effects of charcoal addition on spring wheat yield- a greenhouse study

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Preface:

This 30 credits master thesis is a result of my researche during my studies in Master of Science in International Environment studies at Norwegian University of Life Sciences (UMB). Using this opportunity, I would like to thank people who gave me full support during my period of study and living at Ås.

My specials thank goes to Professor Mikael Ohlson, not only for supervising my master thesis but also for being supportive during the whole of my project.

I would like to thank my beloved husband Hamid Reza Firoozi for his patience and being by my side all the time. I also thank my dearest friend Zuzana Mičeková, for her unlimited helps that make this project easier for me and for the time we spend together in Ås.

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Abstract:

In this thesis I have investigated if addition of charcoal to the soil improves the growth and yield of spring wheat. My thesis is based on an experimental greenhouse study in which different amounts of charcoal were added to a nutrient poor sandy soil. The experiment included five charcoal treatments, i.e. a control (no addition of charcoal) and additions of 0.63, 6.30, 12.60, and 25.20 g charcoal per pot, which corresponds to 150, 1500, 3000 and 6000 g charcoal m^{-2}.

The spring wheat was mature for harvest after 68 days growth in the greenhouse and I divided the plants in different parts when they were harvested. Roots, stems, leaves and spikes were dried and weighed separately in order to estimate plant production and biomass allocation patterns. My results show that charcoal addition significantly impact on biomass allocation patterns and has positive effects on the production of spring wheat. However, there was no clear dosage effect in how the plants responded on the charcoal additions, which indicates that rather low dosages of additions may be considered when using charcoal in agricultural systems in an applied and practical perspective.

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Introduction:

Biochar is the product of thermal degradation of organic materials in the absence of air (pyrolysis)(Lehmann and Joseph, 2009). There are some research that shows biochar can be used as a possible means to improve soil fertility as well as other ecosystem services and sequester carbon for reduction of carbon mitigation (C) to mitigate climate change (Lehmann et al., 2006), (Lehmann, 2007a), (Laird, 2008) and (Sohi et al., 2010).

Charcoal is the dark grey residue consisting of carbon, and any remaining ash, obtained by removing water and other volatile constituents from vegetation substances. Charcoal is usually produced by slow pyrolysis at temperatures from ca. 300 to 600 °C (Rajkovich2012) and the heating of wood or other substances should be in the absence of oxygen.

Although the history of making and using charcoal in humans daily life date back to 3000 years ago, and the use of charcoal as a soil amendment has been investigated since the early 1800s, the use of charcoal to increase crop production recently it has been rekindled due to concern about global energy shortages and climate change (Lehmann et al., 2006; Lehmann and Joseph, 2009).

Mostly the pragmatic effects on how much the soil can be fertile explained by a pH increase in acid soils (Van Zwieten et al., 2010a) or improved nutrient retention through cation adsorption (Liang et al., 2006). However, charcoal has also been shown to change soil biologi in terms of the quality and quantity of soil microorganisms.(Kim et al., 2007).According to Steiner (2008), these changes may well have effects on nutrient cycles and soil structure (Rillig and Mummey, 2006), which in turn can lead to differences in plants growth and productivity (Warnock et al., 2007). The possible connections between biochar properties and the soilbiota, and their implications for soil processes have not yet been systematically described. (Lehmann et al 2010)

The effectiveness of using charcoal as an approach to mitigate climate change rests on its relative recalcitrance against microbial decay and thus on its slower return of terrestrial organic C as carbon dioxide (CO_2) to the atmosphere (Lehmann, 2007b). Both the composition of the decomposer community as well as metabolic processes of a variety of soil organism groups may be important in determining to what extent charcoal is stable in soils, as is known for wood decay (Fukami et al., 2010). Changes in microbial community composition or activity induced by charcoal may not only affect nutrient cycles and plant growth, but also the cycling of soil organic matter, (Kuzyakov et al., 2009) and (Liang et al., 2010). In addition, charcoal may change emissions of other greenhouse gases from soil such as nitrous oxide (N2O) or methane (CH4) (Rondon et al., 2005), such changes may either reduce or accelerate climate forcing. The driving processes are still poorly identified (Van Zwieten et al., 2009).

Charcoal may pose a direct risk for soil fauna and flora, but could also enhance soil health. Charcoal properties vary widely and profoundly; not only in their nutrient contents and pH (Lehmann, 2007a), but also in their organo-chemical (Czimczik et al., 2002).

