Response of soil to different farming practices – case studies in Iceland and Austria

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Abstract

Arable land covers approximately one fourth of the global land area, but only half of it can be used efficiently for cultivation to feed the growing population. Modern agriculture has developed highly productive food and biomass-producing systems based on industrial principles, which has lead to a considerable environmental burden. Organic agriculture has expanded as a movement towards more sustainable food production, which aims to maintain the key functions and ecosystems services of soils. At present, approximately 0.7% of global and 4% of European agricultural lands are managed organically (Willer and Youssefi, 2007). Soil organic matter (SOM) and its turnover play a pivotal role in the biogeochemical cycling of nutrients and in the response of terrestrial carbon to future climate scenarios. Its fate and dynamics are mainly governed and understood by its properties and physiology of the soil organisms (von Lützow and Kögel-Knabler, 2009).

A key to understand and define a sustainable agricultural soil system is to quantify the impact of different land use on soil structure and biogeochemistry, with emphasis on nutrient turnover. The goal of our future research is to evaluate SOM pools in different soil aggregate sizes under different farming systems (organic vs. conventional) and link them to soil biodiversity. Soils were selected along cultivation age gradients under sub-arctic (Iceland, Andosols) and continental climate (Austria, Chernozems).

The further outcome of this research is to identify quantifiable natural indicators for farm sustainability assessments. Gained data will also be linked to energy balance and food productivity in order to get more insights in benefits of different farming practices.

1. Agricultural production facing a challenge

The Earth's soil resources are unequally distributed and non-renewable in a human time perspective (Lal, 2009), which partly has brought agriculture to a crossroads. The current agriculture has developed highly productive food and biomass-producing systems based on industrial principles (Manlay *et al.*, 2007). However, the system is facing diverse challenges, such as loss of natural ecosystems and pollution due to population growth, increasing demand for food, energy, water and land for industrialization (Lal, 2007). The driving forces behind the four known unknowns; availability of fertilizers, fuel, energy and feed; and their future development also remain unanswered (Smedshaug, 2010). Arable land covers approximately one fourth of the global land area, but only half of it can be used efficiently for cultivation to feed the growing population and most of the best quality land is already in use (Tilman *et al.*, 2002). Small-scale farming transformed into monocultures over large agricultural areas across the world has also inhibited the possibility of recycling of materials on the farms and made farmers dependent on long transports (Pretty, 2002).

The EC Thematic Strategy for Soil Protection defines food and other biomass production; filtering, buffering and transformation of water, nutrients and contaminants; storage of carbon; and biological habitat and gene pool as the key and most essential soil functions (European Commission, 2006). Soil fertility denotes the ability of a well structured soil to store and supply essential plant nutrients in sufficient amounts, while maintaining preferable living conditions for the soil biotic communities and enabling effective soil organic matter dynamics (Mäder *et al.*, 2002). Soils store carbon in far greater quantities (2500 Pg) than the atmospheric and biotic pool together (1320 Pg), only the oceanic (38.000 Pg) and geologic pool (5000 Pg) store more carbon (Lal, 2004). Soil organic matter (SOM) and its turnover play a pivotal role in the biogeochemical cycling of nutrients and in the response of terrestrial carbon to future climate scenarios (Schlesinger, 1995; Marzaioli *et al.*, 2010). Its fate and dynamics are mainly governed and understood by its properties, the substrate availability and physiology of the soil organisms (von Lützow and Kögel-Knabler, 2009). The most severe threats to soils are defined as erosion, declining soil fertility, loss of soil carbon and changes in biodiversity (European Commission, 2006). In agricultural soils the stress for land misuse and soil mismanagement often comes from economic pressure to increase yields in the short term and poor knowledge in how to maintain the ecosystem services of the natural resources at hands (Lal, 2009).

Sustainable multifunctional agricultural systems aim to meet the requirements for increased net primary productivity per unit input, but to keep the production within the limits of natural resources available and to maintain the ecosystem services for future generations (Brussaard *et al.*, 2007; Kibblewhite *et al.*, 2008). It is also of pivotal importance to keep in mind the maintenance of human health and the active role of local knowledge in finding solutions for the challenges (McIntyre *et al.*, 2009). In terms of soil management this means maintaining and enhancing e.g. the soil carbon pool and biodiversity (Lal, 2009).

