LONG-TERM FIELD EXPERIMENTS ON BIODYNAMIC FARMS IN SWEDEN, 1987 – 2017

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Preface

This report is a part of an ongoing project to evaluate long term farming system studies started already in 1958 to develop biodynamic agriculture and compare different farming systems under Nordic conditions. We present an overview of projects which have been completed and then describe two newer projects in more detail. One ongoing new on-farm project stated 2012 on Nibble farm in Järna in central Sweden which was converted to biodynamic farming 1964.

In the on-farm field experiment in Järna, focus is on the manuring system within the same crop rotation. We compare effects of different qualities and quantities of manure: composted to raw manure (Skilleby farm 1991-2005), liquid manure to composted manure, with and without use of biodynamic preparation (from 2012) and also use of biochar (from 2013) at Nibble farm. Results of short and long-term effect on yield of cereal crops and legume grass ley are presented. Further on-going studies of effects of manuring systems, with biodynamic and biochar treatments, on quality on crop products and soil fertility, including carbon sequestration, will be presented and discussed in subsequent reports. Further results of this experiment will be published in cooperation with our partners in Scania as a supplemental report later this year, with financial support from Ekhaga Foundation.

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Summary

Nibble farm converted to biodynamic farming practices in 1964 and has used the same crop rotation for the past 20 years. The farm has likely built up a long-term mineralization capacity similar to that documented in the earlier long-term experiment (K-experiment) and on-farm studies on Skilleby experimental farm.

At Nibble farm, two new research questions, use of liquid manure and use of biochar in biodynamic agriculture, were introduced by farmers working together with researchers. The goal of the new long-term studies is to identify effects of liquid manure compared to composted manure and to evaluate use of biodynamic treatments and of biochar application.

Current results showed very low direct manure effect of both composted manure and liquid manure. For liquid manure, this can partly be explained by the loss of NH_4 N to the atmosphere, particularly when manure is spread in the autumn before sowing, without a crop which can utilize nutrients directly. In Nibble field experiment 3, the long-term manure effect was observed for up to four years after manure application. In the experiment 2 and 3, a distinct effect of the use of biochar was shown, with between 8- 23% higher yield affecting soils with both high and low organic matter content, with effects seen up to four years after application.

The first four years of Nibble on-farm field experiment indicate that it is possible to observe some differences between use or not of the biodynamic preparations which in some cases support better yields (increasing 2-7%) with the older cultivar 'Jacoby Borst' in experiment 1, and also higher yields in experiment 2 with same cultivar and in the clover-grass ley. Biodynamic preparation in legume-grass ley in experiment 2 gave an additional higher yield, both with and without biochar. Experiment 3 showed a significant effect of biochar, but not of biodynamic treatments.

The promoting effect on yields found in this study can be explained by N-mineralization of organic fertilizers. Biochar can facilitate immobilization of soluble mineral nitrogen and slow release nitrate in biochar amended compost and soil. Further studies are required to understand the contradictory results in the literature and the biological and chemical mechanisms in the soil crop systems behind the results of biochar application. The hypothesis is that biochar is resistant to decomposition and works as a soil conditioner for several years. Biochar retention times have been estimated to at least hundreds, but more likely thousands of years. From this aspect it is also possible to argue that use of biochar as soil conditioner also is an important long term working "carbon sink".

The main explanation for the weak direct manuring effect of organic manure is found in the long-term inherent mineralization capacity of the soil. The role of manure is to support this long-term effect. Thus, manure only has a marginal effect on yield the year it is applied.

The results at Nibble farm point to the importance of fertilizing soil instead of crops, the long-term effects of manure, the effect BDP treatment, the unexpected large effect of biochar application and the support for carbon sequestration using biochar.

Introduction

Questions of the impact of different agricultural practices on soil fertility have engaged farmers and researchers for many decades, but since the 1980's and forward they have also reached a broader and more general audience. Sustainability aspects of agricultural practices are now widely considered to be fundamental questions for the future, particularly when considering issues such as resource limitations, the long-term fertility of arable soils, and environmental impacts stemming from agricultural production and global food security, both in terms of quantity as well as quality.

Aim

Final evaluation of long-term farming system trials comparing conventional, organic and biodynamic agriculture located in central Sweden and Scania in southern Sweden with a focus on the quality of soil, yield, food quality and to reduce the global warming trough carbon sequestration in soil.

Long-term experiments in conventional and organic farming

Cultivation methods in agriculture have a long-term effect on the physical, chemical, biological, and microbial parameters of soils with consequences for the crop yield and production capacity (Boguslawski 1965). After introducing of new methods, it often takes decades for the quantity and quality of soil organic matter (SOM) to reach a new dynamic equilibrium (Johnston et al. 2009). Degradation of SOM and soil production capacity can only partly be compensated through use of external resources, including organic fertilizers.

In organic farming systems which are based on local, renewable resources, farmers are completely dependent on local site conditions including production capacity of the soil. Long-term field experiments make it possible to distinguish the effects of crop rotations and organic fertilization on soils and, as a result, on crops (Johnston & Poulton 2018). Continuation of long-term experiments is therefore of particular importance to organic agriculture. Long-term field experiments have been conducted at a range of site conditions in Germany, England, Italy, Denmark, Switzerland, Austria, Israel and the USA (Raupp et al. 2006). Each of these experiments has a unique concept and scientific approach but the common objective is to investigate characteristics of organic agriculture regarding key parameters of soil fertility, crop yield and quality.

The unique Rothamsted experiments, started in 1852, show how SOM can increase for a long time with a continuous supply of manure for long-term stabilization at a high level relative to surrounding conditions, but also how the humus levels decrease once addition of raw humus, such as manure, ceases (Johnston et al. 2009; Johnston & Poulton 2018). In Sweden, experiments have been on-going for over 60 years, carried out on clay soils with low organic content, initially with low carbon levels (1.5% C) (Kätterer et al. 2011). Humus content in these soils continues to increase with a continuous supply of organic fertilizer (Kätterer, Bolinder, Andrén, Kirchmann, & Menichetti, 2011).

Long-term experiments in biodynamic farming

The first long-term biodynamic field experiment was established in Järna, Sweden in cooperation between Professor Herbert Koepf, Agronomy Licenciat Bo D Pettersson and the Nordic Research Circle. These were the so-called 'quality experiments' (K-trial), encompassing eight differing manuring systems, that ran between 1958-1990 (Pettersson et al. 1992; Granstedt et al. 2005) In Europe, a long-term experiments comparing conventional , organic and biodynamic farming systems started in Switzerland in 1978, the so called DOK-trial (Mäder et al. 2002), followed by a long-term field trial in Darmstadt in 1980 (Abele 1987).

Results from the initial K-trial formed the basis for the UJ-trials, which were carried out by the Nordic Research Circle for Biodynamic Farming in collaboration with Swedish University of Agricultural Sciences at two locations, Ultuna and Järna (Pettersson 1982). UJ trials are named after the two locations, Ultuna in Uppsala and Järna south of Stockholm. Results from these field experiments are published in the first Swedish doctoral thesis on what at the time was called 'alternative agriculture' (Dlouhý, 1981).

These experiments were subsequently followed by a range of similar initiatives in Europe and the U.S., as well in Sweden. Long-term field experiments were established in both central and southern Sweden to gain practical knowledge for organic farmers. The goal of these experiments was to gain knowledge about how to improve soils for productivity and high-quality agricultural products.

In Järna, a long-term field trial on Skilleby research farm was established in 1991 and concluded with the last field trial in 2011. This was an on-farm experiment comparing different manure regimes including the influence of biodynamic preparations within a farming system. A new field trial was established on a neighbouring farm Nibble in 2012. Both are well established biodynamic farms with crop rotations and nutrient recycling documented in case studies (Granstedt 1992; Granstedt 1990).

A large project comparing farming systems was initiated in the region of Skåne, southern Sweden, which saw the establishment of three long-term field experiments in cooperation with the region's three secondary education schools of agronomy in Bollerup, Önnestad and Östra Ljungby (Gissén & Larsson 2008). These comparative cultivation experiments have been in place in Skåne since 1987 in Bollerup (ended 2012) and Önnestad which ended 2014.

K-trial in Järna, 1958 – 1990

The K-trial in Järna lasted for 32 years from 1958 to 1990. The main research question concerned the quality of agricultural food products under different farming and specifically fertilization conditions. Interactions and influence of different manuring techniques on soil fertility were also studied (Kjellenberg & Granstedt 1998).

The long-term K-trial was run with one crop rotation without replications but with each crop grown each year from 1958 – 1990: 1) spring wheat, 2) ley with legumes, 3) potatoes and 4) beets. The eight different treatments included: K1 biodynamic composted manure and biodynamic field preparation; K2 biodynamic composted manure without the BD field preparation; K3 raw farmyard manure; K4 raw farmyard manure and mineral fertilizer (NPK); K5 no manure or fertilizer; K6 low, K7 medium and K8 high levels of mineral fertilizer (NPK).

Potatoes and beets were fertilized in the organic treatments and potatoes, beets and wheat were fertilized in the mineral fertilized treatments. For the whole period, annual NPK kg per ha was averaged in the composted farmyard manure in K1 and K2 to NPK 80/38/76 and in the fresh manure in K3 to NPK 95/32/91. These amounts correspond to the potential production of fodder crops in the crop rotation with a livestock density of 0.9 animal units per ha. The average, annual amount of NPK per ha in the combined organic and mineral fertilized treatment K4 was NPK 62/24/66, in the mineral fertilized treatments K6 NPK 29/18/41, K7 NPK 58/36/81 and in K8 NPK 117/36/81.

Summarized results

The difference between cultivation using organic and mineral fertilizer with comparable yields can, according to the results from the K-trial (Kjellenberg & Granstedt 1998), be summarized as:

Soil

- higher enzyme-activity and soil respiration
- greater occurrence of earthworms
- soil processes at greater depth
- considerably higher nitrogen-mineralization capability
- better soil-fertility with increased carbon content

Crop

- lower storage losses and better resistance to decay
- more mature crops
- higher percentage biomass of leguminous plants in the clover-grass ley

The fully biodynamic treatment was characterised by a considerably higher amount of carbon in the soil, especially below plough depth. Biodynamic treatment also made the plants less susceptible to potato blight. Biodynamic preparation tended to normalize yields, with increased yields during years when the common yield level was low and decreased yields when the common yield level was high (Granstedt et al. 2005; Granstedt & Kjellenberg 2008; Raupp & König 1996).

UJ-trial, 1971 – 1979

The UJ-trials took place between 1971 and 1979 in a collaboration between the Biodynamic Institute in Järna and the Swedish University of Agricultural Sciences (SLU), Ultuna (Dlouhý 1981; Pettersson 1982). The aim was to evaluate the association between farming methods and quality of agricultural crops by comparing biodynamic and conventional agriculture.

Biodynamic cultivation without leys (B1- spring wheat, barley, potato) and with leys (B2 - spring wheat, ley with clover-grass, potato) was compared to conventional cultivation without leys (A1-spring wheat, barley, potato) and with leys (A2 - spring wheat, ley with clover-grass, potato) in three-year crop rotations. The field experiments had the same layout at both locations; four replications, split-plot design with all three crops in the three-year crop rotation each year.

The biodynamic plots received biodynamic composted farmyard manure in an amount comparable to manure production realisable by the fodder crop (0.7 animal units per ha) while conventional plots received mineral fertilizers comparable to standard recommendations at the time for these crops (average NPK 95/45/110 kg/ha).

After 9 years, the fully biodynamic treatment with one year of clover-grass in the three-year crop rotation (spring wheat, clover-grass and potatoes) was characterised by considerably higher amount of total carbon in the soil.

Results from the two experiments corresponded well with each other as well as with the K-trial (Kjellenberg & Granstedt 2015; Granstedt et al. 2005).

In comparison with conventional methods, the biodynamic treatment had:

- 10 % less yield (spring wheat)
- Less storage losses (potato)
- Higher dry matter content (potato)
- Superior protein quality (potato)
- Higher content of vitamin C (potato)
- Better cooking quality and taste (potato)

Skilleby trial, 1991 – 2011

When the K-trial ended in 1990, field experiments were established at Skilleby research farm to evaluate effects of different treatments within a specific farm situation. The aim was to study how farm manure could best be treated and used to promote soil fertility, efficient use of nutrients, output (yield) level and nutrient quality of agricultural products, while minimising negative impacts to the environment, all in the context of biodynamic agriculture (Granstedt, 2000).

Effects of applications of fresh and composted manure in long-term experiment were studied, with and without biodynamic preparation treatments, at three levels of application (12.5, 25 and 50 tons per ha from 1991-1995 and 0, 25 and 50 tons per ha from 1996-1997), 12 treatments with 2 – 4 replications of each crop and established on each of five fields in the five-year crop rotation: oats with insowing, ley I, ley II, ley III and winter wheat with the application of farmyard manure (Granstedt, 1992).

In this experiment, SOM was higher after 14 years in a five-year crop rotation with recycling of manure. Clover-grass ley was grown for three years to support milk production adapted to farm carrying capacity, considering milk and manure production (Granstedt, 2017). Farm manure seemed to result in higher SOM in treatments with use of biodynamic preparation of composted and fresh farm manure, compared to manure without BDP treatments. This difference was significant after the first four years (Granstedt, 2017). After the first six years, yields of winter wheat on five randomised field experiments with replicate distributed to the five fields were also evaluated.

Long-term farming system study in central Sweden comparing organic and biodynamic agriculture at Nibble farm

Nibble farm was established as a biodynamic dairy farm in 1964. Long-term trials were established in 2012. Here, farmers working together with researchers introduced two new research questions: use of liquid manure and biochar in biodynamic agriculture.
Results are here presented for the first five-year period until 2017 on three field experiments.

The farm
Nibble farm is adjacent to Stavbofjärden in the Baltic Sea, 50 km south of Stockholm in eastern Södermanland (Figure 1). The position is N 59°30´, height above sea level 5 - 15 metres, with an annual average precipitation 590 mm, yearly average temperature 6.2° C with 6 to 8 snow free months (Table 1). Topsoil is generally frozen 3-4 months every year, from December to March. The farm includes 100 ha arable land and of this, 20 ha is permanent pasture. Climate data is attached as Appendix II.

