PROJECT PROPOSAL

FiBL
Forschungsinstitut für biologischen Landbau
Institut de recherche de l'agriculture biologique
Research Institute of Organic Agriculture

EXCELLENCE FOR SUSTAINABILITY

Determination of sources and sinks of greenhouse gases in Swiss arable soils



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Content

1. Background and state of the art

1.1 Agricultural soils as sources for greenhouse gases

About 38% of annual global agricultural emissions are derived from fertilized soils (2.1 Gt CO_2-eq; in relation to an average of 5.6 Gt CO_2-eq; Bellarby et al. 2008), followed by enteric fermentation (32%, 1.8 Gt CO_2-eq), biomass burning (12%, 0.7 Gt CO_2-eq), paddy rice (11%, 0.6 Gt CO_2-eq) and manure handling (7%, 0.4 Gt CO_2-eq). In Switzerland 2.10 Mill. t CO_2-eq are emitted from agricultural soils which account for 35.6% of the agricultural emissions and are mainly in form of nitrous oxide (N_2O) (BAFU, 2010). Nitrous oxide is formed during the microbial processes of nitrification and denitrification (Firestone und Davidson, 1989). These two processes can occur simultaneously in the same soil aggregate although nitrification is performed under aerobic and denitrification under anaerobic conditions. The main factors influencing nitrous oxide formation in soil are: soil water content regulating oxygen availability, nitrate and ammonium concentration availability of organic carbon as well as pH. It was found that most of the annually emitted nitrous oxide is released particularly after freezing/thawing cycles, when nitrogen and carbon availability is high, and oxygen is limited due to water saturation in the soil (Sehy, 2004).

Despite the existence of a solid knowledge basis there is a great lack of understanding in the temporal pattern of nitrous oxide dynamics in temperate climate. “Nitrous oxide fluxes are the uncertainty of the agricultural greenhouse gas inventories” was a recent statement by Andreas Gensior, vTI Braunschweig/Germany. There are 27 cropland sites in Germany with year-round measurements of nitrous oxide fluxes showing a variation between < 0.5 and 17 kg N_2O-N ha^{-1} a^{-1} (Jungkunst et al., 2006). In Switzerland, however, year-round nitrous oxide measurements exist only for grassland (e.g. Amman et al., 2009) but not for arable soils so far. In addition the knowledge basis on nitrous oxide fluxes from organically managed soils is even worse. In a current meta-analysis by Skinner et al. (in preparation) only 15 published studies are found worldwide comparing N_2O fluxes from organically and non-organically managed soils. Pronounced emission peaks of nitrous oxide from arable soils occur particularly after application of organic/mineral fertilizer and ploughing up of clover-grass leys (Chirinda et al., 2010; Sehy, 2004). Both management activities are typical elements of mixed cropping systems in Switzerland but there is a significant knowledge gap to what extent the factors “fertilization” and “management of clover-grass leys” influence greenhouse gas emissions from arable soils.
Also the influence of reduced and no-tillage on nitrous oxide emissions from soils lacks a clear understanding. Field measurements have shown both decreased and increased emissions of N_2O under no-till conditions (MacKenzie et al., 1998; Kaharabata et al. 2003; David et al., 2009). The different duration of the experiments may explain the contradicting observations. In a meta-analysis of paired experiments on the influence of tillage treatments it was found that newly converted no-till systems increase global warming potential relative to conventional tillage in humid and dry climate regimes, and longer-term adoption (>10 years) only significantly reduces global warming potential in humid climates (Six et al., 2004). The influence of soil tillage on greenhouse gas emission and carbon sequestration in a Swiss long-term trial will be investigated in a separate study and is not part of this project.

1.2 Agricultural soils as sinks for greenhouse gases

Agricultural soils can act as sinks for greenhouse gases mainly for CO_2 through carbon sequestration. Carbon sequestration in soils implies transferring atmospheric CO_2 into long-lived pools and storing it securely so it is not immediately reemitted. Thus, soil carbon sequestration means increasing soil organic carbon and soil inorganic carbon stocks through judicious land use and recommended management practices (Lal, 2004). Although soil carbon sequestration does not mean avoidance and reduction of the formation of greenhouse gases it is considered as a significant mitigation strategy because of the soils' potential to store large amounts of CO_2 at a global scale (IPCC, 2007).

