ from the atmosphere to mitigate climate change, scientist worldwide are concentrating their research to answer questions such as: How and for how long can carbon be stored in soils? What are the potentials of agricultural measures to sequester carbon? As part of the project EJP Soil, we collected information on the available knowledge of achievable carbon sequestration in mineral soils in agricultural land, including pasture/grassland for 21 European countries, under different farming systems, soil types and pedo-climatic conditions as well as on GHGs mitigation measures for managed organic soils. The objective is to prepare an inventory as basis for the efforts to be taken by the EJP SOIL consortium members to estimate these potentials under different conditions, including the inventory of past and current studies on the topic and methodology used, and to identify potential gaps. First results indicate that the available knowledge is unevenly distributed across the continent (Fig. 1)

![Figure 1: Data density (Studies per 10'000 km²) for each environmental zone (EZ) across Europe, normalized by its agricultural area. Value unit: Alpine North (ALN), Boral (BOR), Nemoral (NEM), Atlantic North (ATN), Alpine South (ALS), Continental (CON), Atlantic Central (ATC), Panonian (PAN), Lusitanian (LUS) Anatolian (ANA), Mediterranean mountains (MDM), Mediterranean North (MDN), Mediterranean South (MDS). EZ according to Metzger et al., 2005.](image)

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Large clay contents in arable land do not limit soil structure quality and vulnerability

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High clay contents are often considered an obstacle for keeping good soil structure quality and large soil organic carbon (SOC) contents in arable land. This is particularly a concern since the soil structure vulnerability was shown to depend on SOC:clay ratio threshold values, with 1:10 being the structure vulnerability index (SVI) lower acceptable limit (Fell et al., 2018; Johannes et al., 2017). In this study, we sampled 96 fields from 58 farms in the Jura region with clay content up to 51.5%. Undisturbed soil samples were collected and measured for their physical properties, namely bulk density at -100 hPa, gravimetric water content at -100 hPa, gravimetric air content at -100 hPa. The soil structural degradation index (SDI) was calculated as the ratio of air to water gravimetric content at -100 hPa as proposed by Johannes et al. (2019) such as food production, carbon and nutrient cycling or water regulation and filtration strongly depend on soil structure quality (SSQ). The samples were then visually scored with the CoreVESS method. Although the SVI was low in this study, the relationship between SOC and clay was linear on the whole clay content range (Figure 1). Physical properties were not impacted by clay content and were explained by SOC, suggesting that SOC is the main driver of the soil physical properties. The SDI structural quality classes and the CoreVESS observations did not show significantly different clay contents. We conclude that large clay contents are neither an obstacle for soil structure quality and vulnerability, nor for SOC content management. The characterization of the associated cropping systems was also discussed according to clay content.

Figure 1: Linear model and “lowess” non-parametric local regressions between soil organic carbon (SOC) and clay content; black solid line: linear regression line; light grey dashed line: lowess smooth curve (polynomial degree 2); light grey dotted lines: 95% confidence interval; grey solid line: 10% SOC:clay ratio.

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11.12
Termites as soil engineers

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Fungus-growing termites (FGT) have long been considered as ecosystem engineers (Dangerfield et al., 1998) for the modifications they bring to the soil, their ability to concentrate nutrients, and their capacity to create patches of fertile land. Only a few studies have highlighted the ability of FGT to modify the grain-size distributions of the sediments and soils that are forming the environment where they develop (Jouquet et al., 2002). The aim of this talk is to present new data on soil textures affected by FGT and collected in a semiarid subtropical region of southern Africa. The key questions of the study relies on the capacity of fungus-growing termites (i) to adapt to any kind of parent material to build their mounds, (ii) and to enrich or deplete this parent soil to meet their texture requirements in terms of mound stability and appropriate settings to insure the success of the colony. In order to assess the sedimentary modifications carried out by termites on parent materials and their associated constructed mounds, the used techniques were mostly based on grain size distributions and soil micromorphology. Only a few studies have combined both methods to highlight the role FGT play in the selection of grain sizes to build their epigeal mounds (Abe et al., 2009). The study targeted the evaluation of the potential impact of FGT on texture modifications in an environment of contrasted grain sizes: (i) in soils dominated by sands and (ii) in soils dominated by fine material, in this case diatomites. Moreover and for the first time in this context, Electrical Resistivity Tomography (ERT) was used to investigate a fullsize underground fungus-growing termite mound. The 2D resistivity inversion ERT data emphasized the FGT amendments to the parent soil material, as expected. Consequently, from the above-mentioned results, it can be concluded that the FGT built mound converges to a required optimum, whatever a given parent material. Indeed, by selecting, transporting, and mixing at will the various grain sizes at disposition from the surrounding environment, FGT reach the mandatory texture adapted to the functions and properties for their mounds. Over time, these mounds will be flattened by erosion and will become a new soil/sediment. These results clearly recognize the role of fungus-growing termites not only as soil engineers, but also as biogeological agents able to modify the grain size distribution of the sediments in their environment.