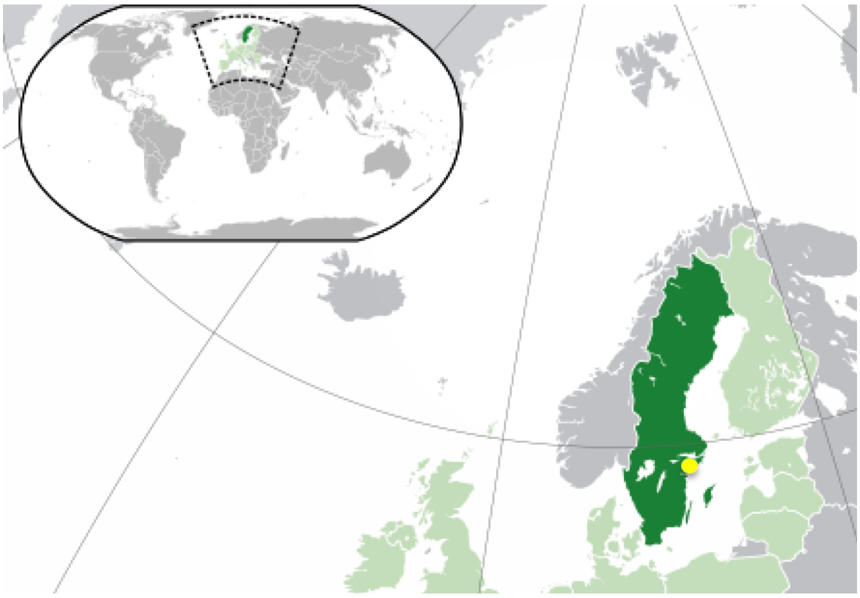


Figure 1 Location of Nibble on-farm long-term experiment in east central Sweden (yellow dot), at 59°N and 18°E, 5-15 m above sea level. Sweden is dark green, European Union lighter green. By NuclearVacuum - CC BY-SA 3.0,

Soil conditions
Soils are mainly sedimentary clay loam. Ten meters above sea level, soil humus content is between 2.5 and 4%. Soil under topsoil depth is stratified, with glacial clay found at greater depth. Secondary sorting of soil texture fractions (post glacial clay, loam and silt) has occurred. Under 10 m above sea level humus content is up to 9%, with a large proportion of silt which predisposes soils to crust formation despite higher content of organic gyttja clay. Glacial clay is close to topsoil in elevated areas and these soils dry out more quickly during spring, compared to the more low-lying areas. Generally, soils are high in potassium, low in phosphorus and have a pH of 6.1 – 6.5 (Appendix III).

Table 1 Site characteristics, Nibble farm

Site	Järna
Position	59°N 18° E
Mean annual precipitation (1961-90)[1]	590 mm
Mean annual temperature (1961-90)	6.2 °C
Bedrock[2]	Paleoproterozoic bedrock
Soil texture (subsoil)[3]	Fine grained sediment
Top soil classification	Forest brown soil
Earlier land use	Crop rotation with ley.
	Manure applied.
Soil-moisture regime[4]	Udic
Soil taxonomy (WRB)[5]	Gleyic Cambisol

Crops, fodder production, animal husbandry, manure and plant nutrient recycling

Animal husbandry consists of milk and meat production adapted to farm fodder production on about 85% of the total arable area according the principles for ecological recycling agriculture (Granstedt, 2012). In total, about 15% of 86 ha is used for human food crops. Nitrogen input is based on biological nitrogen fixation mainly in the first and second year clover-grass crops. Plant nutrients in harvested field crops are mainly recycled through farmyard manure and liquid manure. Total livestock density is 0.7 animal units per ha, producing an average of 500 tonnes of farmyard manure and 500 tonnes urine per year. Livestock, crop rotation and plant nutrient and production recycling are presented in Figure 2 and Table 2.

[1] As according to the Swedish Meteorological and Hydrological Institute's (SMHI) latest 30-years standard normal period of measurement, SMHI.se
[2] Own analysis
[3] Own analysis
[4] SGU
[5] SGU

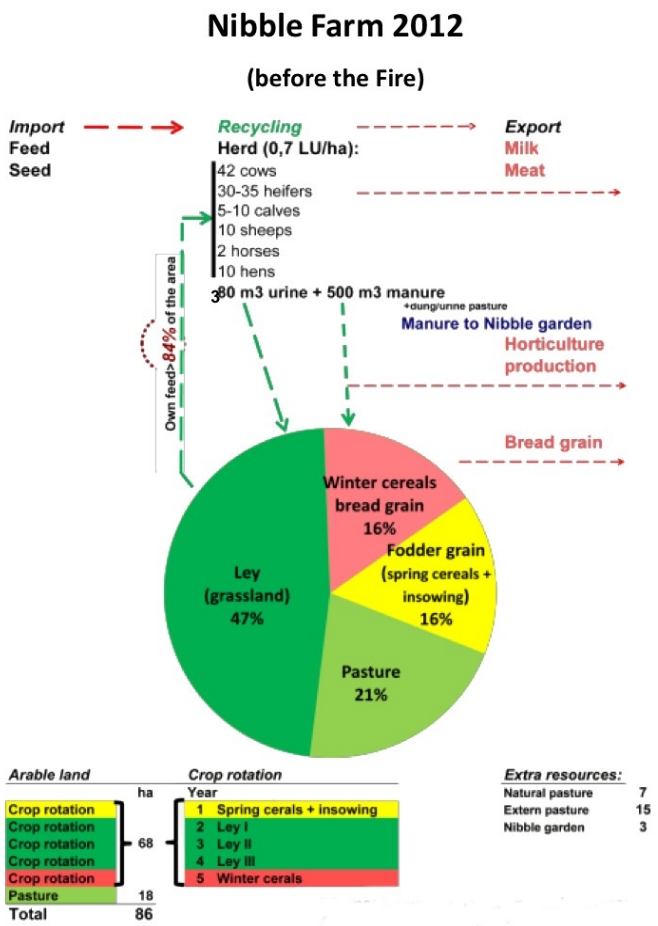


Figure 2 Fodder crops, cash crops, food and animal production and recycling of farmyard manure and urine on Nibble farm until 2012.

Crop rotation

From the start in 1967, this biodynamic farm had a six-year crop rotation with three years of legume-grass ley followed by bread grains, oats, green fodder, bread grains and insowing of oats or barley. From 1991, a new five-year crop rotation was established:

1. oats with undersown legume-grass
2. legume-grass ley I
3. legume-grass ley II
4. legume-grass ley III (one early harvest, soil sampling, cultivation, application of farm yard manure and sowing winter wheat)
5. winter wheat (with additional liquid manure some years)

This crop rotation was designed to improve humus content and soil fertility and is now under modification.

Table 2 Crop rotation, compared treatments and experimental design, Nibble farm

Crop rotation on three fields	**Crop rotation**	**Compared treatments**	**Experimental design**
Experiment 1 on Nibble field 1	2012 legume - grass 2013 Wheat 2014 Oats 2015 Ley I 2016 Ley II	Zero plot Composted manure 3 levels Liquid manure 3 levels Farmyard manure 1 level Two cultivars of wheat With and without biodynamic treatments (BDP)	Start 2012 Three blocks 24 main plots 48 subplots 96 sub-subplots
Experiment 2 on Nibble field 2	2013 Ley-grass II 2014 Winter wheat 2015 Oats undersown with legumes 2016 Ley I 2017 Ley II	Zero plot Composted manure 3 levels Liquid manure 3 levels Farmyard manure 1 level With and without biodynamic treatments (BDP) (sub plots) With and without biochar	Start 2013 Four blocks 32 main plots 64 subplots 128 sub-subplots
Experiment 3 on Nibble field 3	2013 Ley II 2014 Winter wheat 2015 Oats undersown with legumes 2016 - Ley I 2017 Ley II	Zero plot Composted manure 3 levels Liquid manure 3 levels Farmyard manure 1 level With and without biodynamic treatments (BDP) (Sub plots) With and without biochar (Sub-sub plots)	Start 2013 Four blocks 32 main plots 64 subplots 128 sub-subplots

Materials and methods

Experimental design

Effects of applications of composted and liquid manure were studied, with and without biodynamic preparation treatments, at three levels of application: 18, 30 and 50 tonnes per ha. Liquid manure was sourced from Säby farm (adjacent to Nibble) and farmyard manure was from Nibble farm.

Field experiments are located on representative sites in each field (Figure 3). Field experiments were incorporated into customary farm management practices with fall ploughing and no irrigation. Manure treatment of 30 tonnes/ha corresponds to normal application. All crop cultivars in the experiments are ordinarily used on the farm.

Cultivars

Triticum aestivum L.
Winter wheat 'Jacoby Borst'
Winter wheat 'Stava'
Spring wheat 'Dacke'

Avena sativa L.
Oats 'Kerstin'

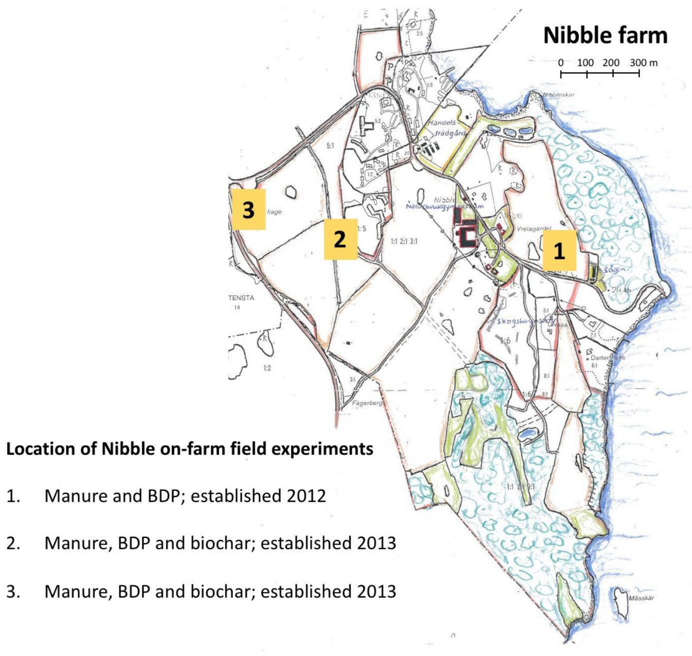


Figure 3 Nibble farm map with the three field experiments started in 2012, 2013 and 2014 marked.

In autumn 2012 experiments were started with sowing winter wheat on field number one. The following year, winter wheat sown on field number 2 and 3. The schedule of farm activities, sampling and treatments Nibble on-farm field experiments 1-3, 2013 – 2017 is shown in Table 3.

Table 3 Schedule of farm activities, sampling and treatments Nibble on-farm field experiments 1-3, 2013 – 2017.

Time	Year	Early spring		Spring	Summer	Autumn						
Treatment/ task		Compost pile building	P 502-507	P 500	P 501	Manure treatments after soil sampling each subplot	Sowing	Crop	P 500	P 502-507	Harvest of subplots	
Field experiment 1												
	2012	12-May				03 Sept.	10 Sept.	Winter wheat	16 Oct.	04Sept.		
	2013		15-May	17-May	01-June			Spring wheat			26-Aug	
	2014			22-May	04-June		06-May	Oats with undersown ley			21-Aug	
	2015			15-May	02-June			Ley I			5-June 16-July	
Field experiment 2												
	2013	08-Apr	10-Apr			02 & 03 Sept.	09 Sept.	Winter wheat	12-Sept.			
	2014			22-May	01-June			Winter wheat			06-Aug	

	2015			15-May	03-June		29-May	Oats with undersown ley			15-Jul	Silage
	2016			22-May	05-June			Ley I				
	2017			18-May	26-May			Ley II				
Field experiment 3												
	2013	08-Apr	10-Apr			03 & 04 Sept.	09 Sept.	Winter wheat	12-Sept.			
	2014			22-May	01-Jun			Winter wheat			15-Aug	
	2015			15-May	03-Jun		29-May	Oats with undersown ley			16-Jul	Silage
	2016			28-May	05-Jun			Ley I				
	2017	01-Feb.	03-Feb	18-May	26-May	30-Sept.	1-Oct.	Ley II	19-Oct.	19-Oct.		

Code **Full name**

BDP Biodynamic preparation according to Svenska Demeterförbundet (2017)
P 500 Humus Biodynamic Spray Preparation applied on BDP plots
P 501 Silicon Biodynamic Spray Preparation applied on BDB plots
P 502-507 Biodynamic Compost Preparation and preparation

Field experiment one

Experiment one was established after the third-year legume-grass ley 2012 with three types of manure: composted manure three different quantities (18, 30, 50 tonnes/ha), liquid manure three different quantities (18, 30, 50 tonnes/ha) and fresh farmyard manure one quantity (30 tonnes/ha); with and without use of biodynamic preparation (BDP) in a split-plot design and with three replicates divided in three blocks according the experimental plan in Figure 4. Soil samples were taken before spreading manure. After spreading manure treatments by hand in respective plots manure was worked into the soil Figure 7. The whole field, including the experimental plot, was then harrowed and sown.

10 m (width), 3.5 m (subplot)

Block	Subplot number			Subplot number
	48	B+	A-	1
	47	B-	A+	2
	46	F-	E-	3
Block 1	45	F+	E+	4
	44	D+	G+	5
	43	D-	G-	6
	42	H	C+	7
	41	H	C-	8
	40	A-	G-	9
	39	A+	G+	10
	38	D-	E+	11
Block 2	37	D+	E-	12
	36	F-	H	13
	35	F+	H	14
	34	B+	C-	15
	33	B-	C+	16
	32	D+	F-	17
	31	D-	F+	18
	30	G-	E+	19
Block 3	29	G+	E	20
	28	H	B-	21
	27	H	B+	22
	26	C+	A+	23
	25	C-	A-	24

Treatment main plot	Plot	Manure sub plot tonnes/ha
	A-	0
	A+	0
Composted manure	B-	18
	B+	18
Liquid manure	C-	18
	C+	18
Composted manure	D-	30
	D+	30
Liquid manure	E-	30
	E+	30
Composted manure	F-	50
	F+	50
Liquid manure	G-	50
	G+	50
Liquid manure	H	30

Biodynamic treatments (BDP)
Without BDP marked -
With BDP marked +

Total quantity in tonnes used
Composted manure 2.75
Liquid manure 3.58

Plot size
Main plot 7*10 m
Subplot 3.5*10 m
Sub-sub plot 3,5*5 m

Figure 4 Experimental plan 1, Nibble field experiment


Figure 5 Manure compost, Nibble farm.

Field experiments two and three

Experiments 2 and 3 were established after clover-grass ley in 2013 with three types of manure: composted manure, liquid manure, and fresh manure. Clover-grass ley II was terminated with ploughing and harrowing. Composted manure was used in three different quantities (18, 30 and 50 tonnes/ha) and liquid manure in three different quantities (18, 30 and 50 tonnes/ha); without use of biodynamic preparation (BDP) in a split-plot design and with four replicates divided in four blocks according the experimental plan in Figure 6. Soil samples were taken in topsoil to 20 cm depth within each subplot before manuring according to the plan. Soil analysis results are attached as appendix III. Liquid manure from Säby farm was transported to the site in a tank trailer. Farmyard manure from compost pile on Nibble farm was transported to the site with trailer. All manure was distributed as in experiment 1, Figure 7.

