Soil for life

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Biochar application in agriculture

Results from field trials in the Netherlands from 2010 to 2012

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Content

Summary & conclusions

Application of biochar is believed to improve natural soil fertility, not only due to its positive influence on organic matter and nutrient dynamics but also due its ability to affect soil structure. During the period 2010 to 2012 several biochars have been tested at three locations in the Netherlands. These field experiments are located at two clayey soils in Kollumerwaard and Lelystad and one sandy soil located in Valthermond. These sites vary in soil characteristics and crop rotation systems. The biochars tested include the Romchar (as part of the Interreg project Climate Saving Soils) and three other products ('biochar norit', 'biochar ECN', and 'biochar wood'). All these products have been tested in comparison with common agricultural practices like the amendment of soils with compost or slurry or chemical fertilizers only. The crops involved are spring wheat, seed potato and winter wheat (Kollumerwaard), spring barley, sugar beet and onion (Lelystad), and sugar beet, starch potato and spring barley (Valthermond). Both crop and soil were monitored during the three years. This report describes all crop data (crop yield and quality) but limits the changes in soil properties to the final year of this experiment (so, after three years of biochar application).

Both crop yield and crop quality were not affected by biochar incorporation at all three locations. Similar findings were shown for the soil food web's composition and size, the composition of the dissolved organic matter fraction, the basic soil solution chemistry (such as EC, pH and nutrients), the organic matter levels and characteristics (hot water carbon, CN-ratio, N supplying capacity and anaerobic mineralization rate), and the basic soil chemical and physical properties (like pH, CEC, infiltration capacity, penetration resistance, etc.). If any changes occur, then they didn't develop in a consequent direction giving doubt whether biochar application itself was the main factor driving the soil variables to change.

Location specific characteristics like soil type and crop variety seemed to have confounding effects on the changing soil properties. In addition, it might be possible that any positive changes are only detectable after a few years of practices incorporating resistant organic carbon into the soil. Because the experimental design differed among the locations, and the soil analyses have been made on combined samples without replication, it is difficult to make robust and statistically sound conclusions on potential benefits of biochar amendment on soil quality aspects. Nevertheless, since both crop yields, crop quality as basic soil properties hardly changed during the three years of application, it can be questioned whether the possible benefits accounts from a practical farmers perspective.

1 Introduction

Biochar production and application is a relatively new development. Several partners within the North Sea Region started therefore in 2009 a transnational partnership to investigate and evaluate the possibilities of biochar application, and the methods for producing it. Biochar is a product of thermal biomass-to-energy processing systems. Application of biochar in agricultural systems might help to sequester carbon in the soil, making the soil climate change resilient.

Climate change in the North Sea Region is predicted to have a pronounced effect on annual rainfall patterns. Prolonged periods of severe droughts or heavy rains will impact the sustainability of farming. Soils, rich in organic matter and biological life, function both as a water buffer during periods of drought and as drainage during periods of heavy rains. Skilled farmers and land managers can increase the amount of carbon sequestered in soils by applying dedicated agricultural land managing practices which increase soil organic matter. Organic matter in soils is rapidly degraded by micro-organisms. Thermal treatment like pyrolysis converts rapid degradable biomass into non-degradable inert biochar. Urban, industrial and agricultural biomass residues can be used as raw material for thermal conversion. Application of biochar into soils is also a carbon capture and storage strategy because it actually creates a sink for carbon in soils and prevents its release into the atmosphere.

The ‘Biochar climate saving soils’ project aims to 1) implement biochar knowledge dissemination strategies for authorities, produces and end-users of biochar and public opinion for raising awareness and building confidence in biochar applications, 2) transnational development and compilation of knowledge base and methodological standards on biochar feedstocks, logistics, production, biochar characterisation and environmental impact assessment, and 3) transnational development and compilation of knowledge base and methodological standards on biochar applications for soil quality and fertility improvement, for soil remediation and for carbon capture and storage.

Part of this on-going Interreg project is the evaluation of biochar application in field experiments. This report describes the results of the experiments performed by NMI (in cooperation with others) in the Netherlands from 2010 up to 2012. These results include 1) a common field trial that has been performed with one type of biochar (similar trials have been performed in all countries participating in the Interreg project), and 2) results from a ‘long-term’ field experiment evaluating the performance of soil improvers including biochar on three locations in the Netherlands during 2010 to 2012. The latter experiment was performed by PPO-AGV and NMI in cooperation with SPNA and IRS (for details, see Paauw et al., 2010).

2 Material & Methods

2.1 General information

The Interreg project ‘Biochar: Climate saving soils’ aims to demonstrate the effects of biochar on soil and crop growth in the North Sea Region, and has therefore established biochar field trials in all partner countries, being the Netherlands, Germany, Norway, Sweden, Denmark, UK (Scotland) and Belgium. In each of the participating countries, one common field trial was established with the same biochar and according to a standard protocol (see section 2.2.). Within the scope of the project one batch of ~8 tons of biochar was prepared (also called “Romchar”) and used in the field experiments in aforementioned countries.

Apart from the treatments with pure Romchar and the comparison with a control, some countries have extended the common field trial with other Romchar treatments in order to investigate additional factors or have established additional field trials with other biochars (see section 2.3.).

2.2 Experiment in Valthermond

2.2.1 Experimental design and location characteristics

As part of the common field trial, a field experiment was conducted in Valthermond, a location in the north eastern part of the Netherlands. The soil is classified as a sandy soil rich in organic matter (Dutch classification: dalgrond; reclaimed peat soil). The soil contains 2.8% clay, 7.2% silt and 90% sand. Basic soil properties are shown in table 2.1. The crop rotation on this field was starch potato (2009), sugar beet (2010), starch potato (2011) and spring barley (2012). The biochar used in the common field trial, also called ‘Romchar’, was only tested during the growing season of 2012. The experimental design was a randomized complete block design with three replicates. The size of the individual plots was 6 x 20 m.

Table 2.1. Basic soil properties of the field location in Valthermond (source: Blgg AgroXpertus).

Parameter	**N-total**	**CN**	**P-AL**	**K**	**pH**	**CEC**	**SOM**
Units	*mg N kg^{-1}*	*-*	*mg P_2O_5 100 g^{-1}*	*mg K kg^{-1}*	*-*	*mmol+ kg^{-1}*	*%*
Value	2875	23.5	30	52	5.2	158	12

The field trial was part of a bigger experiment where several soil improvers were tested. This bigger experiment started in 2009 and included the following products: Xurian Optimum (micro-organisms stimulating soil life), PRP-SOL (a calcium fertilizer enriched with micronutrients), Condit 5%N (hydrolised proteins and zeolites), pig slurry, rock powder and four biochars including Romchar. All these products have been claimed to improve the physical and chemical soil fertility. The performance of these products have been evaluated in comparison with common agricultural fertilizer practices, such as 1) only chemical fertilization, 2) pig slurry and chemical fertilization, and 3) compost and chemical fertilizer.

The Romchar was applied in autumn 2011 at a rate of 24.5 ton fresh weight per ha corresponding to 20 ton dry matter per ha (see figure 2.1). During spring 2012 the field was cultivated after which the spring barley (variety Prestige) was sown. The inorganic N content in the plough layer in February 2012 was 17 kg N ha^{-1}. Based on this inorganic N level, additional chemical fertilizer was given according to standard fertilizer recommendations for barley. No pig slurry was used in the treatment with Romchar.

Figure 2.1. Application of biochar in Valthermond.

In total about 93 kg N ha^{-1} was given by chemical fertilizers in such a way that the available N pool was similar for all treatments. The total nutrient given by fertilization ranged from 75 to 91 kg effective N ha^{-1}, from 0 to 30 kg P_2O_5 ha^{-1}, and from 180 to 201 kg K_2O ha^{-1} (Table 2.2.).

Table 2.2. Fertilization with N, P and K for each treatment.

Treatment	**Slurry** (kg N ha^{-1})	**N-effective** (kg N ha^{-1})	**N-total** (kg N ha^{-1})	**P_2O_5** (kg P_2O_5 ha^{-1})	**K_2O** (kg K_2O ha^{-1})
Fertilizer	0	85	85	0	180
Compost	0	91	157	30	180
Slurry	0	87	87	0	201
Romchar	0	93	93	0	180

A short time-line of the activities during this common field trial is visualized below. Shortly, biochar was applied and incorporated in autumn 2011. In spring 2012, soil inorganic N was analyzed to adjust fertilizer gifts after which the soil was cultivated and fertilized at 23 March. The crop was sown at 30 March and harvested at 14 August. Within the overall soil improvers project, soil samples were collected in June for an extensive analysis of biological, chemical and physical soil quality. Soil inorganic N levels after harvest was analyzed in August.

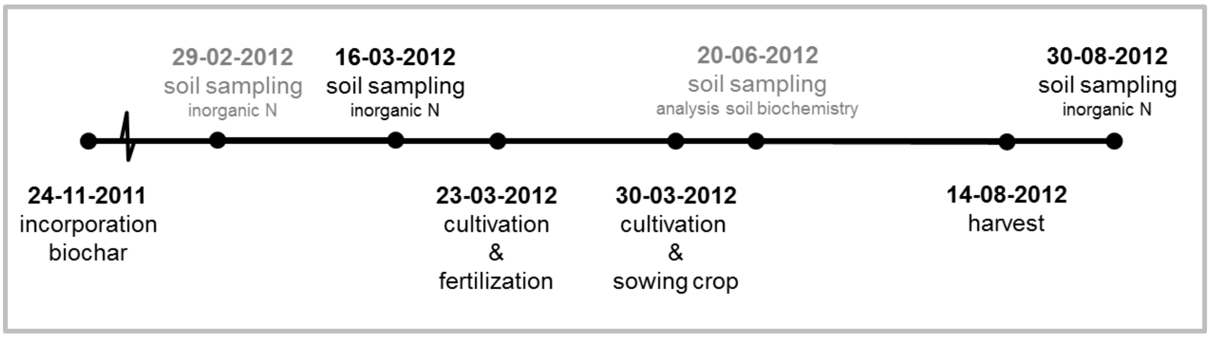

Figure 2.2. Timeline of activities performed during common field trial at Valthermond. Gray activities are sampling events within the overall project dealing with soil improvers.

A plot amended with biochar is visualized in fhe figure below.

Figure 2.3. A biochar amended plot before incorporation and cultivation.

2.2.2 Biochar characteristics

The biochar in these trials, further called ‘Romchar’, is produced by Carbon Terra with a mix of woody feed stocks (Norwegian Spruce, Silver fir, Scots Pine, beech and oak) and at a pyrolysis temperature of 450-480 °C. The process takes a few days and leads the char to a small fire-front in the end of the system what helps to destruct potential harmful substances such as PAHs and dioxins. The Romchar contained 69% carbon and 0.4% nitrogen (determined in the biochar received by ILVO). The pH (KCl extract) was 8.6 (Source: ILVO). This is high but not exceptional for biochar. The majority of the particles had a size ranging from 0.5 to 8 mm (determined on the biochar received by Danish parties, source: Riso DTU). The biochar was not pretreated before application (Source: Interreg Biochar Climate Saving Soils, Newsletter 3).

2.2.3 Analyses

The effect of biochar amendment on soil properties was evaluated for the following soil properties:

- basis soil properties such as pH, lutum, total N, P-Al and CEC; and
- inorganic N levels in spring and after harvest of the main crop;

In addition to these soil analyses, the following crop analyses were done:

- crop yield at harvest;
- crop quality parameters such as dry matter content, protein content, the percentage grains in different size classes (> 2.8 mm; > 2.5 mm; > 2.2 mm; and < 2.2 mm); and
- the crop development was evaluated by visual inspection and judgement (score 1-10).

2.3 Additional experiments

2.3.1 Experimental design and location characteristics

In the Netherlands different biochars are compared with other soil improvers (e.g., compost and carbonate-fertilizers) at different locations: at Valthermond, Kollumerwaard and Lelystad. The experiment started in 2010, is part of a bigger experiment investigating the role of soil improvers, and is still running. A complete description of the field experiment and the results over the last years has been published in annual reports (Paauw et al., 2010; 2011; 2012). This report summarizes the results of these experiments focusing on the role of biochar.

Basic soil properties and location characteristics are summarized in table 2.3 for all participating locations.

Table 2.3. Basic soil properties and location characteristics of field experiments with biochar.

Property	Kollumerwaard	Lelystad	Valthermond
Clay content (%)	25	18	<3.2
Texture class (USDA)	Clay Loam	Loam	Sand
Organic matter (%)	3.5	2.0	11.6
Total N (mg N kg^{-1})	1420	970	2875
CN ratio (-)	12	10	23.5
pH (-)	7.0	6.8	5.2
CEC (mmol+ kg^{-1})	169	139	158
P-AL (mg P_2O_5 100 g^{-1})	42	42	30
K (mg K kg^{-1})	89	57	52
Crop rotation			
2009	Sugar beet	Seed Potato	Starch potato
2010	Spring wheat	Spring barley	Sugar beet
2011	Seed Potato	Sugar beet	Starch potato
2012	Winter wheat	Onion	Spring barley
2013	Sugar beet	Winter Carrot	Starch potato

The tested biochars and organic products are listed in table 2.4. The tested biochars included a classic charcoal produced by Carbo Europe BV ("biochar wood"), an activated carbon ("biochar norit") and torrified wood chips ("biochar ECN"). **The nutrient supply in all treatments was optimized by mineral fertilizers, so that any nutritional effects were counterbalanced.** An overview of the fertilization schemes is given in Appendix V.

Table 2.4. Experimental treatments with organic products at the 5 experimental locations

Treatments	Kollumerwaard	Lelystad	Valthermond
Biochar type	Biochar wood Biochar norit	Biochar wood	Biochar ECN Biochar wood Biochar norit Romchar
Control situation	Fertilizer only Compost Pig slurry	Fertilizer only Compost Pig slurry	Fertilizer only Compost Pig slurry

The experiment was designed in such a way that the performance of the involved organic products can be compared with common agricultural practices such as the application of compost, pig slurry or chemical fertilizers. The type and number of organic products and their application rate varied among the five locations. A summary of the experimental treatments is given in table 2.5.

Table 2.5. Experimental treatments with organic products at the 5 experimental locations

Location	Treatment	2010 spring	2010 autumn	2011 spring	2011 autumn	2012 spring
Kollumerwaard	Biochar wood	5		5	5	
	Biochar norit	5		5	5	
	Compost	9	9		9	
	Pig slurry	25				25
Lelystad	Biochar wood*	2.5		2.5		2.5
	Biochar wood*	5		5		5
	Compost	9	9		9	
	Pig slurry		15			
Valthermond	Biochar ECN	15				
	Biochar wood	5		5		5
	Biochar norit	5		5		5
	Romchar				24.5	
	Compost	18		9		9
	Pig slurry	20		20		

* treatments with biochar were additionally fertilized with pig slurry at this location (rate 15 m^3 ha^{-1})

In Valthermond, the crops in the field experiment were sugar beet, starch potatoes and spring barley. The classic charcoal ('Biochar wood') and the activated carbon ('Biochar norit') were applied at a dose of 5 ton ha^{-1} in spring each year. The torrified wood chips from ECN were applied at a dose of 15 ton ha^{-1} in spring 2010. There was no sufficient material present for applications in the other years, but the crop productivity and soil properties were monitored each year. The Romchar was applied in autumn 2011 being part of the Interreg project 'Biochar climate saving soils' at a dose of 24.5 ton ha^{-1} (see also section 2.2.). Compost was applied in spring 2010 at a dose of 18 ton ha^{-1} and at 9 ton ha^{-1} for the last two years. Pig slurry is only given in spring 2010 and 2011. In Kollumerwaard, the crops in the field experiment were spring wheat, seed potatoes and winter wheat. Activated carbon and charcoal ("biochar wood") were applied each year at a dose of 5 ton ha^{-1} and compost at a dose of 9 ton ha^{-1} per year. In Lelystad, the crops in the field experiment from 2010 to 2012 were spring barley, sugar beets and onions. Charcoal ("biochar wood") was applied each year at a dose of 2.5 and 5 ton ha^{-1} and compost at a dose of 9 ton ha^{-1} per year. In all locations, mineral fertilizers were applied according to fertilizer recommendation guidelines (see Appendices). The biochars were incorporated in the top layer of the soil (0-25 cm depth) by common cultivation techniques.

2.3.2 Characteristics organic fertilizers/ products

Different kinds of biochar products have been tested. These products include 1) the Romchar, 2) the charcoal produced by Carbo Europe BV ('biochar wood'), 3) activated carbon ('biochar norit'), and the torrified wood chips produced by ECN. The wood chips produced by ECN originated from poplar trees. The four biochar products were not analyzed for their chemical and physical properties, except for the Romchar within the Interreg Biochar project. The chemical properties of the Romchar are listed in table 2.6.

Table 2.6. Main biochar characteristics of the tested products (source: BVU GmbH, 2011).

Product	Romchar	Biochar norit
Dry matter (%)	88.6	98
Organic matter (% DM)	86.9	-
pH ($CaCl_2$)	7.8	Alkaline
CN-ratio (-)	217	-
CH-ratio (-)	46.3	-
C-content (g C kg^{-1} DM)	759	-
N-content (g N kg^{-1} DM)	3.5	-
P-content (g P_2O_5 kg^{-1} DM)	3.9	-
K-content (g K2O kg^{-1} DM)	3.1	-
Density (kg m^{-3})	387	290

As an example, two pictures of the 'Biochar wood' and 'Biochar norit' are shown in the figure below.

Figure 2.4. Two examples of the biochars used within the experiments.

Within this report, the biochars are denoted as BC1 ("Biochar norit"), BC2 ("Biochar wood"), BC3 ("Biochar ECN") and BC4 ("Romchar").

2.3.3 Analyses

Because the biochar treatments are part of a bigger experiment dealing with the effect of soil improvers on the soil structure, an extensive combination of soil and crop properties were analyzed each year. The current report focuses on the role of biochar application and integrates the analyses reported in the annual reports of this soil structure experiment (Paauw et al., 2010; 2011; 2012). For the mechanistic background regarding experimental design, which analyses were done, and the hypotheses regarding the role of soil improvers in soil, we refer to the aforementioned annual reports.

The effect of biochar amendment on soil properties was evaluated for the following **soil properties**:

- aggregate stability (wet sieving method; WUR, 2010; determined by lab Wageningen University)
- several sub-fractions of the dissolved organic carbon fraction (Van Zomeren & Comans, 2007; measured by ECN Netherland);
- total and active number of fungi and bacteria (food-web-analysis; measured by BLGG AgroXpertus)

- basis soil properties such as bulk density, pH, lutum, total N, P-Al and CEC (measured by Blgg AgroXpertus);
- the content of hot water extractable carbon (Ghani et al., 2003; measured by CBLB Wageningen University);
- anaerobic mineralization assay (Waring & Bremner, 1966; measured by Blgg AgroXpertus);
- soil penetration test (Eijkelkamp; v5.08; 2010; used by NMI); and
- saturated hydraulic conductivity (Koopmans & Brands, 2003, determined by NMI).

