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Effects of biochar on the water-holding capacity of soils – field experiments in asparagus cultivation on Gotland

Effekter av biokol på markens vattenhållande förmåga – fältförsök i sparrisodlingar på Gotland

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Abstract

Biochar is a residual product that is produced by combustion of organic material at a restricted amount of oxygen, so called pyrolysis. It has been seen that biochar could have positive effects when incorporated in soils, such as increasing the water-holding capacity and decreasing the dry bulk density. The water-holding capacity of a soil is of interest since the future holds a warmer climate which could result in soils being a subject of water scarcity. Biochar could also be a useful way to sustainably store carbon to deal with global warming.

In this report the results from a field experiment with biochar is represented and discussed. The experiment was conducted at Stenhuse gård which is located in Klintehamn on Gotland. Gotland is known for having problem with water scarcity and the soil at Stenhuse gård is a sandy soil. The experiment was initiated by Waila AB and financed by the EU. The purpose of the field experiment is to decide the effect biochar has on the water-holding capacity in the soil.

The result from this study show tendencies of an effect from the application of biochar on the soils water-content, dry bulk density, organic carbon and water-holding capacity. The results show no significant effect from any of the four biochar treatments compared to the control group. The reason for the lack of statistical significance is probably due to too few samples taken on each trial square of the experiment on Stenhuse gård. It would likely have been a lower variance between the observations if more samples had been conducted and therefore the statistical analysis could have a shown a statistical significance. The experimental design should also have focused on designing the five treatments to have only one changing variable (in this case the biochar), since the treatments had different amounts and types of fertilizers. More studies should be conducted to ensure the effect biochar has on a soil after incorporation.

*Keywords:*Waila AB, water-holding capacity

Sammanfattning

Biokol är en restprodukt vid förbränning av organiskt material som sker vid en restriktiv syrehalt. Denna metod av förbränning kallas för pyrolys. Tidigare studier har visat att biokol skulle kunna ha en positiv effekt i en jord genom att öka jordens vattenhållande förmåga och minska dess skrymdensitet. Den vattenhållande förmågan i marken är ett ämne som är viktigt eftersom framtidens klimat kommer att innebära högre temperaturer och mer extremt väder. Dessa klimatförändringar kan i sin tur kan leda till att jordbruksmarker blir lidande av vattenbrist och avkastningen minskar. Biokol kan även ses som en del i att hållbart lagra kol i marken för att försöka minska den globala uppvärmningen.

I denna rapport är resultaten från ett fältexperiment med biokol presenterat och diskuterat. Experimentet utfördes på Stenhuse gård som ligger i Klintehamn på Gotland. Gotland har tidigare somrar haft problem med vattenbrist. Experimentet initierades av Waila AB och finansierades av EU.

Resultaten från denna studie visar att tillsatsen av biokol i jorden på Stenhuse gård har tendenser till en påverkan på vattenhalten, skrymdensiteten, halten av organiskt kol och jordens vattenhållande förmåga. De statistiska analyserna visar dock ingen signifikant effekt från någon av de fyra biokolsbehandlingarna jämfört med kontrollgruppen. Orsaken till att ingen statistisk signifikans kunde observeras är förmodligen på grund av att det togs för få prover i varje provruta. Det skulle troligtvis ha blivit en lägre varians mellan observationerna om fler prover hade tagits och det hade i sin tur eventuellt påvisat en statistisk signifikans. Fokus borde även ha lagts på att utforma de fem behandlingar i experimentet på att utesluta andra parametrar utöver biokolen, då behandlingarna i detta experiment hade olika mängd och sorter av gödselmedel. Fler studier behöver göras för att med säkerhet kunna koppla tillsatsen av biokol till biokolens effekt på jorden.

Nyckelord: Waila AB, jordens vattenhållande förmåga

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1 Introduction

The approaching climate crisis consists of weather changes that will include a warmer climate and more extreme weather. Generally, the climate becomes more humid when the temperature rises because the evaporation of water increases. This leads to an increase in precipitation and overall more extreme weather. (IPCC 2012) These extreme weather changes can result in problems for crops since heat in combination with temporary drought is a stress factor. Given these changes we need to find ways to tackle the increasing potential evaporation with techniques to store more water in our soils for a longer time.

Biochar can be one of the ways to withhold water in soils that is incorporated with it. The importance of understanding the connection between biochar and its ability to retain water is linked to water scarcity, that is a problem in some parts of the world today and will most likely spread to more parts of the world in the near future due to climate change. Studies have shown that biochar can increase the maximum water-holding capacity (Verhejen et. al. 2019) but the state of knowledge is still uncertain since a study by Soinne et. al. (2020) did not see a significant change in the water retention after a biochar application.