In this paper, I set an experiment to show how different amounts of charcoal have different effects on spring wheat growth and production. Later on in the result part of this paper it is shown how different doses of charcoal have different effects on yield of spring wheat.

3. Materials and methods:

Preparing of soil: For preparing the soil for this experiment I used a chemically inert pure sandy soil that was mixed with a small amount of organic soil matter and four different levels of charcoal additions. The sandy soil was of glacifluvial origin and is frequently used as a standard soil-component in plant production research at the Norwegian University Life Sciences. Further information about the sandy soil is available at the Department of Plant- and Environmental Sciences at the Norwegian University Life Sciences. The organic soil was a commercially available and fertilized peat soil (86 % of volume Sphagnum turf, 10% of volume sand, 4% of volume granulated clay, organic matter include 35% of solids and ph of this soil was 5.5-6.5) and it made 3% of the total soil dry mass.

Charcoal: The type of wood used for preparing charcoal was Scots pine (Pinus sylvestris) ca 90 %, birch (Betula pubescens) ca 5%, and aspen (Populus tremula) ca 5 % + some traces of grey alder (Alnus incana) and coaling temperature was 450-500 C. Two sieves were used t standardized size-distribution of 0.5 - 2mm of the charcoal that was added to the soil. The amounts of charcoal that were used in this experiment were:

Level	g per pot
Control	0
Group A	0.63
Group B	6.30
Group C	12.60
Group D	25.20

Setting the experiment:

After preparing soil we set the pots. The pot size used was 16 cm diameter and two litter capacity. I had 15 pots in each replicate. It means 15 pots in each of these five replicates, giving in total 75 pots. I filled the pots with the soil (sandy soil+ organic matter+ charcoal) and I watered them for one week so the charcoal could start to work and be active.

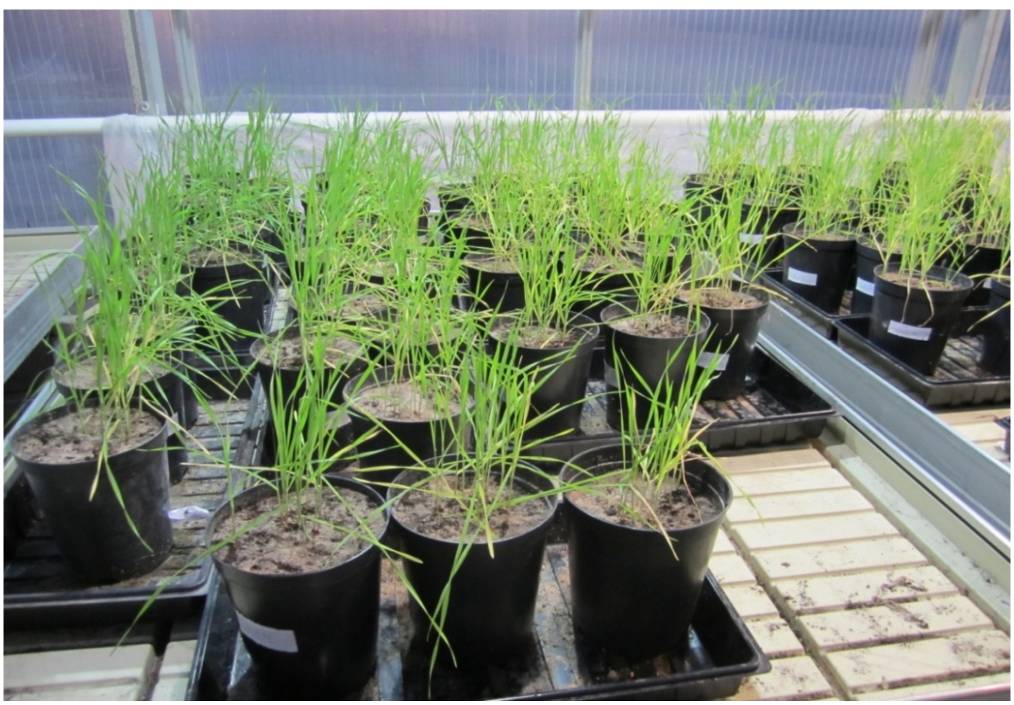

Figure number 1 pots after removing weakest seedlings

After one week I planted 15 seeds in each pot. The seeds started to germinate after 2 days, and during the next seven days all were germinated and had established seedlings. After ten days, I removed 5 of the weakest seedling and kept 10 strong seedlings in each pot (Fig.1). It took 68 days from planting, until the plants were mature and ready for harvest (Fig3). In the harvest, I divided each plant in 4 different parts that were spike, stem, root, leaf and one additional separate part for extra roots from each pot (Fig.2) (this was done in order to sum up the total root biomass for each pot - a proportion of the fine roots were always lost from the individual plant when extracting it form the pot soil.