All soil samples were taken from the top layer of the soil layer, in particular from the 0-25cm depth layer.

In addition to these soil analyses, the following **crop analyses** were done:
- crop yield at harvest (determined by PPO-agv);
- crop quality parameters (variable among crops)
    - total N for spring barley, winter wheat and spring wheat;
    - size distribution for onion and potato; and
    - sugar content, harvest losses and nutrient content for sugar beet.

The items described in this report include:
- all crop analyses from the period 2010 to 2012 (crop yield and crop quality parameters); and
- soil analyses performed in 2012 (after three years of biochar application). Soil parameters analyzed in the years 2010 and 2011 are published in the annual reports (Paauw et al., 2010; 2011; 2012).

We like to note that the data are not statistically analyzed separately for the current report: statistical information on the significance of differences among treatments was taken from the evidence reported in the annual reports (e.g. L.S.D. values). Main reason for this was the fact that differences among treatments were so small that any additive statistical analyses would not have changed the outcome of the study. In addition, soil properties had been analyzed on a combined sample of the replicated plots, limiting the possibilities to perform robust statistical tests on field scale (especially since not all biochar treatments were available at all locations and the variation within biochar treatments differs across the three locations).

3 Results & Discussion

3.1 Experiment in Valthermond

This section describes the common field trial from the project Biochar Climate Saving Soils, and hence, it focuses on the evaluation of the Romchar amendment on crop yield, crop quality and soil parameters during the cultivation of spring barley. For the evaluation of the Romchar, the effect of biochar application (the Romchar treatment) was compared with the situation that only chemical fertilizers have been used (the control treatment). The evaluation of the other biochar products and organic soil improvers are described elsewhere (section 3.2).

3.1.1 Soil inorganic N levels

The amount of inorganic N was determined before and after the cultivation of spring barley. Most of the inorganic N was present in the form of NO_3. In spring 2012, the inorganic N levels varied between 46 and 58 kg N ha^{-1} with slightly higher values in the Romchar treatment (Table 3.1.). After harvest, about 92 to 96 kg N ha^{-1} was remaining in the first 90 cm of the soil profile with slightly higher values in the Romchar treatment. Because the crop N-uptake was not significantly different between the treatments, this higher level after harvest might be related to both the higher initial values and the fact that the amount of fertilizer N added was slightly higher in the Romchar treatment (93 kg N compared to 85 kg N in the control).

Table 3.1. Inorganic N content (kg N ha^{-1} over 0-90cm depth) before and after the cultivation of spring barley.

Depth	**Spring (16-03-2012)**		**After harvest (30-08-2012)**	
	Control	Romchar	Control	Romchar
0 – 30 cm	28	16	52 (10)	56 (32)
30 – 60 cm	16	17	29 (6)	25 (6)
60 – 90 cm	14	13	15 (2)	11 (5)
Total (kg N ha^{-1})	**46**	**58**	**92**	**96**

* Values between brackets are stdev of replicates (n = 3); samples analysed in spring are combined into one mixed sample before analysis; inorganic N analyses after harvest done by ILVO, in spring by Blgg AgroXpertus.

This also indicates that the application of biochar didn't increase the risk of N losses to the water environment: the remaining N in the soil profile (and its distribution over the soil profile) is quite similar for both treatments. It should be noted that strong variation exists among the three replicates of the Romchar treatment: the inorganic N levels in the topsoil (0-30 cm) varied from 33 to 93 kg N ha^{-1}. The reason for this variability is unknown, but it might be related to the presence of biochar since this variability is not present in the control treatment and only visible in the top layer where the biochar is incorporated.

3.1.2 Crop yield and characteristics

The crop was sown at 30 March 2012. The crop development was judged by field workers using standard protocols for the period May to July. The judgement score can vary from 1 (bad development) to 10 (top development) and reflects the crop quality judgement from an experienced farmer. Just before harvest, the crop was also judged for the presence of lodging (in Dutch 'legering'; score is inversely related to presence of lodging).

There was no significant difference between the control and biochar treatment. Crop development increased over time and the scores varied from 6.3 to 8.0 during the months May to July. Similarly, no difference in lodging was present between both treatments. Hence, we may conclude that biochar amendment had no influence (either positive or negative) on the crop development of the spring barley.

Table 3.2. Visual judgement crop quality development during the growing season.

	Judgement score (ranging from 1 – 10)		
Date	**Control**	**Romchar**	**L.S.D.**
Crop stand			
11 May	6.3 (0.3)	6.5 (0.5)	0.65
7 June	6.8 (0.8)	6.7 (1.0)	1.71
27 June	7.7 (0.3)	7.0 (1.0)	1.16
30 July	8.0 (0.5)	7.5 (1.3)	1.39
Crop lodging			
27 June	9.0 (0.0)	9.0 (0.0)	1.86
30 July	8.5 (0.0)	8.3 (1.2)	2.94

* Values between brackets are stdev of replicates (n = 3)

These results for crop development were collaborated by the measured crop yield for both grain and straw. Differences between both the control and the biochar amended treatment were negligible. Grain yield was 5697 kg DM ha^{-1} for the biochar treatment and 5773 kg DM ha^{-1} for the control treatment. Similar to the variation present in soil inorganic N levels, there was also stronger variation present in the biochar amended treatments.

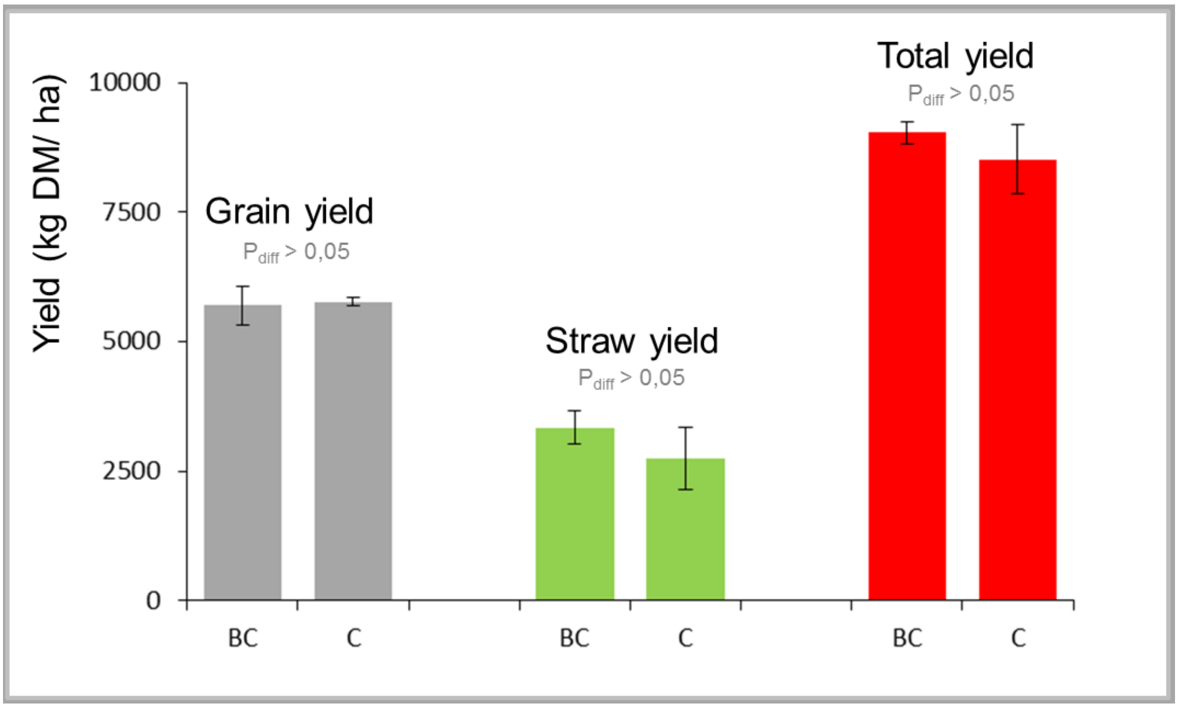

Figure 3.1. Mean crop yield (kg DM ha^{-1}) for the biochar (BC) and control (C) treatment. Error bars are SD (n=3).

The grain yield varied from 6100 to 6911 kg fresh ha^{-1} where it varied from 6533 to 6722 kg fresh ha^{-1} in the control soil. This might be related to inhomogeneous distribution of the biochar suggesting that the applied dose is a relevant factor affecting crop yield and biochar performance. Nevertheless, the differences between both treatments were quite small for both crop yield and grain composition, suggesting that the variation present simply reflects (spatial) variability commonly present in field experiments. Based on the results of this experiment, it is not possible to unravel the cause of this variability.

As mentioned before differences in grain composition were negligible. The 1000 grain weight was ~58 g, most of the grains (~95%) had a size bigger than 2.8 mm, the dry matter content was ~12%, the protein content varied between 12.2 and 12.7%, the N content was ~2% and the P-content was ~0.4% (Table 3.4.). Consequently, the application of biochar in autumn had no significant and relevant effect on crop quality aspects.

Table 3.4. Crop characteristics in control soil and biochar amended soil.

Crop data	**Grain**		**Straw**	
	Control	Romchar	Control	Romchar
Yield fresh (kg ha^{-1})	6615 (97)	6541 (410)	3033 (666)	3700 (361)
Yield (kg dry matter ha^{-1})	5773 (86)	5697 (366)	2744 (594)	3343 (319)
1000 grain weight (g)	58.4 (0.4)	58.3 (1.5)	-	-
Grain composition				
Fraction > 2.8 mm (%)	95 (0.3)	95 (1.1)	-	-
Fraction 2.5 - 2.8 mm (%)	4 (0.2)	4.2 (0.2)	-	-
Fraction 2.2 – 2.5 mm (%)	0.5 (0.1)	0.6 (0.3)	-	-
Fraction < 2.2 mm (%)	0.4 (0.1)	0.3 (0.0)	-	-
Protein content (%)	12.7 (0.3)	12.2 (0.2)	-	-
N-content (%)	2.03 (0.24)	2.08 (0.16)	0.84 (0.07)	0.84 (0.02)
P-content (%)	0.42 (0.01)	0.41 (0.01)	0.13 (0.02)	0.12 (0.01)

* Values between brackets are DS of replicates (n = 3); grain and straw composition were analysed by ILVO.

3.1.3 Other analyses

Before and after the cultivation of spring barley, a soil sample was analysed on basic soil properties (Table 3.3). None of the parameters tested was significantly altered by biochar addition and crop cultivation. Given the stability of these parameters in soil, this was also not expected.

Table 3.3. Change in soil properties during the growing season (analysis by ILVO; within Interreg ring trial).

Soil parameter	**Spring (16-03-2012)**		**After harvest (30-08-2012)**	
	Control	Romchar	Control	Romchar
Organic Carbon (%)	9.8 (1.9)	10.9 (2.7)	10.1 (1.0)	10.4 (2.0)
N-total (%)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)
pH (1M KCl)	5.0 (0.1)	5.1 (0.2)	5.0 (0.1)	5.0 (0.2)
Fe-content (mg Fe 100 g^{-1})	25 (5.4)	27 (0.9)	24 (5.6)	24 (1.1)
K-content (mg K 100 g^{-1})	9.4 (2.8)	11.4 (1.7)	7.9 (1.1)	9.9 (1.5)
Mg-content (mg Mg 100 g^{-1})	18 (1.5)	20 (3.5)	18 (0.1)	17 (2.1)
Ca-content (mg Ca 100 g^{-1})	292 (36)	323 (73)	295 (10)	290 (43)
Mn-content (mg Mn 100 g^{-1})	4.7 (0.6)	5.1 (1.3)	4.6 (0.3)	4.3 (0.9)
Na-content (mg Na 100 g^{-1})	3.7 (1.4)	3.6 (1.0)	3.6 (0.4)	4.0 (0.4)
P-content (mg P 100 g^{-1})	13.7 (1.1)	14.6 (1.2)	12.0 (1.3)	12.7 (2.7)

* K, Mg, Ca, Mn, Na and P are determined by ammonium lactate extraction method (source: ILVO).

Weather conditions during growing period were obtained from a KNMI-weather station nearby. The daily variation in precipitation and mean temperature are visualized in figure 3.2.

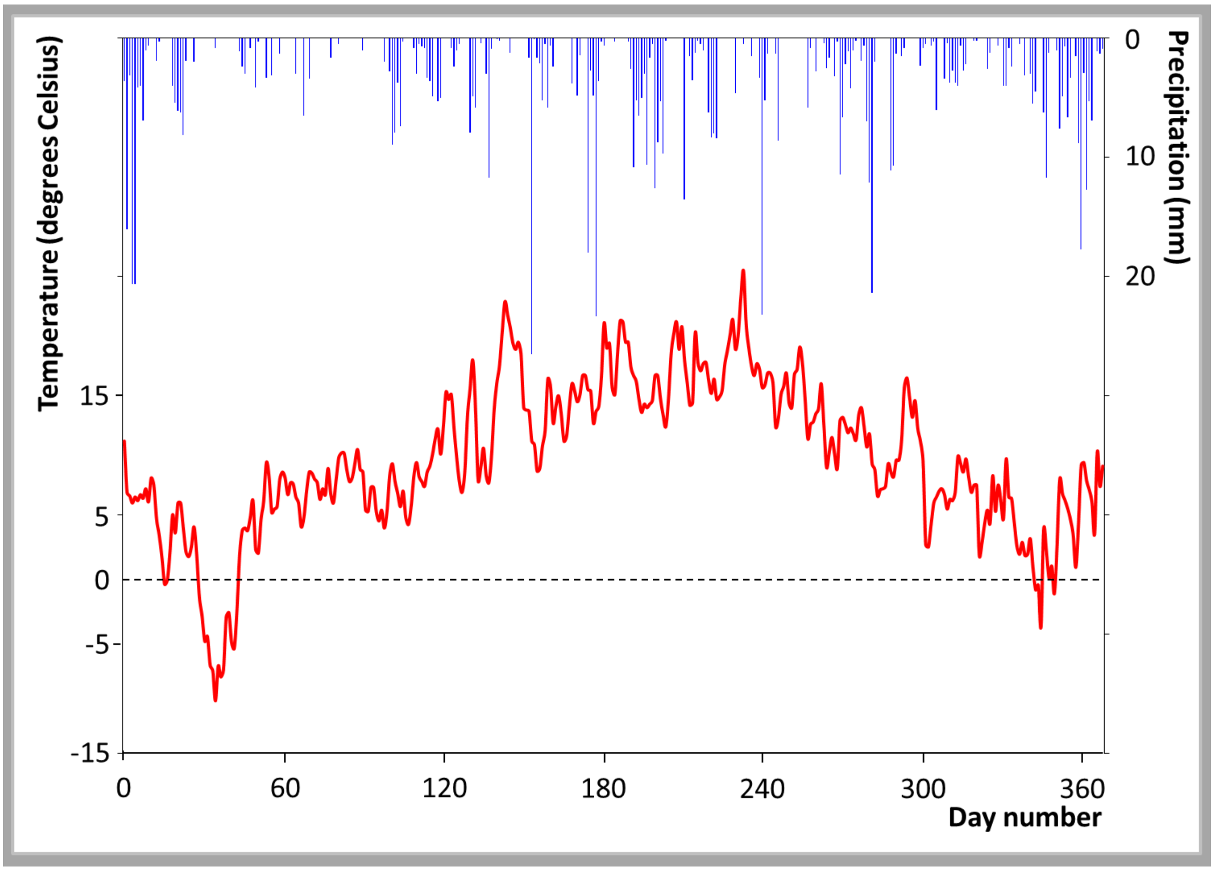

Figure 3.2. Daily variation in precipitation (mm) and temperature (°C) nearby experimental location

The mean monthly temperature varied from 7.7 °C in March up to 17.8 °C in August. The total sum of monthly precipitation varied from 16 mm in March up to 108 mm in June. The spring of the year 2012 was relatively mild, sunny and relatively dry. The mean monthly temperature was 10.4 °C in comparison with a long-term mean monthly temperature of 9.5 °C. The total amount of precipitation (138 mm) was lower than usual (172 mm). The mean temperature during summer was in accordance with the long-term average temperature with slightly higher temperatures in August and lower temperatures in June and July. The summer was relatively wet with 286 mm precipitation compared to 225 mm for the long-term average.

3.2 Additional experiments

3.2.1 Soil inorganic N levels

Soil inorganic N levels were determined in spring, autumn and after the harvest of the main crop. These analyses were done during the years 2011 to 2012 and for the locations on clay soils: Kollumerwaard and Lelystad. In addition, the sandy soil at Valthermond was analyzed in spring 2012 and after harvest of the main crop for the analysis of the Romchar (as part of the Interreg common field trial). The analysis done in spring 2011 at Valthermond was part of the common experiment regarding the soil improvers. The variation in inorganic N (as determined on maximally three occasions per year) is shown in figure 3.3. Almost all inorganic N levels represent the availability of N of the 0-60 cm soil layer (except for three analyses). All individual analyses (from both top and subsoil) are presented in the Appendix.

Inorganic N levels varied between 15 and 40 kg N ha^{-1} during spring and are within levels usually found in agricultural fields before the growing season starts. The initial content is slightly higher in Valthermond due to the higher nitrogen supplying capacity of the soil. During the year, inorganic N levels increased up to 50 to 100 kg N ha^{-1} depending on location, sampling date and crop type (especially potato crops).

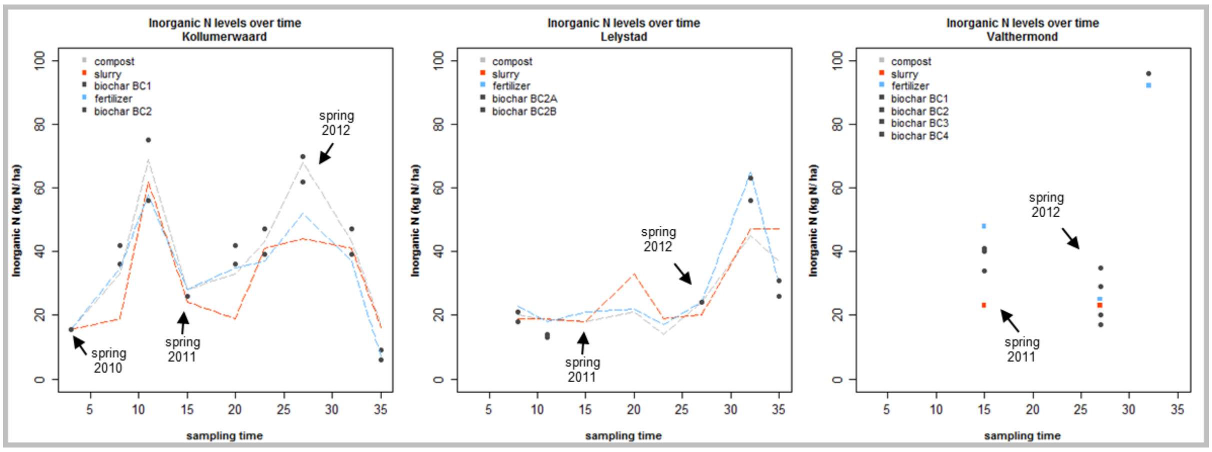

Figure 3.3. Variation in inorganic N over time for the 3 experimental locations. Sampling events are aggregated on month-level (spring=3, harvest=8, winter=12; coloured lines are common practices, dots are biochar treatments).