In this rapport the result from a field experiment is presented. The field experiment was conducted at Stenhuse gård which is located in Klintehamn on Gotland. Gotland is an island made up of limestone from Silurian age and therefor has a distinctive geology and hydrology. The limestone bedrock and a fast drainage contributes to a problem with groundwater cultivation on Gotland, which makes the island exposed to water scarcity. (Djurberg 2016) The soil at Stenhuse gård is a sandy soil. The experiment was initiated by Waila AB and financed by the EU.

1.1 Background

1.1.1 Biochar

Biochar is a residual product that is produced by combustion of organic material at a restricted amount of oxygen, so called pyrolysis (Wang et. al. 2020). Biochar contains a high amount of carbon and has a large specific area (Laxmar 2017). It is highly resistant to mineralization which contributes to the result of binding carbon dioxide from the atmosphere to land, creating a carbon source, and is therefore a way of counteracting climate change (Eriksson 2016).

It has been shown that biochar has an influence on increasing the water-holding capacity of a soil (Verheijen et. al. 2019, Karhu et. al. 2010). A meta-analysis that studied literature published between 2010-2019 on biochar's impacts on soils concluded that biochar has a decreasing effect on a soils bulk density and an increasing water-content at field capacity, wilting point and plant-available water for sandy soils (Razzaghi et. al. 2019).

1.1.2 Water-holding capacity

A soils ability to bind plant-available water is an outcome of the soils structure and texture, which determines the pore system (Eriksson 2015).

Field capacity is the amount of water left in the soil after the soil has been saturated with water and drainage, due to gravity and capillary forces, has occurred. At this point, the capillary bound water is theoretically in a state of equilibrium with the groundwater level and the big pores are filled with air, while the smaller pores are filled with water. The smaller pores water-content is additionally depending on the height of the pores from the groundwater level. It is important to remember that in natural systems the possibility for precipitation to water saturate the soil is low because the amount of infiltrating water might not have the ability to displace all the air in the soil. (Eriksson 2015)

Wilting point is the point when plants are not able to take up the water that still exists in the soil. This is because of below that point, the water that is in the soil is bound in small pores with a force equal to the pressure of at least -1500 kPa. At this pressure the water remaining in the soil is no longer possible to utilize for the plants and they will therefore wilt. The plant-available water is by definition the difference between field capacity and wilting point. (Eriksson 2015)

Since the soils potential to provide plants with a good growth habitation is a result of the structure and texture which together creates the relation between water-and air-filled pores, biochar might increase this potential as it affects both structure and texture (Verhejen et. al. 2019).

1.1.3 pF value

The pF-unit is a logarithmic pressure unit in cm. The binding pressure for water is explained in meter water column (1 meter water column = 10 kPa). A certain binding energy is correlated to a certain pore size and this makes the pF-curve a distribution function of pore sizes in the soil. The curves derivative is a frequency distribution of the soils varied pore sizes. Therefore, the pF-curve is a way to identify how much plant-available water a soil can contain. By measuring how much water the soil drains at different pressures (pressures that is equal to the binding pressure) it is possible to know how much water the soil contains in different pore sizes. This also gives the distribution of the different pore sizes in the soil. Field capacity has a pF value of 2.0±0.4 when the groundwater level is 100 cm under ground level and wilting point has a pF value of 4.2±0.1. (Eriksson 2015)

1.2 Research question

How does the amount of biochar affect the water-holding capacity of an asparagus cultivation on Gotland?

2 Material and method

2.1 Field experiment at Stenhuse gård

Initially the experiment was initiated by Waila AB at an asparagus cultivation at Stenhuse gård, which is located on Gotland. The asparagus plantation was divided into a Latin square trial design with five treatments and five repetitions for each treatment, resulting in 25 trial plots, see Figure 1. The five treatments consisted of one control group (C) and two different biochar substrates (CP and ATS) that was incorporated in the soil with a high and a low application rate (-H and -L). The biochar substrates were also mixed with different organic nitrogen amendments and the control group with mineral fertilizer, see Table 1. The biochar substrates were incorporated on both sides of the asparagus rows in 0.25 m broad layer.