Organic agriculture has expanded as a movement towards more sustainable food production, which is based on numerous core ecological principles (Scialabba, 2007). First, organic farming aims at recycling as much material at the farm as possible. Second, it is a holistic and systems approach to farming. Third, it relies on the usage of biological and ecological processes, i.e. crop rotation, shelterbelts and legumes, in order to supply the soil with sufficient amount of nutrients. At present, only approximately 0.7% of global and 4% of European commercial agricultural lands are managed organically (Willer and Youssefi, 2007). Austria was the first country in the world to provide official guidelines for organic farming and currently about 16 % of the country's utilized agricultural area (approximately 3610 km^2) is managed under those principles. In Iceland only about 1 % of the utilized agricultural area (approximately 10 km^2) is under organic management, even though the first biodynamic farm according to the principles of Rudolf Steiner started as early as in 1930. Nevertheless, for the first time funding is available for farmers that want to adapt organic farming (Bændablaðið, 2011). The Farmers Association in Iceland and the Ministry for Agriculture and Fisheries have jointly developed a framework, which aim to increase and financially support organically managed agriculture, sustainable development and sustain and enhance rural development.

2. History of mineral fertilizer use as an indicator for intensive yield production

Data for fertilizer consumption was collected from fertilizer.org in order to present trends for the development of fertilizer usage in Austria and in Iceland over the last decades. Figure 1 demonstrates the fertilizer consumption in Austria, which differs significantly from the global trends (Tillman et al., 2001 and 2002, Figure 1 in both). Globally the fertilizer consumption has been increasing steadily during the past decades, whereas in Austria it has seen a drop in the 1970s during the oil crises and more significantly after the mid 1980s. The increased environmental concerns lead to the establishment of the Austrian Agri-Environmental Programme ÖPUL in the mid 1990s, and its effects can also be seen in the fertilizer usage trends. Other factors influencing the negative trend are increased oil and fertilizer price, of which the later can be seen e.g. as increased price spikes in international cereals price index (Gillis, 2011). Figure 2 shows the fertilizer usage trends for Iceland, where the negative trend comes a little bit later, starting from the beginning of 1980s. This fits with the start of restrictions for production and modification of the subsidy system in place for fertilizer use (Jóhannesson, 2010). There is a clear positive trend starting from mid 1990s, when the economy was booming. During the latest economic recession in the late 2000s, there is a negative trend again.

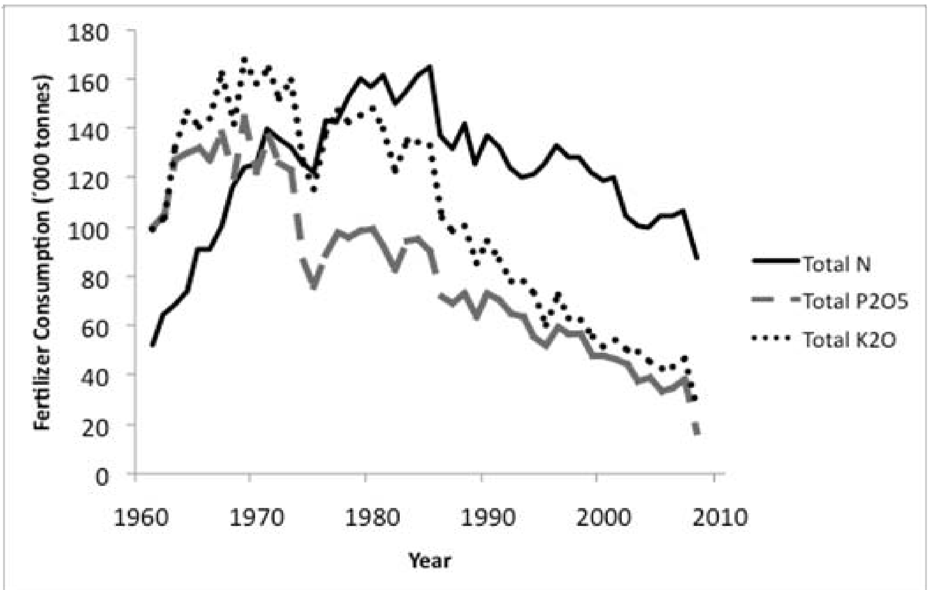

Figure 1 Total uses of nitrogen, phosphorous and potassium fertilizers in Austria 1961-2008. Data source: http://www.fertilizer.org.