The amendment of biochar had no strong effect on net N residue in soil during winter and resulted in similar levels compared to fertilizer and compost. This can be explained by the fact that all treatments received similar levels of available nitrogen via chemical fertilizers. Anyway, the net effect of biochar on soil N processes resulted in similar levels during the year.

3.2.2 Crop yield and characteristics

In the figure below all crop yield data are visualized for the common treatments compost, slurry, fertilizer and the biochar treatments. It is clearly visible that none of the biochar treatments had a significant positive influence on crop yield in comparison with common practices. Mean crop yields varied from 6 to 15 ton dry matter ha^{-1} for the barley and wheat crops with slightly higher yields on the clays compared to the sandy soil. The crop yield of the other crops varied from 40 (starch potato) up to 120 ton dry matter for the sugar beet. Overall, biochar addition to the soils did not enhance crop yield. Doubling the biochar amendment rate from 2.5 to 5 ton ha^{-1} at the location Lelystad had also no effect in all three experimental years. Differences among biochars were small, indicating that any nutritional differences were counter-balanced by the chemical fertilization given. In addition, possible positive effects on soil fertility and nutrient delivery might be present, but were not visible in crop yields for all investigated crops over 3 years of research.

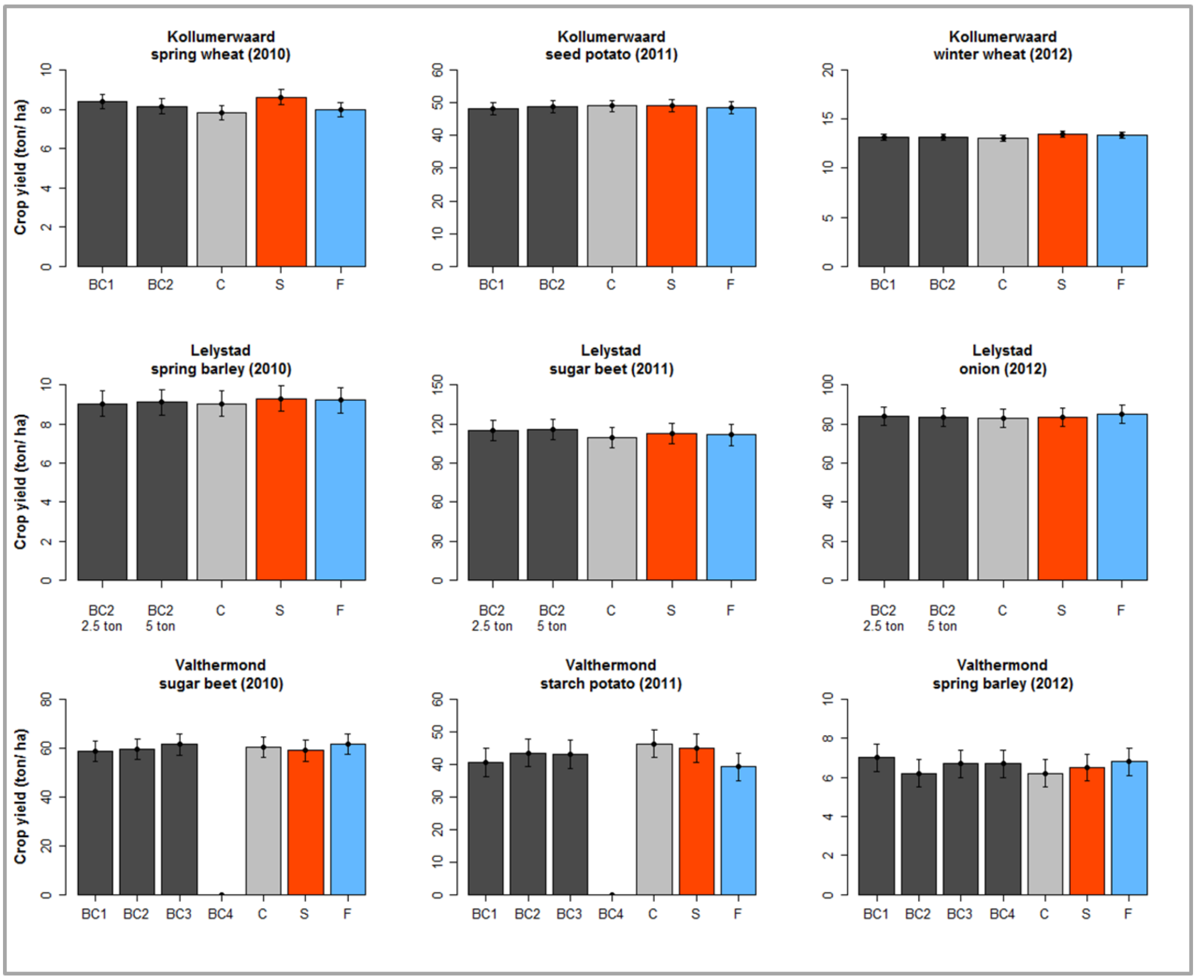

Figure 3.4. Crop yield (ton dry matter ha^{-1}) for the 3 locations during 2010-2012. Error bars are LSD (P<0.05). Treatments are abbreviated as “C“ (compost), “S“ (slurry), “F“ (fertilizer), “BC1“ (biochar norit), “BC2“ (biochar wood) , “BC3“ (biochar ECN) and “BC4“ (Romchar).

Similar results were observed for the uptake of nitrogen and phosphorus, although the differences varied among the different crops. For example, differences were small for the plots cultivated with wheat, barley and sugar beet, but increased for the crops potato and onion. Nevertheless, differences were not significant, except for onion. *However, there is some uncertainty for this result since part of the samples lost their sample code during transport to the laboratory.* No crop nutrient analyses have been done for the sandy soil of Valthermond, except for the common biochar trial of Interreg project (see section 2.2.).

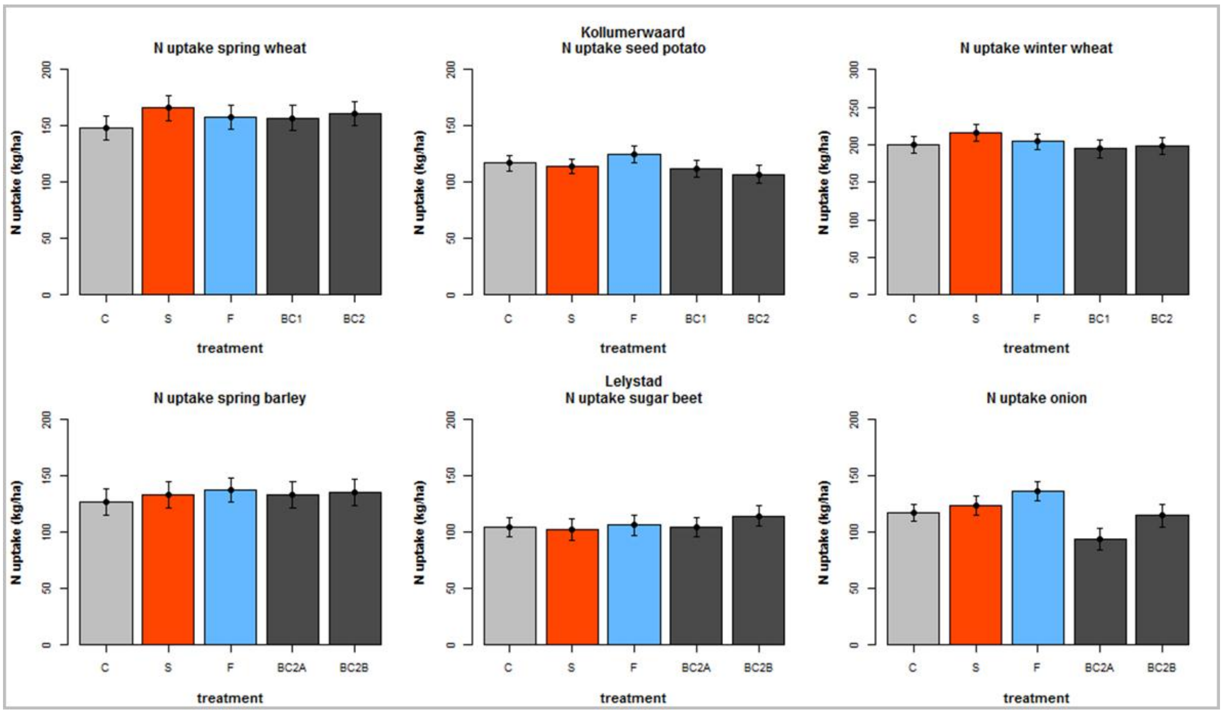

Figure 3.5. Crop N uptake (kg N ha^{-1}) for the 3 locations during 2010-2012. Error bars are LSD ($P<0.05$). Treatments are abbreviated as “C“ (compost), “S“ (slurry), “F“ (fertilizer), “BC1“ (biochar norit), “BC2“ (biochar wood) , “BC3“ (biochar ECN) and “BC4“ (Romchar).

Similar results were observed for the phosphorus uptake (data not shown), indicating that none of the treatments significantly altered the N-to-P ratio of the harvested crop products.

From each crop several crop quality characteristics have been determined, varying from visual judgement scores in winter wheat to sugar and amino content in sugar beets. All detailed analyses are listed in the appendices, but a selection of these variables is visualized in figure 3.5. These include (among others):

- size distribution parameters for barley: which proportion of the grain has a size above 2.5 mm;
- size related yield for potato and onion;
- under water weight for starch potato;
- sugar content of the sugar beet; and
- the N index (ratio between grains and straw) and a visual color judgment for winter wheat.

The results presented here indicated that not only the crop yield but also the crop quality parameters were not significantly altered by the amendment of biochars over a period of three years.

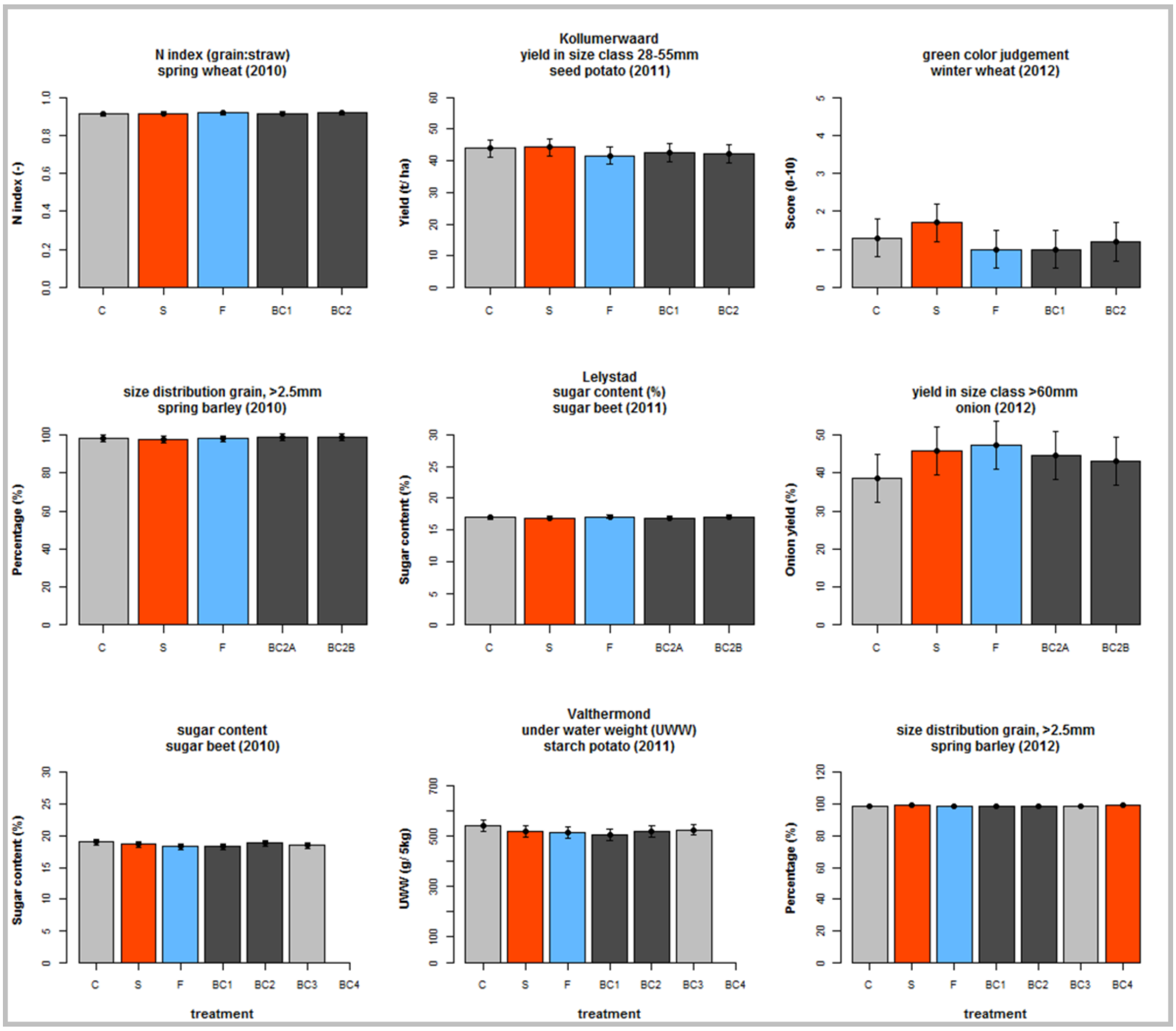

Figure 3.6. Crop quality parameters for the 3 locations during 2010-2012. Error bars are LSD (P<0.05) values. Treatments are abbreviated as “C“ (compost), “S“ (slurry), “F“ (fertilizer), “BC1“ (biochar norit), “BC2“ (biochar wood) , “BC3“ (biochar ECN) and “BC4“ (Romchar).

3.2.3 Soil analyses

During the experimental period 2010 to 2012, soil samples have been analyzed yearly, and the results are described in several annual reports. The current report focuses on the biochar treatments compiling the data presented in the individual reports. Hence, the data are not separately analyzed statistically. All collected data from 2012 are given in the appendix, and this section describes the variation in soil chemical, biological and physical parameters after 2 years of biochar amendment. Hence, the presented results are derived from samples taken in year 2012. Because the soil samples of the three replicated plots are combined before analyses, no statistical analysis has been made on field scale.

Soil food web analyses

In the figure below the presence and activity of bacteria and fungi in the top layer of the soil are visualized. The majority of the microbial biomass consisted of non-active bacteria, varying between approximately 200 and 350 µg per gram soil (data not shown). The highest levels of total bacterial and fungal mass were found in a biochar treatment across all locations: biochar norit at Kollumewaard, biochar wood (2.5 ton ha^{-1}) in Lelystad and the Romchar in Valthermond.

Most of the active biomass consisted of bacteria with levels varying between 20 and 65 µg per gram soil. There was no general trend among the treatments for both groups (fungi or bacteria) separately, as shown for both total biomass and several ratio indexes (Figure 3.7.). In addition, no differences in hyfediameter were visible. Hence, biochar amendment had no consistent effect on the composition of the soil food web.

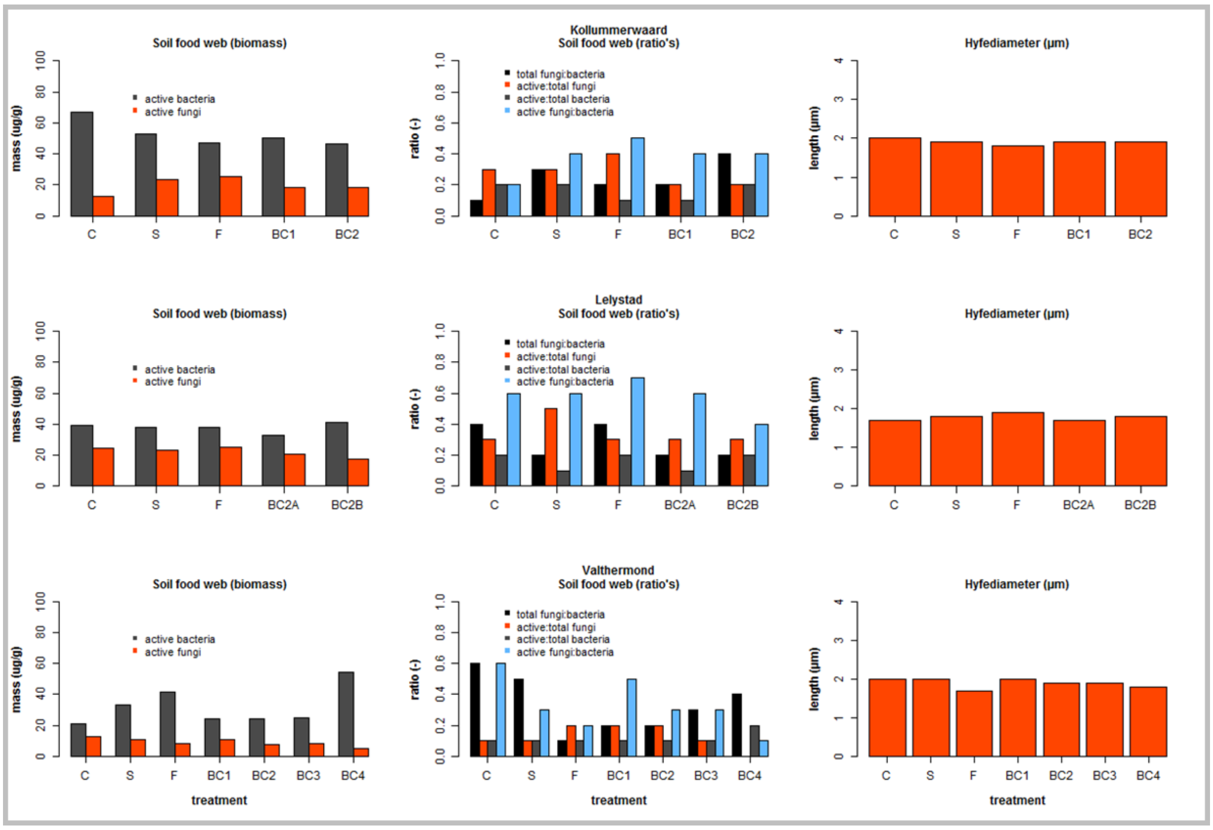

Figure 3.7. Effect of organic amendments (compost, slurry and biochars) on size and foodweb composition. Treatments are abbreviated as “C“ (compost), “S“ (slurry), “F“ (fertilizer), “BC1“ (biochar norit), “BC2“ (biochar wood) , “BC3“ (biochar ECN) and “BC4“ (Romchar).