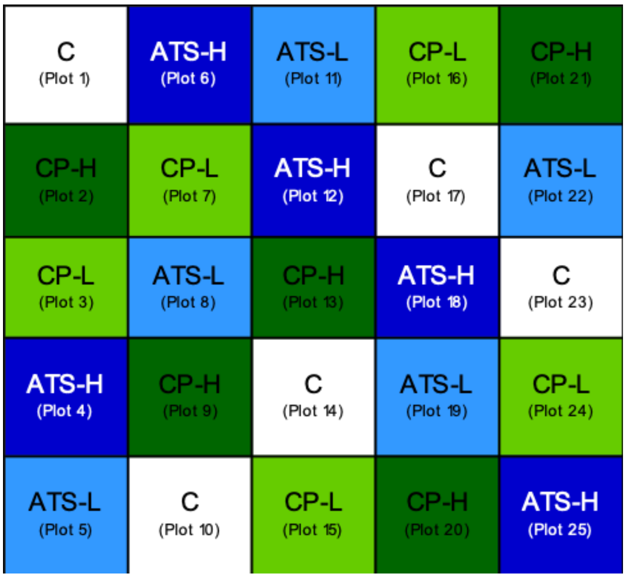

Figure 1. Latin square trial design at Stenhuse gård.

Table 1. Amount of biochar and fertilizer application for every treatment.

Treatment	Biochar (dry mass application per ha)	Fertilizers (fresh mass application per ha)
Control (CO)	-	calcium nitrate fertilizer (225 kg)
CP-L (CL)	Rejected grain/wood biochar (1,247 kg)	cattle manure (5,455 kg) and water (11,688 kg)
CP-H (CH)	Rejected grain/wood biochar (2,494 kg)	cattle manure (10,909 kg) and water (23,377 kg)
ATS-L (AL)	hard-wood biochar (1,978 kg)	sugar cane molasses, vinasse and microorganisms (740 kg)
ATS-H (AH)	hard-wood biochar (3,957 kg)	sugar cane molasses, vinasse and microorganisms (1,485 kg)

Samples for this report was collected on the 25th of April 2019 and was conducted by firstly digging a quadratic hole in the soil beside the asparagus cultivation lines to see how deep the biochar layer was, see Figure 2-3.

After determining at what depth the biochar layer was, a 5 cm high cylinder (7.2 diameter) was placed on top of the ground at 2.5-3 cm above the biochar layer. This was to ensure that the samples would contain the layer of biochar, this to reduce the error source. When the cylinder was placed, a weight was used to hammer the cylinder into the soil. When the cylinder was fully underground a knife was used to remove all the soil surrounding the cylinder to be able to extract the cylinder from the soil and before removing the cylinder from the soil, a filter paper and plastic lid was placed on top of the cylinder to seal it, see Figure 4-6.

To ensure to get a full cylinder sample, the shovel was used to dig a couple of cm under the cylinder and by being very gentle while turning the cylinder, once it was out of the soil, will minimize the risk of soil releasing from the cylinder. The excess soil was removed by knife before putting a filter paper and plastic lid on the bottom of the cylinder.

Another sample was extracted by the same method but instead of putting a lid on the cylinder, the soil samples was placed from the cylinder into plastic bags that afterwards was sealed.

This procedure was replicated in all of the trial squares and ended up being 25 cylinder samples and 25 plastic bag samples.

Figure 2. Digging a quadratic hole to locate the biochar layer.

Figure 3.Determining the depth of the biochar layer.

Figure 4. The cylinder in the soil after it was hammered down,

Figure 5. Extracting the cylinder from the soil.

Figure 6. Cylinder with filter paper and plastic lid.

Day two a soil profile was conducted to get a description of the soil by digging a 50 cm deep hole in the plantation, see Figure 7. At the depth of 50 cm there was limestone bedrock which made it impossible to dig any deeper. Five samples were collected, three from the surface horizon and one from each deep horizon (two in total).

Figure 7. Determining the soils profile and horizons at Stenhuse gård.

2.2 The soil at Stenhuse gård

The water-content at the time of sampling is highest in the three A horizons plus the C horizon and lowest in the B horizon. The pH increases deeper down in the soil. Bulk density is about the same in all the horizon but is highest in the B horizon. Carbonate carbon is highest in the C horizon and lowest in the B horizon. Total carbon is highest in the three A horizons, intermediate in the C horizon and lowest in the B horizon. Organic carbon is highest in the A3 horizon, intermediate in A1 and A2 horizons and lowest in horizon B and C.

Table 2. Mean values for water-content, pH, bulk density and carbon.

Horizon	**Water-content (%mass)**	**pH**	**Bulk density (g/cm^3)**	**Carbonate carbon (%)**	**Total carbon (%)**	**Organic carbon (%)**
A1	0.18	7.60	1.02	0.21	2.19	1.98
A2	0.20	7.49	1.05	0.22	2.19	1.97
A3	0.22	7.51	0.97	0.23	2.46	2.23
B	0.13	7.66	1.43	0.01	0.15	0.14
C	0.19	7.81	1.15	0.95	1.11	0.16

Figure 8. The horizon was a A_p, B, C.