The average seed weight for the wheat was determined to calculate the net growth of the plants by subtracting the seed weight from the plant weight.

Figure number 2 plants after removing form pots.

All these different plant parts were then put in marked packets. After harvesting all of the plants I dried the plant materials for seven hours in 70 ° C. After all of the plant materials were dried the weighing part started.

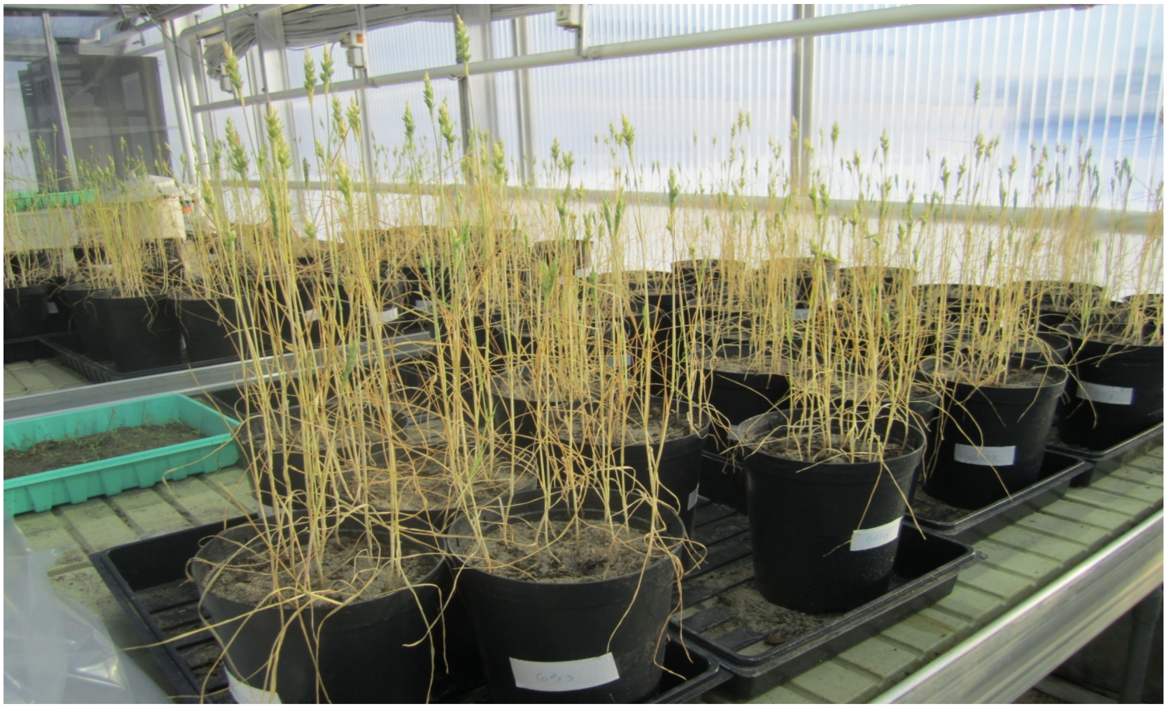

Figure number 3 plants in maturity stage

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Results:

According to the information I get from the data there is significant deference in yield between the treatments with different amount of charcoal additions. However, the yield died not always increase by increasing charcoal addition, which was somewhat unexpected. The following data give more information about the effects of charcoal on the growth and allocation of biomass to different plant parts in spring wheat.

Roots mass:

Figure 4 shows that root mass is one of these parts that are not increasing according to the charcoal proportion in the soil. This number has difference with second treatment with low amount of charcoal. These differences have up and downs according to different treatments but the most important part is the treatment with no charcoal has higher root mass and according to standard error graph (Fig.5) I have highest variation among the observations in control group.