Nevertheless, strong differences occur among the treatments tested. Unfortunately, this variation is not controlled or affected by the type of organic matter application. For example, compost addition strongly increased fungal population in Valthermond whereas it simultaneously decreased the population at Kollumerwaard. This suggests that other factors then organic matter application had a strong influence too. It is for example unknown how this outcome depends on sampling time (soils have been sampled in June 2012) and whether the differences found in this study are within natural monthly variation. Anyway, since the effect of biochar addition is not consequent, there is no conclusive evidence for any changes in soil food web composition and activity.

Composition dissolved organic matter

Dissolved organic matter is operationally defined as an ensemble of organic molecules of different sizes and structures able to pass through a filter with a pore size of 0.45 um. It consists of complex high molecular weight compounds collectively termed humic substances and more simple low molecular weight hydrophilic (Hy) compounds. It is believed that this fraction plays an important role in both biotic and abiotic soil processes, such as sorption, mineralization and aggregate stability. In addition, it can have a large impact on the transport of nutrients and pollutants to groundwater and surface waters.

Humic substances represent the hydrophobic fraction of DOM and consist of humic acids (HA) and fulvic acids (FA). The hydrophilic fraction is composed of a range of moderately transformed plant-derived polysaccharides as well as microbial metabolites and compounds originating from cell lysis. After three years of organic amendments, there was however no consistent change in the levels of dissolved organic carbon: it ranged between 2 and 4 mg C l^{-1} (extract solution) for the location Kollumerwaard, between 1.5 and 3 mg C l^{-1} for the location Lelystad and varied between 8 and 14 mg Cl^{-1} for the sandy soil at Valthermond. These differences reflect both the effect of soil texture and soil organic matter levels. Three years of organic matter amendments resulted in a slightly lower DOC concentration in Kollumerwaard and Valthermond with respect to the control with fertilizer. Surprisingly, all organic residues tend to decrease the DOC concentration in all fields, with highest changes in the sandy soil.

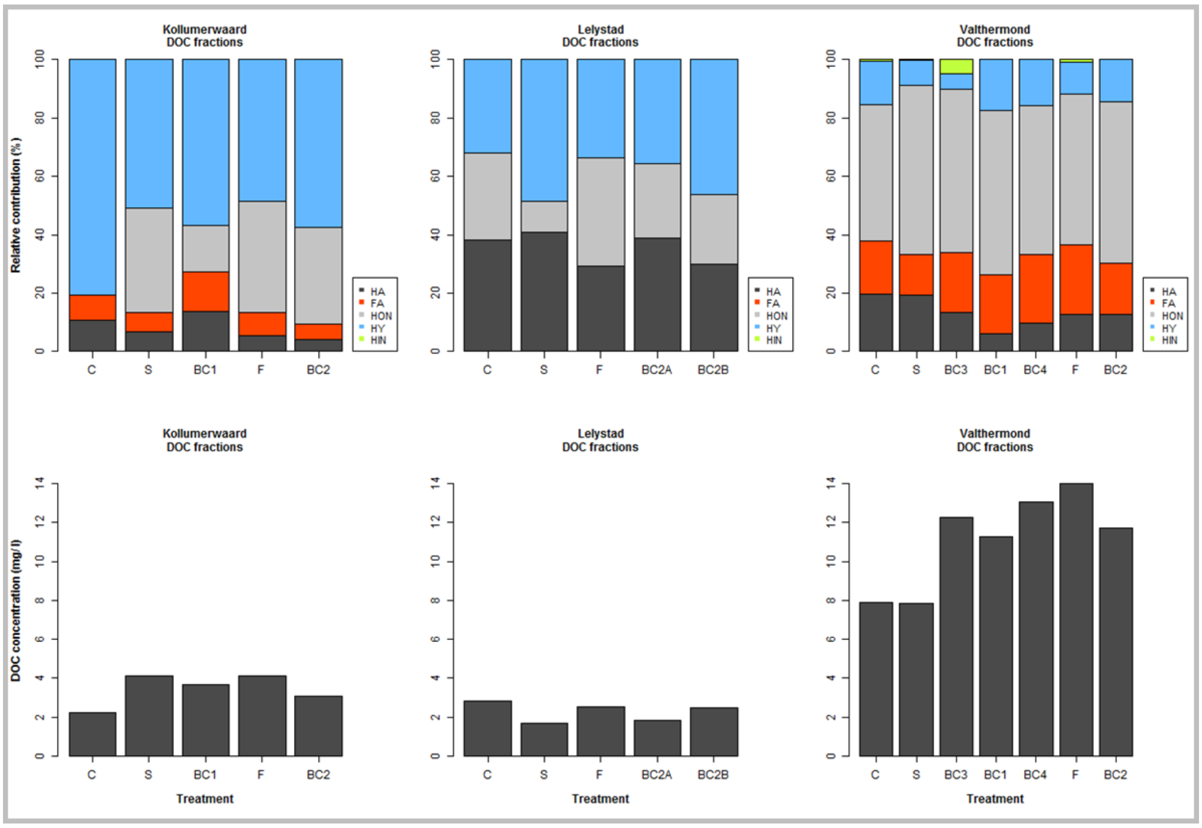

Figure 3.8. Effect of organic amendments (compost, slurry and biochars) on DOC levels and composition. Treatments are abbreviated as “C“ (compost), “S“ (slurry), “F“ (fertilizer), “BC1“ (biochar norit), “BC2“ (biochar wood) , “BC3“ (biochar ECN) and “BC4“ (Romchar).

The composition of the DOC fraction was highly influenced by soil type: most of the DOC fraction was composed of hydrophilic acidic compounds in the clayey soils whereas the majority of the organic compounds in the sandy soil were found in the hydrophobic neutral organic carbon fraction. The amendment of various kinds of organic products had almost no effect on the composition of DOC indicating that the fate of dissolved organic matter fraction is strongly determined by the solid soil carbon chemistry rather than of labile organic residues. Since only a small amount of carbon is added (in comparison with the total C content in the soil) and the soil solution chemistry is usually quick governed by abiotic and biotic processes, any changes that might have occurred are likely only present in the first days (to weeks) after incorporation.

Basic soil solution properties

After three years with different organic residue applications, soil solution chemistry was analyzed for EC, pH and main macro and micronutrients. In the next figure, a few examples are given to show how the soil solution was affected by the incorporation of biochars. The data from the different locations are plot in the same figures to show whether any changes (if they occur) are consequent present in all locations. Because the experiment was not designed as a full factorial experiment, some bars are missing. Differences were more pronounced in the sandy soil than in both clay soils, in particular for the potassium concentration (Figure 3.9.). In addition, most of the soil solution properties were not affected by biochar application. These include the EC-value, soil solution pH, and the nitrogen, and the Mg and SO_4 concentration in the soil solution. Differences in the availability of P, Ca and Na were small, indicating that the availability of these nutrients was not changed due to biochar application and its possible effect on sorption processes. Incorporation of biochar might have an influence on the K availability since both biochar norit ("BC1") and the Romchar ("BC4") increased the K concentration at the location Valthermond.

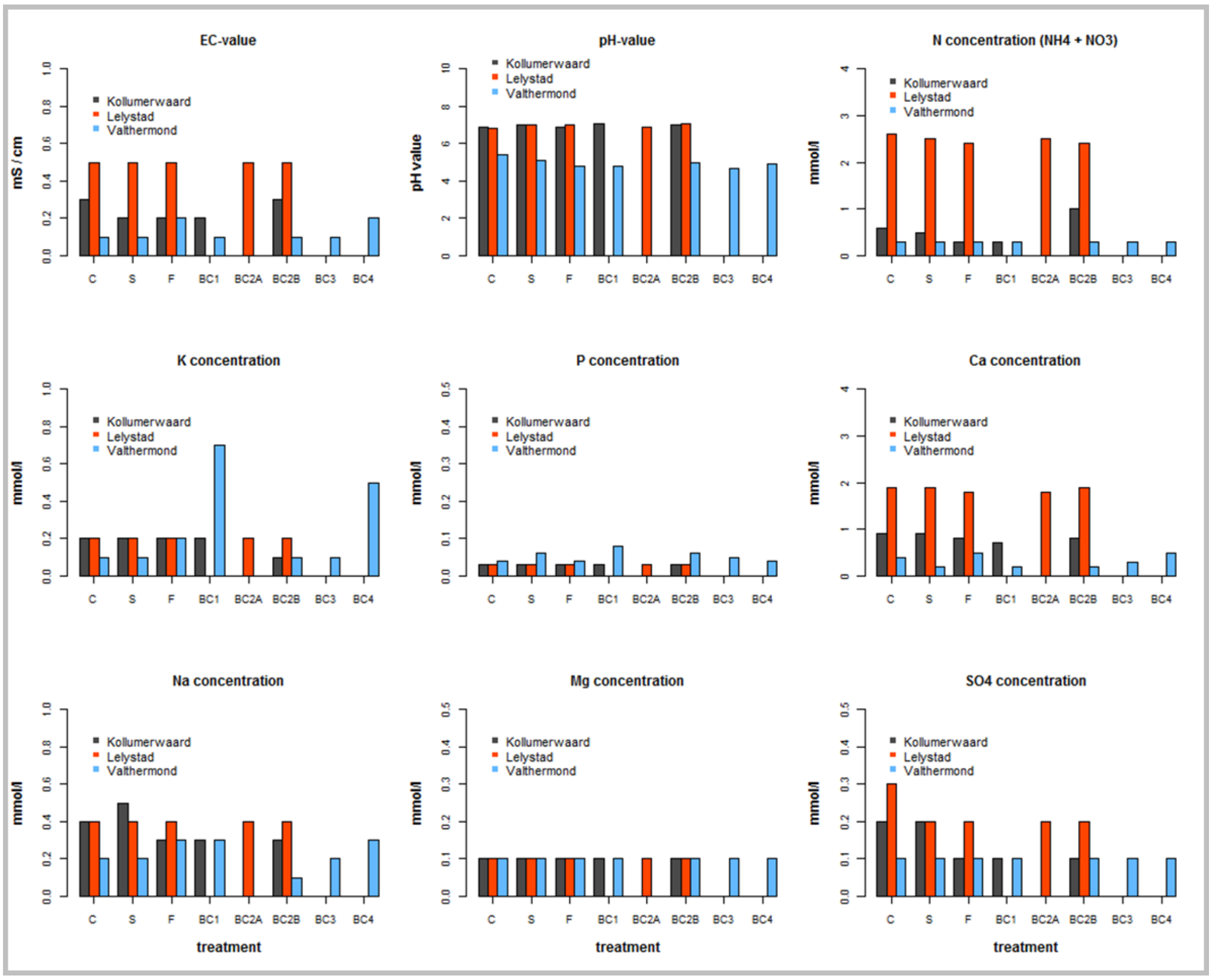

Figure 3.9. Effect of organic amendments (compost, slurry and biochars) on soil solution chemistry (EC, pH, inorganic N levels, and concentrations of K, P, Ca, Na, Mg and SO_4). Treatments are abbreviated as "C" (compost), "S" (slurry), "F" (fertilizer), "BC1" (biochar norit), "BC2" (biochar wood) , "BC3" (biochar ECN) and "BC4" (Romchar).

Organic matter levels and characteristics

Within this project a few aspects related to the amount and quality of the organic matter have been characterized after three years of field experimentation. Results are summarized in the next figure, and again, the data are visualized for the tree locations within each plot to see whether any changes occur in all experiments. Regarding the organic matter content, there were big changes in organic matter content of the sandy soil, and it is not likely that these changes are caused by biochar application simply because the change is much higher than the amount of carbon added. For example, when 15 ton C ha^{-1} was added via amendment of the "biochar norit", this might increase the organic matter content with maximally 1.5% (assuming that all the carbon remained in the top 10 cm of the soil profile). In addition, there is no consistent pattern that organic matter application increases the organic matter content. Hence, the variation within the treatments is likely due to within-field variation or (even worse) analytical uncertainty. Because the three plots for each sample are homogenized before analysis, it is not possible to quantify the uncertainty present for each treatment. The organic matter content for the clay locations and the organic carbon measurements suggests that no change could be detected due to biochar application.

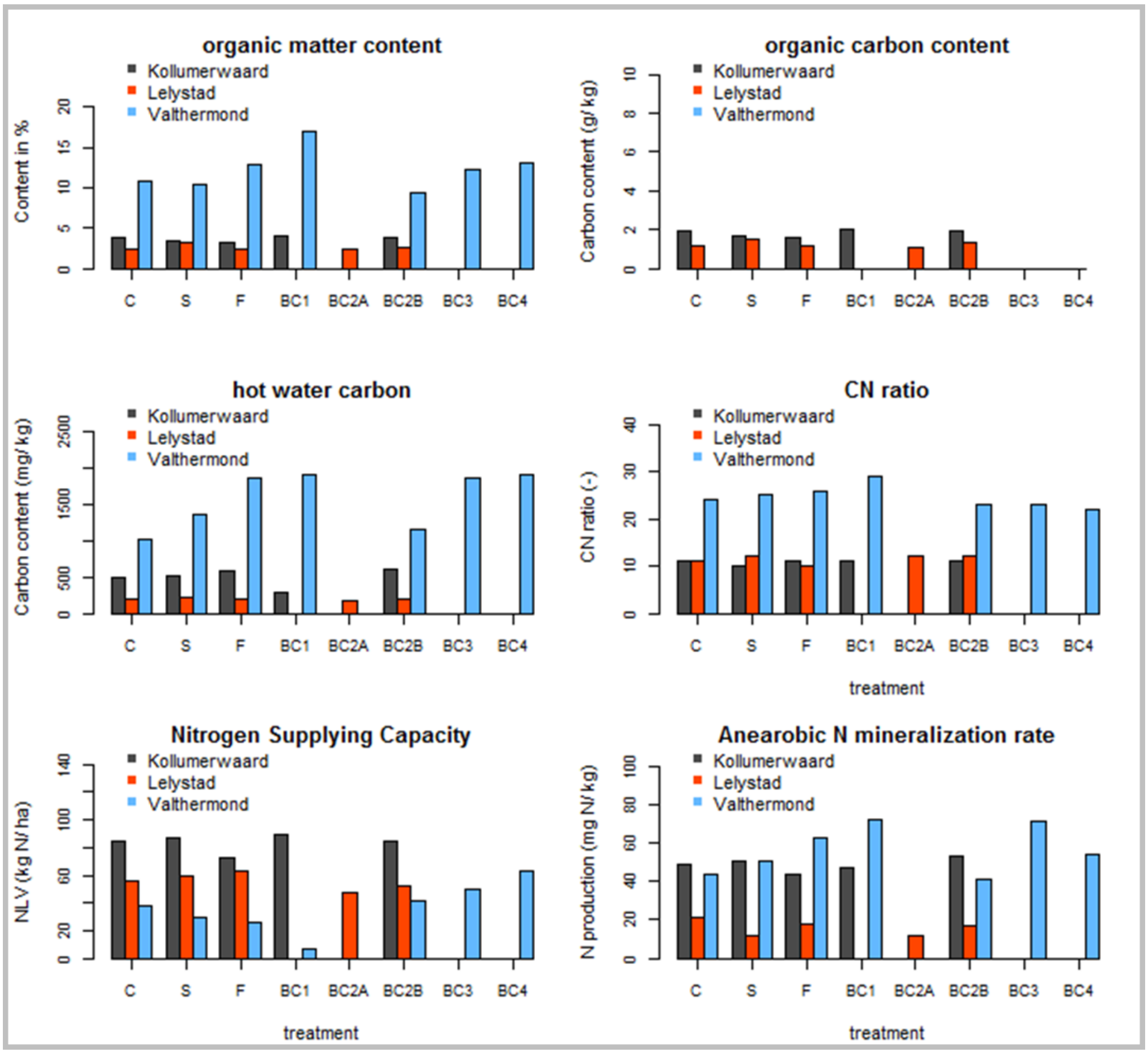

Figure 3.9. Effect of organic amendments (compost, slurry and biochars) on quantity and quality of soil organic matter (OM content, OC content, hot water C, CN ratio, N supplying capacity and mineralization rate). Treatments are abbreviated as "C" (compost), "S" (slurry), "F" (fertilizer), "BC1" (biochar norit), "BC2" (biochar wood) , "BC3" (biochar ECN) and "BC4" (Romchar).

Remarkably, the effect of biochar application on hot water carbon content was also more pronounced in the sandy soil than in the clayey soils. It might suggest that the organic matter quality was affected, but this interpretation is quite complicated. Recent studies suggests that this organic carbon fraction somehow reflects a bioavailable fraction of the organic matter pool, but these data showed that the incorporation of stable organic carbon compounds by biochar incorporation increased the hot water C content, where the incorporation of more labile organic residues such as manure and compost decreased its content in comparison with the fertilized control. For the clay soil in Kollumerwaard, differences among compost, slurry and fertilizer were negligible, whereas the hot water C content strongly decreased after the addition of biochar norit (“BC1”) and increased after the addition of biochar wood (“BC2”). No changes were present in the clay soil of Lelystad.

Since the CN ratio is derived from both the organic C and N analyses, it is likely that they are affected by the uncertainty in C analyses. Anyway, differences were not expected since the amount of C added is small compared to the total amount present. Similarly, there was no consistent pattern in the effect of organic residues on the nitrogen supplying capacity simply because the estimates of this capacity are mainly driven by the total organic N content, soil type and CN ratio.

Surprisingly, there was also no strong effect on the anaerobic mineralization rate, usually a sensitive test for differences in organic matter quality regarding the supply of nutrients. Given the fact that the uncertainty of this biological methods can vary up to 20%, there is no clear pattern present within clay soils. Hence, the amendment of either stabile or labile carbon had no effect on the direct N availability. This might be related to the fact that the soils are collected after the growing season, whereas possible differences in organic matter quality regarding N production are more likely visible before or during the start of the growing season. This might explain why for example the application of manure (as a labile organic matter source) even caused a decrease in N-availability in comparison with the fertilized control.

Basic soil properties

Besides the organic matter properties, a couple of other soil properties were determined including the CEC, the pH, and total and available nutrients. A selection of these parameters is visualized in the figure below.