2.3 Calculations

2.3.1 Gravimetric water-content of the soil (θ_s)

The soil from the plastic bag samples were used to calculate the water-content in the trial squares at the time of sampling. This was done by first weighing a crucible, note the weight, and then putting 4±0.10 g of moist soil (m_{ms}) in the crucible. After this was replicated for all the 25 samples plus the five horizons, the crucible was put in an oven over night in 105 °C. The next day the new weight of the dry soil (m_{ds}) was noted, and water-content could be calculated from the weight difference by the formula: $\theta_s = (m_{ms} - m_{ds})/(m_{ds})$.

The water-content was then recalculated from the gravimetric value to volumetric value based on the entire volume of the soil from the cylinder and is presented under Chapter 3.3.

2.3.2 Dry bulk density of the soil (ρ_d)

The bulk density was calculated by taking the dry mass of the soil sample (m_s) and dividing it with the volume of the cylinder (V_c).

2.3.3 Plant-available nitrogen NH_4-N and NO_3-N (NH_4^+ and NO_3^-)

The plant-available nitrogen was determined by firstly weighing 12±0.10 g of soil from the plastic bag samples and putting the soil in test tubes. After that, 30 ml 2.0 M KCl was added to the test tubes with soil. The test tubes were then shaken in a shaker for two hours and put into a centrifuge for 15 minutes at 3000 RPM. When the samples had been centrifuged, 10 ml of the supernatant was extracted with a syringe through a filter and put in small bottles for analysis. The samples were analysed with an AutoAnalyzer AA3 spectrometer. This was replicated for all the 25 samples. The measured concentration was recalculated to mg N per kg of dry soil.

2.3.4 pH value

The pH value was determined by taking half of the soil from the plastic bag samples and drying it for two days in a drying room at 40°C, stirring the soil a couple of times during this period. When the soil was dry it was sieved through a 2 mm strainer to get rid of bigger elements than 2 mm. Ten (10) ml of the sieved soil was put in test tubes and the rest of the sieved soil was put in plastic containers. Twenty-five (25) ml distilled water was added to the test tubes and then shaken over one night. The next day the samples were placed in a pH meter and pH value and temperature was measured.

Figure 9. pH meter with soil samples.

2.3.5 pF value and water-holding capacity

The water-holding capacity was determined by taking the cylinders with soil from the field experiment (see Chapter 2.1) and placing the samples in a sandbox with an adjustable drainage level. The samples were then put through pressures of -0.5 kPa and -10 kPa, which is equal to a tension of 0.05 and 1 meter. For the pressure of -30 kPa (tension 3 meter) the cylinders were put on a porous plate with adjustable vacuum. To find the wilting point of the soil a pressure of -1500 kPa was managed in a pressure plate extractor where the soil samples was suspended in a small amount of water.

2.4 Statistical analysis

A statistical analysis was conducted by using the program R to see if the biochar treatments had a statistically significant effect on the water-content, dry bulk density and water-holding capacity. A Two-way analysis of variance (ANOVA-test) was preformed and the confidence level was set at 95 %. A Tukey HSD test was used to see if there were any statistical effects between the different treatments ($p<0.05$).

3 Result

3.1 Gravimetric water-content

Figure 10 shows that the water-content at the time of sampling was higher in all of the soils with biochar treatments compared to the control group, but the ANOVA-test (p-value = 0.189) did not show a statistically significant difference between the treatments. The mean value of water-content was higher than the control group in all of the treatments. It is visible that the treatments with a high biochar application (ATS-H and CP-H) has the highest water-content of all treatments.

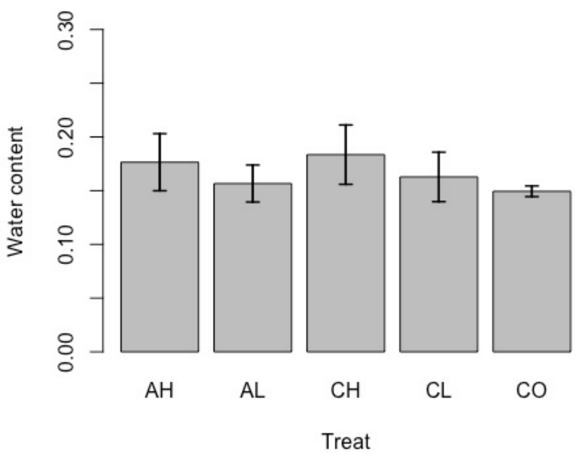

Figure 10. Bar plot for mean value of water-content in every treat. The error bars show the standard error of the mean.

3.2 Dry bulk density

The results of the dry bulk density show that the control group have a higher mean value than the rest of the treatments, see Figure 11. The difference between treatments is not statistically significant (p-value = 0.42). The treatment that had the lowest dry bulk density was the ALS-H, which is also the one that had the highest application of biochar per ha. Variability was highest in the ALS-L group but did not differ that much from the other treatments.