Experimental plan, manure

10 m / 20 m; 3.5 m; 7 m

Block	Subplot number	Biochar		Biochar		Subplot number
	64	B+	B+	A-	A-	1
	63	B-	B-	A+	A+	2
	62	F-	F-	E-	E-	3
Block 1	61	F+	F+	E+	E+	4
	60	D+	D+	G+	G+	5
	59	D-	D-	G-	G-	6
	58	H	H	C+	C+	7
	57	H	H	C-	C-	8
	56	A-	A-	G-	G-	9
	55	A+	A+	G+	G+	10
	54	D-	D-	E+	E+	11
Block 2	53	D+	D+	E-	E-	12
	52	F-	F-	H	H	13
	51	F+	F+	H	H	14
	50	B+	B+	C-	C-	15
	49	B-	B-	C+	C+	16
	48	D+	D+	F-	F-	17
	47	D-	D-	F+	F+	18
	46	G-	G-	E+	E+	19
Block 3	45	G+	G+	E	E	20
	44	H	H	B-	B-	21
	43	H	H	B+	B+	22
	42	C+	C+	A+	A+	23
	41	C-	C-	A-	A-	24
	40	F+	F+	D+	D+	25
	39	F-	F-	D-	D-	26
	38	G+	G+	A-	A-	27
Block 4	37	G-	G-	A+	A+	28
	36	E-	E-	C-	C-	29
	35	E+	E+	C+	C+	30
	34	B-	B-	H	H	31
	33	B+	B+	H	H	32

Treatment main plot	Plot	Manure sub plot tonnes/ha	Biochar sub-sub plots tonnes/ha
	A-	0	32
	A+	0	32
Composted manure	B-	18	0
	B+	18	32
Liquid manure	C-	18	32
	C+	18	32
Composted manure	D-	30	32
	D+	30	32
Liquid manure	E-	30	32
	E+	30	32
Composted manure	F-	50	32
	F+	50	32
Liquid manure	G-	50	32
	G+	50	32
Liquid manure	H	30	0

Biodynamic treatments (BDP)

			Total quantity in tonnes used
Without BDP	marked -	Biochar	2.52
With BDP	marked +	Composted manure	2.75
		Liquid manure	3.58

Plot size

Main plot	7*10 m
Subplot	3.5*10 m
Sub-sub plot	3,5*5 m

Figure 6 Experimental plan 2 and 3, Nibble field experiment

Figure 7 International Youth Initiative Program students spreading manure, Nibble field experiment 2017.

Plots were divided in two sections along the length of the experiment, see Figure 6. Biochar was spread at 32 tons per ha in half of each plot when sowing winter wheat 'Jacoby Borst'. H-parcels are reserved for special experiments but have not yet been utilized.

Statistical methods

Computer program Excel 2010 (Microsoft Corp USA) was used for calculations, graphics and statistical analysis. Design and ANOVA statistical analysis with split plot design of the field experiment was managed according to Little & Hills (1978).

Analysis

All manure and soil samples were analysed by Agrilab AB, Uppsala, Sweden.
Soil samples was taken after Ley III in the five-year crop rotation before manuring and sowing winter wheat. Samples from the upper soil layer (0–20 cm) of each of the 48 plots of the field trial were sent to Agrilab (Uppsala, Sweden), and analysed according to established standards. Total C (carbon) and N (nitrogen) content were measured with a LECO CHN 600 element analyser (SS- ISO 11464). Available P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium) and Na (sodium) were analysed after extraction in ammonium lactate (AL) solution (SS 028310). Total P, K, Mg, Ca and Cu (copper) were determined according to SS 028311 after extraction in hydrochloric acid (HCl) and pH was determined according to SS-ISO 10390.

Table 4 Nutrients in the treatments applied via composted and fresh manure from Nibble farm and liquid manure from Säby farm, experiment 1. Analysis by Agrilab AB.

	Composted manure			Liquid manure			Fresh manure
	B	D	F	C	E	G	H
Manure t/h	18	30	50	18	30	50	30
DM %	21.5	21.5	21.5	4.5	4.5	4.5	20
Applied nutrients							
Tot N kg/ha	108.9	181.5	302.5	46.8	78	130	120
Org N kg/ha	108	180	300	21.6	36	60	84
NH4 N kg/ha	0.4	0.7	1.1	25.2	42	70	36
Tot C kg/ha	1,611	2,685	4,475	360	600	1,000	2,490
C/N	15	15	15	7.6	7.6	7.6	21
Tot P kg/ha	14.0	23.4	39	6.1	10.2	17	18.9
Tot K kg/ha	150.3	250.5	417.5	57.6	96	160	93
Tot Mg kg/ha	17.0	28.4	47.3	6.3	10.5	17.5	20.1
Tot Ca kg/ha	81	135	225	19.8	33	55	66
Tot Na kg/ha	7.92	13.2	22	4.68	7.8	13	5.7
Tot S kg/ha	14.1	23.5	39.2	4.1	6.9	11.5	10.2

Results

Field experiment 1

Yields in Nibble field experiment 1 2013, 2014 and 2015 with treatments for the three years are presented in tables 5 - 10 and figures 7 and 8.

The winter wheat which was sown in autumn 2012 was did not overwinter well and was reseeded with spring wheat 'Dacke' and the "cultural wheat" 'Jacoby Borst' in the central half of the plots according the experimental design (Figure 4). This was not the best start for the experiment and variation in final yield between the plots was high. However, some valuable results have been obtained and will be presented here.

Manured plots of 'Dacke' spring wheat gave a significantly higher yield compared to zero plots in treatment C (LM18) and G (LM50) ($P<0.05$) with a tendency for higher yield ($P<0.1$) for treatment B (CM 18) and H (FM 30) (Table 5).

Table 5 Yields of spring wheat 'Dacke' 2013 Nibble on-farm field manure experiment comparing composted manure (CM), liquid manure (LM) and fresh manure (FM), without (-BDP) and with biodynamic preparation (+BDP).

Yield kg DM/ha Treatment Manure quality	Manure quantity t/ha	-BDP	+BDP	MEAN
No manure	0	2,784	2,750	2,767
CM	18	3,297	3,099	3,198
	Rel. manure/no manure			*1.16*
LM	18	3,358	3,195	3,277
	Rel. manure/no manure			*1.18*
CM	30	2,587	2,596	2,592
	Rel. manure/no manure			*0.94*
LM		2,871	3,105	2,988
	Rel. manure/no manure			*1.08*
CM	50	2,775	3,130	2,952
	Rel. manure/no manure			*1.07*
LM	50	3,228	3,427	3,327
	Rel. manure/no manure			*1.20*
FM	30	2,966	3,440	3,203
	Rel. manure/no manure			*1.16*
MEAN CM		2,886	2,942	2,914
	Rel. manure/no manure			*1.05*
MEAN LM		3,152	3,242	3,197
	Rel. manure/no manure			*1.16*
Rel. CM	+BDP/-BDP		1.02	n.s.
Rel. LM	+BDP/-BDP		1.03	n.s.
Rel.	LM/CM		1.10	n.s.

Yield in subplots with 'Jacoby Borst' was on average 15% lower than 'Dacke'. Yield averaged 15% higher than the zero plot, with no significant difference between manured treatments compared to not manured. Yield averaged 5% higher in the +BDP composted manure treatments compared to –BD (P<0,5) and with decreasing difference in the higher supply of nitrogen supplied as composted manure (Table 6). This was not the case for liquid manure which showed too much variation to see any tendency (Figure 8 and Figure 9).

Table 6 Yields of spring wheat 2013 'Jacoby Borst' Nibble farm field manure experiment comparing composted manure (CM), liquid manure (LM) and fresh Manure (FM) without (-BDP) and with biodynamic preparation (+BDP).

Yield kg DM/ha		Treatment		
Manure quality	Manure quantity t/ha	-BDP	+BDP	MEAN
No manure	0	1,977	2,376	2,177
CM	18	2,447	2,703	2,575
Relative manure/no manure	*1.18*			
LM	18	2,314	2,284	2,299
Relative manure/no manure	1.06			
CM	30	2,391	2,534	2,462
Relative manure/no manure	*1.13*			
LM	30	2,619	2,771	2,695
Relative manure/no manure	*1.24*			
CM	50	2,478	2,447	2,462
Relative manure/no manure	*1.13*			
LM	50	2,593	2,469	2,531
Relative manure/no manure	*1.16*			
FM	30	2,528	2,613	2,571
Relative manure/no manure	*1.18*			
MEAN CM		2,438	2,561	2,500
Relative manure/no manure	*1.15*			
MEAN LM		2,509	2,508	2,508
Relative manure/no manure	1.15			
Relative CM +BDP/-BDP	1.05	(s)		
Relative LM +BDP/-BDP	1	n.s.		
Relative LM/CM	1	n.s.		

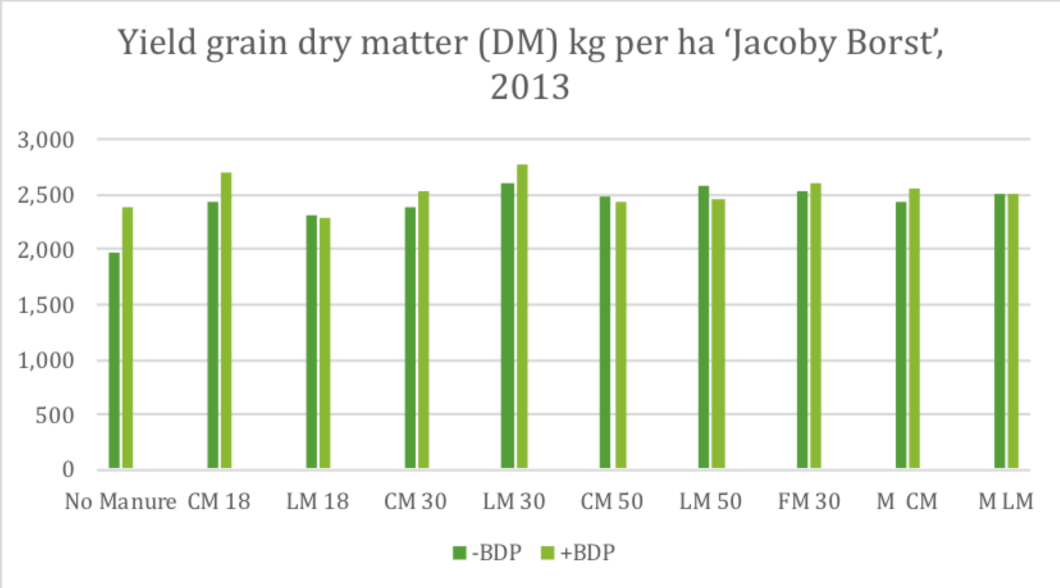


Figure 8 Yield grain dry matter (DM) kg per ha 'Jacoby Borst', Nibble field experiment one, 2013.

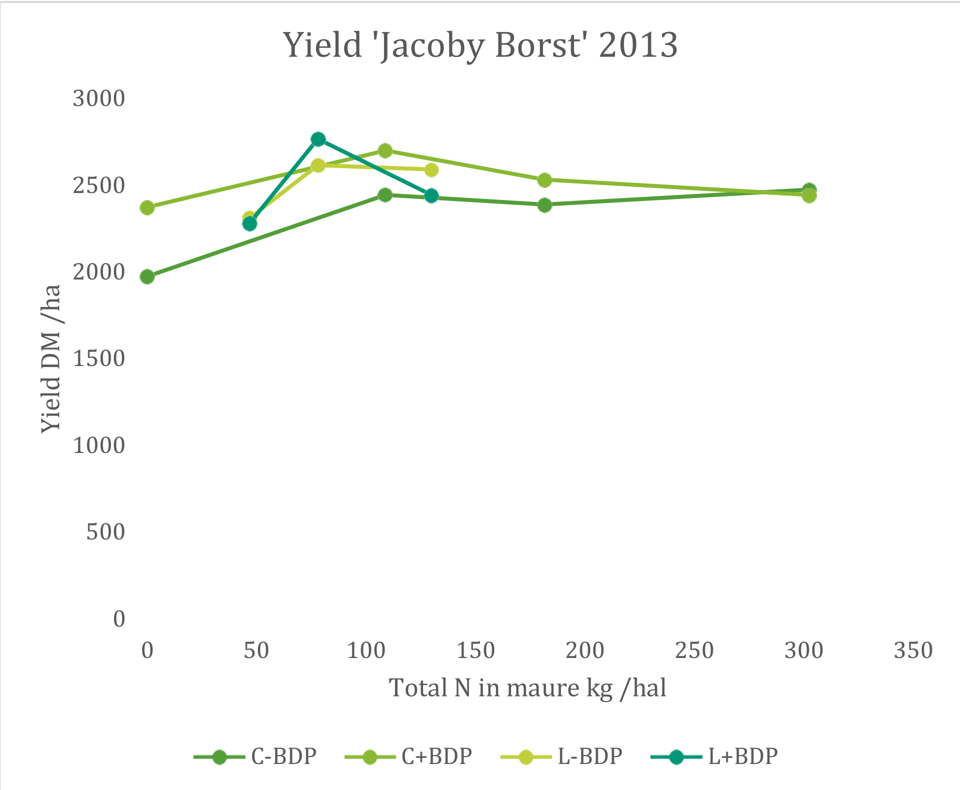


Figure 9 Yield DM kg per kg per ha 'Jacoby Borst' Nibble field experiment 1, 2013 related to applied total N kg/ha in form of composted (C) and liquid manure without (-BDP) and with (+BDP) biodynamic treatments.

Table 7 Yields of oats, 2014 Nibble on farm field manure experiment 1 comparing composted manure (CM), liquid manure (LM) and fresh manure (FM) applied August after ley 2012, without (-BDP) and with biodynamic preparation (+BDP).