There is also a difference in the composition of fertilizers used in Austria and Iceland. In the 1960s and 1970s in Austria, phosphorous and potassium were used in more quantities than nitrogen. This illustrates the various sources of fertilizers that were used in the beginning of the Green Revolution (Soil Association, 2010), compared to more standardized commercial fertilizers that are used today. In Iceland the soil system is more nitrogen limited, which can be seen as nitrogen always being the nutrient most used. The soil also has a high phosphorous retention potential (Arnalds, 2004), due to which phosphorous has been used in more quantities than potassium.

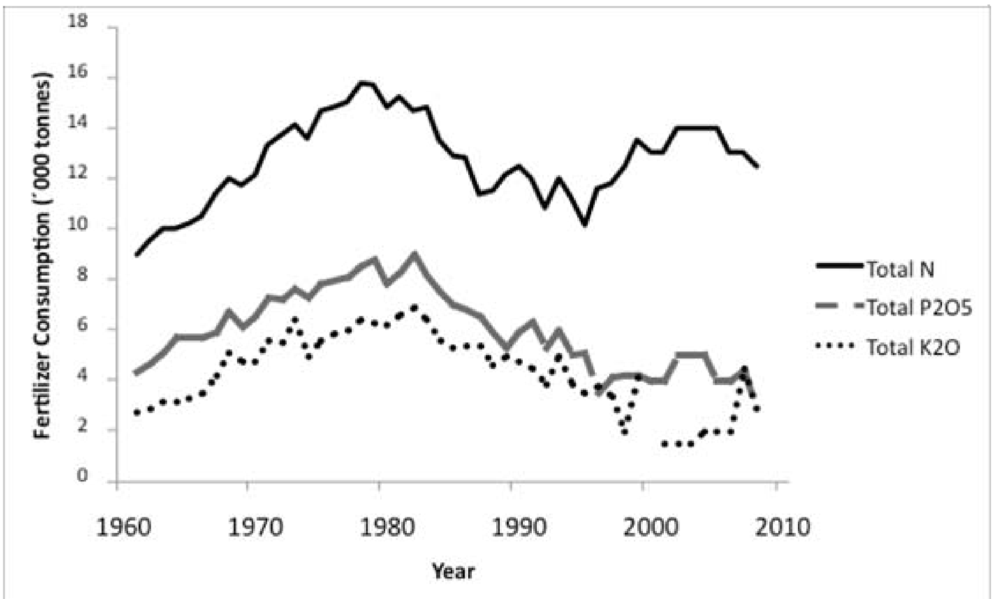

Figure 2 Total uses of nitrogen, phosphorous and potassium fertilizers in Iceland 1961-2008. Data source: http://www.fertilizer.org.

3. Following an increasing interest in organic farming

In order to gain insight in how organic farming research has developed in scientific publications a literature study was carried out. A search on Web-of-Science for “organic farming” was conducted on June 9th 2011, and further search within “organic farming” was conducted with “biodiversity”, “ecology”, “productivity”, “fertilization”, “tillage” and “erosion”. For 2010, search was also conducted with “ “soil organic matter”, “soil properties”, “food web” and “aggregates” within “organic farming”. A similar search was also done for “groundwater pollution” AND “nitrate”.

