Project description:

Effects of anaerobically digested manure on soil fertility - establishment of a long-term study under Norwegian conditions (SOILEFFECTS)

PART 1: The KMB project

1. Objectives

The main aim is to establish a field experiment to compare long-term effects of anaerobically digested versus non-digested manure (slurry) on crucial soil physical, chemical and biological characteristics, and report the results achieved in the early transition period.

Secondary aims are to

- Localize appropriate sites for a long-term field experiment within Tingvoll research farm, and conduct the initial site characterization.
- Observe effects of the early transition period (3 years) on soil fauna (earthworms and other key fauna organisms)
- Observe effects of the early transition period on soil physical, chemical and microbiological conditions (soil density; soil pH, nutrients, organic matter content and quality; accumulated respiration, microbial community diversity).
- Measure the effect of digested manure on the local Tingvoll earthworm population by pot experiments under controlled environmental conditions.
- Characterize the activity of microorganisms and important members of the soil fauna, to increase our knowledge about turnover of plant nutrients in raw and digested manures in Norwegian agricultural soil.

A longer time horizon (>10 years) is obviously required to reveal long-term changes in soil characteristics with different manure treatment. The proposed project will provide important information about fertilizing soils with digested manures in the first 3 years covering the establishment phase and early transition period.

The field experiment will also be well suited for observations of nitrous oxide (N_2O) emissions. This greenhouse gas is about 300 times more harmful than CO_2. Additional funding for this and other activities beyond the limits of the present project will be applied for at a later stage. The proposed experimental site will constitute an excellent platform for future international collaboration – funded e.g. by the EU FP7 program.

2. Frontiers of knowledge and technology

Farm-level biogas plants are still scarce in Norway. However, the Ministry of Agriculture and Food have high ambitions that agriculture should take their share to mitigate climate change e.g. by treating animal manures in biogas plants. The current official aim is that 30 % of the manure should be treated with this technology. Investment costs must be decreased and technology adapted to Norway's scattered population and cool climate. A technology focus may easily override the impacts of the manure treatment on soil fertility. Especially for organic farmers, relying on a farming system with plant nutrient self-sufficiency, a fertile and productive soil is essential. Thus, on-farm recycling of organic matter is crucial for soil fertility, because humus constitutes a very important component in the formation of soil structure and crop nutrition (Elmholt et al., 2008). Humus is essential for soil aggregate formation and stability which governs water and nutrients behavior in the topsoil layer. Humus formation is a crucial part of any cultivation of mineral soil to agricultural land. Loss of humus has caused disasters e.g. in the United States around 1930, where the productivity of the soil decreased drastically with the dark topsoil lost by erosion.

Animal manures are used to maintain soil fertility, partly due to the positive effect on the soil humus content. In Norway, the long-term trials at Møystad (Riley, 2007) have demonstrated increased humus content in soil where animal manure was applied. Based on more than 30 years of research, the DOK-experiment in Switzerland (Mäder et al., 2002) has demonstrated that organic farming systems, as compared to systems with only mineral fertilizers, contribute to establish soil fertility. The organically managed soils contained more humus, had a more desirable structure with a higher capacity of water infiltration, and a more active microbial community to sustain the processes of plant nutrient turnover. In the farming systems comparison experiment at Apelsvoll, the positive effects of animal manure and ley in the crop rotation on earthworm activity and soil structure have also been demonstrated (Riley et al., 2008).

Organic farmers are concerned about what may happen to their soil if they spend a significant proportion of the organic carbon in their animal manure for biogas production. Danish researchers have established the project “BioConcens” to study aspects of bioenergy production in organic farming systems (Johansen et al., 2010). The project includes optimization of energy conversion technology, use of mixed cropping systems for energy crops, waste material (from both bioethanol and biogas production) impact on soil quality and fertility, emissions of green house gasses and socio-economical aspects. Preliminary results (from laboratory experiments) indicate that the amount of carbon (C) applied to the soil will be significantly less with manure digestion. On the other hand, the carbon in non-digested manure is also rapidly mineralized in the soil (Johansen et al., 2010), suggesting that the surplus organic C applied in non-digested manure is transformed to CO_2 in the soil. In this case it may not be contributing more to the humus formation than the digested manure, where the applied amount of C will be lower, but more stable. However, this question has not been sufficiently studied under Northern conditions and needs also to be evaluated under long-term field conditions. A field experiment comparing biogas digested manure and non-digested manure was recently established by the Biodynamic Research Institute in Järna, Sweden, but the results are not available yet.