Yield kg DM/ha		Treatment		
		-BDP	+BDP	MEAN
Manure quality	Manure quantity t/ha			
No manure	0	2,515	2,474	2,495
CM	18	2,739	2,652	2,696
	Relative manure/no manure 2013			*1.08*
LM	18	2,872	3,286	3,079
	Relative manure/no manure 2013			*1.23*
CM	30	2,792	2,726	2,759
	Relative manure/no manure 2013			*1.11*
LM	30	3,062	3,328	3,195
	Relative manure/no manure 2013			*1.28*
CM	50	2,918	2,837	2,878
	Relative manure/no manure 2013			*1.15*
LM	50	2,825	2,610	2,717
	Relative manure/no manure 2013			*1.09*
FM	30	2,753	2,472	2,613
	Relative manure/no manure 2013			*1.05*
MEAN CM		2816	2738	2,777
	Relative manure/no manure 2013			*1.11*
MEAN LM		2,920	3,075	2,997
	Relative manure/no manure 20132013			*1.20*
Relative CM		+BDP/-BDP	0.97	n.s.
Relative LM		+BDP/-BDP	1.05	n.s.
Relative		LM/CM	1.08	n.s.

The following year oats gave an average grain yield of 2,777 kg DM for treatments with composted manure and 2,997 kg with liquid manure which was 11 and 20% higher yield than zero plots. This is a clear second year effect. There was no significant effect between the treatments from the previous year (Table 7).

The undersown clover-grass gave an average yield of 4,133 and 3,680 kg DM per ha, cut 1 and cut 2 respectively, and a total yield of 7,298 kg DM per ha 2015. There were no significant differences but a possibility to have an impression of higher yield were manure was used three years previously (Figure 8, Figure 9, Table 10).

Table 8 Yields of legume-grass ley first cut 2015. Nibble on-farm field manure experiment comparing composted manure (CM), liquid manure (LM) and fresh manure (FM), without (-BDP) and with biodynamic preparation. (+BDP).

Yield kg DM/ha Treatment Manure quality	Manure quantity t/ha	-BDP	+BDP	MEAN
No manure	0	3,253	2,707	2,980
CM	18	3,753	4,027	3,890
	Relative manure/no manure			*1.31*
LM	18	4,307	3,438	3,873
	Relative manure/no manure			*1.30*
CM	30	3,325	4,047	4,018
	Relative manure/no manure			*1.24*
LM	30	4,180	3,465	3,823
	Relative manure/no manure			*1.28*
CM	50	3,316	4,233	3,775
	Relative manure/no manure 2012			*1.27*
LM	50	4,293	3,973	4,133
	Relative manure/no manure			*1.39*
FM	30	3,133	2,893	3,013
	Relative manure/no manure			*1.01*
Mean		3,808	3,718	4,018
	Relative manure/no manure			*1.35*
MEAN CM		3,465	4,102	3,943
	Relative manure/no manure			*1.32*
MEAN LM		4,260	3,626	4,102
	Relative manure/no manure			*1.38*
Relative CM	+BDP/-BDP		1.18	n.s.
Relative LM	+BDP/-BDP		0.85	n.s.
Relative	LM/CM		1.04	n.s.

Table 9 Yields of clover-grass ley second cut 2015. Nibble on-farm field manure experiment comparing composted manure (CM), liquid manure (LM) and fresh manure (FM), without (-BDP) and with biodynamic preparation. (+BDP).

Yield kg DM/ha Treatment				
		-BDP	+BDP	MEAN
Manure quality	Manure quantity t/ha			
No manure		2,960	2,973	2,967
CM	18	3,240	3,087	3,163
	Relative manure/no manure			*1.07*
LM	18	3,913	3,780	3,847
	Relative manure/no manure			*1.30*
CM	30	3,247	3,447	3,347
	Relative manure/no manure			*1.13*
LM	30	3,387	4,080	3,733
	Relative manure/no manure 2012			*1.26*
CM	50	3,187	3,340	3,263
	Relative manure/no manure			*1.10*
LM	50	3,913	4,020	3,967
	Relative manure/no manure			*1.34*
FM	30	2,973	3,347	3,160
	Relative manure/no manure			*1.07*
Mean		3,353	3,509	3,431
	Relative manure/no manure			*1.16*
MEAN CM		3,224	3,291	3,258
	Relative manure/no manure			*1.10*
MEAN LM		3,738	3,960	3,849
	Relative manure/no manure			*1.30*
Relative CM		+BDP/-BDP	1.02	ns
Relative LM		+BDP/-BDP	1.06	n.s.
Relative		LM/CM	1.18	n.s.

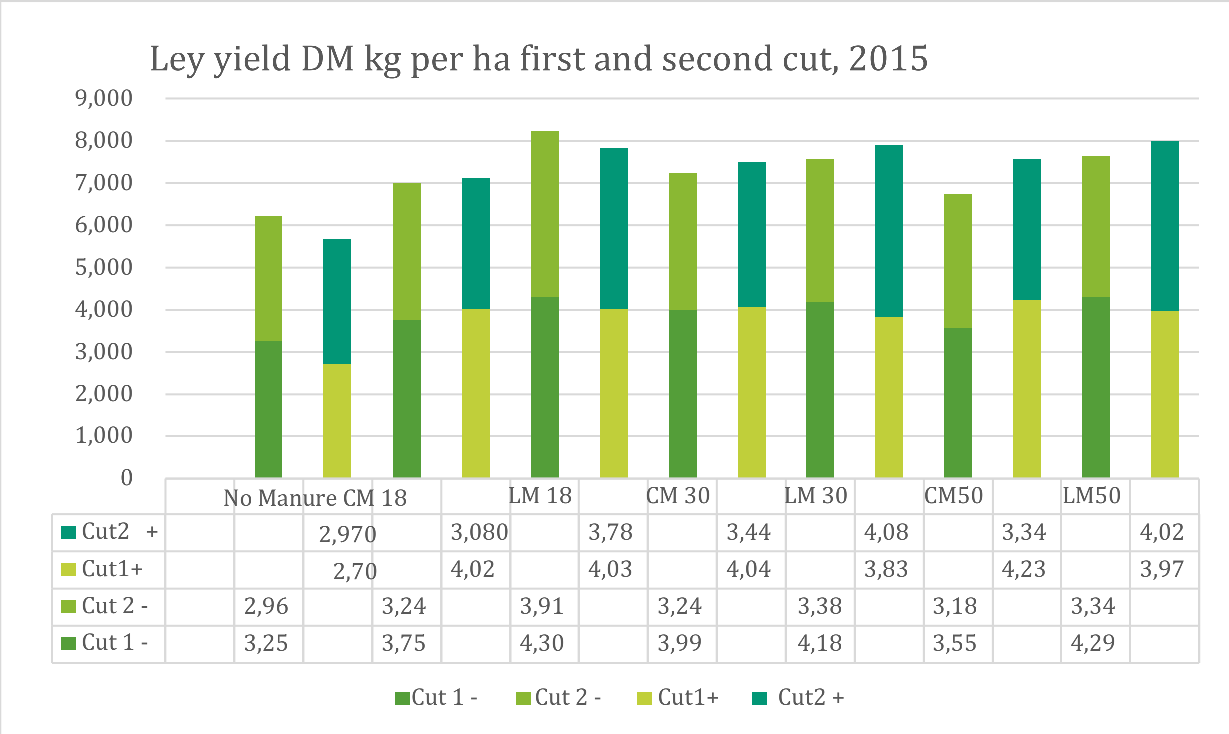


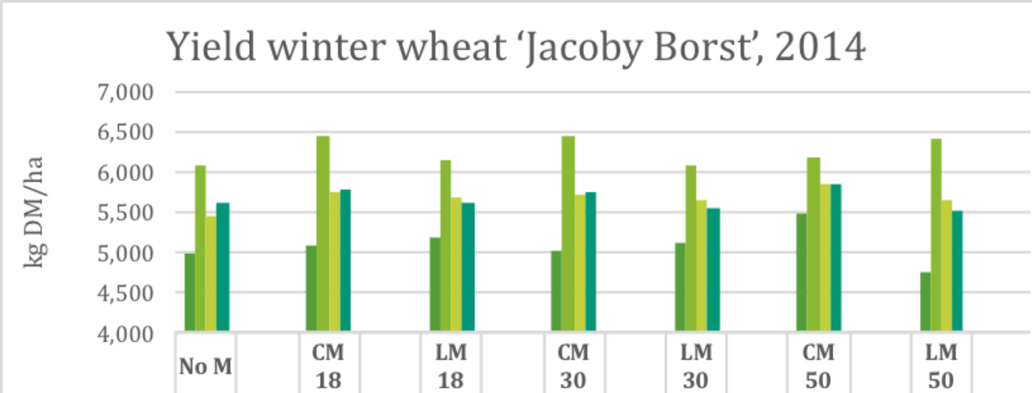
Figure 10 Yield DM kg per ha first and second cut (5 May and 17 June) of legume-grass ley Nibble field experiment 1, 2015 related to applied level by composted (CM) and liquid manure (LM) without (-BDP) and with (+BDP) biodynamic treatments in 2012.

Field experiment 2

Field experiment 2 with winter wheat 'Jacoby Borst' gave a weak response to the different quantities and qualities of manure with an average of only 3 percent higher yield (average 5,702 kg compared to 5,531 kg DM) but a higher response of 23 percent higher yield for treatment with biochar on all subplots, ranging from 13 to 35 percent (Table 10, Figure 11)

Table 10 Nibble on-farm field manure experiment 2. Yields of winter wheat 'Jacoby Borst' 2014 sown after ley August 2013 comparing treatments with composted (CM) and liquid manure (LM) in three manure levels in tonnes per ha (t/ha) without (-BC) and with biochar (+BC) and without (-BDP) and with biodynamic treatments (+BDP) applied August after ley 2013. Relative values *italicised* in the table.

Yield kg DM/ha Manure quality	t/ha	Treatment -BC	+BC	-BDP	+BDP	MEAN
No manure	0	4,977	6,085	5,447	5,615	5,531
	Relative +BC/-BC					*1.22*
CM	18	*5,091*	*6,465*	5,765	5,791	5,778
	Relative +BC/-BC		*1.27*		*Rel. to no manure*	*1.04*
LM	18	5,181	6,140	5,693	5,628	5,661
	Relative +BC/-BC		*1.19*		*Rel. to zero*	*1.02*
CM	30	5,019	6,445	5,706	5,758	5,732
	Relative +BC/-BC		1.28		*Rel. to zero*	*1.04*
LM	30	5,134	6,076	5,650	5,560	5,605
	Relative +BC/-BC		1.18		*Rel. to zero*	*1.01*
CM	50	5,497	6,187	5,844	5,839	5,842
	Relative +BC/-BC		1.13		*Rel. to zero*	*1.06*
LM	50	4,772	6,420	5,671	5,522	5,596
	Relative +BC/-BC		1.35		*Rel.to zero*	*1.01*
MEAN		5,096	6,289	5,722	5,683	5,702
	Relative +BC/-BC		*1.23*		*Rel.to zero*	*1.03*



	No M	CM 18	LM 18	CM 30	LM 30	CM 50	LM 50
-BC	4,97	5,09	5,18	5,01	5,13	5,49	4,77
+BC	6,08	6,46	6,14	6,44	6,07	6,18	6,42
-BDP	5,44	5,76	5,69	5,70	5,65	5,84	5,67
+BDP	5,61	5,79	5,62	5,75	5,56	5,83	5,52

Figure 11 Nibble field experiment two. Yields of winter wheat 'Jacoby Borst' 2014 sown after ley August 2013 comparing treatments with composted (CM) and liquid manure (LM) in three manure levels in tonnes per ha (t/ha) without (-BC) and with biochar (+BC) and without (-BDP) and with biodynamic treatments (+BDP) applied in August 2013 after ley.

Yields in relation to applied total nitrogen are shown in Figure 12 and 11 and for the manure quantity and for the BDP treatments in Figure 14 and Figure 15. There was a tendency towards an effect of biodynamic treatments (+ BDP) in treatments with composted manure and the zero-plot compared to not using biodynamic treatments (-BDP). Effects seemed to be the opposite for treatments with liquid manure, with no effect of biodynamic treatment. This observed result was independent of biochar application.

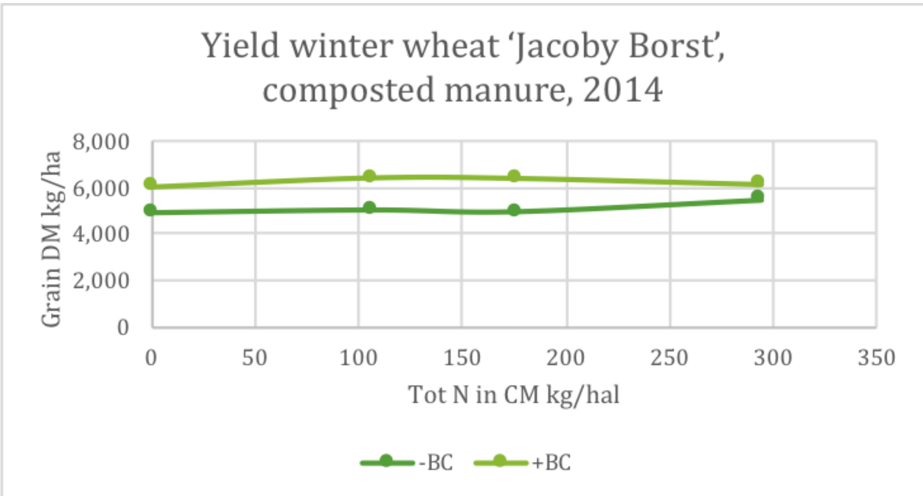


Figure 12 Nibble field experiment two. Yields of winter wheat 'Jacoby Borst' 2014 in relation to applied total nitrogen as composted manure (CM) without (-BC) and with biochar (+BC)) applied in August 2013 after ley.

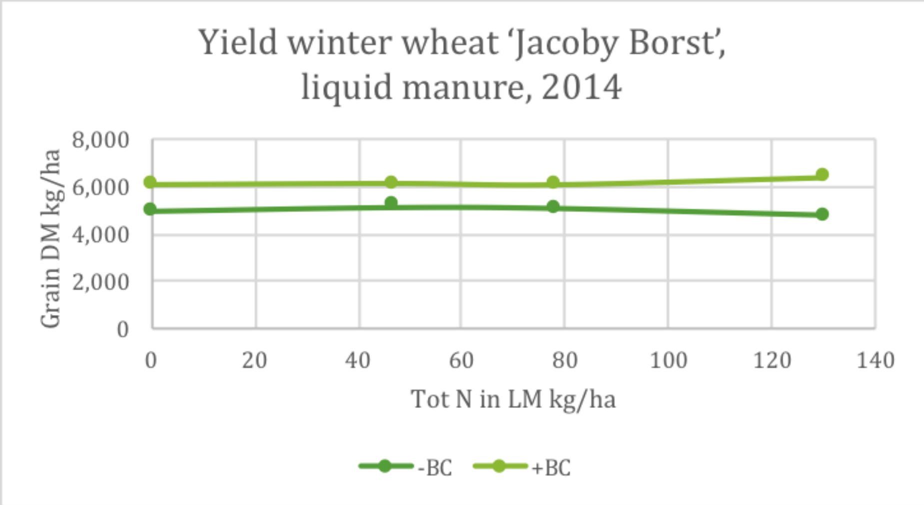


Figure 13 Nibble field experiment two. Yields of winter wheat 'Jacoby Borst' 2014 in relation to applied total nitrogen as liquid manure without (-BC) and with biochar (+BC)) applied in August 2013 after ley.