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11.13
Subsoil warming decreases abundance and modifies community structure of microorganisms

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Global warming is predicted to increase soil temperatures in near-synchrony with air temperatures at all soil depths. How microbial communities of the subsoil (below 30 cm) will respond to the predicted warming remains largely unknown. This knowledge gap causes uncertainty in predictions of future carbon fluxes from the enormous subsoil carbon pool (>50% of the soil organic carbon [SOC] stocks are below 30 cm soil depth) to the atmosphere.

The Blodgett forest field warming experiment (California, USA) warms whole soil profiles to 100 cm soil depth by +4°C compared to control soils. Samples were taken after 4.5 years of continuous warming. We investigated how warming affects the abundance and community structure of microorganisms using proxies for bulk microbial biomass carbon and specific lipid biomarkers, such as phospholipid fatty acids (PLFAs) and branched glycerol dialkyl glycerol tetraethers.

After 4.5 years of warming microbial abundance was 28% lower in warmed subsoils compared to the control plots. In contrast, warming did not affect topsoil microbial abundance. The microbial community composition only changed in the subsoil: the relative abundance of Actinobacteria increased in the warmed plots below 50 cm soil depth and Gram+ bacteria in the subsoil adapted their cell-membrane structure to warming induced stress. Our results show for the first time that subsoil microorganisms are differently affected by uniform soil warming compared to topsoil microorganisms. The decrease in microbial abundance in subsoils was strongly correlated with lower soil organic carbon concentrations. We hypothesize that the microbial responses in subsoils could be related to changes in carbon availability. If easily available SOC becomes depleted and forces subsoil microorganisms to feed on previously stable SOC, these stable SOC pools might become more vulnerable to decomposition under global warming.
Do effective microorganisms (EM) affect the decomposition of organic matter?

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The shallow incorporation of cover crops with the intention to improve soil fertility has become increasingly popular in the recent years. Often, effective microorganisms (EM) are applied during green manure incorporation into soil with the aim to facilitate the decomposition process. Through EM application, the mineralization of the recently incorporated plant material is expected to be facilitated, increasing the nutrient availability for the subsequent crop. However, empirical evidence on the effectiveness of EM application on soils and their subsequent effect on soil parameters, including the availability of nutrients or even detrimental effects, such as mobilisation of toxic trace metals, is scarce.

For that reason, we performed a soil incubation experiment on a Swiss loamy Cambisol, simulating a cover crop decomposition procedure. Fresh topsoil (0-10cm) was passed through a 2mm sieve and amended by eight different treatments: Addition of a commercially available EM solution either 1) equal to vendor-recommendation 2) 100-times the vendor-recommendation 3) 100-times the vendor-recommendation past repeated heat-sterilization and 4) no EM addition. Each of the treatments were either incubated alone or with plant material, simulating fresh organic matter input. During a 28-day soil incubation at 12°C, soil pH, labile organic carbon (permanganate oxidizable carbon "POX-C"), respiration, water-extractable ions as well as trace metals were regularly assessed.

Addition of EM to soils amended with plant material decreased soil pH from 7.1 to 6.8 during the first three days after addition, yet the effect was reduced at later time points. Soil respiration, an indicator on soil microbial activity, was strongly enhanced by plant material addition, while the addition of EM showed no detectable difference compared to the non-amended control. Interestingly, labile carbon did not show any differences between treatments with and without plant material addition, indicating that POX-C is insensitive to recently added plant material. Yet, also EM addition did not alter labile organic C.