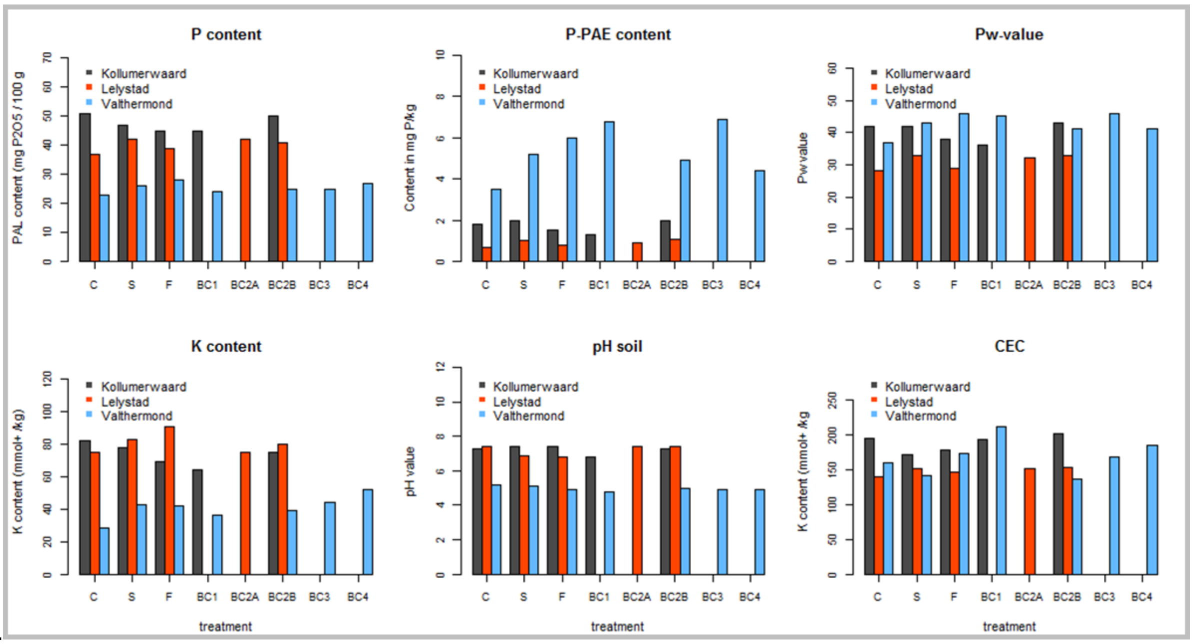

Figure 3.10. Effect of organic amendments (compost, slurry and biochars) on basic soil properties. Treatments are abbreviated as “C“ (compost), “S“ (slurry), “F“ (fertilizer), “BC1“ (biochar norit), “BC2“ (biochar wood) , “BC3“ (biochar ECN) and “BC4“ (Romchar).

Three years of organic matter incorporation of products varying in carbon and nutrient content, had no relevant effect on one of the analyzed properties. One may expect that soil improving products influence the aggregate stability and the calcium availability at the Cation Exchange Complex. Because most of the CEC was governed by calcium (~90 for both clay soil and the sandy soil), and the absence of any change in the CEC, these data suggest that none of the biochars had a structural effect on this soil property. In addition, the proportion of the CEC governed by Ca, Mg, K and Na, and the soil pH were not strongly altered (data not shown).

The CEC was higher in Kollumerwaard than in both other locations due to the higher clay content of the soil. The CEC in Valthermond was relatively high due to the high organic matter content. The mean levels varied from 166 mmol+ kg^{-1} in Lelystad up to 204 mmol+ kg^{-1} in Kollumerwaard.

Soil physical parameters

Within this project, the effect of soil improvers including biochars were evaluated for their contribution to or effect on soil permeability, penetration resistance and aggregate stability. The permeability of the soil was determined by water infiltration in small rings and this rate reflects (or might reflect) differences in soil texture, aggregate stability and actual moisture content of soils. Since organic residues amendment is likely to affect processes controlling soil structure, it is likely that the associated parameters as permeability, resistance and stability will change after frequent residue incorporation.

Soil aggregate analyses are often used as surrogates of the complex soil matrix because aggregation not only affects the protection of organic matter but also the microbial community structure, it limits oxygen diffusion, regulate water flow and determines nutrient adsorption and desorption (Six et al., 2004). The Aggregate Stability Index (ASI) distinguishes between aggregates smaller than or bigger than 250 μm, and as such, it might give an indication of the contribution of stabile aggregates since the stability and functioning of aggregates depends on their size. Overall, the ASI index is lower in the sandy soil compared to the clayey soils, simply reflecting the influence of soil texture (Figure 3.11.). Organic residue incorporation had no consistent effect on this Index, indicating that no structural changes have been taken place during the first three years of this experiment. The ASI index tended to be slightly lower in the biochar amended plots in Valthermond, whereas it increased in Kollummerwaard (in comparison with the fertilizer treatment).

The capacity of the soil to water infiltration varied between 0.1 and 0.4 mm s^{-1} with higher values for the sandy soil than both clayey soils (Figure 3.11). Amendment of the soil with biochars increased the infiltration capacity in Valthermond for the biochar norit (“BC1”) and the biochar ECN (“BC 3”) in comparison with the chemically fertilized control (“F”). In contrast, incorporation of biochar wood (“BC2”) decreased the infiltration capacity. All biochar (and other organic matter) treatments at Kollumerwaard increased the infiltration capacity whereas the capacity decreased in all organic treatments at Lelystad. Overall this suggests that the infiltration rate is improved or remains similar after biochar application.

Soil compaction, as a consequence of increased soil strength or resistance, restricts the rate of downward extension of roots and their lateral movement within compacted pans, which reduces the potential uptake of nutrients and water. The sensitivity of crops to disturbing root activity varies over crop varieties and the stage of growth. For example, potatoes are very sensitive to compaction at all stages of growth but particularly in the first month after emergence. Root growth rates are usually rapid when resistance is <1 MPa and decreased to almost 50% by a resistance above 1.5 MPa. Root growth becomes very slow at resistances above 3 MPa in most soils, although they continue to extend deeper into well-structured sub soils using natural burrows. In addition, a strong interface between two layers limits also optimum growth, even at a resistance lower than 3 MPa.

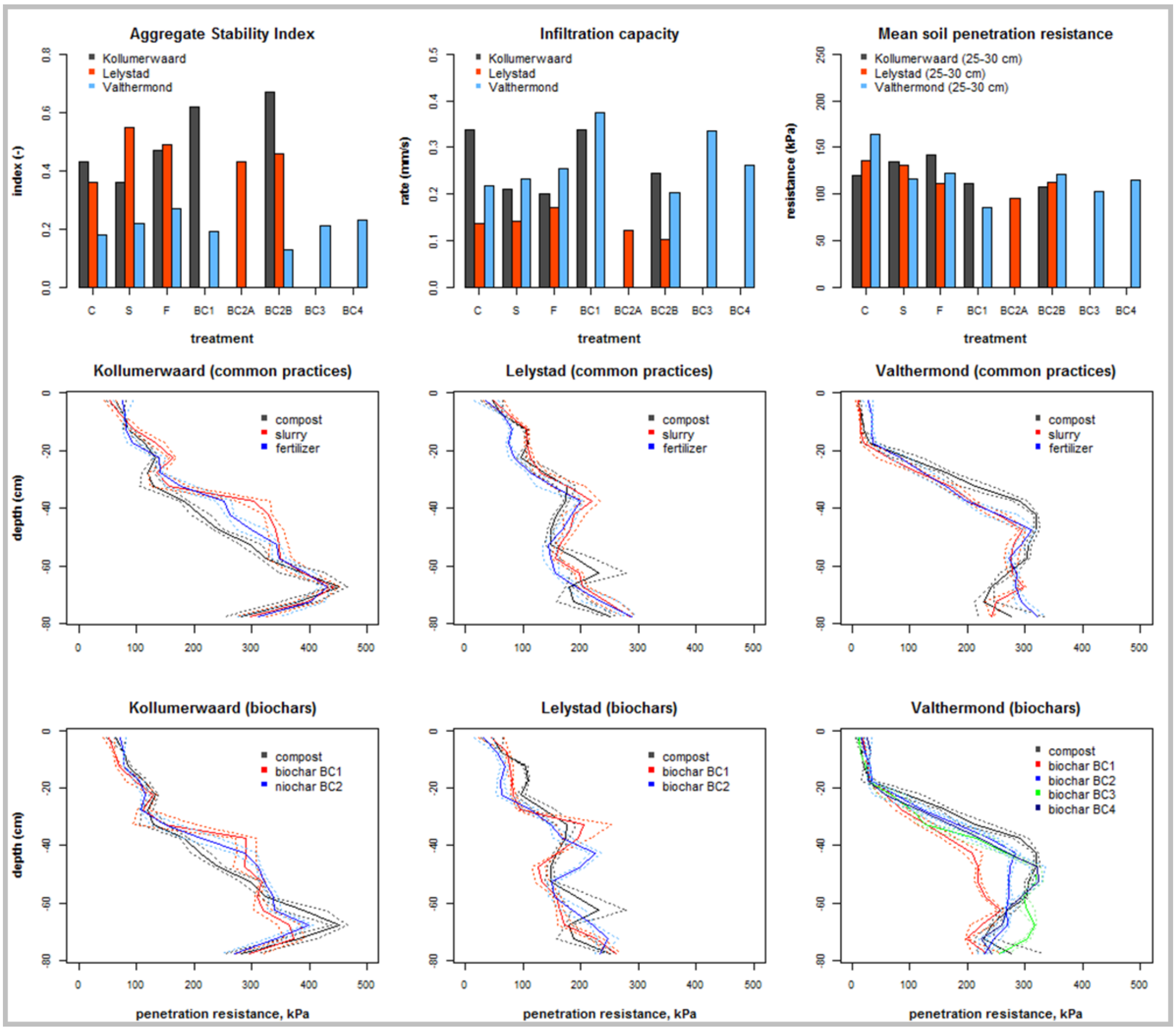

Figure 3.11. Effect of biochar application on aggregate stability, infiltration capacity and penetration resistance.

The soil penetration tests showed how the resistance of the soil profile changes over depth (Figure 3.11.), clearly indicating the presence of a ploughing layer in all locations but especially in Kollumerwaard and Valthermond. It is usually recommended that the resistance should be smaller than 3 MPa to ensure optimum root growth, and this threshold is not exceeded at all three locations. In comparison with the compost treatment was the penetration resistance of the subsoil slightly higher in Kollumerwaard and decreased in Valthermond in both other biochar treatments. Since biochar application is not likely to affect the subsoil penetration resistance (it is applied in the topsoil) after only three years of experimentation, this variation might reflect spatial variability present within the experimental field. The resistance in the ploughing layer was only slightly decreased in the clayey soils due to biochar application. On average, biochar tend to decrease the resistance of the topsoil compared to the treatment with chemical fertilizers only.

4 Conclusion

Application of biochar is believed to improve natural soil fertility not only due to its positive influence on organic matter and nutrient dynamics but also due its ability to affect soil structure. During the period 2010 to 2012 several biochars have been tested at three locations in the Netherlands. These field experiments were located at two clayey soils and one sandy soil, varying in soil characteristics and crop rotation systems. The biochars tested include the Romchar (as part of the Interreg project Climate Saving Soils) and three other products from national companies (‘biochar norit’, ‘biochar ECN’, and ‘biochar wood’). All these products have been tested in comparison with common agricultural practices like the amendment of soils with compost or slurry or chemical fertilizers only. The crops involved are spring wheat, seed potato and winter wheat in Kollumerwaard, spring barley, sugar beet and onion in Lelystad, and sugar beet, starch potato and spring barley in Valthermond. Both crop and soil were monitored during the three years. This report describes all crop data (crop yield and quality) but limits the changes in soil properties to the final year of this experiment (so, after three years of biochar application).

Both crop yield and crop quality were not affected by biochar incorporation at all three locations. Similar findings were shown for the soil food web’s composition and size, the composition of the dissolved organic matter fraction, basic soil solution chemistry (such as EC, pH and nutrients), organic matter levels and characteristics (hot water carbon, CN-ratio, N supplying capacity and anaerobic mineralization rate), and basic soil chemical and physical properties (like pH, CEC, infiltration capacity, penetration resistance, etc.). If any changes occur, they didn’t develop in a consequent direction giving doubt whether biochar application itself is the main factor driving the soil variables to change. Location specific characteristics like soil type and crop variety seem to have confounding effects on the changing soil properties. In addition, it might be possible that any positive changes are only detectable after a few years of practices incorporating resistant organic carbon into the soil. Because the experimental design differed among the locations, and the soil analyses have been made on combined samples without replication, it is difficult to make robust and statistically sound conclusions on potential benefits of biochar amendment on soil quality aspects. Nevertheless, since crop yields, crop quality and basic soil properties were hardly changed, it can be questioned whether the possible benefits accounts from a practical farmers perspective.

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Appendix I. Crop and soil data common field trial at Valthermond

Table I.1. Crop data part 1

	Stand judgement (score 1-10)				Lodging (Score 1-10)		Yield
Treatment	*11 May*	*7 June*	*27 June*	*30 July*	*27 June*	*30 July*	*ton/ ha*
Romchar 12	6.0	5.5	6.0	6.5	9.0	9.0	6.24
Romchar 21	6.5	7.5	7.0	7.0	9.0	9.0	6.77
Romchar 29	7.0	7.0	8.0	9.0	9.0	7.0	7.10
Control 18	6.0	7.0	8.0	7.5	9.0	8.5	6.71
Control 30	6.5	7.5	7.5	8.5	9.0	8.5	6.90
Control 32	6.5	6.0	7.5	8.0	9.0	8.5	6.76

* yield estimated with 15% moisture

Table I.2. Crop data part 2

	Protein	Grain composition at harvest (% in classes. mm)			
Treatment	*Content (%)*	*> 2.8*	*2.5<x<2.8*	*2.2<x<2.5*	*<2.2*
Romchar 12	12.1	95.7	3.4	0.6	0.3
Romchar 21	12.1	95.7	3.7	0.3	0.3
Romchar 29	12.4	93.8	5.0	0.9	0.3
Control 18	12.4	95.2	4.0	0.4	0.4
Control 30	12.8	94.7	4.3	0.6	0.4
Control 32	12.9	94.6	4.3	0.6	0.5

Table I.3. Crop data part 3

	Grain yield fresh		Moisture	Dry matter	Grain yield	Grain-weight
Treatment	kg/ plot	kg/ ha	%	%	kg ds/ ha	g/ 1000
Romchar 12	27.45	6100	13.0	87.0	5307	57.2
Romchar 21	29.75	6611	13.0	87.0	5752	60.0
Romchar 29	31.10	6911	12.7	87.3	6033	57.7
Control 18	29.40	6533	12.7	87.3	5704	58.4
Control 30	30.25	6722	12.7	87.3	5869	58.1
Control 32	29.65	6589	12.8	87.2	5746	58.8

Table I.4. Crop data part 4

	Straw yield fresh		Dry matter	Straw yield
Treatment	kg/ m2	kg/ ha	%	kg ds/ ha
Romchar 12	0.41	4100	0.903	3702
Romchar 21	0.34	3400	0.910	3094
Romchar 29	0.36	3600	0.898	3233
Control 18	0.23	2300	0.906	2084
Control 30	0.36	3600	0.899	3236
Control 32	0.32	3200	0.910	2912

Table I. 5. Inorganic N levels before crop sowing in spring (in kg N/ ha) (source: Blgg AgroXpertus)

	Top-layer (0-30 cm)		**Subsoil (30-60 cm)**		**Subsoil (60-90 cm)**	
Treatment	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
Romchar 12						
Romchar 21	16	<4	17	<4	13	<4
Romchar 29						
Control 18						
Control 30	28	<4	16	<4	14	<4
Control 32						

* samples analysed in spring are combined into one mixed sample before analysis

Table I. 6. Inorganic N levels after crop harvest (in kg N/ ha) (source: ILVO, Belgium)

	Top-layer (0-30 cm)		**Subsoil (30-60 cm)**		**Subsoil (60-90 cm)**	
Treatment	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
Romchar 12	33.0	7.8	24.1	3.4	6.8	3.4
Romchar 21	29.2	4.1	15.2	3.4	4.2	3.4
Romchar 29	87.4	5.4	25.7	3.4	12.9	3.4
Control 18	37.5	3.9	23.9	3.4	10.7	3.4
Control 30	50.8	4.2	20.3	3.4	13.7	3.4
Control 32	52.5	7.5	32.8	3.4	9.3	3.4

Table I. 7. Basic soil properties analysed during the growing season of 2012 (source: ILVO, Belgium)

				Extractable elements (mg/ 100 g dry soil)						
	OC	**pH-KCl**	**N-total**	**Fe**	**K**	**Mg**	**Ca**	**Mn**	**Na**	**P**
Treatment	%	-	%	-	-	-	-	-	-	-
				Analysis in spring						
Romchar 12	8.14	5.32	0.315	26.1	11.0	17.2	255.3	3.84	3.26	15.9
Romchar 21	10.92	5.04	0.396	27.9	9.9	19.9	313.3	4.88	2.88	14.1
Romchar 29	13.51	5.03	0.482	26.9	13.3	24.1	399.4	6.44	4.76	13.7
Control 18	7.70	5.07	0.355	21.4	6.6	16.1	253.5	3.95	2.29	13.5
Control 30	11.05	4.87	0.446	22.0	9.5	18.6	325.4	4.99	5.04	12.7
Control 32	10.77	4.92	0.391	31.0	12.2	18.7	298.2	5.04	3.63	14.9
				Analysis after harvest						
Romchar 12	8.29	5.21	0.321	23.6	8.5	15.7	251.8	3.41	3.60	15.7
Romchar 21	10.64	4.95	0.396	24.7	9.6	15.9	280.7	4.13	4.05	11.9
Romchar 29	12.35	4.90	0.497	22.5	11.5	19.4	336.9	5.28	4.37	10.4
Control 18	8.93	5.06	0.351	21.6	7.1	17.5	287.2	4.24	3.11	12.2
Control 30	10.28	4.89	0.436	20.2	7.5	17.7	290.8	4.59	3.73	10.6
Control 32	10.95	4.93	0.399	30.5	9.2	17.5	306.8	4.91	3.82	13.1