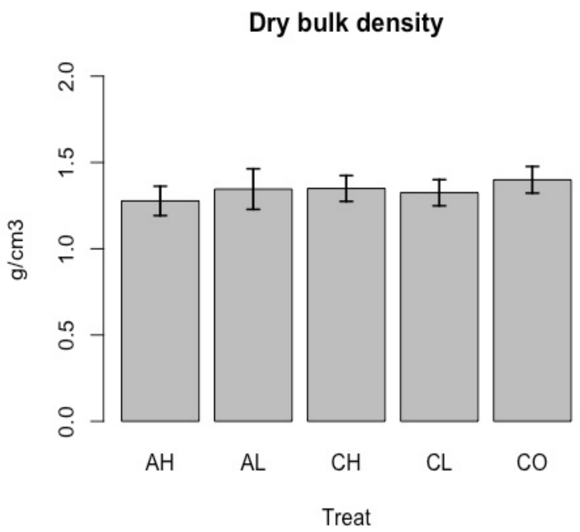

Figure 11. Bar plot for mean value for the dry bulk density in every treat. The error bars show the standard error of the mean.

3.3 pF value and water-holding capacity

The water-content while exposing the soil to different pressures did not give any statistical significance for any pressure. The ANOVA-test showed that field capacity had a p-value of 0.453 and wilting point had a p-value of 0.97. The water-content between pF value 2 (field capacity) and pF value 4.2 (wilting point) show that all the biochar treatments have a higher volume of water than the control group. In Figure 12 it shows that the CP-H treatment has the highest difference in water-content between pF 2 and pF 4.2 of all treatments. This could be the result of a high biochar application, but since the ATS-H treatment (which in comparison with the CP-H treatment had an even higher application of biochar per ha) did not have a higher water-content, it is difficult to prove that a higher biochar application is the cause for a higher water-content in this case. The ANOVA-test shows no statistically significant difference between all the treatments (p-value= 0.312). The variation in the treatments was highest in the ALS-H, CP-L and control, intermediate in ALS-L and lowest in CP-H.

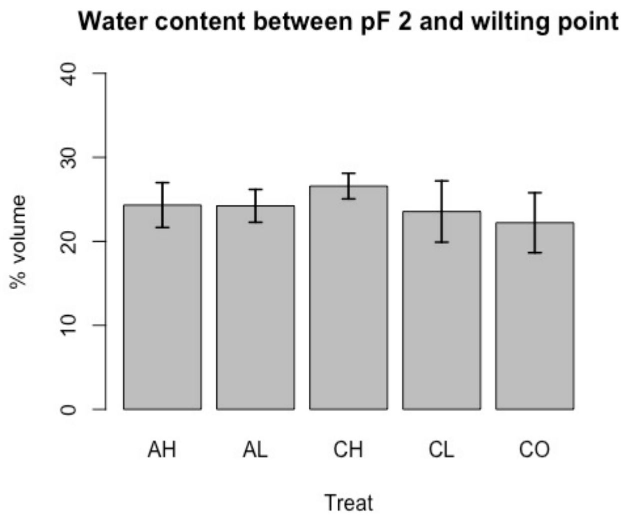

Figure 12. Bar plot for mean value for the water-content between pF 2 and pF 4 in every treat. The error bars show the standard error of the mean.

3.4 Total carbon and organic carbon

The total carbon and organic carbon were highest in the ALS-groups, intermediary in the CP-groups and lowest in the control. No treatments were significantly different from each other. The variability was about the same for every treatment in every property.

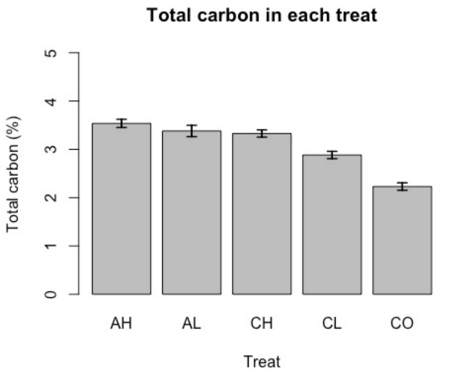

Figure 13. Bar plot for mean value for the total carbon in each treat. The error bars show the standard error of the mean.

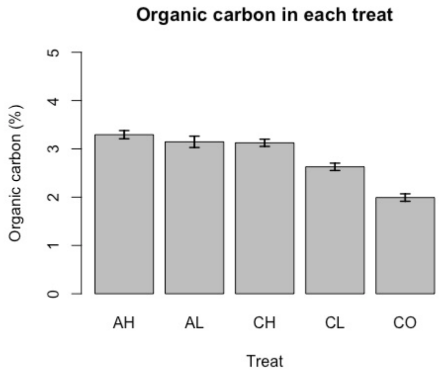

Figure 4. Bar plot for mean value for the organic carbon in each treat. The error bars show the standard error of the mean.