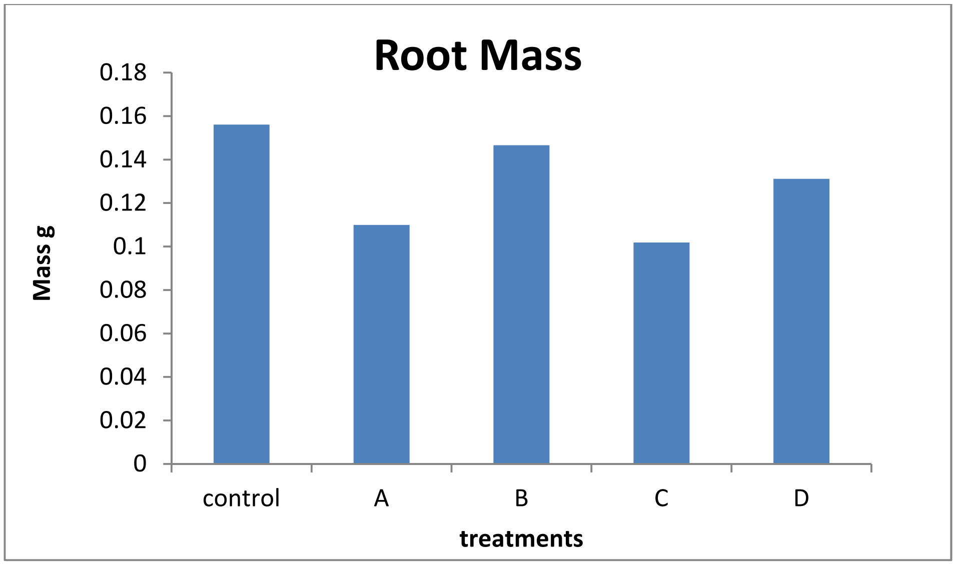

Figure number 4 root mass average

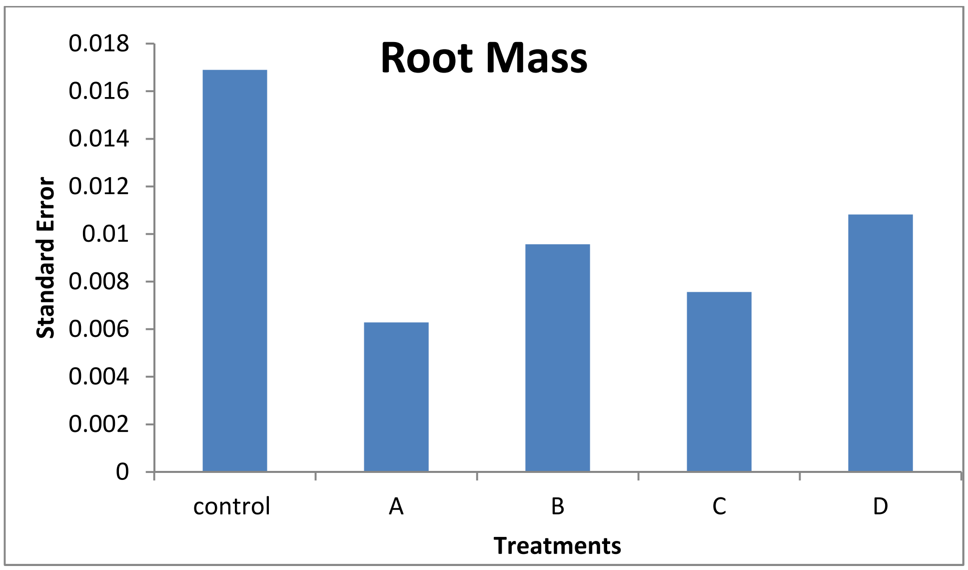

Figure number 5 Root standard error

According to ANOVA table below since the P-value is much less than 0.05 my result has significant difference.

ANOVA Root Mass						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.032	4	0.008	4.539	0.0025	2.502
Within Groups	0.124	70	0.001			
Total	0.156	74				

Table 1 root mass standard error

Figure number 6 roots after removing from the pots.

Leaf mass:

The results for leaf mass were quite different as compared with those for root mass. It seems like the role of charcoal for improving leaf mass is uncertain because there was no clear trend among the different charcoal treatments. The highest amount of leaf mass was in group B (Fig.7).