Appendix II. Experimental design and details common field trial

Algemene gegevens I

Datum 09-03-2012

Onderzoeker: Jan Paauw

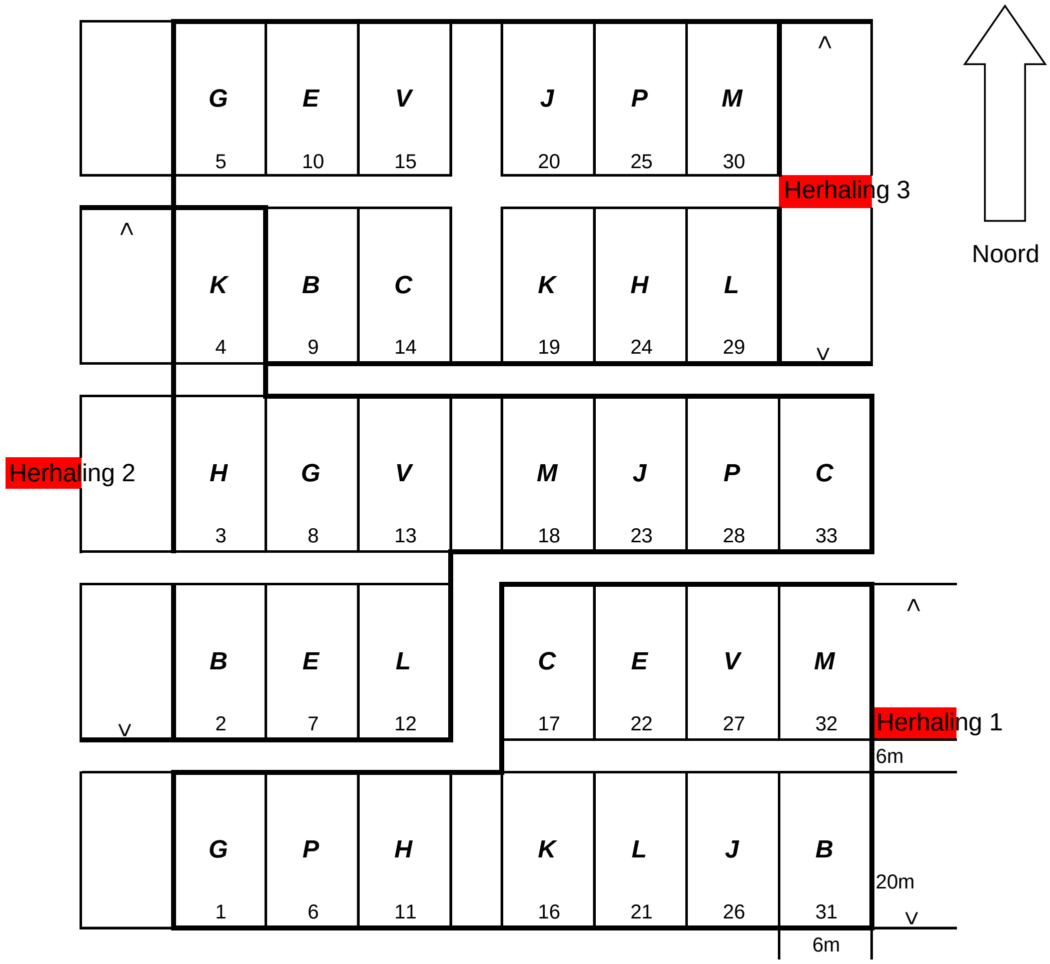
Vervanger: Klaas Wijnholds

Algemene gegevens II:

Gewas	:	Zomergerst
Voorvrucht	:	Zetmeelaardappelen
Ras	:	
Zaai-/Plantmoment	:	Volgens praktijk
Zaai-/Plantmethode	:	Volgens praktijk
Bemesting	:	N: Volgens proefplan
		P: Volgens proefplan
		K: Volgens proefplan
Onkruidbestrijding	:	Volgens praktijk
Plaagbestrijding	:	Volgens praktijk
Ziektebestrijding	:	Volgens praktijk
Oogst	:	
Aantal parallellen	:	3
Aantal objecten	:	11
Veldjesgrootte	:	bruto : 6 m. breed x 20 m. lang
		netto : 3 m x 16 m. lang
Oogst wel/niet vernietigen	:	*Indien van belang schema bijvoegen !*
Bijzondere wensen	:	*Zie draaiboek.*
Specifieke veiligheidsmaatregelen	:	
Bouwplan	:	2010 suikerbieten
		2011 zetmeelaardappelen
		2012 zomergerst
		2013 zetmeelaardappelen
		2014 suikerbieten
		2015 zetmeelaardappelen

Schema van het proefveld

KP 678 Bodemstructuur verbeteraars



Totale opp	51 * 124 m
Perceel	70 a
Bruto veld algemeen	6 * 20 m
Bruto veld object J	4 * 14 m
Netto veld oogst	3 * 12
Gewas	Zomergerst

Appendix III. Crop data field experiments 2010 to 2012

Table III.1. Crop data Kollumerwaard (spring wheat, 2010)

		Visual inspection score			**Length**	**Ripening**#	**Lodging**		**Moisture**	**Grain yield**	**Straw yield**	**Yield**
Treatment		stand	stand	stand	(cm)		score	(%)	(%)	(kg/ ha)	(ton/ ha)	(ton/ ha)
Code	Rep	1-jun	9-jun	9-jul	10-aug	10-aug	10-aug	10-aug				(at 15% moisture)
BC1	1	6	7	7	90	3	9	0	21.2	9439	4.31	8.75
BC1	2	6.5	7	7	90	2	8	10	21.0	9164	4.08	8.52
BC1	3	7	7	7	90	3	9	0	21.1	8330	3.15	7.73
BC2	1	7	7	7	90	3	9	0	21.1	8910	2.91	8.27
BC2	2	7.5	7	7	95	4	8	10	20.9	8967	4.66	8.35
BC2	3	7	7	7	90	4	8	10	20.8	8375	4.31	7.80
C	1	7.5	6.5	7	90	2	8	10	21.3	8430	3.15	7.81
C	2	6.5	7	7	90	2	8	10	20.9	8469	3.85	7.88
C	3	6.5	7	7	95	4.5	8	10	20.9	8417	5.01	7.83
F	1	7	7.5	7	90	2	8	10	21.1	8880	3.96	8.24
F	2	7	7.5	7	90	2	9	0	21.0	8861	3.26	8.24
F	3	7.5	7	7	95	4	8	10	20.9	8000	4.90	7.44
S	1	7	7	7	90	5	9	0	20.9	9453	4.08	8.80
S	2	8	7	7	90	2	9	0	20.9	9310	4.20	8.66
S	3	6.5	7	7	85	4	8	10	20.6	8875	4.43	8.29

* BC1 stands for Biochar norit; BC2 for Biochar wood, C for compost, F for fertilizer and S for slurry

Ripening score varies from 1 to 10: 1 is early and 10 is late

Table III.2. Crop data Kollumerwaard (spring wheat, 2010)

Treatment		**Grain data**					**Straw data**					**Total nutrient uptake**	
Code	rep	g N/ kg ds	g P/ kg ds	g P_2O_5/ kg ds	kg N/ ha	kg P2O5/ ha	g N/ kg ds	g P/ kg ds	g P_2O_5/ kg ds	kg N/ ha	kg P_2O_5/ ha	kg N/ ha	kg P2O5/ ha
BC1	1	19.9	3.5	8.0	148	60	4.1	0.6	1.4	14.4	4.8	162	64
BC1	2	20.2	3.8	8.7	146	63	4.1	0.6	1.4	13.6	4.6	160	68
BC1	3	20.9	3.8	8.7	137	57	4.1	0.6	1.4	10.5	3.5	148	61
BC2	1	21.1	3.5	8.0	148	56	4.1	0.6	1.4	9.7	3.3	158	60
BC2	2	20.9	3.8	8.7	148	62	4.1	0.6	1.4	15.6	5.2	164	67
BC2	3	22.3	3.7	8.5	148	56	4.1	0.6	1.4	14.4	4.8	162	61
C	1	19.5	3.5	8.0	129	53	4.1	0.6	1.4	10.5	3.5	140	57
C	2	19.5	3.8	8.7	131	58	4.1	0.6	1.4	12.8	4.3	143	63
C	3	21.6	3.9	8.9	144	59	4.1	0.6	1.4	16.7	5.6	161	65
F	1	20.5	3.7	8.5	144	59	4.1	0.6	1.4	13.2	4.4	157	64
F	2	21.5	4.0	9.2	151	64	4.1	0.6	1.4	10.9	3.6	161	68
F	3	22.2	3.9	8.9	140	57	4.1	0.6	1.4	16.3	5.5	157	62
S	1	19.5	3.7	8.5	146	63	4.1	0.6	1.4	13.6	4.6	159	68
S	2	20.9	3.9	8.9	154	66	4.1	0.6	1.4	14.0	4.7	168	70
S	3	22.1	3.8	8.7	156	61	4.1	0.6	1.4	14.8	5.0	171	66

* BC1 stands for Biochar norit; BC2 for Biochar wood, C for compost, F for fertilizer and S for slurry

Table III.3. Crop data Kollumerwaard (potato, 2011)

		Crop yield (ton/ ha/ size classes)									Number of tubers (number/ are/ size classes)									Inspection scores			
Treatment		<25	25-28	28-35	34-45	45-55	50-55	>55	28-55	Total	<25	25-28	28-35	34-45	45-55	50-55	>55	28-55	Total	Stand	Green score	Crop lays down	Number of stems
code	rep																			12-jul	12-jul	12-jul	(/m2)
BC1	1	0.1	0.5	1.1	8.4	19.5	12.9	3.4	41.9	46.0	108	283	350	1158	1667	825	192	4000	4583	7.5	7	ja	14.1
BC1	2	0.1	0.4	1.6	10.0	17.1	15.5	4.3	44.2	49.1	142	275	583	1450	1483	1042	225	4558	5200	7.5	7	ja	15.4
BC1	3	0.1	0.6	1.7	9.4	15.7	14.9	7.3	41.6	49.6	100	325	567	1292	1350	925	375	4133	4933	7	7	ja	15.9
BC2	1	0.1	0.6	1.5	10.1	16.3	13.6	5.5	41.5	47.7	117	308	492	1442	1392	875	267	4200	4892	7	7	ja	16.5
BC2	2	0.2	0.7	1.3	9.7	17.1	14.2	6.7	42.2	49.8	133	400	433	1392	1467	883	358	4175	5067	8	7	nee	15.8
BC2	3	0.2	0.5	1.3	8.4	17.9	15.4	5.8	42.9	49.4	175	250	433	1200	1608	992	333	4233	4992	8	7	nee	15.1
C	1	0.2	0.6	1.2	11.7	16.9	14.7	2.4	44.4	47.5	158	325	700	1592	1450	950	133	4692	5308	7	7	ja	14.6
C	2	0.2	0.6	1.3	9.3	17.2	16.5	5.6	44.3	50.7	142	342	433	1208	1467	1075	275	4183	4942	8	7	nee	15.4
C	3	0.1	0.5	1.3	9.8	15.3	16.9	5.5	43.2	49.2	142	267	417	1433	1325	1083	300	4258	4967	8	7.5	nee	16.9
F	1	0.3	0.5	1.4	10.0	17.8	13.7	4.6	42.9	48.2	150	233	475	1400	1583	917	250	4375	5008	7.5	7	ja	14.6
F	2	0.2	0.6	1.4	10.0	15.4	13.1	6.6	39.8	47.2	183	317	500	1433	1317	833	342	4083	4925	8.5	7	nee	16.8
F	3	0.2	0.6	1.4	9.7	14.8	16.2	7.5	42.0	50.2	142	325	467	1392	1308	1075	417	4242	5125	8	7	nee	15.4
S	1	0.1	0.5	1.0	11.4	15.2	15.0	6.0	42.6	49.2	150	408	317	1567	1275	992	317	4150	5025	8	6	nee	17.1
S	2	0.2	0.5	1.1	12.1	17.1	15.1	2.7	45.3	48.6	158	233	350	1708	1467	967	158	4492	5042	7	6	ja	18.6
S	3	0.1	0.4	1.3	10.8	19.1	13.8	4.3	45.0	49.8	100	217	425	1508	1617	892	242	4442	5000	6.5	6	nee	16.2

* BC1 stands for Biochar norit; BC2 for Biochar wood, C for compost, F for fertilizer and S for slurry

Table III.4. Crop data Kollumerwaard (winter wheat, 2012)

		Yield		Visual inspection score							
Treatment		(kg/ ha)	(ton/ ha)	stand	greenscore	stand	greenscore	stand	greenscore	length	Lodging
Code	rep	bij 15% moisture	ton/ha	(-)	(-)	(-)	(-)	(-)	(-)	(cm)	(%)
				24-apr	24-apr	11-jun	11-jun	17-aug	17-aug	17-aug	17-aug
BC1	1	13160	13.16	6.0	6.0	7	7	7	1	85	0
BC1	2	13035	13.04	6.5	6.0	7	6.5	7	1	80	0
BC1	3	13411	13.41	6.5	6.5	7	7	7	1	85	0
BC2	1	13176	13.18	6.0	6.0	7	7	7	1	80	0
BC2	2	13317	13.32	6.5	6.0	7	7	7	1	85	0
BC2	3	13192	13.19	6.0	6.5	7	7	7	1.5	80	0
C	1	13457	13.46	6.5	6.0	7	6.5	7	1	85	0
C	2	13065	13.07	6.5	6.5	7	6.5	7	1.5	85	0
C	3	12869	12.87	5.5	6.0	7	7	7	1.5	85	0
F	1	13410	13.41	6.5	6.0	7	7	7	1	85	0
F	2	13302	13.30	6.5	7.0	7	7	7	1	80	0
F	3	13423	13.42	6.5	6.0	7	6.5	7	1	85	0
S	1	13644	13.64	6.5	7.0	7	7	7	1.5	85	0
S	2	13593	13.59	6.5	7.0	7.5	7	7	2	90	0
S	3	13395	13.40	6.5	7.0	7	7	7	1.5	80	0

* BC1 stands for Biochar norit; BC2 for Biochar wood, C for compost, F for fertilizer and S for slurry

Table III.5. Crop data Lelystad (spring barley, 2010)

Treatment		Visual inspection score			Yield	Size fractionation grain yield				Grain composition				Straw composition	
		Stand		Lodging	at 15% moisture	(%, in size class, in mm)				Content		Uptake		Uptake	
Code	rep	23-jun	7-jul	5-aug	(ton/ ha)	< 2.2	2.2-2.5	2.5-2.8	>2.5	g N/ kg ds	g P_2O_5/ kg ds	kg N/ ha	kg P_2O_5/ ha	kg N/ ha	kg P/ ha
BC2A	1	8	8	25	9.1	0.5	1.1	8.8	98.4	15.7	7.8	121.0	60.0	11.2	3.3
BC2A	2	8	8	15	8.5	0.3	0.3	5.3	99.4	16.1	7.8	116.7	56.5	11.2	3.3
BC2A	3	8	8	40	9.3	0.7	2.5	11.0	96.9	16.3	8.2	129.4	65.4	11.2	3.3
BC2B	1	8	8	40	8.9	0.4	1.3	9.3	98.3	15.1	8.5	114.3	64.2	11.2	3.3
BC2B	2	8	8	0	9.4	0.2	0.9	5.3	98.9	16.7	8.0	134.1	64.4	11.2	3.3
BC2B	3	8	8	0	8.9	0.2	0.2	4.3	99.6	16.5	7.1	124.2	53.4	11.2	3.3
C	1	8	8	15	8.8	0.3	1.0	6.4	98.7	14.3	8.0	107.1	60.0	11.2	3.3
C	2	8	8	25	9.6	0.8	2.3	10.6	97.0	15.2	8.5	123.5	68.8	11.2	3.3
C	3	8	8	0	8.6	0.3	0.5	4.2	99.2	15.6	7.6	113.8	55.1	11.2	3.3
S	1	8	8	40	9.4	0.5	2.3	12.0	97.1	16	7.8	128.5	62.5	11.2	3.3
S	2	8	8	25	8.9	0.9	2.1	10.1	97.0	14.9	7.8	112.8	59.0	11.2	3.3
S	3	8	8	15	9.4	0.4	0.9	5.1	98.7	15.7	7.1	124.8	56.4	11.2	3.3

* BC2A stands for Biochar wood (applied 2.5 ton/ ha), BC2B for the same biochar (applied 5 ton/ ha), C for compost, F for fertilizer and S for slurry

Table III.6. Crop data Lelystad (sugar beet, 2011)

Treatment		Nr. of plants	Visual judgement score			Yield	Composition						
Code	rep	(/ ha)	Stand	Soil cover	Leafspots/ Cercospora	(ton/ ha)	sugar	sugar	Tarra		K	Na	N-amino
			25-may	(%)	28-sep		(%)	(ton/ ha)	soil	beet top	(mmol/ kg)	(mmol/ kg)	(mmol/ kg)
BC2A	1	99000	8	90	8	111.77	16.98	18.98	12.08	3.12	31.90	1.88	9.65
BC2A	2	103333	8	90	8	108.31	17.08	18.50	9.63	2.16	32.43	1.73	9.70
BC2A	3	104000	8	95	8	114.39	17.02	19.47	8.89	3.34	30.96	1.91	9.88
BC2B	1	96500	8	90	8	112.80	17.19	19.39	8.12	3.65	31.94	1.75	8.56
BC2B	2	101500	7.5	95	8	116.95	17.11	20.01	9.39	3.40	29.74	1.92	8.92
BC2B	3	97000	8	90	8	112.13	16.58	18.60	7.10	1.10	31.47	1.95	9.15
C	1	101500	7.5	98	8	-	17.19	-	12.31	1.61	31.04	1.75	8.51
C	2	99500	8	90	8	116.03	16.72	19.40	10.02	0.92	28.89	1.92	7.36
C	3	104000	8	95	8	105.28	16.96	17.86	9.19	1.80	32.06	2.01	9.21
S	1	98000	8	90	8	113.33	16.71	18.94	9.98	3.26	29.64	1.89	8.45
S	2	105000	8	95	8	110.44	16.94	18.71	12.32	2.85	30.30	1.79	8.31
S	3	91000	8	90	8	113.94	16.96	19.33	11.15	1.97	30.21	2.01	9.69

* BC2A stands for Biochar wood (applied 2.5 ton/ ha), BC2B for the same biochar (applied 5 ton/ ha), C for compost, F for fertilizer and S for slurry

Table III.7. Crop data Lelystad (onion, 2012)

Treatment		Yield (Fresh) per size class (mm)							Visual judgement score					
		Total yield	<35	35-40	40-60	60-80	>80	loss	Stand		Green score	Lodging		
Code	rep	(ton/ ha)	(ton/ ha)	(ton/ ha)	(ton/ ha)	(ton/ ha)	(ton/ ha)	(ton/ ha)	10-jul	8-aug	27-aug	15-aug	27-aug	11-sep
BC2A	1	93.1	0.6	1.3	30.5	49.4	1.8	0.0	8	8	7	7	2	1
BC2A	2	90.3	0.5	0.7	38.9	43.6	0.4	0.1	8	8	7	7	1	1
BC2A	3	90.0	0.6	1.5	42.8	37.9	0.7	0.2	8	8	7	8	1.5	1
BC2B	1	93.9	0.7	1.0	35.0	47.2	0.2	0.4	8	8	7	7.5	2	1
BC2B	2	91.4	0.5	1.2	36.4	46.2	1.4	0.2	8	8	7	6.5	1	1
BC2B	3	90.8	0.8	1.1	46.0	34.1	0.5	0.2	8	8	7	7	1	1
C	1	90.3	0.5	1.1	40.8	33.4	0.9	0.1	8	8	7	6.5	1	1
C	2	91.7	0.6	1.1	38.1	44.4	1.1	0.2	8	8	7	8	3	1
C	3	92.2	0.7	2.0	47.3	35.1	0.7	0.2	8	8	7	7.5	1.5	1
S	1	91.9	0.4	1.0	37.2	43.2	3.1	0.4	8	8	7	7	1.5	1
S	2	90.6	0.3	0.9	32.2	48.2	2.1	0.3	8	8	7	7	1	1
S	3	93.6	0.5	1.1	38.6	40.4	0.5	0.1	8	8	7	7	1.5	1
F	1	90.3	0.4	1.1	34.6	45.9	2.6	0.4	8	8	7	8	2	1
F	2	90.6	0.4	1.1	33.1	48.4	1.9	0.1	8	8	7	7	1.5	1
F	3	92.8	0.7	1.0	39.7	42.4	0.7	0.6	8	8	7	8	2	1.5