Current research on European croplands based on the observation of five crop rotations and two monocultures for 4 years at 7 different sites show carbon losses in average of 3.5 ± 3.2 t CO_2-eq ha^{-1} a^{-1} (Kutsch et al., 2010). These results challenge current good practice guidelines, as even at sites where farmer applied organic manure and increased residue incorporation a neutral carbon balance could not be achieved. According to Kutsch et al. (2010) humus loss in spite of good practice is most pronounced in soils with high carbon concentrations, which are not in equilibrium. The authors assumed that it may also be a result of an already ongoing climate change as this leads to increased soil microbiological activity due to higher average temperatures. Leifeld et al. (2009) investigated the carbon sequestration for representative Swiss farming systems by analysing soils from the DOK long-term trial. They found under all management systems a carbon loss with the lowest losses found under bio-organic (-126 kg C ha^{-1} a^{-1}) and the highest losses under conventional management with mineral fertilisation (-219 kg C ha^{-1} a^{-1}). Leifeld et al. (2009) explained the overall carbon decline in the soils of the DOK trial with reduced carbon inputs since commencement of the experiment. However, they considered only the uppermost 20 cm of soil in their study. A sound determination of the carbon sequestration potential in agricultural soils, however, should consider 0-50 cm soil depth (Pete Smith, personnel communication).

1.3 Trade-off between soil carbon accumulation and greenhouse gas release

When determining the climate relevance of cropping systems the trade-off between source and sinks of greenhouse gases or in other words the trade-off between soil carbon accumulation (= sequestration) and greenhouse gas release as influenced by farming practices has to be considered. Long-term application of organic fertilizer increases soil carbon content in soil (Diacono and Montemuro (2010), but the risk for higher nitrous oxide emission increases along with that (Bouwman et al. 2002). Hence, for a sound estimation of the global warming potential for a given farming system, carbon sequestration and greenhouse gas fluxes need to be measured at the same time, but this has rarely been done for European cropping systems so far.

Arable soils apart from rice paddies are considered to act as sinks for methane because of the activity of autochthonous methane oxidizing bacteria (Conrad, 1996). However, this function can be lost due to repeated application of cattle manure loaded with rumen-derived methanogenic *Archaea*. This can cause a change in the soil's properties turns from a net sink to a net source for the greenhouse gas methane (Gattinger et al., 2007; Radl et al., 2007). This phenomenon has rarely been studied in regions such as Bavaria and Switzerland where cattle manure is a major component of the fertilizer strategy and needs a thorough investigation.

1.4 Account of one's own research in the field

The Research Institute of Organic Agriculture (FiBL) is a private research institution dedicated to organic and sustainable forms of crop and livestock production in almost all domains of agricultural sciences. The Soil Sciences group at FiBL focuses on 1) long-term farming system comparisons, based on the DOK experiment at Therwil/CH (Mäder et al., 2002), which serves as a stepping stone for similar field studies in the tropics; 2) factorial experiments, where soil tillage operations in organic farming are investigated together with optimised fertilisation schemes (Berner et al., 2008; Gademeier et al., 2011); 3) the use of up-to-date techniques in soil biology to evaluate the management effects incurred by soils (e.g. Esperschütz et al., 2007) and 4) the climate relevance of organic and non-organic cropping systems because of carbon sequestration (Fliessbach et al., 2007; Niggli et al., 2009; Gattinger et al., in prep.) and greenhouse gas fluxes (Gattinger et al., 2007; Skinner et al., in prep.).

The proposed project combines these research activities to determine management induced effects on the soils' function to act as a source and sink for greenhouse gases. Numerous techniques in applied soil ecology that have been adopted at FiBL in the last 15 years and techniques that were employed by individual members of the Soil Science Group will be used to determine the temporal dynamics of greenhouse gas fluxes (sources) and the concomitant carbon storage processes (sinks) in arable soils.

Specific expertise in climate change research

The FiBL Soil Science group is engaged in climate change research since years. Fliessbach et al. (2007) investigated the long-term carbon dynamics in organically and conventionally managed soils The carbon sequestration potential for the soil systems of the DOK trial and for those from other long-term field trials worldwide were elucidated by Niggli et al. (2009). Currently a global meta-analysis based on 74 studies covering all major cropping types (i.e. arable, grassland, vegetable, horticulture/vineyard) is conducted to compare soil carbon stocks under organic and non-organic management and to determine a potential carbon gain in organic farming because of enhanced sequestration (Gattinger et al., in prep.). In a second meta-analysis greenhouse gas fluxes from paired experiments comparing organically and non-organically managed soils are evaluated (Skinner et al., in prep.). The carbon and nitrogen dynamics and the sequestration potential of soils under reduced and no-tillage is a further topic of the Soil Science Group since recent years (Berner et al., 2008; Gadermeier et al., 2011; Gattinger et al., 2011).