According to standard error chart (Fig8) the highest amount of discrepancy among the observations belongs to group A.

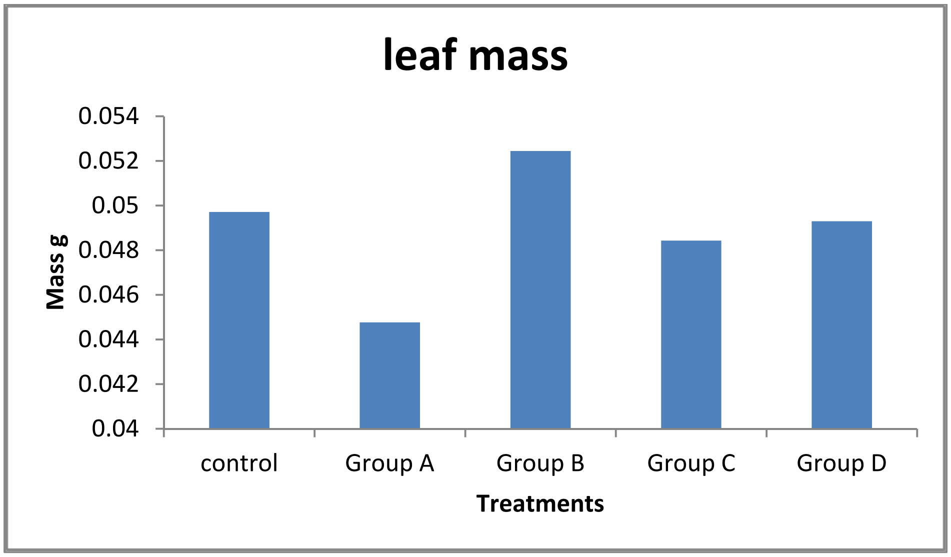

Figure number 7 leaf Mass average

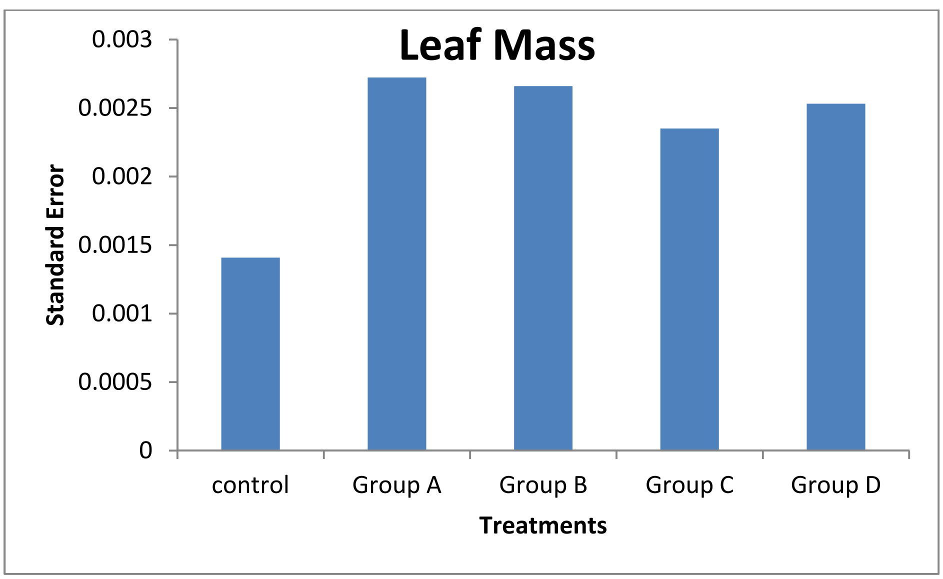

Figure number 8 Leaf Standard Error

Since the P-value is much larger than 0.05, I do not have any significant difference in this group of data.

ANOVA Leaf Mass						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0004	4	0.0001	1.349	0.260	2.502
Within Groups	0.005	70	8.5225E-05			
Total	0.006	74				

Table2 Leaf Mass standard error

Stem mass:

According to Fig. 9 the highest stem mass is in the control group and by adding more charcoal to the soil the amount of stem mass decrease. By the last treatment in group D, with the highest amount of charcoal in the soil, the stem mass was lowest. In the standard error chart (Fig. 10) the most variation among the samples is in Control group.