* BC2A stands for Biochar wood (applied 2.5 ton/ ha), BC2B for the same biochar (applied 5 ton/ ha), C for compost, F for fertilizer and S for slurry

Table III.8. Crop data Valthermond (sugar beet, 2010)

Treatment		**Visual judgement score** Stand			**Yield** (ton/ ha)	**Composition** sugar	sugar	tarra		K	Na	N-amino
Code	Rep	24-aug	21-sep	16-nov		(%)	(ton/ ha)	soil	beet top	(mmol/ kg)	(mmol/ kg)	(mmol/ kg)
BC1	1	7	7.5	6	52.48	18.42	9.67	6.24	9.17	31.15	4.61	10.19
BC1	2	8	8.5	9	59.69	18.09	10.80	4.74	9.14	33.11	6.56	13.49
BC1	3	8.5	9	7.5	63.54	18.25	11.60	4.52	8.34	31.88	5.93	12.61
BC2	1	6	7.5	7.5	59.42	18.97	11.27	4.68	7.21	29.46	3.54	11.33
BC2	2	7.5	8	7.5	62.50	18.40	11.50	5.50	8.39	33.89	5.33	12.85
BC2	3	9	9	8.5	56.53	19.06	10.77	5.87	8.91	30.25	3.48	12.14
BC3	1	8	9	8	61.93	18.43	11.41	5.24	9.02	33.56	5.17	12.98
BC3	2	7	8	7.5	60.88	18.56	11.30	5.28	9.17	31.35	4.54	12.61
BC3	3	8.5	9	9	61.32	18.49	11.34	5.28	8.73	30.78	5.20	11.43
BC4**	1	7.5	8	7	59.60	18.66	11.12	7.09	11.42	30.59	4.73	12.78
BC4**	2	8	9	8.5	56.05	18.14	10.17	7.74	10.51	33.28	5.42	12.76
BC4**	3	8.5	8	8.5	63.17	18.29	11.56	6.28	8.54	31.35	4.86	14.06
C	1	7	8.5	8	59.45	19.14	11.38	4.96	8.88	29.39	3.48	9.55
C	2	7	8	6.5	61.16	18.86	11.53	4.43	9.16	28.59	3.98	9.98
C	3	6	8	8	60.84	19.10	11.62	5.49	10.17	31.75	3.57	11.06
F	1	7.5	9.5	8.5	60.77	18.34	11.14	4.77	8.07	28.73	5.17	12.91
F	2	9	9	8.5	60.41	18.21	11.00	5.87	8.85	29.98	5.08	13.80
F	3	9	8.5	9	64.07	18.46	11.83	5.72	7.61	32.24	5.55	12.84
S	1	8	7.5	7.5	59.12	18.93	11.19	4.22	7.67	29.56	3.98	11.73
S	2	7.5	8.5	8.5	56.78	18.28	10.38	7.07	9.58	31.65	5.43	11.77
S	3	8	8.5	8	60.91	18.83	11.47	5.34	9.05	28.79	4.89	12.17

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

** this BC4 treatment received no biochar until 2011, plots were treated like the ‘F’ treatment for all other years.

Table III.9. Crop data Valthermond (starch potato, 2011)

Treatment		Visual score			Crop yield	Under water weight	Visual judgement score				
		Stand	Stand	Stand	ton/ ha		SCF score	Tuber damage	Tuber damage	Green	Scabies
Code	Rep	14-jun	14-jul	9-sep		(g/ 5 kg)	(-)	light	heavy	color	
BC1	1	7.5	6.5	8	42.0	508.9	94	5	10	10	9
BC1	2	7	8	9	40.5	502.1	96	8	10	9	9
BC1	3	7.5	8.5	9	39.4	501.0	93	5	10	9	9
BC2	1	6.5	6	7.5	42.9	527.0	93	5	10	9	9
BC2	2	7.5	6	8	41.5	506.3	92	8	10	5	9
BC2	3	7.5	7.5	8	46.0	519.4	97	8	10	9	10
BC3	1	7	8	8.5	41.8	508.0	96	8	10	9	9
BC3	2	7	7	8.5	43.5	541.2	93	8	10	10	5
BC3	3	7.5	8	9	44.1	523.8	96	8	10	9	9
BC4**	1	7	7	8	44.3	515.6	96	8	10	9	9
BC4**	2	7	8.5	9	47.2	512.2	93	5	10	9	9
BC4**	3	8	8	8.5	42.7	489.7	92	8	10	9	5
C	1	7.5	6	8.5	44.8	516.3	92	8	10	5	9
C	2	7.5	7	7.5	45.7	552.9	97	8	10	9	10
C	3	6	7	7	48.3	546.1	96	8	10	9	9
F	1	6.5	6.5	7.5	35.9	496.4	92	8	10	5	9
F	2	8	8	9	42.6	521.9	92	8	10	9	5
F	3	8	7.5	8	39.2	519.7	97	8	10	10	9
S	1	6.5	7.5	7.5	46.2	517.0	93	5	10	9	9
S	2	8	7.5	8.5	43.4	513.8	97	8	10	10	9
S	3	8	7.5	9	45.3	523.5	92	8	10	9	5

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

** this BC4 treatment received no biochar until 2011, plots were treated like the ‘F’ treatment for all other years.

Table III.10. Crop data Valthermond (spring barley, 2012)

Treatment		**Visual judgement score**						**Yield at**	**Protein**	**Size distribution grain yield (%) per size class (in mm)**			
		Stand	Stand	Stand	Stand	Lodging		15% moisture	content				
Code	rep	11-may	7-jun	27-jun	30-jul	27-jun	30-jul	(ton/ ha)	(%)	>2.8	2.5-2.8	2.2-2.5	<2.2
BC1	1	6.5	7.5	7.5	8.5	8.5	8	6.91	12.1	94.9	4.1	0.6	0.4
BC1	2	6	7.5	6.5	6	9	9	6.84	12.1	95.3	3.7	0.5	0.5
BC1	3	6.5	7.5	7.5	7.5	9	8.5	7.11	12.0	95.4	3.7	0.6	0.3
BC2	1	6.5	6	6.5	7	8.5	9	5.75	12.4	94.1	5.0	0.6	0.3
BC2	2	6.5	7	7.5	8	8.5	9	6.08	12.1	94.2	4.8	0.6	0.4
BC2	1	6.5	7	7.5	9	5	2	6.87	13.1	92.4	6.5	0.6	0.5
BC3	1	6.5	7	7.5	8.5	9	8.5	6.56	12.0	94.3	4.6	0.7	0.4
BC3	2	6.5	7	7	8	9	9	6.71	12.3	94.9	3.8	0.9	0.4
BC3	3	7	8.5	7.5	8	9	9	6.90	12.3	94.7	4.0	0.8	0.5
BC4	1	6	5.5	6	6.5	9	9	6.24	12.1	95.7	3.4	0.6	0.3
BC4	2	6.5	7.5	7	7	9	9	6.77	12.1	95.7	3.7	0.3	0.3
BC4	3	7	7	8	9	9	7	7.10	12.4	93.8	5.0	0.9	0.3
C	1	6	7	7.5	8	9	8.5	7.19	12.0	95.4	3.6	0.6	0.4
C	2	6.5	6.5	6.5	7	9	9	5.87	12.0	93.6	5.1	0.7	0.6
C	3	6.5	5.5	6.5	6	9	9	5.63	12.3	94.2	4.8	0.4	0.6
S	1	6	6.5	7	7	9	9	5.69	12.3	95.8	3.4	0.3	0.5
S	2	6.5	7.5	7	8	9	9	6.77	11.8	96.0	3.3	0.4	0.3
S	3	7	8	8.5	8.5	8	5	6.88	12.6	93.1	5.7	0.7	0.5
F	1	6	7	8	7.5	9	8.5	6.71	12.4	95.2	4.0	0.4	0.4
F	2	6.5	7.5	7.5	8.5	9	8.5	6.90	12.8	94.7	4.3	0.6	0.4
F	3	6.5	6	7.5	8	9	8.5	6.76	12.9	94.6	4.3	0.6	0.5

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Appendix IV. Soil data field experiments 2010 to 2012

Table IV.1. Soil properties: soil food web analyses and DOM fractions

	Kollumerwaard					Lelystad					Valthermond						
	BC1	**BC2**	**C**	**F**	**S**	**BC2A**	**BC2B**	**C**	**F**	**S**	**BC1**	**BC2**	**BC3**	**BC4**	**C**	**F**	**S**
Soil foodweb data (ug/ g)																	
MB (active)	50.07	46.26	66.87	47.11	52.9	32.71	41.30	39.02	38.03	37.8	24.21	24.14	24.77	54.59	20.78	41.64	33.37
MB (total)	404.7	289.0	385.6	375.0	286	293.7	265.7	235.1	252.4	280	261.9	268.1	278.2	289.6	232.3	277.9	254.7
FBM (active)	18.57	18.20	12.72	25.22	23.3	20.87	17.25	24.57	25.25	23.3	10.98	7.55	8.21	5.19	12.76	7.99	10.81
FBM (total)	95.88	117.3	46.38	62.05	84.5	61.07	65.60	89.77	93.16	48.7	63.89	46.33	86.84	108.8	148.1	41.38	123.9
Hyfediameter (µm)	1.90	1.90	2.00	1.80	1.90	1.70	1.80	1.70	1.90	1.80	2.00	1.90	1.90	1.80	2.00	1.70	2.00
Ratio MB : FBM	0.24	0.41	0.12	0.17	0.30	0.21	0.25	0.38	0.37	0.17	0.24	0.17	0.31	0.38	0.64	0.15	0.49
Ratio active: total FBM	0.19	0.16	0.27	0.41	0.28	0.34	0.26	0.27	0.27	0.48	0.17	0.16	0.09	0.05	0.09	0.19	0.09
Ratio active: total MB	0.12	0.16	0.17	0.13	0.18	0.11	0.16	0.17	0.15	0.14	0.09	0.09	0.09	0.19	0.09	0.15	0.13
Ratio active FBM: MB	0.37	0.39	0.19	0.54	0.44	0.64	0.42	0.63	0.66	0.62	0.45	0.31	0.33	0.10	0.61	0.19	0.32
Dissolved organic carbon (DOC) fractions (mg C/ L)																	
Humic acids	0.51	0.13	0.24	0.23	0.27	0.71	0.74	1.09	0.75	0.68	0.70	1.51	1.64	1.29	1.55	1.80	1.50
Fulvic acids	0.50	0.16	0.19	0.32	0.28	0.00	0.00	0.00	0.00	0.00	2.27	2.03	2.52	3.04	1.44	3.32	1.10
Hydrophobic neutrals	0.58	1.01	0.00	1.57	1.46	0.47	0.59	0.85	0.94	0.18	6.33	6.50	6.86	6.70	3.68	7.23	4.53
Hydrophilic acids	2.10	1.76	1.81	2.01	2.09	0.65	1.14	0.91	0.86	0.81	1.95	1.70	0.65	2.04	1.19	1.52	0.67
Hydrophilic neutrals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.03	0.14	0.02
Total DOC	3.69	3.06	2.24	4.12	4.10	1.83	2.47	2.85	2.55	1.67	11.25	11.74	12.26	13.07	7.90	14.01	7.82

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

** FBM stands for fungal biomass, MB for microbial biomass

Table Iv.2. Soil solution characteristics

	Kollumerwaard					Lelystad					Valthermond						
	BC1	**BC2**	**C**	**F**	**S**	**BC2A**	**BC2B**	**C**	**F**	**S**	**BC1**	**BC2**	**BC3**	**BC4**	**C**	**F**	**S**
EC (mS/ cm)	0.20	0.30	0.30	0.20	0.20	0.50	0.50	0.50	0.50	0.50	0.10	0.10	0.10	0.20	0.10	0.20	0.10
Acidity, pH (-)	7.10	7.00	6.90	6.90	7.00	6.90	7.10	6.80	7.00	7.00	4.80	5.00	4.70	4.90	5.40	4.80	5.10
Ammonium (mmol/ L)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Potassium (mmol/ L)	0.20	0.10	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.70	0.10	0.10	0.50	0.10	0.20	0.10
Sodium (mmol/ L)	0.30	0.30	0.40	0.30	0.50	0.40	0.40	0.40	0.40	0.40	0.30	0.10	0.20	0.30	0.20	0.30	0.20
Calcium (mmol/ L)	0.70	0.80	0.90	0.80	0.90	1.80	1.90	1.90	1.80	1.90	0.20	0.20	0.30	0.50	0.40	0.50	0.20
Magnesium (mmol/ L)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Nitrate (mmol/ L)	0.20	0.90	0.50	0.20	0.40	2.40	2.30	2.50	2.30	2.40	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Chloride (mmol/ L)	0.20	0.20	0.20	0.20	0.20	0.60	0.60	0.70	0.70	0.70	0.20	0.20	0.60	1.40	0.90	1.10	0.20
Sulphate (mmol/L)	0.10	0.10	0.20	0.10	0.20	0.20	0.20	0.30	0.20	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.10
HCO3 (mmol/ L)	1.30	1.30	1.20	1.40	1.30	0.80	0.90	0.80	0.80	0.80	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Phosphorus (mmol/ L)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.08	0.06	0.05	0.04	0.04	0.04	0.06
Silicium (mmol/ L)	0.48	0.48	0.47	0.49	0.47	0.30	0.31	0.29	0.30	0.30	0.08	0.08	0.04	0.05	0.06	0.04	0.04
Iron (umol/ L)	1.80	0.80	0.50	1.20	0.50	0.50	0.50	0.50	0.50	0.50	8.70	8.20	4.70	3.60	4.60	3.70	5.80
Manganese (umol/ L)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Zinc (umol/ L)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.50	0.60	0.60	0.30	0.70	0.50
Boron (umol/ L)	11.00	14.0	15.0	15.0	14.0	5.70	5.70	5.20	5.10	5.80	2.80	2.90	3.20	3.60	3.50	3.20	3.10
Copper (umol/ L)	0.10	0.10	0.20	0.20	0.20	0.10	0.10	0.10	0.10	0.10	0.30	0.30	0.30	0.20	0.10	0.30	0.30

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Table IV.3. Basic soil properties

	Location Kollumerwaard					Lelystad					Valthermond						
	BC1	**BC2**	**C**	**F**	**S**	**BC2A**	**BC2B**	**C**	**F**	**S**	**BC1**	**BC2**	**BC3**	**BC4**	**C**	**F**	**S**
Total N (mg/ kg)	1760	1740	1770	1500	1640	980	1080	1030	1100	1240	3370	2340	3130	3380	2540	2920	2390
CN ratio (-)	11	11	11	11	10	12	12	11	10	12	29	23	23	22	24	26	25
P-PAE (mg P/ kg)	1.30	2.00	1.80	1.50	2.00	0.90	1.10	0.70	0.80	1.00	6.80	4.90	6.90	4.40	3.50	6.00	5.20
Pw (mg P2O5/ L)	36	43	42	38	42	32	33	28	29	33	45	41	46	41	37	46	43
P-AL (mg P2O5/ 100 g)	45	50	51	45	47	42	41	37	39	42	24	25	25	27	23	28	26
K-PAE (mg K/ kg)	64	75	82	69	78	75	80	75	91	83	36	39	44	52	28	42	43
K (mmol+/ kg)	5.20	5.60	5.70	5.80	5.60	4.30	3.90	4.10	4.10	4.20	3.80	3.10	3.00	3.70	3.70	3.20	2.70
S-total (mg S/ kg)	970	910	940	880	1040	780	540	550	560	900	880	490	650	750	590	690	570
S supply (kg S/ ha)	69	69	69	69	69	69	62	63	63	69	18	14	16	21	17	17	16
Mg-PAE (mg Mg/ kg)	86	87	86	80	77	39	42	38	44	51	110	92	103	118	81	133	125
Na-PAE (mg Na/ kg)	23	20	27	22	31	16	18	16	26	17	23	14	14	19	14	21	23
pH (-)	6.80	7.30	7.30	7.40	7.40	7.40	7.40	7.40	6.80	6.90	4.80	5.00	4.90	4.90	5.20	4.90	5.10
CaCO3 (%)	7.80	8.10	8.10	8.00	7.70	6.50	6.90	6.90	6.50	6.50	NA	NA	NA	NA	NA	NA	NA
Lutum (%)	25	25	24	22	22	19	18	17	18	16	2	1	1	1	2	2	2
CEC (mmol+/ kg)	194	202	196	178	172	151	154	140	147	152	212	136	168	185	160	174	142
Ca-CEC (%)	90	90	90	90	90	14	23	21	21	17	111	110	109	101	105	108	106
Mg-CEC (%)	6.50	6.70	6.30	6.40	6.60	93	93	92	92	92	71	73	74	78	81	77	81
K-CEC (%)	2.70	2.80	2.90	3.30	3.30	3.60	4.00	4.30	4.50	4.90	11	9.60	11	8.60	10	8.80	9.20
Na-CEC (%)	0.60	0.50	0.50	0.60	0.60	2.80	2.50	2.90	2.80	2.80	1.80	2.30	1.80	2.00	2.30	1.80	1.90
Available Ca (kg Ca/ ha)	938	665	544	772	813	1332	841	1562	1963	1748	350	282	326	369	351	342	315
Ca-total (ton Ca/ ha)	10.09	10.48	10.20	9.21	8.88	8.58	8.74	7.89	8.28	8.03	6.99	5.63	6.52	7.38	7.02	6.85	6.30

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Table IV.4. Organic matter properties and soil physical parameters