Andreas Gattinger, who is coordinating the climate change research at FiBL since 2010 has a significant publication record on greenhouse gas fluxes and the underlying processes in soil-plant systems. During his time as senior scientist and leader of the biomarker/mass spectrometry laboratory at the Helmholtz Centre for Environment and Health in Munich/Germany he studied particularly the sources and sinks of the greenhouse gas methane in agricultural soils (Gattinger et al., 2002a; Gattinger et al., 2007; Radl et al., 2007), in peat soils (Wachinger et al., 2000), paddy rice (Bai et al. 2000; Gattinger et al., 2003), in methanogenic and methanotrophic monocultures (Gattinger et al., 2002b; Gebert et al., 2004), in slurry and compost (Petersen et al., 2004; Gattinger et al., 2004), and in permafrost environments of the Russian Arctic (Wagner et al., 2005; Wagner et al., 2007; Griess et al., 2011). At FiBL he coordinated also two recent studies on "Mitigating greenhouse gases in agriculture - A challenge and opportunity for agricultural policies" and "No-till agriculture – a climate smart solution?" for two international charity organizations. He chairs the International Round Table on Organic Agriculture and Climate Change (RTOACC; www.organicandclimate.org).

2. Detailed research plan

2.1 Goals of the project and expected results

The proposed project aims at closing major knowledge gaps in the field of greenhouse gas fluxes in agricultural soil systems. Management factors representing crop production in Switzerland which are likely to influence the source and sink function of soils in the emission of greenhouse gases will be thoroughly investigated. These are organic and mineral fertilization, the impact of organic and non-organic management including the management of clover-grass leys. The influence of tillage practices will be investigated in a separate research project for which we have submitted a proposal to a private foundation.

For a sound quantification of nitrous oxide fluxes it is important to monitor the temporal dynamics all year-round especially during the cold season when freeze/thaw cycles trigger nitrous oxide release as has been reported from long-term measurements in Germany (e.g. Sehy, 2004).

The project has the following main objectives:

- Determination of the temporal dynamics of greenhouse fluxes in soils of the DOK long-term field trial over two vegetation periods.
- Determination of the effect of organic and mineral fertilization and farming system on soil carbon sequestration and on the release of greenhouse gases.
- Investigating the effect of the management of clover-grass leys (cutting, fertilization, ploughing up) on the release of greenhouse gases.
- Assessment of potential trade-offs between soil carbon sequestration and greenhouse gas emissions.
- First model calculations to up-scale obtained emission and sequestration data from field trials (plot level) to regional and country level based on current land use data from Switzerland.

The proposed project will deliver a unique data set on greenhouse gas emissions (nitrous oxide, methane, carbon dioxide) and carbon sequestration from the worldwide longest existing field trial comparing organic and non-organic farming systems. Furthermore, up to now the important greenhouse gas nitrous oxide has only been measured in a Swiss grassland site. With year-round measurements of nitrous oxide, methane and carbon dioxide fluxes a substantial knowledge gap with regards to the climate-relevance of arable soils in Switzerland will be closed. In addition, a deeper sampling of up to 50 cm soil depth will improve the current knowledge on soil carbon sequestration in the DOK farming system trial and enable to determine trade-off of carbon sequestration and greenhouse gas release for the factors “fertilization type”, “management type” and “clover-grass management”.

2.2 The DOK trial

The DOK experiment was set up in 1978 in the vicinity of Basle (at Therwil, Switzerland; 7° 33’ E, 47° 30’ N) and is managed by Agroscope FAL Reckenholz in close cooperation with FiBL. Four farming systems are compared, differing mainly with respect to fertilization strategy and the concept of plant protection management.

The organic systems bio-dynamic (BIODYN) and bio-organic (BIOORG) are fertilized with farmyard manure (FYM) and slurry corresponding to 1.2 (1st and 2nd crop rotation period, CRP) and 1.4 (3rd and 4th CRP) livestock units per hectare (Tab 1). The fertilization intensity of the organic systems is based on the fodder produced in the respective crop rotation and reflects the intensity typically found on Swiss organic farms. One conventional system is fertilized with the same amount of FYM as the organic systems and, in addition, with mineral fertilizers up to the recommended level of the plant- specific Swiss standard recommendation (system CONFYM). The other conventional system was unfertilized during the first crop rotation, but was then amended with mineral fertilizers exclusively (system CONMIN), mimicking a stockless system. Since 1985, the conventional systems are being farmed according to the Swiss national regulations for integrated plant production, representing one type of good agricultural practice. An unfertilized plot (NOFERT) remained in which no fertilizers are applied, and is otherwise maintained as the BIODYN system.