While the effects on water extractable ions and trace metals are currently analysed, we in the meantime conclude that neither the recommended nor the excessive addition of EM during green manure decomposition has detectable effects on soil organic matter decomposition or the utilization of added organic matter by microorganisms. The data set will be further corroborated with analyses whether or not added EM were able to establish in the soil over the period of soil incubation, using genetic tools.
P 11.2

Soil organic phosphorus characterisation in soils at early stages of pedogenesis

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Phosphorus (P) is an essential nutrient and can be found in organic and inorganic form in soil. During soil development, the relative proportion of soil organic P is commonly considered to increase with time. However, information on the occurrence of specific organic P compounds during the early stages of pedogenesis is scarce.

We characterised the organic P fraction of a young soil chronosequence to better understand which organic P compounds accumulate over a period of 136 years of soil development. Topsoil (0-5cm) samples of 21 sites in the forefield of the Damma glacier (Switzerland) were sampled. Soils were classified as Leptosols developed on granitic bedrock. Soil organic P compounds were determined in alkaline (NaOH-EDTA) soil extracts by using an enzyme addition assay: By the addition of substrate-specific phosphatase enzymes, specific organic P compounds were hydrolysed, causing an increase of inorganic orthophosphate in the extract and indicating the presence of specific organic P compounds. Four organic P classes were determined: phytate-like P, monoester-like P, diester-like P and enzyme-stable P (i.e. total organic P minus sum of the three enzyme-labile P classes). Obtained organic P classes were correlated with biotic and abiotic soil properties.

Total extractable organic P (i.e. sum of the four organic P classes) generally increased with soil development, but reached a plateau after 110 years of soil development. Between 60% and 100% of extractable organic P was hydrolysed by the added substrate specific phosphatase enzymes, indicating a potentially high lability of organic P during the early stages of soil development. Phytate-like P was the most abundant organic P compound (5 – 24 mg kg⁻¹), followed by monoester-like P (0 – 23 mg kg⁻¹) and diester-like P (0 – 11 mg kg⁻¹). These three enzyme-labile P classes increased linearly with time, but reached a plateau at the later stages of soil development.

Strong linear correlations of phytate-like P and monoester-like P with P bound in the microbial biomass as well as plant aboveground biomass in the first 78 years of soil development support the idea that both of these two sources were involved in the formation of these organic P classes. Interestingly, no such correlation was observed with the occurrence of Al- or Fe-oxides, which are potential binding sites for these organic P compounds in soil. Therefore, the occurrence of these compounds was more driven by the continuous and increasing input from different sources with time, rather than their stabilisation and protection from degradation on the soil solid phase.

This study thus contributes to an improved understanding on the factors driving the accumulation of specific organic P compounds in soil during early pedogenesis considering different formation, stabilization and degradation mechanisms.
P 11.3
Influence of parent material and weathering on soil organic matter stabilization in alpine ecosystems
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In the global carbon cycle, organic matter (OM) in soils represents the major terrestrial pool of carbon, storing roughly twice the amount of carbon as do the atmosphere and vegetation combined (Ciais et al., 2013). However, under changing environmental conditions, it remains unclear whether soils act as sources or sinks of carbon. Recent research has shown that the persistence of soil organic matter (SOM) is not only controlled by its molecular structure, but rather by the properties of its surrounding environment. The accumulation or loss of OM in soils is regulated by the interplay of climate, soil matrix development, nutrient availability as well as belowground vegetation inputs and microbial community structure (Doetterl et al., 2018). Nevertheless, there exists a lack of a more comprehensive understanding as to what extent these factors affect SOM stabilization. Especially the impact of parent material has remained an understudied control of organic matter cycling in soils. Although recent studies have shown the importance of soil physicochemical properties (which depend on parent material and soil weathering stage) on SOM persistence (e.g. Griepentrog et al., 2018; Rowley et al., 2018), current models of SOM cycling mostly do not include soil geochemical parameters (such as parent material). For example, soils developed on mafic parent materials exhibit relatively lower potential for decomposition of SOM compared to those developed on felsic parent materials, because of relatively higher mineral reactivity (and thus development of essential sites for OM stabilization). Furthermore, soils developed on marl with relatively higher potential to develop soil matrices that are able to stabilize SOM are expected to exhibit relatively lower potential for decomposition of SOM compared to soil developed on dolomite with relatively low development potential for soil matrices that are able to effectively stabilize OM. Additionally, soils at higher elevations are more vulnerable to decomposition compared to those at lower elevations, as they undergo less weathering and therefore have relatively lower potential for SOM stabilization. Taking all these expected effects into account, the hypotheses of this Master’s thesis are the following:

SOM stabilization will be highest in soils that provide a developed soil matrix and reactive mineral surfaces, which leads to large fractions of OM being stored in aggregate or mineral soil fractions where SOM is protected from degradation via physico-chemical interactions. Furthermore, SOM stabilization will be highest in soils that provide nutrients for plant growth through weathering of parent materials.