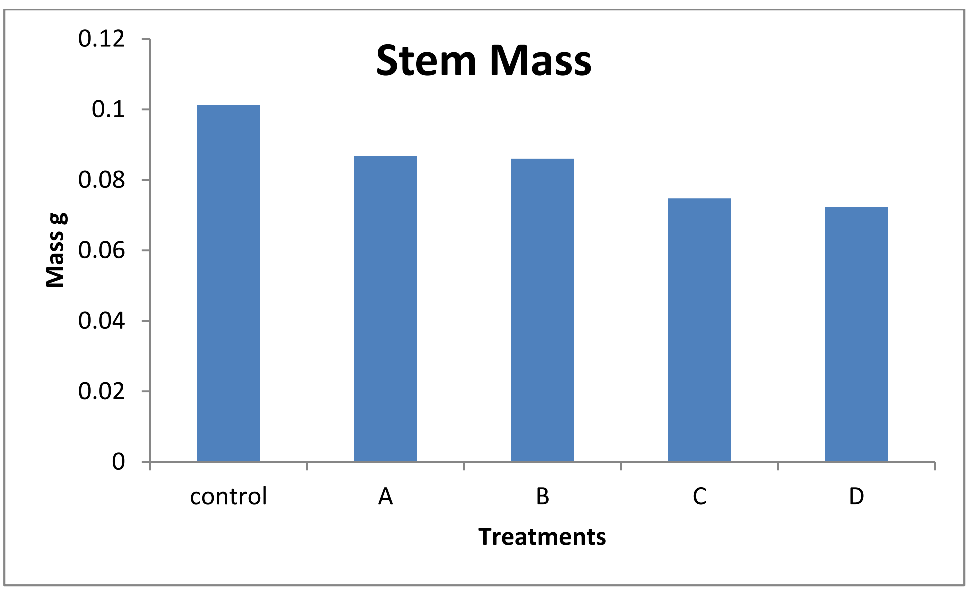

Figure number 9 Stem Mass average

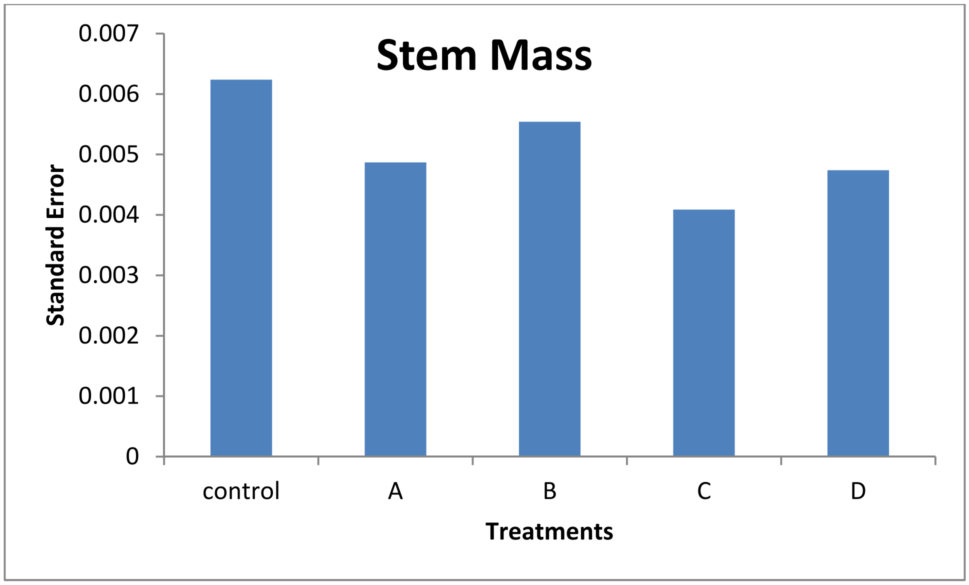

Figure number 10 Stem Standard Error

There is significant difference between data of stem mass samples because P-value is less than 0.05.

ANOVA Stem Mass						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007	4	0.001	4.986	0.001	2.502
Within Groups	0.027	70	0.0003			
Total	0.035	74				

Table3 Leaf Mass standard error

Spike Mass:

For spike mass according to Fig.11 results instead of decreasing in amount of spike mass in group A in other treatments the results are increased in combination of Control group and the highest amount of spike mass is in group B that is second dose of using charcoal. The largest number of variation among the observations, according to standard error (Fig.12) chart is belongs to group D.