Table 1: The DOK farming systems compared in a seven-year rotation since 1978

Practices	**Organic farming systems**		**Conventional farming systems** **Integrated since 1985**[a]	
	BIODYN bio-dynamic	BIOORG bio-organic	CONFYM conventional with farmyard manure	CONMIN[b] conventional sole-ly mineral fertiliz-ers
Fertilization				
Type and level	aerobically compost-ed farmyard manure (FYM) and slurry 1.2/1.4 LU ha^{-1} yr^{-1} [c]	slightly aerobically rotted FYM and slurry 1.2/1.4 LU ha^{-1} yr^{-1} [c]	stacked FYM and slurry 1.2/1.4 LU ha^{-1} yr^{-1} [c] and mineral fertilizer according to official guidelines	exclusively miner-al fertilizer accord-ing to official guidelines
Plant protection				
Weed control	mechanical	mechanical	mechanical and herbicides	mechanical and herbicides
Disease con-trol	indirect methods	indirect methods, copper	fungicides (thresh-olds)	fungicides (thresholds)
Insect control	plant extracts, bio-control	plant extracts, bio-control	insecticides (thresholds)	insecticides (thresholds)
Special treat-ments	Bio-dynamic prepara-tions	none	plant growth regula-tors	plant growth regu-lators

[a] Conventional in the 1st crop rotation period from 1978 to 1984. In the text, CONFYM and CONMIN are referred to consistently as conventional systems, although they have been managed as integrated systems since 1985.
[b] CONMIN was unfertilized in the 1st crop rotation period from 1978 to 1984.
[c] Increase from 1.2 to 1.4 livestock units (LU) ha^{-1} yr^{-1} at the beginning of the 3rd crop rotation period (1992 to 2005).

Plant protection is conducted according to the guidelines of the bio-dynamic and bio-organic systems. In the conventional systems, pesticides are only applied if economic thresholds for infections were exceeded according to the integrated scheme of plant protection (Tab. 1).
The seven-year crop rotation is always identical in all systems, and it is composed currently by: clover-grass (1), clover-grass (2), maize, wheat (1), soya, potatoes, wheat (2). Crop rotation ia a compromise between organic and conventional rotations in practice. Soil tillage is similar in all treatments. The soils are ploughed before planting cash crops. The clover-grass mixture is sown in drills after rotary harrowing the cereal stubble field. The same varieties and grass-clover mixtures were cultivated in each system. Plots are managed both by farmers and technicians.
The soil type is a Haplic Luvisol on deep deposits of alluvial Loess. It contains 15% sand, 70% silt and 15% clay, had initially a pH (H_2O) of 6.3 and an soil organic carbon content of 1.5%. The field experiment is designed as a randomized block with four replicates including three crops planted simultaneously in each system every year. Single plot size is 5 m by 20 m. There is a buffer zone strip (6 m) planted with grass, which is regularly mulched between the experimental plots. The climate at the experimental site is rather dry and mild, with a mean precipitation of 785 mm per year and an annual mean temperature of 9.5°C.

2.3 Research program

The work will be split into four different modules according to the above mentioned objectives and influencing factors. The modules itself are further divided into tasks.

Module 1: Greenhouse gas fluxes and carbon sequestration as influenced by mineral and organic fertilization

Task 1.1 Determination of nitrous oxide, methane and carbon dioxide fluxes at regular intervals over two vegetation periods in the relevant treatments of the DOK trial.

Task 1.2 Determination of soil bulk density and soil pore volumes in soil at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial.

Task 1.3 Determination of soil water content at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments using non-invasive TDR probes.

Task 1.4 Determination of carbon and nitrogen dynamics in soil at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial.

Task 1.5 Determination of carbon content in soil size density fractions at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial to determine stabilization of soil organic matter.

Module 2: Greenhouse gas fluxes and carbon sequestration as influenced by organic and integrated farming management

Task 2.1 Determination of nitrous oxide, methane and carbon dioxide fluxes at regular intervals over two vegetation periods in the relevant treatments of the DOK trial.

Task 2.2 Determination of soil bulk density and soil pore volumes in soil at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial.

Task 2.3 Determination of soil water content at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments using non-invasive TDR probes.

Task 2.4 Determination of carbon and nitrogen dynamics in soil at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial.

Task 2.5 Determination of carbon content in soil size density fractions at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial to determine stabilization of soil organic matter.

Module 3: Greenhouse gas fluxes and carbon sequestration as influenced by clover-grass management

Task 3.1 Determination of nitrous oxide, methane and carbon dioxide fluxes at regular intervals over two vegetation periods in the relevant treatments of the DOK trial.