The search for “organic farming” yielded 3123 hits, the results divided into more detailed groups in each year are presented in Figure 3. A search for “groundwater pollution” AND “nitrate” resulted 919 hits. The first four publications appeared in 1974, increased rapidly in the early 1990s and after a small decrease in the middle of 1990s the publications started increasing again. After 2005 there has been a decrease in “groundwater pollution” AND “nitrate” publications, but in the latest year an increase is visible again. Of the categories within organic farming, biodiversity & ecology got the most total hits, 846, followed by productivity & fertilization (382 hits) and tillage & erosion (289). In general, only single publications were found during the 1970s for all categories. During the 1980s tillage & erosion and biodiversity & ecology had same amount of publications, 13, compared to productivity & fertilization appearing first in 1984 and having 3 publications in total during this decade. A steady increase in number of publications in all categories was seen in the 1990s. During the last decade biodiversity & ecology has remained as the most published category, yielding around 100 publications per year at the end of the decade. In addition, groundwater pollution & nitrate had for the first time fewer publications, 666 compared to 707, during the last decade than biodiversity & ecology.

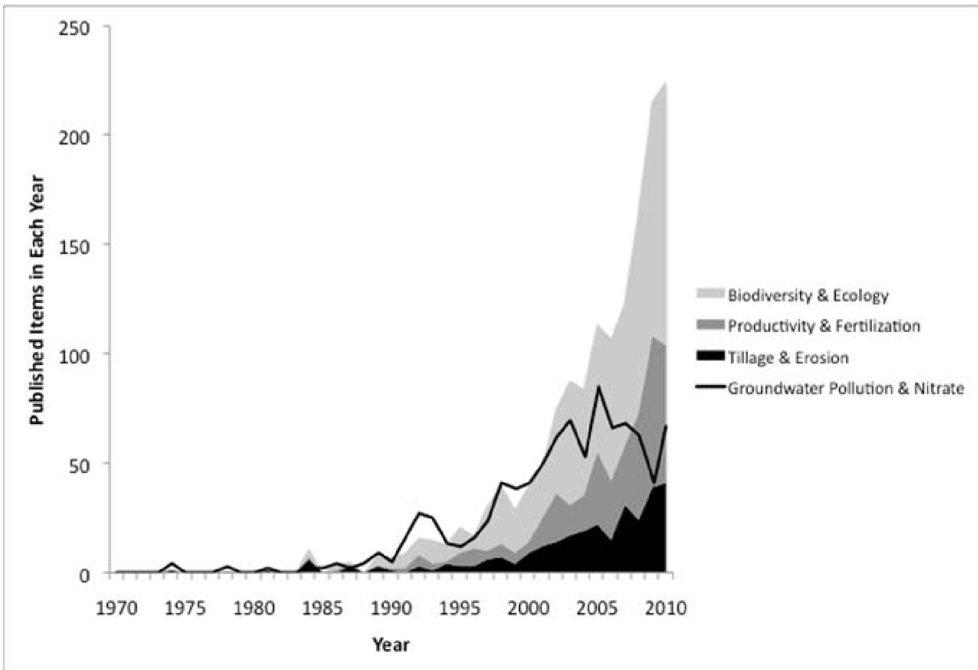

Figure 3 Number of publications found when searching ISI Web-of-Science for “organic farming” AND “XX” and “groundwater pollution” AND “nitrate” on June 9th 2011.

Figure 4 shows the number of publications for the different categories for 2010. The biggest categories biodiversity & ecology, productivity & fertilization and tillage & erosion had 121, 63 and 41 publications, respectively. Soil organic matter had 16 publications, whereas other soil issues received less attention. Soil properties had 5 publication, food web 2 and aggregates only 1 publication.