3.5 Plant-available nitrogen NH_4-N and NO_3-N (NH_4^+ and NO_3^-)

One of the observations from the NO_3-N analysis was abnormal from the rest of the observations in the NO_3-N analyses, see Appendix 1 (sample number 14: 5-ATS-H 3) and therefore the results are not presented in this report.

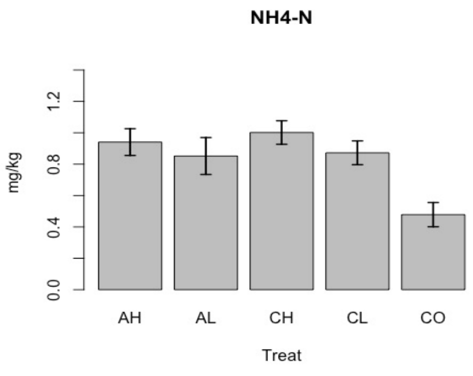

Figure 15. Bar plot for mean value for NH_4-N in every treat. The error bars show the standard error of the mean.

3.6 pH value

The pH value did not deviate much between the biochar treatments and the control group. It was around pH 7.5, which indicates that the soil contains $CaCO_3$ in the parent material.

Table 3. Mean value for pH for every treat.

Treatment	ATS-H (AH)	ATS-L (AL)	CP-H (CH)	CP-L (CL)	Control (CO)
pH	7.55	7.59	7.51	7.56	7.49

4 Discussion

The result from this experiment did not show any statistically significant differences between the treatments and the control group for any of the analyzed aspects. This could be explained by the fact that it was only one sample taken from each trial square. If we would have taken 3-4 samples in each square the possibility to get a significant result would have been more probable since the variation would have been smaller. The reason why we did not take more samples in the first place was that it was too expensive to do more pF determinations. For the other aspects it would have been possible to take more samples financially, but since these analyses was not the main research question it was not a prioritized.

The ANOVA-test showed no statistically significant difference for water-content and that is most likely explained by the big variance between the observations for each treatment (except from the control group) and also by too few parcel samples for each treatment. The control group had a lesser variance of the observations and this also suggests that the biochar treatments has some effect on the soils water-content.

The structure, texture and pore system of a soil is of interest when it comes to its ability to retain plant-available water (Eriksson 2015). Verhejen et. al. (2019) saw that in a sandy soil an increased biochar concentration decreased the soils bulk density and reasoned that the probable effect was a dilution in the soils volume by a lower density material, in this case, the biochar. They also saw a linear decrease in bulk density with an increasing amount of biochar. Verhejen et. al. (2019) had used different particle sizes of biochar from smaller to larger, but they saw the same effect for all the different particle sizes in a sandy soil. In Figure 14 it is visible that all the biochar treatments had a higher percentage of organic carbon of the dry bulk density than the control group. This indicates the same effect that Verhejen et. al. (2019) saw in their experiment but no significance was seen in the statistical analyses.

Figure 13-14 displays that all the treatments had a higher mean value of carbon than the control group. The organic carbon is carbon that contains biochar and the most interesting, see Figure 14. If biochar is the reason for the soils improved water-holding capacity, an increase in carbon is necessary to be able to see a corresponding effect from the biochar and the water-holding capacity. In this case it is possible to see a higher amount of organic carbon, which possibly is in the form of biochar bits in the soil. This gives the indication that the biochar treatment could have an effect on the water-holding capacity, but there was no statistically significant response from any of the treatments. Liu et. al. (2012) did an experiment with both a compost treatment and a biochar treatment and saw that an increase in biochar amount significantly increased the soils organic carbon but saw no significant difference in the organic carbon amount between the control group and the compost treatment. Given the results from Liu et. al. (2012) and with the response from this study, it is promising to see that the carbon in form of biochar is still in the soil after application, which indicates that biochar is a possible way to sustainably store carbon, even if it might not have an effect on the soils water-holding capacity.

Liu et. al. (2012) saw that a biochar and compost addition doubled the water-content between pF 1.8 and pF 4.2 from approximately 6 % in the control group to approximately 12 % in the group with the highest biochar-compost application. In Figure 10 it shows that the CP-H treatment has the highest water-content of all treatments. This could be the result of a high biochar application, but since the ATS-H treatment (which in comparison with the CP-H treatment had an even higher application of biochar per ha) did not have a higher water-content, it is difficult to prove that a higher biochar application is the result for a higher water-content in this case. The results from the study conducted by Verhejen et. al. (2019) showed that the maximum water-holding capacity was related to the biochar dose with an increase in water-holding capacity and a decrease in the bulk density. The results shown in the conducted experiment at Stenhuse gård shows a tendency for the same outcome as in the study conducted by Verhejen et. al. (2019) but it shows no statistically significant results for the different treatments. If a higher amount of biochar would have been incorporated in the soil at Stenhuse gård it might would have shown a higher increase in water-holding capacity and also a statistical significance.