Generally, because crop yield optimization have been in focus (e.g. Möller et al., 2008), the long-term effects of digested animal manure on soil characteristics have been neglected and are therefore not well understood, In Hungary, Makadi and colleagues have studied the impact of digestate application on soil nutrient content and enzyme activity (e.g. Vago et al., 2009). When biogas residues are substituting mineral fertilizers, the content of organic matter in the soil will probably increase. However, in the proposed project we want to study the situation relevant for a farmer with animal production, who recycles the digestate from a manure based biogas plant to the soil as fertilizer, to evaluate if this treatment of the manure can be done without decreasing the soil fertility. The research will be conducted at Tingvoll research farm, where a small biogas plant will be built during 2010 to digest the manure from the herd which consists of about 25 dairy cows. Tingvoll farm has been organically managed with dairy production since 1988. The biogas plant on the farm will allow for a comparison of digested and non-digested manure from the same herd.

In the proposed project, we will cooperate with the researchers responsible for the Danish BioConcens-study, the Järna field trial in Sweden as well as with experts from the Research institute of Organic Farming (FiBL) in Switzerland which manages the DOK-experiment.

3. Research tasks and hypotheses

The proposed project will prepare a ground for identifying how the ability of manure to support soil fertility is affected by waste-stream materials resulting from anaerobic digestion of raw manures. The proposed project will describe the initial status of the experimental sites (2011), and results of the early transition period (2 and 3 years for soil fauna, 3 years for other measurements). Soil fauna is expected to have a larger annual variation than soil physical and chemical characteristics, due to larger sensitivity for weather conditions. Hence, a double registration (in 2012 and 2013) will provide more reliable data. For soil physical and chemical conditions, measurements will be done in 2013, to increase the probability of finding significant differences between the treatments.

The field experiment will be located on two fields with different fertility, both on Tingvoll research farm with organic dairy cow production. The most productive field (A) has been cultivated for a very long time, whereas the less productive field (B) was cultivated about 10 years ago and still demands large applications of manure to increase the level of plant nutrients e.g. phosphorus. On field B, the ability of the manure to increase the soil fertility and quality will be of special interest, whereas the field A is intended to mimic the normal management of the farm. To stress the systems and reveal larger differences between the treatments, the topsoil layer will be removed on a part of both experimental sites. The natural choice of experimental crops would be a perennial grass-clover ley, established in 2011 and with cereals or green fodder as the cover crop. However, the legume component may mask nutritional effects on plant growth due to its N-fixing capacity and a non-legume crop may thus be preferred for experimental reasons. Hence, the final choice of crop will be taken in the start of the project considering soil type variables and also considering the results from BioConcens project. The treatments will comprise two levels of applied manure on each field A and B. On field A, the levels will be 0 (control) and about 60 kg total N ha^{-1} y^{-1} (resembling the normal fertilization level on the farm). On Field B, the levels will be about 60 and 180 kg total N ha^{-1} y^{-1}, resembling the normal level of fertilization and a situation where extra manure is applied to increase the soil fertility. As a control and to increase the relevance of the study for conventional agriculture, one treatment with mineral fertilizers applied in about the same amounts with respect to N, P, K, Mg and S as the normal fertilization level will be carried out.

Processing the raw manure in a biogas plant changes its chemical content to leave a sludge with less dry matter, less easily degradable organic carbon and an enhanced fraction of mineral nitrogen to mention a few characteristics. Hence, the soil microbial community experiences a rather different substrate compared to when raw manure is applied. Data from the BioConcens project (not published yet) show that the soil accumulated respiration following application of raw manure is higher compared to when digested manure is applied. However, this was studied with a soil and digested materials which were different from that included in the proposed project. With a decreased content of organic C the project will evaluate how the microbiota reacts to the digested manure by measuring the microbial biomass as well as detecting major shifts in microbial community structure by using phospholipid fatty acid technique (Johansen & Olsson, 2005).