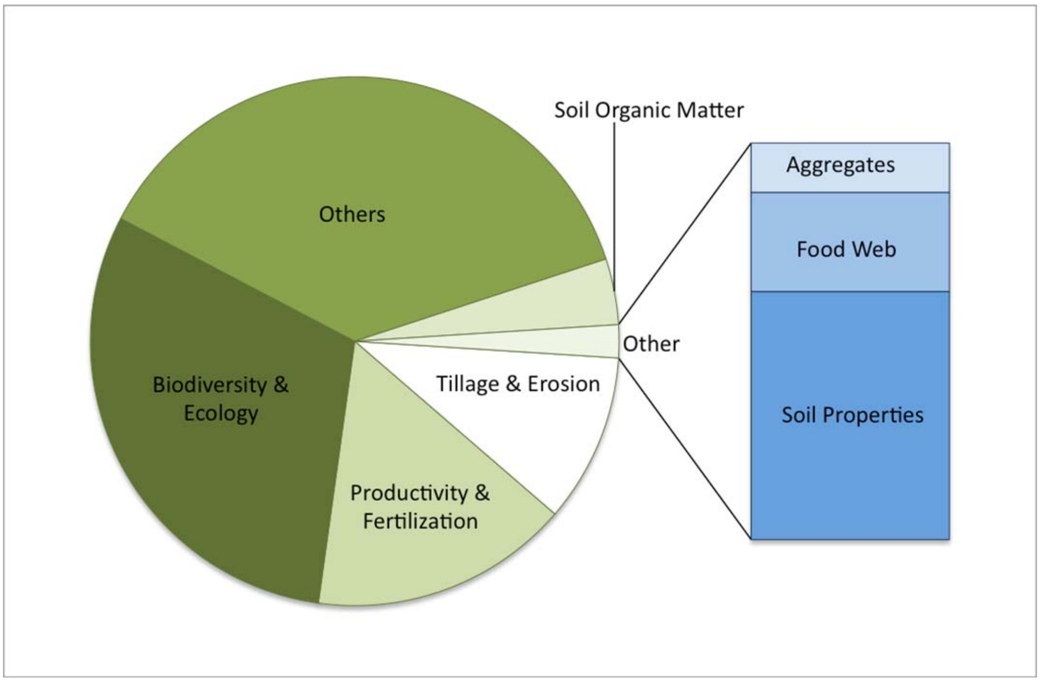

Figure 4 Number of publications for 2010 found when searching ISI Web-Of-Science for "organic farming" AND "XX" on June 9th 2011. Totally there were 373 hits for "organic farming".

4. Conclusions and future outlook

Agricultural soil systems of today are under great stress and expected to double the global food production by end of the century. The challenge is greater than the first doubling of food production during the Green Revolution, due to the lack of available land resources, water stress, environmental concerns as well as future climatic changes (Gillis, 2011). Based on this literature research, a key to understand and define a sustainable agricultural soil system is to quantify the impact of different land use on soil structure and biogeochemistry, with emphasis on nutrient turnover. Therefore the goal of our coming research is to evaluate SOM pools in different soil aggregate sizes under different farming systems (organic vs. conventional) and link them to soil biodiversity. The specific focus points will be on:

- How does different farming practices (organic vs. conventional) influence soil properties and structure?
- How does biodiversity differ in organic versus conventionally managed soils?
- How great is the impact of climate (sub-arctic vs. continental) and soil type (Andosols vs. Chernozems) on the above-mentioned processes?

Soil samples were selected along cultivation age gradients in sub-arctic (Iceland, Andosols) and continental (Austria, Chernozems) climate. Topsoil (0-15 cm) and subsoil (30-40 cm) samples were collected in five replicates and gently crushed to pass a 5 mm sieve in order to gain natural < 5 mm aggregates. A three-step fractionation protocol by

Virto *et al*. (2008) using sodium petatungstate (SPT, $Na_6(H_2O_{40}W_{12})$, Heavy Liquids, Germany) for density fractionation resulting in particulate organic matter (POM), mineral associated organic matter and the mineral matrix of the soil. Using centrifugation and sieving allows to gain the aggregate classes clay sized aggregates (< 2 μm), fine-silt sized aggregates (2-20 μm), and coarse-silt sized aggregates (20-50 μm) as well as the sand sized aggregates (50-250 μm). Previous study in the EU-project SoilTrEC already showed that the most aggregates in the study area in Austria brake down to aggregates size < 250 μm, showing the importance of the gained aggregate classes in our procedure. POM will be characterized by its composition, e.g. carbohydrates and proteins, and related to microbiological characteristics and soil aggregate distribution of the studied soils. Further, the gained data will be linked to energy balance and food productivity in order to get more insights in benefits of different farming practices. The outcome of the coming research will also enable to identify quantifiable natural indicators for farm sustainability assessments.

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