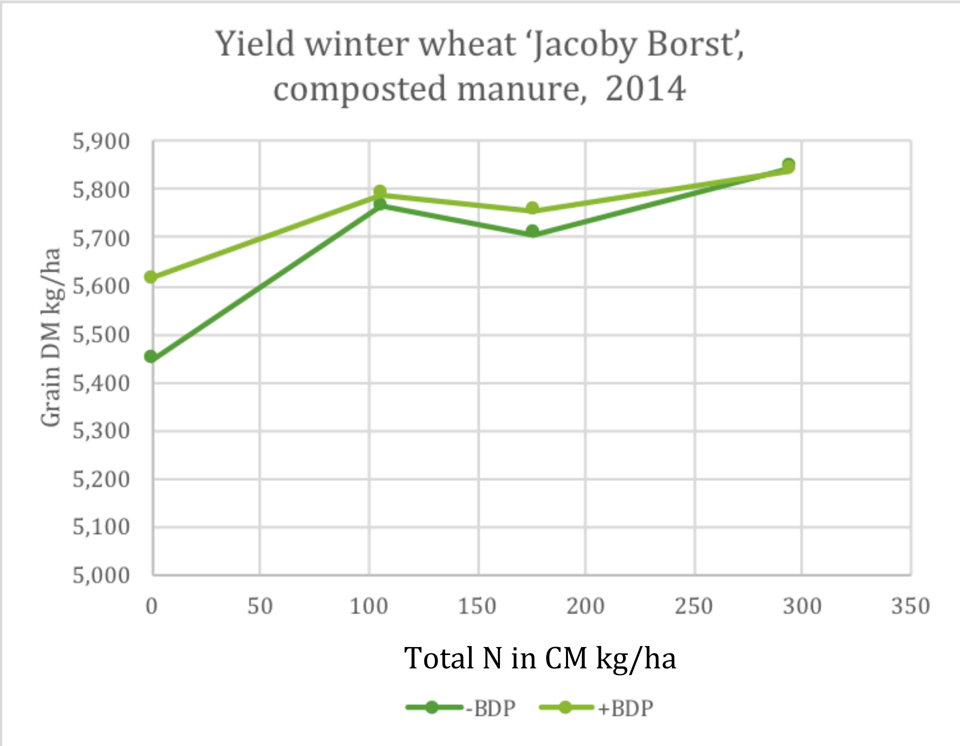


Figure 14 Nibble on-farm field manure experiment two. Yields of winter wheat 'Jacoby Borst' 2014 in relation to applied total nitrogen in form of composted manure (CM) without (-BDP) and with biodynamic treatments (+BDP) applied August 2013 after ley.

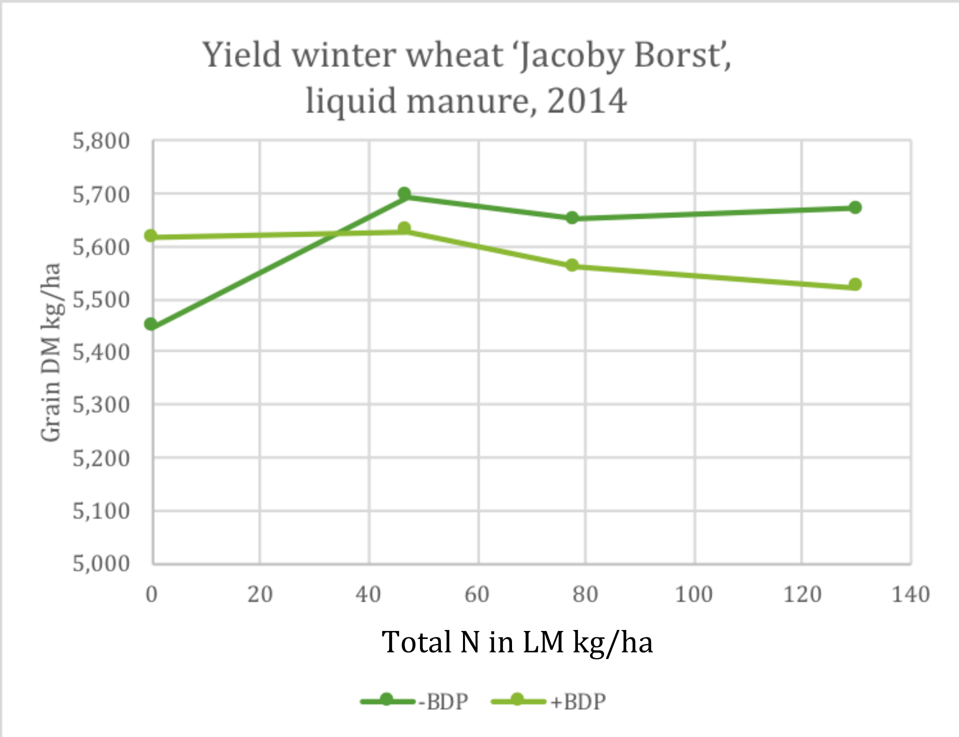


Figure 15 Nibble on-farm field manure experiment two. Yields of winter wheat 'Jacoby Borst' 2014 in relation to applied total nitrogen as liquid manure without (-BDP) and with biodynamic treatments (+BDP) applied August 2013 after ley.

Nibble field experiment 2, 2015 with oats, peas undersown with legume-grass ley

Nibble field experiment 2 with oats, peas and undersown legume-grass ley harvested as green fodder is presented in Table 11. Plots were harvested during poor, wet conditions. Samples (0.5 m^2) were cut by hand and dried. No significant effect could be observed from manure treatments two years before or from biodynamic treatments this year. A tendency, although not statistically significant, could be observed towards higher yields with biochar application on all manure treatments from 2013 with on average 7,908 kg DM yield compared to 7,450 kg DM yield without biochar application. In the zero plots some samples were not complete, so it is not possible to compare biodynamic treatments.

Table 11 Yields of oat green fodder 2015 after manure and biochar treatments 2013 Nibble farm field experiment 2.

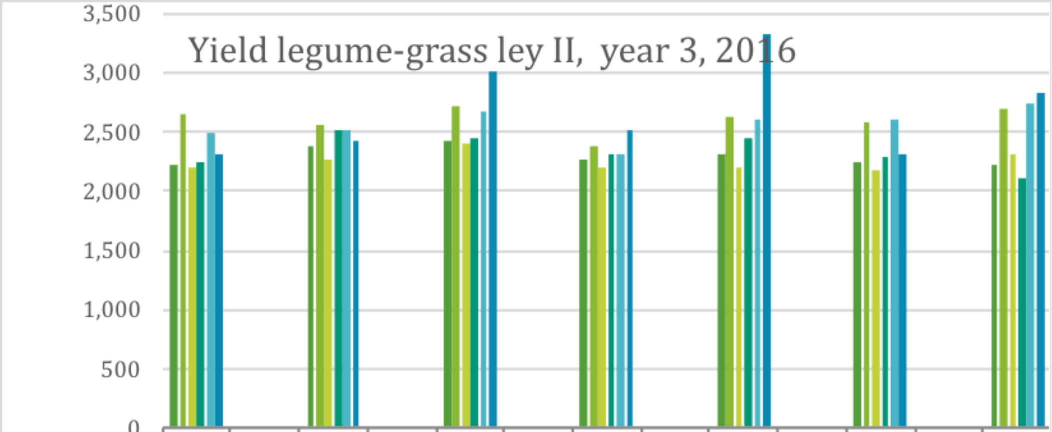
Yield kg DM/ha		Treatment					
Manure quality	Manure t/ha	-BC	+BC	-BC -BDP	-BC +BDP	+BC -BDP	+BC +BDP
CM	18	7,935	7,723	7,245	7,173	6,970	7,070
LM	18	7,758	7,803	7,510	7,620	7,950	7,905
CM	30	7,768	7,830	7,073	7,467	8,430	7,345
LM	30	6,913	7,670	6,780	7,633	6,610	6,690
CM	50	7,038	7,913	8,200	8,180	8,340	7,632
LM	50	7,005	8,280	7,467	7,247	7,467	7,247
Mean		7,450	7,908	7,379	7,553	7,628	7,315
Relative values			*+BC/-BC*		*-BDP+BDP/ -BDP-BDP*		*+BC+BDP/ +BC-BDP*
			1.06		*1.02*		*0.96*

Nibble field experiment 2, 2016 with legume-grass ley

Nibble field experiment 2, 2016 with first cut of clover-grass is presented in Table 15 and figure 15 with an average yield 2,471 kg DM per ha in the 2013 manured treatment which was 5 percent higher than the not manured treatments with an average yield of 2,354 kg DM per ha. Plots with biochar applied in 2013 gave a significantly higher yield (+14 percent) and combined with biodynamic treatments a significantly higher yield (+21 percent) according to the relative values presented in Table 12 and Figure 16.

Table 12 Yields first cut 2016 after manure and biochar treatments 2013, Nibble farm field experiment without (-BC) and with biochar (+BC) and without (-BDP) and with (+BDP) with biodynamic treatments.

Yield kg DM/ha		Treatment						
Manure quality	Manure t/ha	-BC	+BC	-BC -BDP	-BC +BDP	+BC -BDP	+BC +BDP	MEAN
No manure	0	2,222	2,640	2,203	2,241	2,500	2,317	2,354
CM	18	2,386	2,563	2,266	2,506	2,514	2,417	2,442
Relative manure/no manure								*1.04*
With manure (M) to winter wheat 2013 LM	18	2,419	2,726	2,396	2,443	2,680	3,022	2,614
Relative manure/no manure								*1.11*
CM	30	2,256	2,371	2,207	2,306	2,309	2,518	2,328
Relative manure/no manure								*0.99*
LM	30	2,323	2,626	2,189	2,458	2,615	3,324	2,589
Relative manure/no manure								*1.1*
CM	50	2,236	2,591	2,178	2,294	2,596	2,317	2,368
Relative manure/no manure								*1.01*
LM	50	2,217	2,703	2,315	2,120	2,739	2,820	2,486
Relative manure/no manure								*1.06*
Mean		2,306	2,597	2,258	2,**354**	2,575	2,736	2,471
Relative manure/no manure								*1.05*
		1.13	*S*		*1.04*	*S*	*1.06*	*S*
Relative values for manured plots					+BC-BDP/ -BC-BDP 1.14		+BC+BDP/ -BC-BDP 1.21	



	No M	CM 18	LM 18	CM 30	LM 30	CM 50	LM 50
-BC	2,222	2,386	2,419	2,256	2,323	2,236	2,217
+BC	2,640	2,563	2,726	2,371	2,626	2,591	2,703
-BDP	2,203	2,266	2,396	2,207	2,189	2,178	2,315
+BDP	2,241	2,506	2,443	2,306	2,458	2,294	2,120
BC-BDP	2,500	2,514	2,680	2,309	2,615	2,596	2,739
BC+BDP	2,317	2,417	3,022	2,518	3,324	2,317	2,820

Figure 16 Yield legume-grass ley Nibble field experiment 2 year 3, 2016 kg DM yield

Field experiment 3

Nibble field experiment 3 year the first year 2014 is presented in Table 13 and Figure 17. Liquid manure treatments gave an average 3 percent higher yield than plots without manure. Plots with composted manure with an average 6 percent higher yield than zero plots. Biochar treatment (+BC) which was harvested separately from plots without biochar (-BC). Biochar treatments (32 of the 64 sub plots) gave an average over 11-12% percent higher yield ($P < 0,05$, $n=24$) in the manured treatments and overall, including the zero plot without manure, an average 11 percent higher yield. There was no observed, significant effect of the biodynamic treatments.

Table 13 Average yields with four replicates, winter wheat on-farm field experiment 3. 2014 after treatments 2013 before sowing with composted manure (CM) and liquid manure (LM) in three levels without (-BC) and with biochar (+BC) and without (-BDP) and with (+BDP) biodynamic treatments.

Yield kg DM/ha			Treatment			
Manure quality	Manure t/ha	-BC	+BC	-BDP	+BDP	MEAN
No manure	0	3,292	4,190	3,845	3,817	3,831
CM	*18*	3,796	4,269	3,893	3,941	3,917
Relative manure /no manure						*1.02*
LM	18	3,790	4,079	3,724	3,728	3,726
Relative manure /no manure						*0.97*
CM	30	3,802	3,906	3,807	3,778	3,793
Relative manure /no manure						*0.99*
LM	30	3,425	4,468	3,808	3,668	3,738
Relative manure /no manure						*0.98*
CM	50	3,738	4,486	4,010	3,894	3,952
Relative manure /no manure						*1.03*
LM	50	3,808	3,787	3,641	3,771	3,706
Relative manure /no manure						*0.97*
MEAN CM		3,779	4,221	3,903	3,871	3,887
Relative manure /no manure						*1.03*
MEAN LM		3,674	4,111	3,725	3,722	3,723
Relative manure /no manure						*0.99*
Relative CM	+BC/-BC		1.12		0.99	
Relative LM	+BC/-BC		1.12		1.00	