Earthworms are a key species of agricultural soil, but the fauna of cultivated soil is highly diverse. Changing nutrient input patterns in the soil will probably also change the microbiota and, hence, their grassers having specific food preferences as shown for collembolans (Larsen et al., 2008). Mite and collembolan ecology have been very little explored under Norwegian conditions, and this project will provide important initial data.

Hypotheses

1) The digested manure will enhance plant N uptake and hence increase crop yield levels as compared to non-digested manure, because N will be more readily available in the digested manure (Johansen et al., 2010).
2) Increased yield levels in treatments with digested manure will result in more root biomass and other plant residues that will maintain the humus content and quality of the soil. Hence, we do not expect to reveal significant negative effects of anaerobic digestion on the ability of the manure to support soil quality and fertility.
3) The nutrient content of the soil will decrease in treatments with digested manure because higher crop yields will remove more plant nutrients.

4) In treatments where the topsoil is removed, soil quality and fertility will increase more rapidly in the treatments with non-digested manure as compared to digested manure and mineral fertilizer.
5) We expect the earthworm fauna to be negatively affected by the anaerobic digestion of the manure, because these animals are sensitive to ammonium (NH_4^+) (Edwards, 1988), which may be found in relatively high concentrations in anaerobically digested manure. However, as ammonium is usually rapidly transformed to nitrate in cultivated soil, we propose that this risk will be small in practice.
6) We propose that the application of diminished amounts of easily degradable organic C will impact the earthworm population negatively, because the earthworm species that is most common in Norwegian cultivated soil, the field worm (*Aporrectodea caliginosa* Savigny) (Pommeresche & Løes, 2009) is endogeic (soil eating). Endogeic earthworms may not be able to compensate the reduced application of organic C by an increased availability of plant material. By application of digested manure, endogeic earthworms may lose the competition with soil microorganisms for available C, as shown by Ernst et al. (2008).
7) If revealed (see hyp. 6), we propose that reduced earthworm activity will impact negatively soil organic matter content and soil physical characteristics indicating a satisfactory soil quality.
8) We expect that carbon mineralization from soils amended with digested manure will be less as compared to when raw manure is applied. This will be the case in all soil scenarios included and both on a short- and long-term timeline.
9) Differences in the soil microbial community will be induced by both soil treatments and application treatments – and verifiable by using PLFA profiling.

We are aware that some of our hypotheses (2 versus 6) are contradictory. Formulating our research questions as hypotheses contributes to more targeted studies and it will be interesting to see which hypotheses will prove right.

4. Research approach and methods

The agricultural soil at Tingvoll research farm has been sampled regularly for chemical analyses, last time in 2009. Other soil characteristics are available for all fields (texture, organic matter content), but more detailed studies must be performed at potential field sites to select the places which are best suited for the field experiments. Soil tillage to reduce weeds and ensure even conditions, and removing of topsoil will be done in 2010.

In spring 2011, the experimental plots will be sampled for the initial characterization of **soil biology** (earthworms, collembolans and mites), **soil microbiology** (microbial biomass, microbial community structure described by phospholipid fatty acid technique and accumulated respiration measured by Micro-Oxymax respirometer), **soil chemistry** (AL-extractable P, K, Ca, Mg, Na, acid soluble K, pH, total C, total N, mineral N and hot- and cold-water extractable organic C (labile organic C) according to Sparling et al., 1993) and **soil physics** (soil bulk density in field, porosity and pore size distribution (pF), air permeability and (saturated) hydraulic conductivity, aggregate size distribution and soil stability). Relevant techniques and taxonomy for the studies of collembolans and mites will be learnt by a visit to our project partners at Aarhus University (more below).

After soil sampling for initial characterization, the experimental crops will be established (cereals or green fodder as a cover crop for perennial grass-clover ley, see considerations about crop type above). The experimental crops will be recorded to resemble the normal practice on the farm (two or three cuts of perennial leys per season dependent on growth and choice of crop) and the crops will be removed from the field.