Hence, the objective of this Master’s thesis is to develop a mechanistic understanding of the impact of parent material on SOM stabilization through its influence on geochemistry and thus potential for soil matrix development and nutrient supply. The thesis will therefore address the following questions: What is the geochemical composition in soils developed on different parent material and what is its influence on (i) SOM stabilization, (ii) soil matrix development, and (iii) nutrient supply. Investigations will be carried out on soils which were sampled at elevations between 2000 – 2400 m.a.s.l. within five different geologies exhibiting varying geochemistry (i.e. greenschist, gneiss, marl, dolomite, and flysch). In order to get more insight into geochemical dynamics of the aforementioned parent material, weathering indices will be analyzed using Ti/Zr and Fe/Si ratios as well as contents of iron and aluminum oxides. Furthermore, elemental composition, pH, soil texture and cation exchange capacity will be determined, as potentially major geochemical drivers of SOM stabilization.

REFERENCES
P 11.4
Rapid transformation of plant-derived soil organic matter in response to elevated CO2 and warming in a spruce-dominated ombrotrophic bog

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Northern peatlands store approximately one-third of global terrestrial soil carbon, despite occupying less than 3% of the land surface. Rising atmospheric CO2 concentration and temperature (6–10 °C by the end of the 21st century) are predicted to stimulate the decomposition of the stored carbon, contributing disproportionate amounts of greenhouse gases to the atmosphere (Hanson et al., 2020). Thus, peatlands could turn from net carbon sinks to net carbon sources and cause positive feedbacks to future climate. Peatlands are key ecosystem and their warming responses and underlying mechanisms need to be better understood.

In this study we assessed how 0–9°C of deep peat warming (0-200 cm) with ambient or elevated CO2 (+500 ppm) affect the quantity and quality of soil organic matter (SOM) in the climate change manipulation experiment SPRUCE (Spruce and Peatland Responses Under Changing Environments) in Minnesota USA. We assessed how warming and elevated CO2 affected the degradation of plant and microbial residues as well as the incorporation of these compounds into SOM. Specifically, we analysed free extractable n-alkanes and fatty acids combined with compound-specific stable carbon isotope (δ13C) analysis.

We observed a 6‰ offset in δ13C between bulk SOM and n-alkanes, which were uniformly depleted in δ13C when compared to bulk organic matter, confirming previous findings. Surprisingly, already after 4 years of deep peat warming and 2 years of elevated CO2 a strong depth-specific response became visible with changes in SOM quantity and quality. In the upper 0-30 cm depth, the δ13C values of bulk organic matter and of individual n-alkanes increase concurrently with increasing temperatures in both temperature and temperature x elevated CO2 treatments, but not below 40 cm depth. Our results suggest that n-alkanes, which typically turn over slower than bulk SOM, undergo a fast transformation under relatively short period of simulated warming.

It remains to be seen how fast the deep (>40cm) peat will respond to rising temperatures and atmospheric CO2 concentrations, and how this large carbon reservoir will respond to the changing environmental conditions.

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P 11.5

Swiss Mountain Soil Ecology Project

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Currently, undergoing significant climatic changes, terrestrial ecosystems are disturbed or even disordered. Because Swiss mountain ranges are concerned, it is crucial to look at the functioning of alpine environments to understand what the major issues for this natural environment are. In this way, the concerned authorities will be able to take adequate measures for the protection and conservation of these environments, and thus, maintain the ecosystem services supported by alpine environments such as the stability of the terrain, the regulation of water and hosting many animal and plant species. This diversity of landscapes in such a small and diversified territory (especially regarding the topography and rocky substrate) makes all Swiss soil profiles indexed in the Pedolibrary - a soil database - at the University of Neuchâtel, all the more valuable and very interesting. This collection includes more than 4'000 samples referenced by profiles and soil horizons. So far, several people have been involved in updating the database to be able to use it for research. The aim of this project is to gain knowledge in the field of science regarding soil-vegetation interactions while conducting feasible field and laboratory experiments.