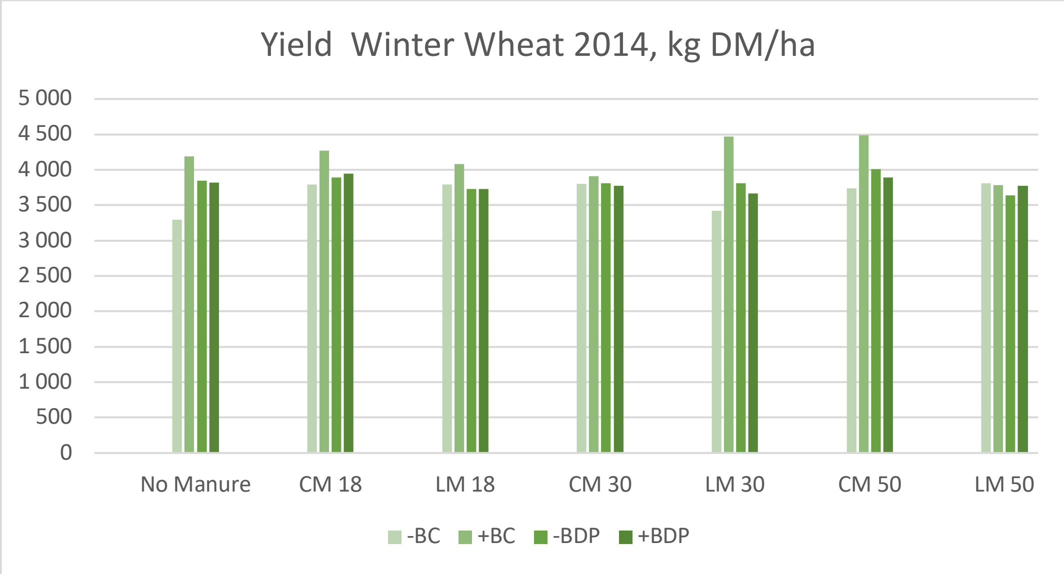


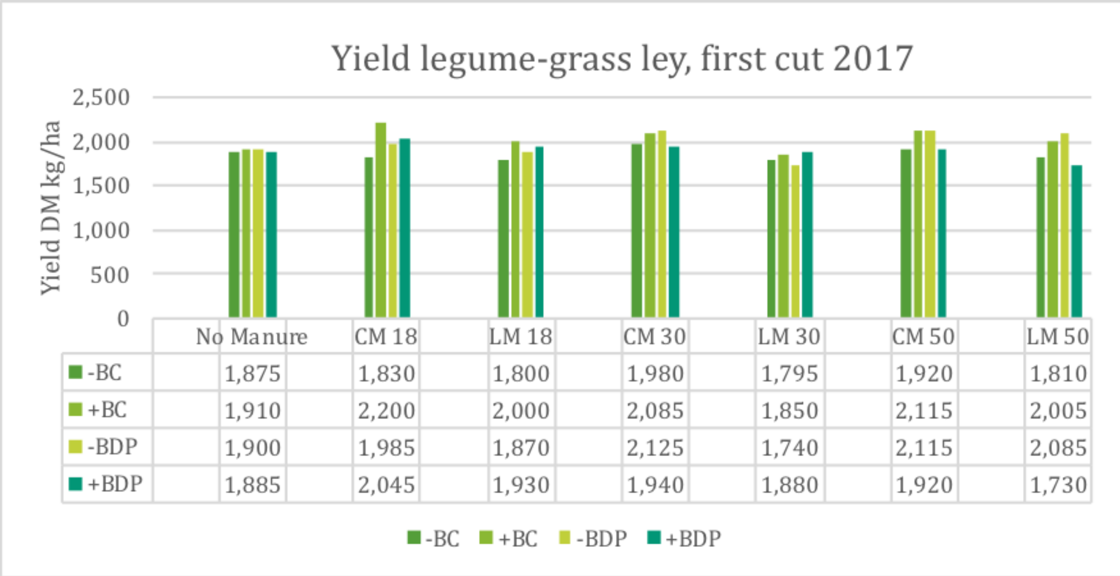
Figure 17 Winter wheat 2014 on-farm field experiment 3. Average yields ley on-farm field experiment 3-year 2017 after treatments 2013 before sowing winter wheat with composted manure (CM) and liquid manure (LM) in three levels, without (-BC) and with biochar (+BC), and without (-BDP) and with (+BDP) biodynamic treatments. Half of the plots were harvested separating without biochar (-BC) and with biochar (+BC) treatments.

Nibble experiment 3, the second year 2015 with oats, peas and undersown legume-grass was not harvested in the field plots due to poor weather conditions. In 2016, not enough resources were available to harvest the field experiment plots but in 2017 blocks 2 and 3 were harvested by hand-cutting and dried in nettle bags.

Results from Nibble Field experiment 3, the fourth year 2017 are presented in Table 14 and Figure 18.

Table 14 Experiment 3 2017. Average yields (kg DM/ ha) with two replicates (block 3 and 4) first cut second year legume-grass ley on farm field experiment 3. 2017 after treatments 2013 before sowing winter wheat with composted manure (CM) and liquid manure (LM) in three levels without (-BC) and with biochar (+BC) and without (-BDP) and with (+BDP) biodynamic treatments.

Yield kg DM/ha	Treatment				
Manure t/ha	-BC	+BC	-BDP	+BDP	MEAN
No manure	1,875	1,910	1,900	1,885	1,898
With manure to winter wheat sowing 2013 CM 18	1,830	2,200	1,985	2,045	2,077
Relative manure /no manure					*1.09*
LM 18	1,800	2,000	1,870	1,930	1,933
Relative manure /no manure					*1.02*
CM 30	1,980	2,085	2,125	1,940	2,050
Relative manure /no manure					*1.08*
LM 30	1,795	1,850	1,740	1,880	1,823
Relative manure /no manure					*0.96*
CM 50	1,920	2,115	2,115	1,920	2,050
Relative manure /no manure					*1.08*
LM 50	1,810	2,005	2,085	1,730	1,940
Relative manure /no manure					*1.02*
MEAN M	1,859	2,024	1,987	1,908	1,973
With manure *Relative manure /no manure*					*1.04*
Relative +/-		1.09		0.96	



	No Manure	CM 18	LM 18	CM 30	LM 30	CM 50	LM 50
-BC	1,875	1,830	1,800	1,980	1,795	1,920	1,810
+BC	1,910	2,200	2,000	2,085	1,850	2,115	2,005
-BDP	1,900	1,985	1,870	2,125	1,740	2,115	2,085
+BDP	1,885	2,045	1,930	1,940	1,880	1,920	1,730

Figure 18 Nibble experiment 3, legume-grass ley first cut 2017

Discussion

The current study on Nibble farm compared to previous studies

Nibble farm converted to biodynamic farming 1964 and 20 years it was later included as one of three biodynamic farms in case studies of nitrogen supply in alternative agriculture compared with conventional agriculture, with and without livestock (Granstedt 1990). The new study on Nibble farm that began in 2012 has a similar design to the earlier long-term study on Skilleby experimental farm (Granstedt & Kjellenberg 2017). These studies all use a multiple, split-plot block design to compare different qualities and quantities of manure, sourced partly on-farm, with and without use of biodynamic preparation (BDP) treatments; in field experiments with established crop rotations. The proceeding crops effect and long-term crop rotation effect of clover-grass on the neighbouring farm Skilleby farm was studied during 1991 to 1995 and published of Granstedt and L-Baeckström (2000).

The difference to the earlier long-term study is that composted manure sourced on-farm is compared to liquid manure from adjacent ecological farm Säby. The three field studies established 2012-2013 on Nibble farm differ from each other in that in field experiment number one, the entire field experiment includes two cultivars through all experimental plots. In experiment two and three, the plots are split with and without use of biochar incorporated in the topsoil, in addition to other treatments.

In this field experiment, it was possible to determine soil capacity to support crop nutrient needs by modifying quantities and qualities of added manure. Earlier studies on Nibble farm concluded that both long-terms effect of applied manure and crop rotation regimes affect soil capacity to support crop nutrient needs (Granstedt & L-Baeckström 2000). This long-term effect of accumulated soil organic matter and improved mineralization capacity was designated "crop rotation effect" and the short-term effect of the pre-crop (here a one, two or three-year legume-grass ley) was designated the "preceding crop effect".

In addition to crop rotation and the preceding crop effect, it is possible to define and quantify what we can call the "manure effect". The manure effect can be described as the additional yield due to application of manure the one, two or three years prior to establishing a crop. Results below will be evaluated taking into consideration the long-term effects including earlier crop rotations, preceding crop effect and manure effects.

Field experiment 1

Despite the poorly overwintered winter wheat that had to be re-established with spring sown wheat, it was possible to register a tendency towards the "manure effect" of compost and liquid manure compared to the zero plots (2,767 kg DM per ha). This tendency ($P<0,1$) showed on average 10 percent higher yield in the manured plots compared to the zero plots, but with higher effect (averaging 15% higher yield) for liquid manure compared to composted manure (averaging 5%

higher yield) according to Table 5. This can be interpreted as an effect of higher content of soluble nitrogen in liquid manure even though there was no distinct effect of different manure quantities. The amount of mineral nitrogen (NH_4 – N) which was applied in the previous autumn is shown in Table 4, corresponding to manure levels 25, 42 and 70 kg N per ha. Nitrogen effect on yield is in accordance with state of the art research on soil-plant interrelations that shows a direct effect of added nitrogen and nitrogen available in the soil on yields (Rending & Taylor 1989). With a nitrogen content in the grain of 1.7% (Granstedt, 1990) additional nitrogen uptake by the crop is estimated to be between 10 – 20 kg N/ha.

The DM yield for cultivar 'Jacoby Borst' in the same experiment gave a lower yield by 18% on average compared to cultivar 'Dacke' (Table 6) and the manure effect gave a higher yield by 15% on average compared to zero plots. For 'Jacoby Borst', yield was on average 5% higher with the BDP treatments compared to no BDP treatments (P<0,05) in composted manure and zero plots for both composted and liquid manure the autumn before. The dose–response effect is illustrated in Figure 9 with a higher yield effect of BDP on zero and lower nitrogen supply. Nutrients bound to soil (zero treatment) and in composted manure need to be mobilized for this result. There seemed to be no effect of BDP treatment on the highest level of composted manure or for liquid manure Figure 9.

The second year with oats there seemed to be a manure effect for composted and liquid manure, with higher yields for all manure treatments, with an average DM yield of 2,777 kg per ha (CM) and 2,997 kg per ha (LM) compared to 2,495 kg per ha in the zero treatment. Third year ley in 2015, after manure treatments in 2012 with composted and liquid manure, with a higher average total DM yield with 7,229 kg DM per ha (first and second cut summed) compared to the zero plot 5,947 kg DM per ha which seemed to be a "pre-preceding" crop effect. This interpretation seemed to be contradicted by the reference treatment with 30 tons fresh manure (FM) this year and the large variation of results Figure 8 and Figure 9. There was also no significant effect of the biodynamic treatments observed this year.

Field experiment 2

This experiment is unique in that we are able to study the effect of biochar with different manure regimes on two soil types with an average humus content of 7.2% (ranging from 7.0 -8.0%) compared to 3.4% (ranging from 3.1-3.6%) and C/N relation of 10.0 within the four blocks. Biochar treatment not was randomised, but there was a distinct, significantly higher yield with biochar treatment on both the zero plot and the different manure regimes. Biochar treatment showed on average 23% higher yield, with an average grain yield of 6,289 compared to 5,096 kg DM per ha.

High humus content and related high mineralization capacity of this soil can explain the weak manure effect both in the plots with and without biochar treatments illustrated in Figure 12 and Figure 13. Composted manure treatments showed on average 5% higher grain yield compared to the zero plot with an average grain yield of 5,531 kg DM. Composted manure seemed to have additional supportive effects. Combined composted manure and BDP treatments showed a stronger effect on yield. However, liquid manure and BDP treatments lead to lower yields Figure 14 and Figure 15.

The following year, 2014, despite poor harvest conditions it was possible to identify a tendency to 6% higher yield in oats with biochar treatments. The third year, 2015, it was possible to follow up the experiment by harvesting all plots immediately before the first ley cut. This showed a long-term effect working even the third year after biochar with a tendency of a third-year manure effect. In this first cut, a significant effect of the biodynamic treatments was also identified in plots, both with and without biochar treatment. Plots with biochar applied in 2013 gave a significantly higher yield (average +14 percent) and combined with biodynamic treatments a significantly additional higher yield according to the relative values presented in Table 12 and Figure 14.

Field experiment 3

Soils in field experiment 3 have a for the region more typical humus content of 3.4% (ranging from 3.1 to 3.7%). There was a is a significant effect of biochar treatment with on average 12% higher grain yield in the plots with biochar compared to the plots without biochar the first year after application (Figure 13). Separate harvests with and without biochar were done only in the southern half of the whole experiment (total 64 subplots) (Table 13Figure 17). Average yield with biochar was lower only on plots treated with 50 tonnes liquid manure per ha. In treatments with composted manure it was possible to observe a manure effect. A weak effect of liquid manure can as in experiment 1 can be explained by the high proportion of NH_4N (52%) of total nitrogen content which leads to atmospheric losses. In composted manure with nearly all nitrogen (< 1% NH_4N) is organically bound and supports the crop through slow mineralization during the growing period. Combining composted manure and biochar seems to be the best combination for a good yield.

Harvest of two of the blocks again showed the long-term (4th year) effect of biochar on all seven treatments with on average 9% higher yield of the legume- grass treatments. Composted manure gave a good long-term effect of 8% higher yield.

Conclusion

Results from Nibble are to date only from four years of experiments. Depending on site conditions, content and quality of soil organic matter often need decades before reaching a new dynamic equilibrium after changes to farming practices and manure regime (Raupp et al 2006). According to Köpke (2006) in the Introduction to Long-term Field Experiments in Organic Farming (Raupp et al 2006), equilibrium is explained as achieving a balance between mobilization and immobilization of nitrogen including the other organic bonded substances as phosphorus, sulphur and essential trace elements in the soil-plant interrelationships (Kätterer et al. 2011; Johnston & Poulton 2018; Rending & Taylor 1989).

Nibble farm converted to biodynamic farming practices in 1964 and has used the same crop rotation for the past 20 years. The farm has likely built up a long-term mineralization capacity similar to that documented in the earlier long-term experiment (K-experiment) and on-farm studies on Skilleby experimental farm (Granstedt & Kjellenberg 2017).

At Nibble farm, two new research questions, use of liquid manure and use of biochar in biodynamic agriculture, were introduced by farmers working together with researchers. The goal of the new long-term studies is to identify effects of liquid manure compared to composted manure and to evaluate use of biodynamic treatments and of biochar application. Utilizing three manure levels makes a better comparison possible of the two manure qualities that differ in total and soluble nitrogen content. One treatment with fresh (not composted) manure is used as reference corresponding to the more common use of manure in ecological agriculture. This treatment is not included in the evaluation in this report.

This experiment with three levels of liquid manure (LM) and composted manure (CM) can show effects of modifications to the manure regime through use of liquid manure compared to composted manure, and with biochar treatment. Evaluation of results needs to take earlier long-term studies with similar site conditions into consideration. The earliest long-term field studies comparing biodynamic and organic farming (1958 to 1990) showed how it was possible to increase soil organic matter (SOM) and carbon content in soil during a long time (Pettersson et al. 1992; A. Granstedt & Kjellenberg 2008). This has been confirmed by on-farm studies on Skilleby farm, Järna (Granstedt & Kjellenberg 2017). A 3-year grazed grass with clover (grass-clover) ley in a 5-year rotation with field crops increased organic carbon (%OC) in the top 20 cm of soil from on average from 2.12% to 2.31% in 14 years on clay soil (Granstedt & Kjellenberg 2017). Similar results are reported with the same crop rotation in the well- known, long-term studies in Rothamsted, England on sandy soil and warmer climatic conditions with an increase of organic carbon in the top 20 cm of the soil from 0.98% to 1.23% in 28 years (Johnston et al 2017). In the Swedish experiment it was also possible to compare different qualities of manure through a randomized field experiment with composted (CM) and fresh manure (FM), without and with use of biodynamic preparations (-BDP; +BDP). The increase of soil organic matter ranged in following order: LM- BDP<LM+BDP<CM- BDP<CM+BDP.