The manures will be analyzed for contents of total C, total and mineral N, total P, K, Mg and S and labile organic C. By manure application (in spring and after the first cut of ley), viscosity and infiltration rate will be measured. Possible differences in smell and appearance will be described. To calculate the amount of digested manure that resembles a certain amount of non-digested manure, the P concentration will be utilized. P is not subject to any gaseous losses in the animal-manure-(gas digestion)- storage-spreading- soil system. Equal amounts of P will be applied in digested and non-digested manure. Possible differences in P concentration will be used to assess the amounts of C and N in digested as compared to non-digested manure, to discuss possible losses of greenhouse gases.

Soil fauna (earthworms, collembolans and mites), will be recorded in the autumn of 2012 and again in 2013. Based on the achieved knowledge about the earthworm fauna in 2011 and 2012 and the initial effects of the manure treatments on these animals, the pot experiment will be planned in detail and conducted during the winter and spring of 2013. The pot experiments will be conducted with earthworms found in the experimental fields, to study the effect of anaerobically digested manure on the ecology of these animals especially with respect to ammonia concentrations and reduced applications of easily degraded C in the digestate. The aim of this study will be to simplify the soil-manure-earthworm system as compared to field conditions, to be able to reveal relationships than cannot be identified in field.

In the autumn of 2013, initial soil characterizations will be repeated to study the effects of the different manure treatments. Accumulated respiration (Micro-Oxymax respirometer) will be measured to describe the transformation of organic C in the soil. The reactions of soil microbiota to the manure treatments will be revealed by changes in microbial biomass and possible major shifts in microbial community structure as measured by phospholipid fatty acid (PLFA) technique. Soil physics will be studied by measuring soil bulk density (in field), possibly also the other mentioned characteristics. However, the detailed program of soil physical analyses will be decided when soil density is measured in field. The significance of differences in this crucial parameter between treatments will decide whether more analyses are relevant.

To fully reveal the possible impact of biogas digestion on important soil characteristics, we need more than three years. However, effects obtained during the early transition period will be described. Peer-reviewed papers describing initial conditions and results of the first sampling with respect to soil fauna, soil chemistry and soil physics will be published.

5. Project organisation and management

As described in a separate letter attached to the web-based application, the project will be coordinated together with possibly four other projects if funded, by the Norwegian Centre for Bioenergy Research. The daily management of the project proposed here will be carried out by senior researcher Anne-Kristin Løes at Bioforsk Organic Food and Farming.

The **core team** in the project is composed of scientists from Bioforsk and the Aarhus University (AU), Denmark. Dr. Hugh Riley from Bioforsk Arable Crops division (Apelsvoll) is a recognized expert in soil physics, especially linked to agronomical field experiments. He will assist in the detailed planning of the field experiment (site localization, initial treatment of soil, experimental design such as crop rotation, manure application, soil sampling etc.) and conduct the soil physical investigations. M Sc Reidun Pommeresche from Bioforsk Organic Food and Farming division (Tingvoll) is an experienced scientist in soil ecology, especially with regard to earthworms. She will conduct the earthworm studies described here, both in field and as pot experiments. Pommeresche will cooperate with experts at AU to broaden her knowledge about other species (e.g. collembolans and mites) and use the planned field experiment as an arena to study these. Dr. Anne-Kristin Løes from Bioforsk Organic Food and Farming has a long experience as a project leader of various research projects in organic food and farming. Her doctoral thesis (2003) was about soil fertility, and soil science is her primary field of expertise. Dr. Anders Johansen is senior scientist at National Environmental Research Institute, Department of Environmental Chemistry and Microbiology (AU). Anders Johansen will conduct the analysis linked to organic C and microbiology in soil and provide contact to other relevant experts at AU.

The core team will be supported by a **resource team** composed of Dr. Paul Mäder from FiBL, Switzerland and Dr. Artur Granstedt from the Biodynamic Research Institute in Sweden. The resource team will meet once per year to discuss project design, details and results. Possibilities for common publications and project proposals will be sought for.