Using a diachronic and synchronic approach, we will deepen our research questions working at different scales:

MACRO  How do soil and vegetation properties correlate across spatial and temporal scales?
MESO    What is the interdependence of soil and vegetation within a homogenous climatic zone?
MICRO   What is the relative contribution of vegetation traits and climatic conditions for explaining soil organic matter formation and pedogenesis?
Understanding dissolved organic matter by destroying it

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Dissolved organic matter (DOM) is a ubiquitous complex mixture that resists usual attempts of identification due to its high chemical diversity (Hawkes et al. 2020, Roth et al. 2019). Even state-of-the-art techniques such as liquid and gas chromatography, coupled to high resolution (tandem) mass spectrometry, are often hampered by characteristic chimeric mass spectra that are difficult to interpret and thus limit our understanding of molecular-level processes in the environment (Hertkorn et al. 2008, Petras et al. 2017). Ecosystem information encrypted within these mixtures thus remains largely elusive and descriptive. Tandem mass spectrometry (MS²) can reveal unknown imprints of isomers and isobars due to exact mass determination (Figure 1). We present an approach to decipher complex chimeric mass spectra of soil dissolved organic matter obtained by direct-infusion electrospray ionization tandem mass spectrometry (DI-ESI MS/MS). Pairwise alignment of all precursor and product ions revealed an exact mass difference (delta mass) matrix that was subsequently matched against two lists of known delta masses: 1) literature-known but non-indicative delta masses and 2) highly indicative delta masses derived from tandem MS experiments using a set of 14 phenolic standard compounds. Additionally, we fragmented four isobaric precursor ion mixtures (m/z 241 301, 361 and 417) at three normalized collision energies (15, 20, 25%) to analyze DOM fragmentation patterns and sensitivity. Our results reveal that full exploitation of MS fragmentation experiments produces valid biogeochemical data and helps to identify novel ecosystem process markers in DOM. Furthermore, our approach resolved the contribution of particular delta masses on the single precursor (molecular formula) level, which added a novel information layer to the frequently used Van Krevelen plot. The identity and number of matched delta masses agreed well with ion abundance and the number of distinct organic species in structure databases. The delta mass matching thus yielded new insight into the underlying patterns of DOM chemodiversity. Altogether, the results open up new avenues to access structural information encrypted within complex mixtures and study their link to ecosystem processes.

Figure 1. Typical non-targeted direct-injection mass spectra of dissolved organic matter resemble a haystack of metabolites, hampering the true identification of unknowns (upper panel). Lower panel: By isolation and fragmentation, certain “needles” (here, at m/z 301) can be “pulled out of the haystack” for MS fragmentation, yielding structural information. Thanks to ultrahigh resolution and exact mass determination, these chimeric tandem MS spectra can be dissected to obtain information on specific “needles”. Three exact mass differences are highlighted: neutral loss of CO₂, which is a common and non-indicative mass loss (m/z 257); neutral loss of C₆H₁₀O₅, which is also observed in flavonoids (m/z 151); and a neutral loss of C₆H₁₂O₅ (m/z 139), which could represent the loss of a sugar moiety.
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Ongoing climate change and specifically the increasing atmospheric CO2 concentration has led to a great interest in an improved understanding of the carbon cycle in terrestrial ecosystems. The increasing atmospheric CO2 concentration can accelerate soil organic matter (SOM) decomposition, which creates an imbalance between carbon input and output into the soil (Bradford et al., 2008). This rapid carbon loss causes soils to move from a carbon sink to a carbon source (Jones et al., 2003).

Following the Kyoto Protocol, afforestation has been acknowledged as a promising strategy for SOM conservation and to mitigate anthropogenic CO2 emissions. The establishment of forests on land that was not forested before leads to an increased carbon pool at the ecosystem scale due to the increase in aboveground tree biomass (Huang et al., 2011). However, the effect of carbon sequestration in soils depends on ecosystem properties, the former land use and on type of trees planted. Some studies show a decline in soil carbon concentration after afforestation of former pastures due to reduced root litter input (Hiltbrunner et al., 2013). Other studies, however, show an increase in soil carbon concentration 30 to 40 years after afforestation (Thuille & Schulze, 2006). Thus, there is a need for well-designed and site-specific experiments over several decades to investigate changes in the dynamics of SOM following afforestation to predict the behaviour of carbon sequestration under changing environmental conditions.