Task 3.2 Determination of soil bulk density and soil pore volumes in soil at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial.

Task 3.3 Determination of soil water content at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments using non-invasive TDR probes.

Task 3.4 Determination of carbon and nitrogen dynamics in soil at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial.

Task 3.5 Determination of carbon content in soil size density fractions at 0-20 cm and 20-50 cm depths during two vegetation periods in the relevant treatments of the DOK trial to determine stabilization of soil organic matter.

Module 4: Assessment of potential trade-offs between soil carbon sequestration and greenhouse gas emissions

Task 4.1 Determination of the climate balance for mineral and organically fertilized cropping systems based on results obtained in tasks 1.1-1.5.

Task 4.2 Determination of the climate balance for organically and integrated managed farming systems based on results obtained in tasks 2.1-2.5.

Task 4.3 Determination of the climate balance for clover-grass phase and two consecutive years of cash crops based on results obtained in tasks 3.1-3.5 and the relevant data sets obtained in module 1 and/or 2 (depending on the experimental design).

Task 4.4 Synthesis of the results obtained in tasks 4.1-4.3 and weighing the impact of the investigated management factors.

Based on the above mentioned research objectives and tasks a meaningful selection of the farming systems and the relevant treatments has to be made. A preliminary compilation is given which will result in a total number of 40 chambers for greenhouse gas measurements (Tab. 2), when four treatment replicates and two chambers per plot are taken into account. A number of 40 gas sampling locations is the maximum number what one researcher can handle by weekly gas samplings.

Table 2. Compilation of relevant treatments of the DOK long-term field trial to investigate the different research tasks within modules 1-4.

Treatment	Module	Plot-Nr.	Crop in 2012	Crop in 2013	Chambers/plot
CONMIN	2, 3, 4	6	Clover-grass 2	Maize	2
CONMIN	2, 3, 4	40	Clover-grass 2	Maize	2
CONMIN	2, 3, 4	56	Clover-grass 2	Maize	2
CONMIN	2, 3, 4	96	Clover-grass 2	Maize	2
BIOORG 2	2, 3, 4	18	Clover-grass 2	Maize	2
BIOORG 2	2, 3, 4	28	Clover-grass 2	Maize	2
BIOORG 2	2, 3, 4	68	Clover-grass 2	Maize	2
BIOORG 2	2, 3, 4	84	Clover-grass 2	Maize	2
CONMIN	1, 2, 4	2	Wheat 2	Clover-grass 1	2
CONMIN	1, 2, 4	42	Wheat 2	Clover-grass 1	2
CONMIN	1, 2, 4	58	Wheat 2	Clover-grass 1	2
CONMIN	1, 2, 4	92	Wheat 2	Clover-grass 1	2
BIOORG 2	2, 4	14	Wheat 2	Clover-grass 1	2
BIOORG 2	2, 4	30	Wheat 2	Clover-grass 1	2
BIOORG 2	2, 4	70	Wheat 2	Clover-grass 1	2
BIOORG 2	2, 4	80	Wheat 2	Clover-grass 1	2
CONFYM 2	1, 2, 4	20	Wheat 2	Clover-grass 1	2
CONFYM 2	1, 2, 4	36	Wheat 2	Clover-grass 1	2
CONFYM 2	1, 2, 4	64	Wheat 2	Clover-grass 1	2
CONFYM 2	1, 2, 4	74	Wheat 2	Clover-grass 1	2

Before the project starts, plots will be finally selected to cope with the slight spatial heterogenity of the site with respect to clay content.

2.4 Methods

The measurement of greenhouse gas fluxes in the field and the determination of soil organic carbon stocks are the key methodologies applied in the proposed project.

Determination of greenhouse gas fluxes

The measurement of greenhouse gas fluxes is based on the so-called closed chamber technique (Fig. 1). For this, circular collars of 15 cm height will be installed permanently on the research plots at a soil depth of 8-10 cm on which non-transparent chambers having the same diameter like the collars will be manually put for gas sampling A diameter of 100 cm is recommended when organic manures are applied on the fields. Aliquots of gas samples from the research plots will be collected once a week in gas-tight, pre-evacuated vials through septa of the closed chambers during the enrichment phase of up to 90 min. Gas samples will be determined for CO_2, N_2O and CH_4 concentration in the laboratory. This is done by a gas-chromatographic (GC) system able to measure all three gases by on GC device (Wang, 2010). A proposal for the investment for an appropriate gas chromatographic device has been submitted to BAFU. Alternatively gas samples can be shipped in air-tight vials to other laboratories for measurement (e.g. University of Hohenheim, who offered collaboration).