Finally, the core team will be supported by a **relevance team** composed of representatives from the local divisions of the Norwegian Farmers' Union and the Norwegian Farmers and Smallholders' Union and the Norwegian Agricultural Extension Service. The relevance team will visit the field experiment once per year to discuss project design, details and results and make sure this is of interest for practical farmers.

6. International co-operation

As described in section 5, we will cooperate closely with colleagues at Aarhus University (AU). Our main contact at AU will be senior scientist Anders Johansen, who will participate actively in the project to conduct soil chemical and microbial analyses. We will also cooperate with soil fauna ecologists at AU, to increase the Norwegian expertise in this field. The project will benefit from the broad experience in long-term field experiments at the Research institute of Organic Agriculture (FiBL) in Switzerland, and the Biodynamic Research Institute (BRI) in Sweden. FiBL is internationally acknowledged for their high quality research in organic food and farming systems, not least because of the long-term DOK field experiment. In the DOK-study, effects of conventional and organic farming systems with different levels of external inputs have been compared especially with respect to soil characteristics for more than 30 years. Until now, the study has been the source for about 40 scientific publications. BRI has conducted several long-term field experiments to study the effects of manure management (e.g. composting) on soil characteristics (Granstedt & Kjellenberg 2009), under conditions that are quite relevant for Norwegian agriculture.

7. Progress plan - milestones

Time period	Milestone/activity	Project deliverables
Autumn 2010	Establishment of field experiments at Tingvoll. Localization of sites and removal of topsoil.	Project website, newspaper publicity
Winter 2010-11	Building storage tanks for digested and non-digested manure. Sampling, storage and analysis of digested and non-digested manure. Study trip to AU (soil biology). First meetings with resource team and relevance team.	Detailed planning of field experiments. Planning of dissemination activities.
Spring 2011	Soil sampling for start characteristics.	Field visits by farmers and advisors.
Spring - Summer 2011	Establishment of experimental crops. Manure application. Crop yield recording.	Pictures, yield results. Practical experiences with the manure. Results of initial soil characterization.
Autumn 2011-Spring 2012	Writing peer-reviewed paper. Sampling, storage and analysis of manure. Second meetings with resource team and relevance team.	Peer-reviewed paper about the initial soil characterization. Paper in newspapers and magazines in Norwegian, news on websites.
Spring - Summer 2012	Manure application. Crop yield recording.	Field visits by farmers and advisors.
Autumn 2012	First sampling of soil fauna to measure effects of manure treatment Half-way seminar Revising project plans	Report and short paper in Norwegian Relevance team involved; discussion of results Resource team involved; amendments of project plan, possibly new applications.
Autumn 2012-Spring 2013	Sampling, storage and analysis of manure. Third meetings with resource team and relevance team.	Conference contributions e.g. at “Bioforskmøtet” and for local farmers
Spring - Summer 2013	Manure application. Crop yield recording.	Field visits by farmers and advisors.
Autumn 2013	Second sampling of soil fauna to measure effects of manure treatment First sampling of soil microbiology, chemistry and physics to measure effects of manure treatment	Peer-reviewed papers (to be submitted in spring 2014)
Winter-Spring 2013-14	Pot experiments with earthworms	Peer-reviewed paper and conference contributions
Autumn 2013-Autumn 2014	Writing peer-reviewed papers. Sampling, storage and analysis of manure. Fourth meetings with resource team and relevance team.	Results, publishing as conference papers, papers in Norwegian. Peer-reviewed papers about effects on earthworms, soil physics, soil chemistry including soil organic matter and microbiology.
Spring 2014	Plans and arrangements made to continue the experiment	Maintenance of the study, to demonstrate more significant effects
Spring - Summer 2014	Manure application. Crop yield recording.	Field visits by farmers and advisors.
Autumn 2014	Project completed. All papers submitted for peer-review.	Final report, international conference contributions.