Current results showed very low direct manure effect of both composted manure and liquid manure. For liquid manure, this can partly be explained by the loss of

NH_4 N to the atmosphere, particularly when manure is spread in the autumn before sowing, without a crop which can utilize nutrients directly. For composted manure, the experiment confirmed the long-term effect of composted manure (Granstedt, 1990; 1992). In Nibble field experiment 3, the long-term manure effect was observed for up to four years after manure application.

In the experiment 2 and 3, a distinct effect of the use of biochar was shown, with between 8-23% higher yield affecting soils with both high and low organic matter content, with effects seen up to four years after application.

The first four years of Nibble on-farm field experiment indicate that it is possible to observe some differences between use or not of the biodynamic preparations which in some cases support better yields (increasing 2-7%) with the older cultivar 'Jacoby Borst' in experiment 1, and also higher yields in experiment 2 with same cultivar and in the clover-grass ley. Biodynamic preparation in legume-grass ley in experiment 2 gave an additional higher yield, both with and without biochar. Experiment 3 showed a significant effect of biochar, but not of biodynamic treatments.

A normalizing effect of BDP treatment on yield has been observed in other studies (Raupp & König 1996) which also according the tested hypotheses can give a lower yield under good conditions while promoting crop quality, and a higher yield under poorer conditions.

Further studies are called for on the effects of lower levels of soluble nitrogen on clover and grass in established ley with different manure regimes.

The promoting effect on yields found in this study can be explained by N-mineralization of organic fertilizers documented in incubation experiments (Tammeorg et al. 2012) and studies observed effect on yield (Brandstaka et al. 2010; Gurwick et al. 2013). It is also observed that biochar can result in immobilization of soluble mineral nitrogen and slow release nitrate in biochar amended compost and soil (Hagemann et al. 2017). Further studies are required to understand the contradictory results in the literature and the biological and chemical mechanisms in the soil crop systems behind the results of biochar application. The hypothesis is that biochar is resistant to decomposition and works as a soil conditioner for several years (Lehmann & Kleber 2015). Biochar retention times have been estimated to at least hundreds, but more likely thousands of years (Lehmann 2007). From this aspect it is also possible to argue that use of biochar as soil conditioner also is an important long term working "carbon sink".

The main explanation for the weak direct manuring effect of organic manure is found in the long-term inherent mineralization capacity of the soil. The role of manure is to support this long-term effect. Thus, manure only has a marginal effect on yield the year it is applied.

The results point to the importance of fertilizing soil instead of crops, the long-term effects of manure, the effect BDP treatment, the unexpected large effect of biochar application and the support for carbon sequestration using biochar.

References

Abele, U., 1987. Produktqualität und Düngung - mineralisch, organisch und Biologisch-dynamisch. Angewandte Wissenschaft.
Boguslawski, E. von, 1965. Zur Entwicklung des Begriffes Bodenfruchtbarkeit. *Z. Pflanzenernähr. Bodenk.*, 108, pp.97–115.
Brandstaka, T. et al., 2010. *Biochar filter: use of biochar in agriculture as soil conditioner*, Helsinki, Finland.
Dlouhý, J., 1981. *Alternativa odlingsformer - vaextprodukters kvalitet vid konventionell och biodynamisk odling*. SLU. In Swedish.
Gissén, C. & Larsson, I., 2008. *Miljömedvetna och uthålliga odlingsformer 1987-2005*, Alnarp.
Granstedt, A., 1992. Case Studies on the Flow and Supply of Nitrogen in Alternative Farming in Sweden. I. Skilleby-Farm 1981–1987. *Biological Agriculture & Horticulture*, 9(1), pp.15–63. Available at: http://dx.doi.org/10.1080/01448765.1992.9754616.
Granstedt, A., 1990. *Fallstudier av kväveförsörjning i alternativ odling = Case studies on nitrogen supply in alternative farming*. Uppsala: Uppsala : Forsknings- och försöksnämnden för alternativ odling, Sveriges lantbruksuniv. In Swedish.
Granstedt, A. & Kjellenberg, L., 2017. Carbon sequestration in long+term on+farm studies in Organic and Biodynamic Agriculture, Sweden. In G. Rahmann et al., eds. *Innovative research for organic 3.0 - Volume 1: Proceedings of the scientific track at the Organic World Congress 2017, November 9-11 in Delhi, India*. Braunschweig: Thünen Report 54 - Volume 1, pp. 200–204.
Granstedt, A. & Kjellenberg, L., 2008. Organic and biodynamic cultivation - a possible way of increasing humus capital. In *16th IFOAM Organic World Congress*. Modena, Italy.
Granstedt, A. & Kjellenberg, L., 2008. Organic and biodynamic cultivation – a possible way of increasing humus capital, improving soil fertility and be a significant carbon sink in Nordic conditions. In *The Second Scientific ISOFAR Conference in Modena 18-20 June 2008.*
Granstedt, A., Kjellenberg, L. & Petterson, B.D., 2005. *The Connection between Soil, Crop and Manure*, Järna.
Granstedt, A. & L-Baeckström, G., 2000. Studies of the preceding crop effect of ley in ecological agriculture. *American Journal of Alternative Agriculture*, 15(2), pp.68–78.
Gurwick, N.P. et al., 2013. A Systematic Review of Biochar Research, with a Focus on Its Stability in situ and Its Promise as a Climate Mitigation Strategy. *PLoS ONE*, 8(9).
Hagemann, N. et al., 2017. Nitrate capture and slow release in biochar amended compost and soil. *PLoS ONE*, 12(2).
Johnston, A.E. & Poulton, P.R., 2018. The importance of long-term experiments in agriculture: their management to ensure continued crop production and soil fertility; the Rothamsted experience. *European Journal of Soil Science*, 69(1), pp.113–125. Available at: http://doi.wiley.com/10.1111/ejss.12521.
Johnston, A.E., Poulton, P.R. & Coleman, K., 2009. Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. *Advances in agronomy*, 101, pp.1–57.
Kätterer, T. et al., 2011. Roots contribute more to refractory soil organic matter than above-ground crop residues, as revealed by a long-term field experiment. *Agriculture, Ecosystems and Environment*, 141(1–2), pp.184–192.
Kjellenberg, L. & Granstedt, A., 2015. Influences of Biodynamic and Conventional Farming Systems on Quality of Potato (Solanum Tuberosum L.) Crops: Results from Multivariate Analyses of Two Long-Term Field Trials in Sweden. *Foods*,

4(3).
Kjellenberg, L. & Granstedt, A., 1998. *Samband mellan mark, gröda och gödsling. Resultat från K-försöket, en 33-årig studie av gödslingens inverkan på mark och grödors egenskaper*, Järna.
Lehmann, J., 2007. A handful of carbon. *Natue*, 447(May), pp.10–11.
Lehmann, J. & Kleber, M., 2015. The contentious nature of soil organic matter. *Nature*, 528(7580), pp.60–68.
Leifeld, J. & Fuhrer, J., 2010. Organic farming and soil carbon sequestration: What do we really know about the benefits? *Ambio*, 39(8), pp.585–599.
Little, T.M. & Hills, F.J., 1978. *Agricultural Experimentation: Design and Analysis*, New York: John Wiley and Sons.
Mäder, P. et al., 2002. Soil fertility and biodiversity in organic farming. *Science*, 296(5573), pp.1694–1697.
Marriott, E.E. & Wander, M.M., 2006. Total and Labile Soil Organic Matter in Organic and Conventional Farming Systems. *Soil Science Society of America Journal*, 70(3), pp.950–959.
Pettersson, B.D., 1982. *Konventionell och biodynamisk odling: jämförande försök mellan två odlingssystem 1971 - 1979*. In Swedish.
Pettersson, B.D., Reents, H.J. & Wistinghausen, E.V., 1992. *Düngung und Bodeneigenschaften, Ergebnisse eines 32-jährigen Feldversuch in Järna, Schweden.*,
Raupp, J. et al., 2006. *Long Term Field Experiments in Organic Farming*, Available at: http://orgprints.org/8554/%5Cnhttp://orgprints.org/8554/1/raupp-etal-2006-long-term-content.pdf.
Raupp, J. & König, U.J., 1996. Biodynamic Preparations Cause Opposite Yield Effects Depending Upon Yield Levels. *Biological Agriculture and Horticulture*, 13(2), pp.175–188.
Rending, V. V. & Taylor, H.M., 1989. *Principles of soil-plant interrelationships* H. M. Taylor, ed., New York: McGraw-Hill.
Svenska Demeterförbundet. 2017. "Regler För Biodynamisk Växtodling och Djurhållning.". In Swedish.
Tammeorg, P. et al., 2012. Nitrogen mineralisation dynamics of meat bone meal and cattle manure as affected by the application of softwood chip biochar in soil. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 103(1), pp.19–30.

Carbon sequestration in long-term on-farm studies in Organic and Biodynamic Agriculture, Sweden

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Key words: carbon sequestration, biodynamic agriculture, compost, crop rotation, manure

Abstract

Beginning in 1958, three sets of long-term field trials have been conducted at the Swedish Biodynamic Research Institute in Järna, Sweden. Design of the field trial described in this paper differs from the earlier long-term experiments - it was established on an integrated biodynamic crop and livestock farm. Treatments were based on resources available on the farm; using only manure produced on-farm. The aim was to evaluate long-term effects on quality and yield in crops and quality parameters in soil, by comparing use of composted and not composted manure, with or without the full set of biodynamic preparations. Increase of carbon was calculated to a carbon sequestration averaging 400 kg carbon per ha and year in the topsoil, with the highest value (500 kg) with use of biodynamic treatments and composted manure, compared to 300 kg with use of not composted manure without biodynamic treatments.

Introduction

Long-term trials on organic farms, compared to conventional farms, have shown increased soil organic carbon (SOC) (Marriott & Wander 2006), However, uncertainty remains about SOC sequestration in organic and biodynamic agriculture (Leifeld & Fuhrer 2010).

Three sets of long-term field trials have been conducted at the Swedish Biodynamic Research Institute in Järna, Sweden, since 1958. The basic aim was to develop biodynamic farming during Nordic conditions. The experiments started as an initiative within the Scandinavian Research circle for biodynamic agriculture, founded already in 1949 with members from the all Nordic Countries.

The results from the initial K-experiment (Kjellenberg, Granstedt, & Pettersson, 2005) formed the basis for one 6- and one 9-year trial, jointly called the UJ-experiments. Results from the two trials corresponded well with each other, as well with the results from the K- experiment (Dlouhy, 1981; Kjellenberg & Granstedt, 2015; Pettersson, 1982).

The design of the field experiment reported from in this paper differs from the earlier long-term experiments. It was established within an integrated biodynamic crop and animal farm. The field trial was established within an integrated biodynamic crop and livestock farm in Järna, Sweden, 59° N. Treatments were based on resources available on the farm; using only manure produced on-farm. The aim was to evaluate long-term consequences on quality and yield in crops as well as quality parameters in soil, by

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comparing the use of composted and not composted manure, with or without use of the full set of biodynamic preparations.

Material and methods

The soil at the field trial site is mainly a clay loam, with an organic carbon content of between 1.9% and 2.9%. Soil under the topsoil is stratified, with glacial layered clay at the bottom. Topsoil has undergone secondary sorting of soil fractions (post-glacial clay, loam and silt) since the last ice age. The soil is generally high in potassium (K), low in phosphorus (P) and has a pH between 5.7 and 6.2.

Design, field trial 1991

Treatment	Plot	Block	Block	Plot	Treatment
NCM25-	25			1	CM50-
NCM25+	26			2	CM50+
CM12,5+	27			3	NCM12,5+
CM12,5-	28			4	NCM12,5-
CM25+	29			5	CM12,5+
CM25-	30	C	A	6	CM12,5-
NCM12,5-	31			7	NCM50+
NCM12,5+	32			8	NCM50-
CM50-	33			9	NCM25-
CM50+	34			10	NCM25+
NCM50+	35			11	CM25-
NCM50-	36			12	CM25+
CM50-	37			13	NCM12,5-
CM50+	38			14	NCM12,5+
NCM50+	39			15	NCM25+
NCM50-	40			16	NCM25-
CM12,5+	41			17	CM25-
CM12,5-	42	D	B	18	CM25+
NCM25+	43			19	CM12,5+
NCM25-	44			20	CM12,5-
NCM12,5-	45			21	NCM50+
NCM12,5+	46			22	NCM50-
CM25-	47			23	CM50-
CM25+	48			24	CM50+

4 m

15 m

Manure treatments

Abbreviations	Type	Tons/ha	Kg N/ha
NCM12,5-	Non-composted manure 1991	12.5	31.3
NCM12,5+			
NCM25-	Non-composted manure 1991, 1995, 2000	25	62.5
NCM25+			
NCM50-	Non-composted manure 1991, 1995, 2000	50	125
NCM50+			
CM12,5-	Composted manure 1991	12.5	31.3
CM12,5+			
CM25-	Composted manure 1991, 1995, 2000	25	62.5
CM25+			
CM50-	Composted manure 1991, 1995, 2000	50	125
CM50+			
Biodynamic preparations	- no + yes		

Figure 8. Field trial design, Skilleby Research Farm

Soil samples was taken after Ley III in the five-year crop rotation before manuring and sowing winter wheat. Samples from the upper soil layer (0–20 cm) of each of the 48 plots of the field trial were sent to Agrilab (Uppsala, Sweden), and analysed according to established standards. Total C (carbon) and N (nitrogen) content were measured with a LECO CHN 600 element analyzer (SS-ISO 11464). Available P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium) and Na (sodium) were analysed after extraction in ammonium lactate (AL) solution (SS 028310). Total P, K, Mg, Ca and Cu (copper) were determined according to SS 028311 after extraction in hydrochloric acid (HCl) and pH was determined according to SS-ISO 10390.