Weekly greenhouse gas samplings will be added by event-based measurements (shortly before and after fertilization, freezing/thawing events etc.). With this approach short-term occurring emission peaks will be considered and the overall error of such an extended sampling protocol compared to an automated, continuous measurement is less than 10% (Flessa et al. 2002).

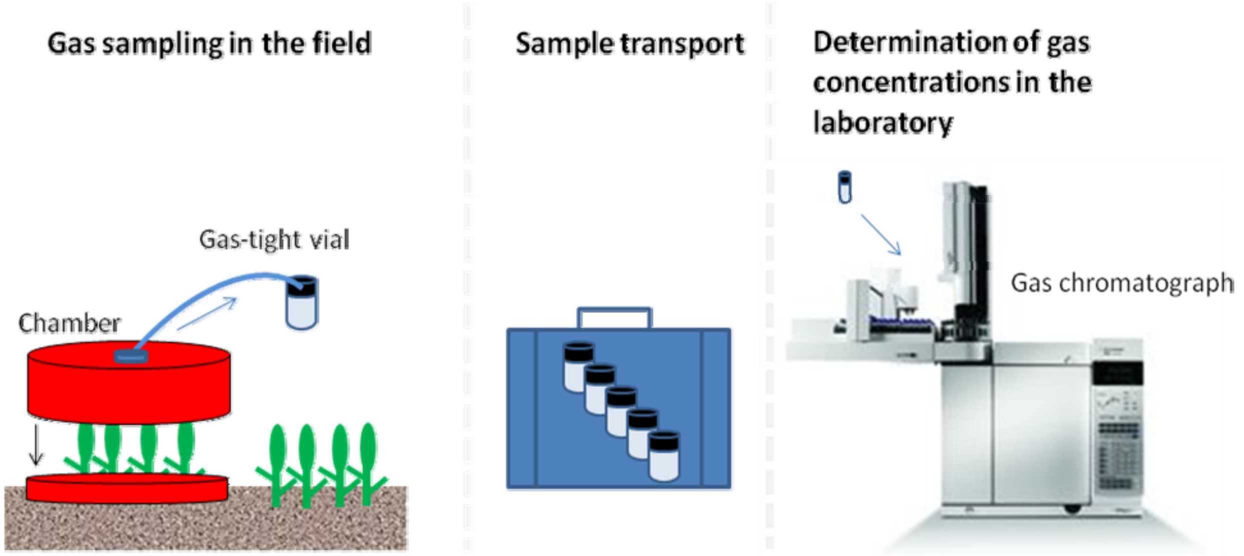


Fig.1. Illustration of the different steps for determining greenhouse gas fluxes in the field.

At the time of gas sampling soil water content as a major driver of greenhouse gas fluxes is determined in all experimental treatments using non-invasive TDR probes. Therefore tecanate tubes are permanently installed in the investigated plots down to 100 cm depth and volumetric soil water content can be read at 10 cm depth increments by insertion of portable TDR probes (IMKO GmbH, Ettlingen, Germany). The so obtained TDR data will be correlated with the measurement of water-filled pore space of the soil which requires the insertion of metal cylinder into various soil horizons as it is done also for soil bulk density and carbon sequestration measurements, respectively. The latter approach for soil water measurement is quite tedious and it also consumes a significant amount of soil material over years which need to be reduced in long-term experiments such as the DOK trial.

Determination of denitrification potential

Soils samples are taken from each farming system at several times during the vegetation period to determine the denitrification potential. This is done in 100 – 500 ml gas tight flasks which are placed near the autosampler for online high-troughput measurements of nitrous oxide concentrations. An example for online high-troughput gas measurements with a similar autosampler can be found elsewhere (Marx et al., 2007). These measurements of N_2O production potentials are complementary to the flux measurements in the field and are used for further explanation of the observed dynamics in N_2O emissions (Chronokova et al., 2009).

Determination of soil organic carbon stocks and carbon sequestration

From the determination of soil organic carbon concentration (SOC %) and soil bulk density (BD; t m^{-3}) soil organic carbon stocks are calculated ($SOC_{t;}$; t ha^{-1}), i.e. the soil organic carbon mass per area for a defined soil horizon or sampling depth (D; m): $SOC_t = BD \times SOC \times D$

Soil carbon sequestration expresses the soil organic carbon stocks changes over a certain period of time. Therefore soil organic carbon stocks will be measured at beginning and at the end of the experimental phase. Soil carbon data from the beginning of the DOK trial will be included for long-term determination of carbon sequestration (see Fliessbach et al., 2007 and Leifeld et al., 2009).