It is important to remember that field capacity is a diffuse concept since it is based on that the groundwater level should be 100 cm under ground level, which may not be the case in the soil at Stenhuse gård. A 50 cm deep hole was dug the second day of the field visit and no groundwater was identified at that depth. There was a ditch containing water on the north and west side of the asparagus field, which could be approximately 1 meter under ground level. This can be an indication for the depth of the groundwater, but no measurements were done to confirm that idea.

The positive effects on the water-holding capacity related to biochar has been shown in multiple studies conducted by others (Verhejen et. al. 2019, Liu et. al. 2012, Karhu et. al. 2010) and in a meta-analysis of literature on the subject that was published between the years of 2010-2019 (Razzaghi et. al. 2019). Since there were too few samples taken in each trial square and also a lack of consistency in the design/conformation of the different treatments in this experiment, it is difficult to track the actual effect from the biochar on the results. All the treatments were differently applied with both different types and amounts of fertilizers. The control group was only given mineral fertilizers, whereas the biochar treatments were given organic amendments. It is therefore difficult to confirm that the results are from the biochar alterations and not from other variables.

The plant-available nitrogen was higher in all the biochar treatments compared to the control group. Since all the treatments were treated with different fertilizers, it is hard to track the relation between the effect of biochar and plant-available nitrogen.

Conclusively, all the statistical analyses that were conducted showed no significant results for any of the aspects on the level of significance $\alpha = 95\%$. This is probably explained by the large variance between the observations for each treatment. What can be seen is that there are tendencies for effects of biochar, but to be sure of this more studies have to be made to establish that these tendencies are not just accidental in this study. Future studies should focus on more intensive sampling for each treatment and also designing the experiment with only one differing element, in this case the biochar application, to be able to conclusively relate the results to the effect of biochar. Mixing different fertilizers like in this experimental design makes it very difficult to interpret the results. It is still important to remember that other studies have shown results from the use of biochar even if this experiment only showed a tendency for the same outcome.

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Appendix 1

Sample number	Plot	Treat	Row	Column	Water-content (%)	pH	NH_4-N (mg/kg)	NO_3-N (mg/kg)	Dry bulk density (g/cm^3)	Carbon carbonate (%)	Total carbon (%)	Organic carbon (%)
2	5-ATS-H 1	AH	1	2	0.178	7.60	1.17	9.20	1.49	0.37	2.44	2.07
8	5-ATS-H 2	AH	2	3	0.158	7.54	0.76	7.64	1.33	0.40	4.64	4.23
14	5-ATS-H 3	AH	3	4	0.226	7.57	1.08	44.9	1.51	0.12	4.58	4.46
20	5-ATS-H 4	AH	4	1	0.151	7.52	0.54	4.63	1.23	0.29	2.77	2.48
25	5-ATS-H 5	AH	5	5	0.169	7.53	1.15	14.6	1.45	0.04	3.27	3.23
3	4-ATS-L 1	AL	1	3	0.139	7.58	0.65	14.1	1.33	0.48	3.69	3.21
6	4-ATS-L 2	AL	2	5	0.150	7.60	0.89	13.5	1.32	0.08	2.06	1.97
12	4-ATS-L 3	AL	3	2	0.172	7.57	0.89	5.51	1.23	0.19	2.79	2.60
17	4-ATS-L 4	AL	4	4	0.182	7.58	1.14	11.2	1.34	0.22	5.93	5.72
21	4-ATS-L 5	AL	5	1	0.141	7.61	0.68	10.0	1.37	0.20	2.43	2.23
5	3-CP-H 1	CH	1	5	0.137	7.54	0.82	7.72	1.45	0.24	2.08	1.84
10	3-CP-H 2	CH	2	1	0.212	7.64	0.78	9.11	1.33	0.13	3.20	3.07