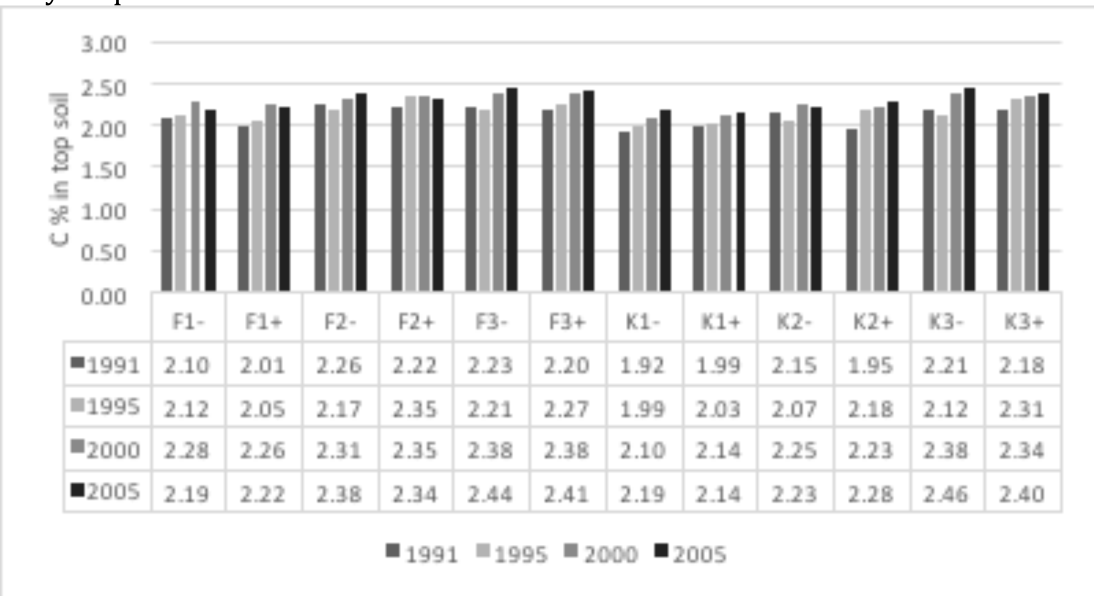
Carbon balance for each year based on total carbon yield, incorporation of crop residues in soil, harvested carbon and recirculation via manure, increase of carbon through SOM (soil organic matter), formation and decrease of organic carbon in SOM through mineralisation during the five-year crop rotation was calculated according the model developed and tested by Granstedt & L-Baeckström (2000). Values calculated in the model were compared to values obtained in trials in 1995, 2000 and 2005.

Computer program Excel 2010 (Microsoft Corp., Redmond, WA, USA) was used for calculations and statistical evaluations.

Results

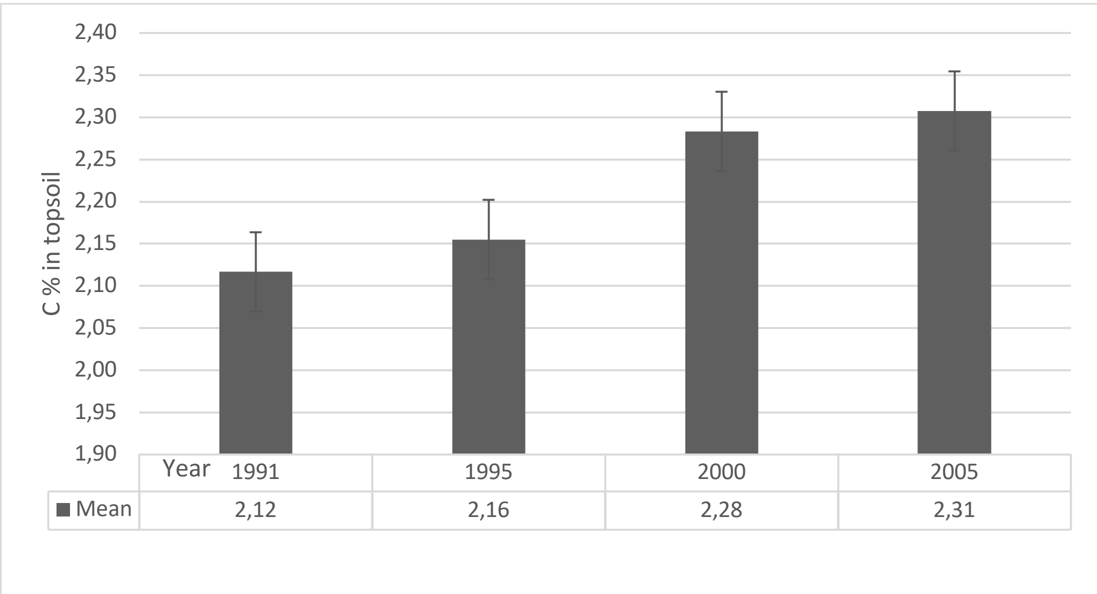
During the 15-year period 1991 to 2000 pH, P-Al, K-Al, Mg and Ca increased in all manure treatments despite of negative values for P and K in the farm gate balances. Soluble P content in the soil is very low (P class 1 to P class 2) but soluble K is at a sufficient level (K class 3).

Average total organic carbon content in topsoil increased in all treatments during the 14-year period from 1991 to 2005.



	F1-	F1+	F2-	F2+	F3-	F3+	K1-	K1+	K2-	K2+	K3-	K3+
1991	2.10	2.01	2.26	2.22	2.23	2.20	1.92	1.99	2.15	1.95	2.21	2.18
1995	2.12	2.05	2.17	2.35	2.21	2.27	1.99	2.03	2.07	2.18	2.12	2.31
2000	2.28	2.26	2.31	2.35	2.38	2.38	2.10	2.14	2.25	2.23	2.38	2.34
2005	2.19	2.22	2.38	2.34	2.44	2.41	2.19	2.14	2.23	2.28	2.46	2.40

Figure 9. Total carbon content in topsoil in the 12 different treatments 1991, 1995, 2000 and 2005.



Year	1991	1995	2000	2005
Mean	2,12	2,16	2,28	2,31

Figure 10. Average total carbon in topsoil, all treatments, in 1991, 1995, 2000 and 2005. General trend concerning total carbon content in the top soil in the 12 different treatments. Error bars indicate standard error (SE).

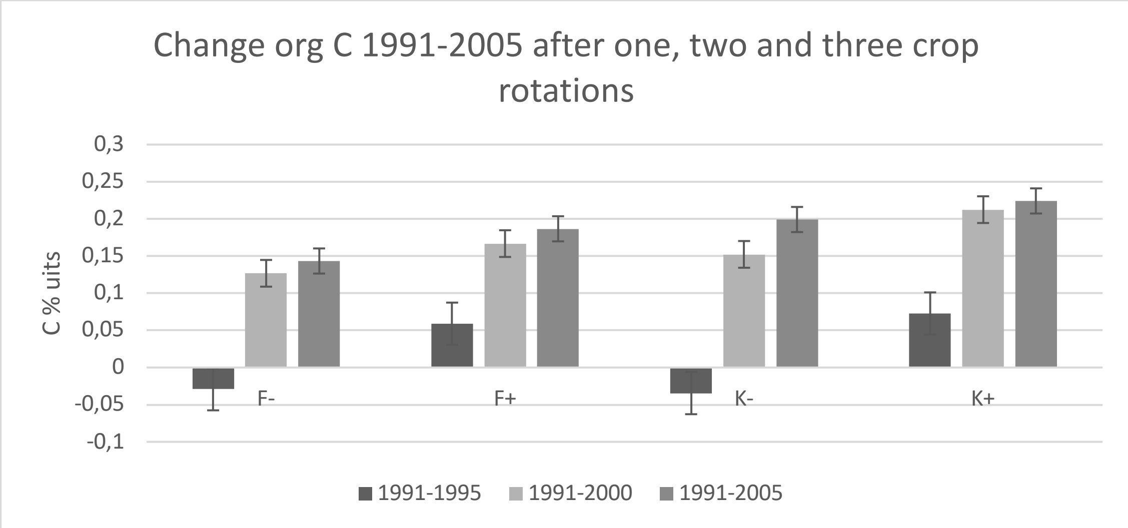


Figure 11. Average increase of total organic carbon content in topsoil in treatments with not composted manure without (NCM-) and with biodynamic (NCM+), and composted manure without (CM-) and with biodynamic (CM+) from 1991 - 1995, 1991-2000 and 1991-2000.

Discussion

Increase in soil carbon averaged 400 kg carbon per ha and year in the topsoil (0-20 cm and an average bulk density of 1.25 g/cm^3) from 1991-2005. During the first 4 years, we observed a significant increase ($p<0,05$) for composted and not composted manure with use of biodynamic treatments compared use of manure without biodynamic treatments. Additionally, we observed an average increase of 0.14 % in organic carbon in the B horizon (60-90 cm).

During the first 14 years of the field trial there was a positive correlation between the calculated total increase in soil carbon content and the measured value. There was a higher carbon sequestration in treatments with biodynamic composted manure compared to composted manure without biodynamic treatments in accordance earlier long-term studies (Mäder et al. 2002) and Bachinger (1996). With background of this results long term studies and evaluation of already obtained results are going on under Nordic conditions.

References

Bachinger, J. 1996. Der Einfluss unterschiedlicher Düngungsarten (mineralisch, organisch, biologisch-dynamisch) auf die zeitliche Dynamik und die räumliche Verteilung von bodenchemischen und mikrobiologischen Parametern der C und N-Dynamik sowie auf Pflanzen- und Wurzelwachstum von Winterroggen. Diss. Univ. Giessen. Schriftenreihe Bd. 7, Inst. F. biol.-dyn. Forschung, Darmstedt.

Dlouhy, J. (1981). *Alternativa odlingsformer- växtprodukters kvalitet vid konventionell och biodynamisk odling*. Diss. Uppsala:SLU.

Granstedt, A. & L-Baeckström, G., 2000. Studies on the preceding crop effect of ley in ecological agriculture. *American Journal of Alternative Agriculture*, 15(2), pp.68–78.

Granstedt, A. & Kjellenberg, L. Organic and biodynamic cultivation - a possible way of increasing humus capital, improving soil fertility and providing a significant carbon sink in Nordic conditions. In: *Proceedings of Second Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR) held at the 16th IFOAM Organic World Congress*, Modena, Italy, June 18-20, 2008 2008.

Kjellenberg, L. & Granstedt, A. (2015). Influences of Biodynamic and Conventional Farming Systems on Quality of Potato (*Solanum tuberosum* L.) crops: Results from multivariate analyses of two Long-Term Field Trials in Sweden. FOODS 3, 440-462.

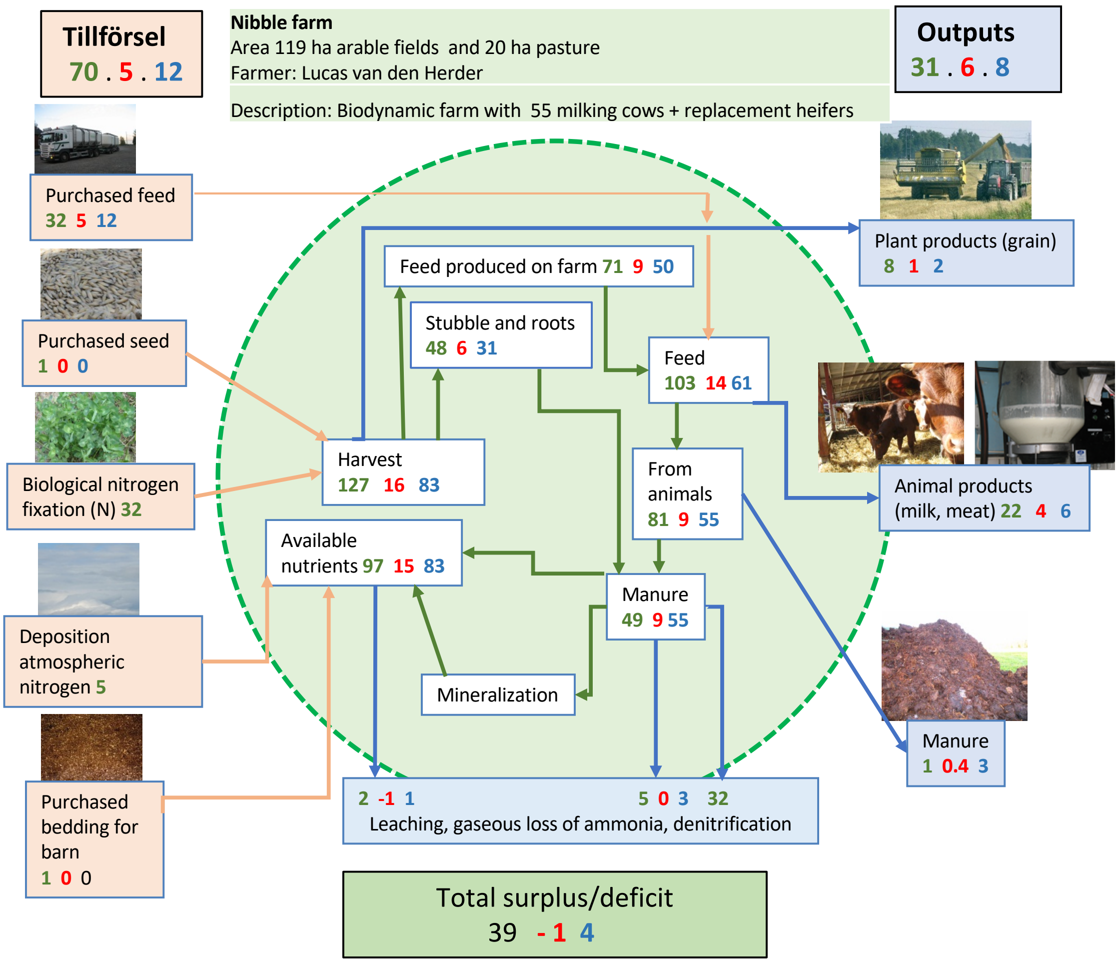
Leifeld, J. & Fuhrer, J., 2010. Organic farming and soil carbon sequestration: What do we really know about the benefits? *Ambio*, 39(8), pp.585–599.

Mäder Mäder, P., Fliessbach, A.,Dubois D., Gunst L., Fried P. & Niggli, U. 2002. Soil Fertility and Biodiversity in Organic Farming. Science VOL 296 pp 1592-1597

Marriott, E.E. & Wander, M.M., 2006. Total and Labile Soil Organic Matter in Organic and Conventional Farming Systems. *Soil Science Society of America Journal*, 70(3), pp.950–959.

Plant nutrient pathways

Flow of nitrogen (N) , phosphorus (P), potassium (K) kg/ha
Nibble farm 2017 (0,7 AU/ha)



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