8. Costs incurred by each research performing partner (in 1000 NOK)

Partner	Personal and indirect costs	Analyses, travels and other costs	Equipment	Total
Bioforsk Organic	605	1395	50	2 050
Bioforsk Arable Crops	120	280		400
AU	165	335		500
Resource team (FiBL, BRI)	55	45		100
Norwegian Farmers' Union (share of employment)	150			150
Total	1095	2055	50	3 200

9. Financial contribution by partner (in 1000 NOK)

Sparebanken Møre	Norwegian Center for Ecological Agriculture	Agricultural Agreement Research Fund	Research Council of Norway	Total funding
50	60	530	2560	3200

PART 2: Exploitation of results

10. Relevance for knowledge-building areas

The project is well rooted within an essential field of competence *bioproduction*, prioritized by the Research Council of Norway in the research program "Natur og næring". Research required to develop bioenergy production based on agricultural resources are supported by this program. The most important contribution of the proposed project to the knowledge development will be increased ability to assess the risks and possible benefits on soil fertility and quality when available animal manure is anaerobically digested to produce biogas. The research will increase the knowledge about the cultivated soil fauna under Norwegian conditions, and bring Norwegian researchers in closer connection to relevant foreign research institutes. Bioforsk Organic Food and Farming has ambitious aims, and also required instruments (e.g. the popular website Agropub, regional network for farm-scale biogas plants, close contact to agricultural extension service) to communicate the results to organic as well as non-organic farmers.

11. Importance to Norwegian industry

The output of the proposed project will not be increased income due to new and innovative commercial products. However, fertile soil is essential for any farmer. In a world with increasing population and decreasing reserves of important plant nutrients such as phosphorus, possible sources of plant nutrients and organic matter must be carefully utilized. Animal manure is well known to support soil fertility. Digestion for biogas production should not decrease this positive effect. Assessment of the long-term effects of biogas utilization on manure and soil quality is of high interest for Norwegian farmers, as has also been confirmed by the positive responses to the invitations for cooperation in the project relevance team (see attachments to the online application scheme).

12. Relevance for call for proposals and programmes

The call emphasizes the importance of research to achieve the ambitious official goals that have been put up for agriculture to decrease its emissions of greenhouse gases. The proposed project, focusing on soil quality indicators, might seem outside of this scope. However, in fact such knowledge is urgently required to ensure that Norwegian farmers make sound and sustainable choices about the utilization of the manure available on the farm. The ambitious official aims are dependent on Norwegian farmers' will to cooperate and make their manure available for bioenergy purpose. The results of this project will provide important first indications as to whether we can recommend them to do so.

13. Environmental impact

Utilization of farmyard manure for biogas production has a large potential to reduce greenhouse gas emissions, and thereby decrease one important negative environmental impact of agriculture. However, this relies on 1) reduced emissions of methane (CH_4) during manure storage, and 2) reduced emissions of nitrous oxide during manure spreading. Especially the second of these preconditions is not properly studied under Norwegian conditions. The proposed study implies an opportunity and additional funding will be applied for.

Biogas utilization of manure reduces the content of organic, especially the easily degradable carbon fractions. If this impacts the humus content and quality of the soil negatively, the soil fertility will decrease. Productive soil is a very important resource for mankind, and reduced soil fertility will be a significant negative environmental impact of the studied technology.

14. Information and dissemination of results

Nationally, the project will focus on Norwegian farmers and advisors in the dissemination of results. Farm-level biogas plants are still few in Norway, and the Tingvoll plant will likely create interest among farmers and other visitors. A long-term field experiment close to the plant for demonstration purpose will add interest. Regionally, there is a close contact between Bioforsk and other actors interested in establishing farm-level pilot biogas plants. A farm-level biogas network for Mid-Norway will be established in May 2010, to exchange experiences and knowledge. This will be a useful arena for dissemination of information.

To reveal the impact of biogas digestion on basic soil characteristics, more than three years are required. Hence, the proposed project will not produce the same body of results as more restricted scientific questions. Peer-reviewed papers describing initial conditions with respect to soil fauna (1 paper), soil chemistry (1 paper) and soil physics (1 paper) will be produced. Results of the first sampling will be described in the final report and conference papers.

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