One approach to trace the sources of organic matter (OM) is the application of molecular proxies like phospholipid fatty acids (PLFA; Gunina et al., 2017) or cutin and suberin monomers (Huang et al., 2011). Though, focusing only on one compound class may lead to flawed conclusions due to missing information offered by other compound classes. One way to obtain more solid information on SOM dynamics is the combination of multiple compound classes (Li et al., 2018). The aim of this project is to identify possible sources of OM in soils in a subalpine afforestation sequence (40-130 years) with Norway spruce (Picea abies L.) on a former pasture in Jaun, Switzerland, by combining molecular proxies from several compound classes originating from various plant and microbial sources. This allows a more precise determination of the sources of OM and a better understanding of its transformation.

Root frequencies of living roots counted during field work revealed a larger quantity (+70%) of fine roots (<2 mm) in pasture compared to forest soils (P < 0.001). However, there was no significant age effect (P = 0.09) in terms of root quantities between the different forest stand ages. Nevertheless, the number of fine roots in the topsoil (0-10 cm) exceeds the number of fine roots in the subsoil (20-40 cm) by a factor of three, both under pasture and in forest stands of all ages. The lower root frequency and the changes in litter composition under spruce compared to pasture affects the quality of the SOM. As shown by Hiltbrunner et al. (2013), who observed changes in SOM dynamic through changes in quality and quantity of litter input following afforestation of former pastures as fine roots of grass have a lower lignin content (240 mg g⁻¹) compared to fine roots of spruce (310 mg g⁻¹). Further, they observed a decline of the SOM stock of the mineral soil after 30 years, with a minimum 40-45 years after afforestation. In contrast, mineral SOM stocks in the old forest (120 yr) are equal to that in the original pasture. This is explained as older forests typically produce more biomass than younger forests, which leads to the accumulation of a forest floor with a large C amount originated from needle fall (Hiltbrunner et al., 2013). In our project, we further want to identify a precise rate of SOM input into soil, e.g. plant- and microbial-derived, decomposition and losses of old SOM following afforestation by combining molecular compound classes originated from various sources.

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Luminescence dating to unravel Ferralsol evolution in SE Brazil

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Thick and deeply weathered tropical soils are the basis for the most diverse ecosystems worldwide and an important pillar of global food production. Under today’s increasing pressure on soils, the understanding of soil formation and its rate are essential. There is remaining debate if in-situ processes sufficiently explain the genesis and distribution of thick tropical soils, or if additionally, allochtonous components transported by e.g. water or wind have to be taken into account.

Luminescence dating is a promising tool of Quaternary research and increasingly recognized in soil science. Mainly regarded as tool to date sedimentation, it can also be used to evaluate rates of soil turnover by bioturbation. In this presentation, we present first luminescence ages from > 3 m thick Ferralsols near Piracicaba, SP, southeastern Brazil. Our data indicate Late Pleistocene to Holocene reworking. We discuss the significance of these ages to understand the formation of these soils and the implications for the paleoenvironmental development and present land-use.
Potential for inverse modeling to assist in source apportionment of organic matter in soil and peat using molecular biomarkers

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To study past environmental conditions, such as climate and vegetation, molecular biomarkers stored in soil and sedimentary archives have been used across a variety of studies. These biomarkers originate primarily from plants and include straight-chain lipids (particularly n-alkanes), suberin, cutin, and lignin monomers. While molecular markers can provide a wealth of information, their use can lead to problematic interpretations. It is often assumed that following deposition, there is little to no change in the concentration or distribution pattern of biomarkers, such as n-alkanes. A systematic literature review regarding the fate of n-alkanes in soil has indicated that this is an overly simplistic view. Preservation can vary based off of a variety of factors including climate and soil conditions. Additionally, most studies focus on only one or two compound classes of biomarkers, which can lead to an incomplete or incorrect understanding of results. To improve the use of molecular markers to reconstruct palaeoenvironments or identify sources of organic matter, we propose an inverse modeling approach to enable simultaneous analysis of multiple compound classes and increase the quantitative nature of results. Preliminary analyses show great promise for the use of our model in soil and peat archives. We will show findings gleaned from our literature review that will be used to determine essential parameters necessary for further improved source quantitation.