	Kollumerwaard					Lelystad					Valthermond						
	BC1	**BC2**	**C**	**F**	**S**	**BC2A**	**BC2B**	**C**	**F**	**S**	**BC1**	**BC2**	**BC3**	**BC4**	**C**	**F**	**S**
Organic matter characteristics																	
Organic matter (%)	4.00	3.80	3.80	3.20	3.40	2.30	2.50	2.30	2.30	3.10	16.90	9.30	12.20	13.00	10.70	12.90	10.40
C-org (%)	2.00	1.90	1.90	1.60	1.70	1.10	1.30	1.20	1.20	1.50	NA	NA	NA	NA	NA	NA	NA
N supplying capacity (kg N/ ha)	89	85	84	72	87	47	52	56	63	59	7	42	50	63	38	26	30
Hot water carbon (mg C/ kg)	282	609	501	576	523	174	197	191	190	207	1894	1157	1856	1897	1002	1844	1352
Anaerobic mineralization rate (mg N/ kg)	47	53	49	44	51	12	17	21	18	12	72	41	71	54	44	63	51
Soil physical parameters																	
Lutum (%)	25.85	25.85	25.85	25.85	25.85	16.85	16.85	16.85	16.85	16.85	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Silt (%)	36.40	36.40	36.40	36.40	36.40	30.55	30.55	30.55	30.55	30.55	7.20	7.20	7.20	7.20	7.20	7.20	7.20
Sand (%)	37.75	37.75	37.75	37.75	37.75	52.60	52.60	52.60	52.60	52.60	90.05	90.05	90.05	90.05	90.05	90.05	90.05
Aggregate Stability Index (-)	0.62	0.67	0.43	0.47	0.36	0.43	0.46	0.36	0.49	0.55	0.19	0.13	0.21	0.23	0.18	0.27	0.22
Infiltration rate	0.34	0.25	0.34	0.20	0.21	0.12	0.10	0.14	0.17	0.14	0.38	0.20	0.34	0.26	0.22	0.25	0.23

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Table IV.5. Mean penetration resistance (n=50) per soil layer

Depth	Kollumerwaard					Lelystad					Valthermond						
(cm)	BC1	BC2	C	F	S	BC2A	BC2B	C	F	S	BC1	BC2	BC3	BC4	C	F	S
0-5	52.8	72.7	65.0	76.9	54.8	45.6	31.3	46.8	35.4	49.2	17.9	16.0	11.7	26.3	9.8	27.7	9.2
5-10	61.4	78.9	78.5	79.7	71.4	73.3	55.0	63.2	65.6	75.7	23.1	22.1	14.9	31.5	16.2	34.8	13.7
10-15	70.0	78.0	85.1	81.7	95.9	76.3	68.2	104.4	80.0	107.0	27.4	31.2	23.9	26.2	20.5	34.1	14.6
15-20	97.5	105.1	113.0	94.1	134.4	80.6	60.8	108.3	73.8	107.3	30.1	34.2	27.5	27.6	29.3	36.0	20.6
20-25	129.9	115.7	133.3	139.6	162.5	82.6	62.4	96.5	83.9	112.3	58.1	75.5	67.4	57.3	96.2	82.6	64.2
25-30	111.9	107.7	120.5	142.4	134.8	94.8	113.0	136.4	111.8	130.5	85.4	121.5	103.3	114.6	163.4	122.1	115.9
30-35	148.6	148.6	129.0	176.2	156.3	204.8	148.3	175.3	152.3	177.7	128.1	182.5	127.0	170.8	214.3	163.3	169.5
35-40	290.5	212.4	183.3	253.2	303.4	194.9	168.8	174.7	199.4	219.9	167.3	237.6	214.0	221.9	291.9	197.9	206.0
40-45	290.6	288.8	211.4	261.3	328.6	160.7	224.7	158.9	184.0	188.0	209.0	282.4	267.5	270.2	318.5	255.9	252.8
45-50	288.3	312.2	242.8	300.2	341.3	126.6	199.4	147.4	168.6	181.6	217.4	274.1	320.1	320.9	319.2	310.4	294.4
50-55	318.5	321.4	298.0	342.4	347.3	132.6	150.6	147.8	143.9	163.8	217.7	271.3	319.7	323.7	304.9	292.7	280.1
55-60	309.8	337.5	322.9	347.1	348.4	158.5	153.9	192.4	148.5	156.0	230.7	272.3	297.6	292.9	303.0	271.2	275.1
60-65	319.1	340.2	388.3	395.4	388.7	164.2	186.2	230.5	156.4	196.6	257.9	268.3	303.9	268.0	269.3	285.0	277.4
65-70	365.2	398.7	452.5	429.7	442.6	172.6	220.9	179.9	191.5	203.4	224.1	269.0	317.1	259.1	241.5	283.4	296.5
70-75	373.7	341.8	381.4	402.9	396.5	226.4	246.7	187.9	235.1	244.3	198.0	245.6	303.3	224.2	228.8	292.4	249.9
75-80	296.3	270.1	282.2	312.5	298.8	260.0	232.3	251.2	289.4	283.8	233.6	230.8	255.7	241.5	275.7	320.7	241.8

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Table IV.6. SD values on mean penetration resistance (n=50) per soil layer

Depth	**Kollumerwaard**					**Lelystad**					**Valthermond**						
(cm)	**BC1**	**BC2**	**C**	**F**	**S**	**BC2A**	**BC2B**	**C**	**F**	**S**	**BC1**	**BC2**	**BC3**	**BC4**	**C**	**F**	**S**
0-5	9.9	10.0	16.5	17.4	10.4	21.8	16.6	18.7	20.7	18.0	3.1	5.2	2.9	7.5	4.0	9.0	3.4
5-10	0.8	0.9	0.4	2.1	6.7	2.8	4.4	0.1	4.8	4.2	1.5	1.2	0.1	0.3	2.2	0.4	0.7
10-15	5.0	0.5	7.0	5.2	9.4	7.1	6.8	4.7	2.4	3.5	0.9	0.9	2.1	0.9	0.5	1.1	0.7
15-20	15.5	9.6	9.0	9.2	15.6	2.3	5.3	1.2	3.0	4.0	2.9	2.0	0.3	2.5	12.9	5.5	5.6
20-25	6.3	5.4	4.7	9.4	6.1	4.6	9.8	7.3	8.2	5.1	10.8	18.0	24.5	21.6	25.6	16.9	22.0
25-30	9.4	2.7	10.0	3.6	13.0	6.1	13.2	20.3	6.3	11.7	11.7	15.0	8.6	11.7	10.2	16.4	9.4
30-35	54.0	24.4	23.0	26.1	33.4	48.4	2.9	16.7	29.2	30.6	15.1	18.1	11.5	26.2	27.3	13.1	17.0
35-40	18.0	32.1	8.6	13.8	28.0	22.9	17.2	5.5	4.0	14.1	12.5	16.7	36.4	21.6	12.9	5.8	8.7
40-45	17.4	20.0	17.1	7.4	6.6	3.4	10.0	6.3	9.7	19.9	16.9	8.0	9.2	11.4	3.8	30.9	16.7
45-50	19.7	4.1	8.8	26.2	13.0	10.7	7.4	5.0	12.1	10.0	3.3	5.4	7.3	13.0	5.2	8.3	6.1
50-55	4.9	7.2	18.9	6.6	16.3	13.2	8.5	8.7	9.7	8.7	5.3	1.5	11.0	5.0	6.3	12.0	12.6
55-60	3.5	7.8	9.2	12.0	20.6	6.9	10.0	27.9	13.8	7.8	4.6	4.8	5.3	6.5	3.6	5.9	11.9
60-65	16.3	11.8	39.7	15.2	21.6	5.4	21.0	47.8	4.6	7.6	5.5	3.5	12.7	11.2	13.2	3.9	8.3
65-70	20.4	7.3	14.5	8.7	8.8	12.2	4.9	5.3	14.9	7.4	19.1	4.9	1.9	9.3	4.7	3.8	5.2
70-75	16.9	17.2	31.8	23.2	23.2	11.8	17.8	29.8	32.3	22.1	2.1	11.7	6.6	4.7	16.5	10.8	19.1
75-80	23.7	21.2	27.0	37.0	26.7	8.5	6.6	8.7	8.3	10.3	26.0	2.4	15.2	23.7	57.8	13.7	1.8

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Table VI.7. Inorganic N values determined over the three years of the field experiment: location Kollumerwaard

Kollumerwaard		**Inorganic N (kg N/ ha)**					**Inorganic N (kg N/ ha)**		
Treatment	Date	0-30	30-60	0-60/100#	**Treatment**	Date	0-30	30-60	0-60/100#
C	23-8-2010	22	11	-	C	26-10-2011	17	26	-
S	23-8-2010	8	11	-	S	26-10-2011	23	18	-
BC1	23-8-2010	24	12	-	BC1	26-10-2011	19	28	-
F	23-8-2010	21	14	-	F	26-10-2011	21	16	-
BC2	23-8-2010	26	16	-	BC2	26-10-2011	22	17	-
C	16-11-2010	5.5	10.5	-	C	5-3-2012	-	-	68
S	16-11-2010	5.5	10.5	-	S	5-3-2012	-	-	44
BC1	16-11-2010	5.5	10.5	-	BC1	5-3-2012	-	-	70
F	16-11-2010	5.5	10.5	-	F	5-3-2012	-	-	52
BC2	16-11-2010	5.5	10.5	-	BC2	5-3-2012	-	-	62
C	23-2-2011	-	-	28	C	23-8-2012	17	26	-
S	23-2-2011	-	-	24	S	23-8-2012	23	18	-
BC1	23-2-2011	-	-	26	BC1	23-8-2012	19	28	-
F	23-2-2011	-	-	28	F	23-8-2012	21	16	-
BC2	23-2-2011	-	-	26	BC2	23-8-2012	22	17	-
C	23-8-2011	22	11	-	C	25-10-2012	10	7	-
S	23-8-2011	8	11	-	S	25-10-2012	9	7	-
BC1	23-8-2011	24	12	-	BC1	25-10-2012	5	4	-
F	23-8-2011	21	14	-	F	25-10-2012	5	2	-
BC2	23-8-2011	26	16	-	BC2	25-10-2012	4	2	-
C	26-10-2011	17	52	-					
S	26-10-2011	26	36	-	F	26-10-2011	21	37	-
BC1	26-10-2011	19	56	-	BC2	26-10-2011	22	34	-

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar
# Depth of the analysis depends on the main crop: cereal crops are analyzed for the 0-100 cm depth, other crops for 0-60 cm.

Table VI.8. Inorganic N values determined over the three years of the field experiment: location Lelystad

Kollumerwaard		Inorganic N (kg N/ ha)					Inorganic N (kg N/ ha)		
Treatment	Date	0-30	30-60	0-60/100#	**Treatment**	Date	0-30	30-60	0-60/100#
C	8-9-2010	12	8	-	C	22-2-2012	-	-	24
S	8-9-2010	9	10	-	S	22-2-2012	-	-	20
F	8-9-2010	11	12	-	F	22-2-2012	-	-	24
BC2A	8-9-2010	10	8	-	BC2A	22-2-2012	-	-	24
BC2B	8-9-2010	11	10	-	BC2B	22-2-2012	-	-	24
C	1-11-2010	5.5	13	-	C	26-9-2012	9	36	-
S	1-11-2010	8.0	11.0	-	S	26-9-2012	13	34	-
F	1-11-2010	5.0	13.0	-	F	26-9-2012	12	53	-
BC2A	1-11-2010	5.0	8.0	-	BC2A	26-9-2012	10	46	-
BC2B	1-11-2010	7.0	7.0	-	BC2B	26-9-2012	10	53	-
C	21-2-2011	-	-	18	C	5-10-2012	19	36	-
S	21-2-2011	-	-	18	S	5-10-2012	13	47	-
F	21-2-2011	-	-	21	F	5-10-2012	16	46	-
BC2A	21-2-2011	-	-	-	BC2A	5-10-2012	14	35	-
BC2B	21-2-2011	-	-	-	BC2B	5-10-2012	15	40	-
C	12-10-2011	13	8	-	C	10-12-2012	11	26	-
S	12-10-2011	10	23	-	S	10-12-2012	14	33	-
F	12-10-2011	7	15	-	F	10-12-2012	8	22	-
BC2A	12-10-2011	-	-	-	BC2A	10-12-2012	7	24	-
BC2B	12-10-2011	-	-	-	BC2B	10-12-2012	12	14	-
C	31-10-2011	7	7	-					
S	31-10-2011	8	11	-					
F	31-10-2011	10	7	-					

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar
# Depth of the analysis depends on the main crop: cereal crops are analyzed for the 0-100 cm depth, other crops for 0-60 cm.

Table VI.9. Inorganic N values determined over the three years of the field experiment: location Valthermond

		Inorganic N (kg N/ ha)					Inorganic N (kg N/ ha)		
Treatment	Date	0-30	30-60	0-60/100#	**Treatment**	Date	0-30	30-60	0-60/100#
C	25-2-2011	27	-	-	C	29-2-2012	19	-	-
S	25-2-2011	23	-	-	S	29-2-2012	23	-	-
BC3	25-2-2011	40	-	-	BC3	29-2-2012	29	-	-
BC1	25-2-2011	34	-	-	BC1	29-2-2012	35	-	-
BC4	25-2-2011	-	-	-	BC4	29-2-2012	17	-	-
F	25-2-2011	48	-	-	F	29-2-2012	25	-	-
BC2	25-2-2011	41	-	-	BC2	29-2-2012	20	-	-

* BC1 stands for biochar norit, BC2 for biochar wood, BC3 for the biochar produced by ECN and BC4 for the Romchar

Depth of the analysis depends on the main crop: cereal crops are analyzed for the 0-100 cm depth, other crops for 0-60 cm.

Appendix V. Fertilization schemes field experiments

Table V.1. Fertilization realized in the field experiments at Kollumerwaard (for details, see reports of Paauw et al., 2010; 2011; 2012).

	Gift via soil improvers			Manure gift			Fertilizer gift				Total nutrient gift			
Soil improver	N-eff	P_2O_5	K_2O	N-eff	P_2O_5	K_2O	N-gift 1	P_2O_5	K_2O	N-gift 2	N-total	N-eff	P_2O_5	K_2O
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Growing season 2010														
Biochar norit	0	0	0	0	0	0	80	130	144	60	140	140	130	144
Biochar wood	0	0	0	0	0	0	80	130	144	60	140	140	130	144
Compost	8	33	58	0	0	0	80	100	90	52	209	140	133	148
Pig slurry	0	0	0	63	81	122	48	40	0	29	234	140	121	122
Fertilizer	0	0	0	0	0	0	80	130	144	60	140	140	130	144
Growing season 2011														
Biochar norit	0	0	0	0	0	0	105	80	130	0	105	105	80	130
Biochar wood	0	0	0	0	0	0	105	80	130	0	105	105	80	130
Compost	0	33	58	0	0	0	105	80	100	0	182	105	113	158
Pig slurry	0	0	0	0	0	0	105	80	130	0	105	105	80	130
Fertilizer	0	0	0	0	0	0	105	80	100	0	105	105	80	130
Growing season 2012														
Biochar norit	0	0	0	0	0	0	158	0	0	0	158	158	0	0
Biochar wood	0	0	0	0	0	0	166	0	0	0	166	166	0	0
Compost	0	33	58	0	0	0	160	0	0	0	237	160	33	58
Pig slurry	0	0	0	81	95	135	96	0	0	0	259	177	95	135
Fertilizer	0	0	0	0	0	0	176	0	0	0	176	176	0	0

Table V.2. Fertilization realized in the field experiments at Lelystad (for details, see reports of Paauw et al., 2010; 2011; 2012).

	Gift via soil improvers			**Manure gift**			**Fertilizer gift**				**Total nutrient gift**			
Soil improver	N-eff	P_2O_5	K_2O	N-eff	P_2O_5	K_2O	N-gift 1	P_2O_5	K_2O	N-gift 2	N-total	N-eff	P_2O_5	K_2O
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Growing season 2010														
Biochar wood 2.5 ton	0	0	0	0	0	0	90	40	0	0	90	90	40	0
Biochar wood 5.0 ton	0	0	0	0	0	0	90	40	0	0	90	90	40	0
Compost	6	28	60	0	0	0	84	10	0	0	144	90	38	60
Slurry	0	0	0	0	0	0	90	40	0	0	90	90	40	0
Fertilizer	0	0	0	0	0	0	90	40	0	0	90	90	40	0
Growing season 2011														
Biochar wood 2.5 ton	0	0	0	11	42	60	159	33	40	0	233	169	75	100
Biochar wood 5.0 ton	0	0	0	11	42	60	159	33	40	0	233	169	75	100
Compost	0	28	60	0	0	0	169	47	40	0	229	169	75	100
Slurry	0	0	0	11	42	60	159	33	40	0	233	169	75	100
Fertilizer	0	0	0	0	0	0	169	75	100	0	169	169	75	100
Growing season 2012														
Biochar wood 2.5 ton	0	0	0	0	0	0	158	0	0	0	158	158	0	0
Biochar wood 5.0 ton	0	0	0	0	0	0	166	0	0	0	166	166	0	0
Compost	0	33	58	0	0	0	160	0	0	0	237	160	33	58
Slurry	0	0	0	81	95	135	96	0	0	0	259	177	95	135
Fertilizer	0	0	0	0	0	0	176	0	0	0	176	176	0	0

Table V.2. Fertilization realized in the field experiments at Valthermond (for details, see reports of Paauw et al., 2010; 2011; 2012).

	Gift via soil improvers			Manure gift			Fertilizer gift				Total nutrient gift			
Soil improver	N-eff	P_2O_5	K_2O	N-eff	P_2O_5	K_2O	N-gift 1	P_2O_5	K_2O	N-gift 2	N-total	N-eff	P_2O_5	K_2O
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Growing season 2010														
Biochar ECN	0	0	0	0	0	0	149	85	170	0	149	149	85	170
Biochar Norit	0	0	0	0	0	0	149	85	170	0	149	149	85	170
Biochar wood	0	0	0	0	0	0	149	85	170	0	149	149	85	170
Compost	15	67	115	0	0	0	134	20	55	0	287	149	87	170
Slurry	0	0	0	90	62	108	48	0	26	0	176	138	62	134
Fertilizer	0	0	0	0	0	0	149	85	170	0	149	149	85	170
Growing season 2011														
Biochar ECN	0	0	0	0	0	0	203	70	200	0	203	203	70	200
Biochar Norit	0	0	0	0	0	0	214	70	200	0	214	214	70	200
Biochar Romchar	0	0	0	0	0	0	180	70	200	0	180	180	70	200
Biochar wood	0	0	0	0	0	0	201	70	200	0	201	201	70	200
Compost	7	30	48	0	0	0	219	40	152	0	293	226	70	200
Slurry	0	0	0	97	81	118	136	0	97	0	275	234	81	215
Fertilizer	0	0	0	0	0	0	189	70	200	0	189	189	70	200
Growing season 2012														
Biochar ECN	0	0	0	0	0	0	81	0	180	0	81	81	0	180
Biochar Norit	0	0	0	0	0	0	75	0	180	0	75	75	0	180
Biochar Romchar	0	0	0	0	0	0	93	0	180	0	93	93	0	180
Biochar wood	0	0	0	0	0	0	90	0	180	0	90	90	0	180
Compost	7	30	48	0	0	0	84	0	132	0	157	91	30	180
Slurry	0	0	0	0	0	0	87	0	201	0	87	87	0	201
Fertilizer	0	0	0	0	0	0	85	0	180	0	85	85	0	180

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