A compilation of all employed methods is given in table 3.

Table 3. Compilation of the various investigation criteria und methods

Criterion	Methodology	Reference
Greenhouse gas fluxes	Soil-borne gas samples are collected in air-tight vials at weekly intervals using the closed chamber technique. Measurement intervals can be increased according to management events (Fertilization, tillage, freezing/thawing). Concentrations of CO_2, N_2O und CH_4 are determined by gas chromatography. Additionally determination of denitrification potential.	Ruser et al. (1998); Sehy et al. (2003); Wang (2010); Chronokova et al. (2009)
Carbon and nitrogen dynamics and carbon sequestration	Soil organic carbon, dissolved organic carbon, total nitrogen and mineral nitrogen are determined at certain times throughout the measurement phase and are adapted to management events.	FAL et al. (1996); Gadermeier et al. (2011)
Stabilization of soil organic matter	Organic carbon will be determined in size density fractions of soils to determine stabilization of soil carbon.	Fliessbach & Mäder (2000); Lützow et al. (2006)
Soil bulk density and water filled pore space	At various times per year soil bulk density per year water filled pore space of the soil is determined using defined metal cylinders.	Ruser et al. (1998)
Soil water content	Soil water content is determined in all experimental treatments at the time of gas sampling using non-invasive TDR probes. Therefore tecanate tubes are permanently installed in the investigated plots down to 100 cm depth and volumetric soil water content can be	IMKO GmbH (2011)

	read at 10 cm depth increments by insertion of portable TDR probes (IMKO GmbH, Ettlingen, Germany).	
Carbon and nitrogen content in farmyard manure	Total carbon and nitrogen are determined in the applied farmyard manures.	FAL et al. (1996); Gadermeier et al. (2011)
Weather data (Air temperature, preciptiation, soil temperature)	Via weather station	

3. Timetable of the planned activities

Activity	Time period
Experimental planning incl. field preparations for greenhouse gas measurements	April 2012
Weekly greenhouse gas measurements (Modules 1-3) incl. soil water dynamics	April 2012-December 2014
Carbon and nitrogen dynamics in soil including carbon sequestration (Modules 1-3)	April 2012-December 2014
Trade-offs between soil carbon sequestration and greenhouse gas emissions (Module 4)	December 2014-January 2015
Interim reports	December 2012 and June 2014
1 manuscript for publication in an agricultural journal	January 2015– February 2015
2 manuscripts for publication in a scientific journal (peer-reviewed)	February 2015 – September 2015
End report	September 2015

4. Budget

The proposed project is planned for a duration of 3 ½ years (= 42 months).

	Costs
Researcher (PhD, 100%, 42 months)	170‘000 CHF
Senior Researcher (8 months)	65‘000 CHF
Trainee (3x 3 months)	27‘000 CHF
Laboratory consumables	30‘000 CHF
Travel expenses	3‘000 CHF
Total	**295‘000 CHF**

5. Project team and partners

The FiBL project team consists of:

Colin Skinner (Geographer, Univ. Basel, PhD candidate, project execution)

Dr. Andreas Gattinger (Subject Leader Climate, project coordination)

Dr. Andreas Fliessbach (Soil Ecologist)

Dr. Paul Mäder (Leader Soil Sciences Group)

FiBL Soil Sciences Group co-operates with the following institutions/persons/ in this project:

Agroscope Reckenholz-Tänikon Research Station ART:

Dr. Albrecht Neftel (offered to be a member of the project group, which will be established at project start)

Dr. Jochen Mayer (Co-ordinator DOK trial)

Universität Basel, Institut für Umweltgeowissenschaften

Dr. Franz Conen (Supervision PhD thesis, in collaboration with Prof. Dr. Christine Alewell, both experts have confirmed)