Sample number	Plot	Treat	Row	Column	Water-content (%)	pH	NH_4-N (mg/kg)	NO_3-N (mg/kg)	Dry bulk density (g/cm^3)	Carbon carbonate (%)	Total carbon (%)	Organic carbon (%)
13	3-CP-H 3	CH	3	3	0.191	7.53	1.16	4.42	1.30	0.37	3.85	3.48
19	3-CP-H 4	CH	4	2	0.208	7.41	1.31	9.60	1.14	0.22	4.95	4.72
24	3-CP-H 5	CH	5	4	0.170	7.43	0.95	4.76	1.32	0.05	2.57	2.51
4	1-CP-L 1	CL	1	4	0.163	7.48	1.60	20.0	1.28	0.43	3.56	3.13
9	1-CP-L 2	CL	2	2	0.202	7.59	0.98	8.46	1.15	0.26	3.51	3.25
11	1-CP-L 3	CL	3	1	0.170	7.62	0.77	7.56	1.49	0.08	2.64	2.56
16	1-CP-L 4	CL	4	5	0.136	7.52	0.27	6.74	1.39	0.13	1.96	1.83
23	1-CP-L 5	CL	5	3	0.143	7.58	0.74	4.51	1.38	0.37	2.75	2.38
1	2-C 1	CO	1	1	0.157	7.63	0.64	4.36	1.41	0.17	2.08	1.91
7	2-C 2	CO	2	4	0.148	7.58	0.51	4.99	1.38	0.30	2.43	2.14
15	2-C 3	CO	3	5	0.143	7.19	0.60	4.80	1.32	0.01	1.79	1.78
18	2-C 4	CO	4	3	0.147	7.52	0.28	4.67	1.23	0.50	2.41	1.91
22	2-C 5	CO	5	2	0.153	7.55	0.37	12.0	1.30	0.21	2.43	2.22

Appendix 2

Sample number	Plot	Treat	Row	Column	pF 0.5	pF 2	pF 3	Wilting Point (WP)	pF 0.5-WP	pF 2-WP	pF 3-WP
2	5-ATS-H 1	AH	1	2	36.2	31.4	25.3	7.8	28.4	23.5	17.5
8	5-ATS-H 2	AH	2	3	37.8	33.7	27.4	9.8	28.0	23.9	17.6
14	5-ATS-H 3	AH	3	4	43.5	37.7	29.8	8.2	35.3	29.5	21.5
20	5-ATS-H 4	AH	4	1	37.5	31.7	24.4	8.9	28.5	22.8	15.4
25	5-ATS-H 5	AH	5	5	42.8	28.9	21.6	6.9	35.9	22.0	14.6
3	4-ATS-L 1	AL	1	3	37.6	35.7	30.3	12.0	25.6	23.7	18.3
6	4-ATS-L 2	AL	2	5	40.6	27.0	19.8	6.4	34.3	20.7	13.4
12	4-ATS-L 3	AL	3	2	41.6	33.9	25.2	8.9	32.6	24.9	16.2
17	4-ATS-L 4	AL	4	4	40.7	32.9	25.6	7.1	33.6	25.8	18.4
21	4-ATS-L 5	AL	5	1	38.4	33.3	26.2	7.3	31.1	26.0	18.9
5	3-CP-H 1	CH	1	5	39.9	30.8	22.7	7.0	33.0	23.8	15.7
10	3-CP-H 2	CH	2	1	39.9	34.5	26.3	8.2	31.7	26.3	18.1

Sample number	Plot	Treat	Row	Column	pF 0.5	pF 2	pF 3	Wilting Point (WP)	pF 0.5-WP	pF 2-WP	pF 3-WP
13	3-CP-H 3	CH	3	3	42.9	38.6	30.5	10.3	32.5	28.2	20.2
19	3-CP-H 4	CH	4	2	40.6	37.0	28.8	10.0	30.6	27.1	18.8
24	3-CP-H 5	CH	5	4	44.0	35.2	25.5	7.8	36.3	27.5	17.8
4	1-CP-L 1	CL	1	4	36.8	32.1	25.1	8.9	28.0	23.2	16.2
9	1-CP-L 2	CL	2	2	39.8	34.2	25.3	9.3	30.5	24.9	16.0
11	1-CP-L 3	CL	3	1	40.4	35.7	27.1	8.3	32.1	27.4	18.8
16	1-CP-L 4	CL	4	5	37.1	21.7	15.4	4.9	32.1	16.8	10.5
23	1-CP-L 5	CL	5	3	40.1	33.8	24.0	8.2	31.9	25.5	15.8
1	2-C 1	CO	1	1	38.7	32.9	24.2	7.5	31.2	25.4	16.6
7	2-C 2	CO	2	4	37.0	30.4	23.8	9.9	27.1	20.5	13.9
15	2-C 3	CO	3	5	32.7	22.0	16.2	5.8	26.9	16.2	10.5
18	2-C 4	CO	4	3	37.7	34.8	26.5	8.8	29.0	26.0	17.7
22	2-C 5	CO	5	2	40.9	31.5	24.2	8.6	32.4	22.9	15.6