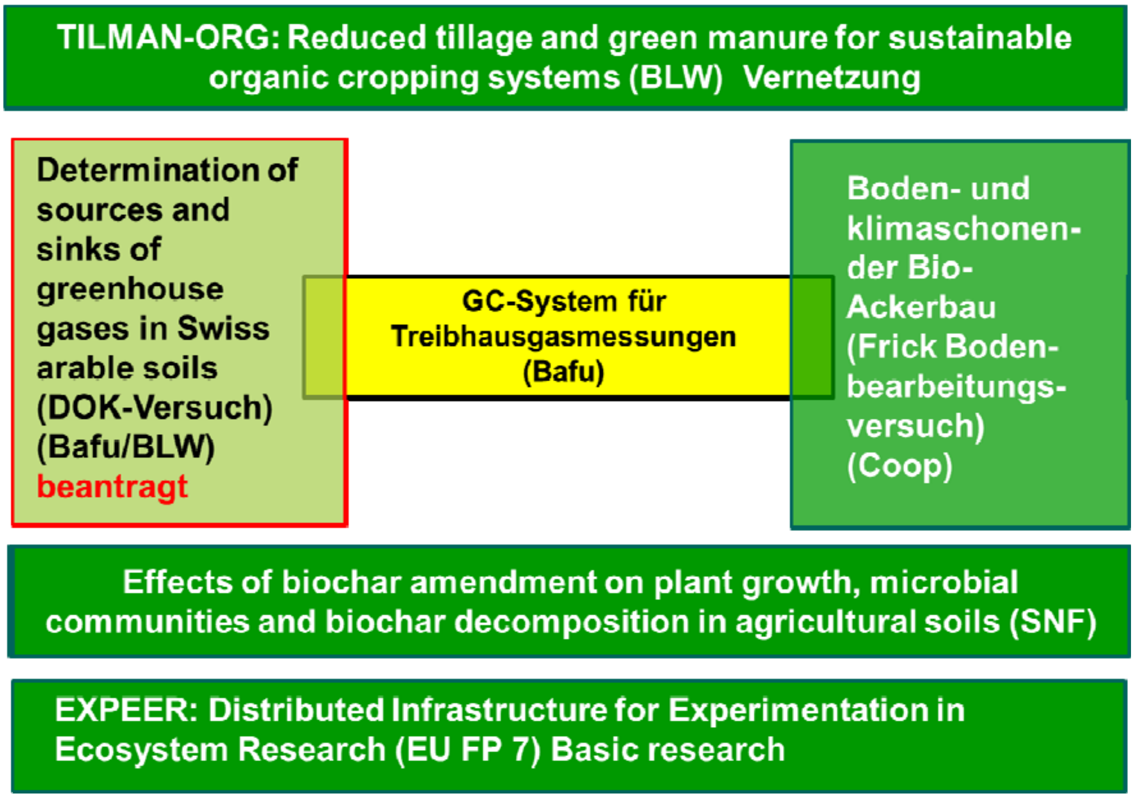
Universität Hohenheim, Institut für Kulturpflanzenwissenschaften, Fachgruppe Düngung/Bodenchemie

Dr. Reiner Ruser and Prof. Dr. Thorsten Müller

(in GHG project assessing effects of reduced tillage, PhD cand. Maike Krauss, see below)

A **project expert group**, including potential donors (BAFU, BLW) will be set-up at project start.

6. Project links and project environment



The figure above depicts running research projects at FiBL in which the proposed study „Determination of sources and sinks of greenhouse gases in Swiss arable soils” will be embedded.

In this study, GHG are determined under different fertilisation and farming systems on a Loess soil. It is complementary to the project “Boden- und klimaschonender Bio-Ackerbau”, where the effects of tillage and fertilisation systems are studied on a clayey soil (thesis of Maike Krauss at FiBL in collaboration with Prof. Thorsten Müller and Dr. Reiner Ruser from University Hohenheim (start date 1.1.2012). This nearly simultaneous start of both GHG studies offer synergisms at the technical and scientific level. GHG measurements will be performed on the Agilent GHG GC station coupled with a freely programmable Gerstel MPS autosampler, which allows an efficient simultaneous determination of N_2O, CH_4 and CO_2 in a wide range of concentrations. Data obtained in both studies will be used in GHG emission models that are based on the life cycle assessment (LCA) and IPCC 2006 methodology. At FiBL, modelling is realised in the group of Dr. Christian Schader.

Further GHG studies are conducted in TILMAN-ORG (“Reduced tillage and green manure for sustainable organic cropping systems”) which is run under FiBL lead, an Era Net CORE-Organic II project with 11 countries and 15 partners.

A further link exists to the SNF project on “Effects of biochar on plant growth, microbial communities and biochar decomposition in agricultural soil”, which started in September 2011. The PhD thesis of Michael Scheifele at FiBL in collaboration with Prof. Rainer Schulin at ETH also uses DOK soils. Charcoal is suggested as one option to sequester carbon in the soil, and as such has a link to climate mitigation strategies.

The DOK long-term experiment, where the GHG measurements in the proposed study will be performed, is one of the few agronomic sites in the EXPEER on "Distributed Infrastructure for Experimentation in Ecosystem Research", where key long-term trials, ecotrons and analytical platforms are joined in a network. That means that data generated in the DOK trial will have an extended reach within the EXPEER community.

7. References

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