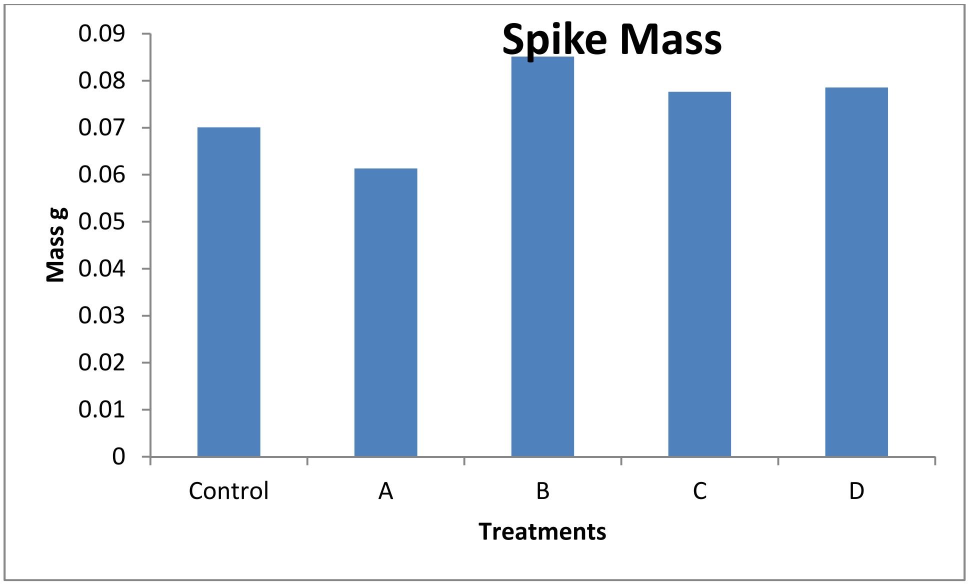

Figure number 11 Spike Mass average

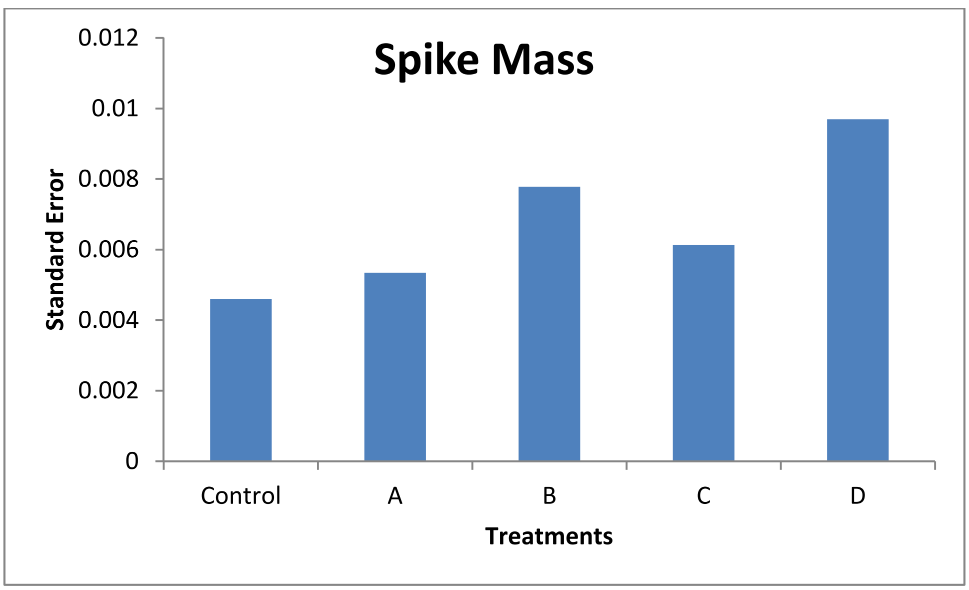

Figure number 12 Spike Standard Error

According to P-value in ANOVA chart differences in this result is not significant because it is bigger than 0.05.

ANOVA Spike Mass						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004	4	0.001	1.715	0.156	2.502
Within Groups	0.0507	70	0.0007			
Total	0.055	74				

Table4 Leaf Mass standard error

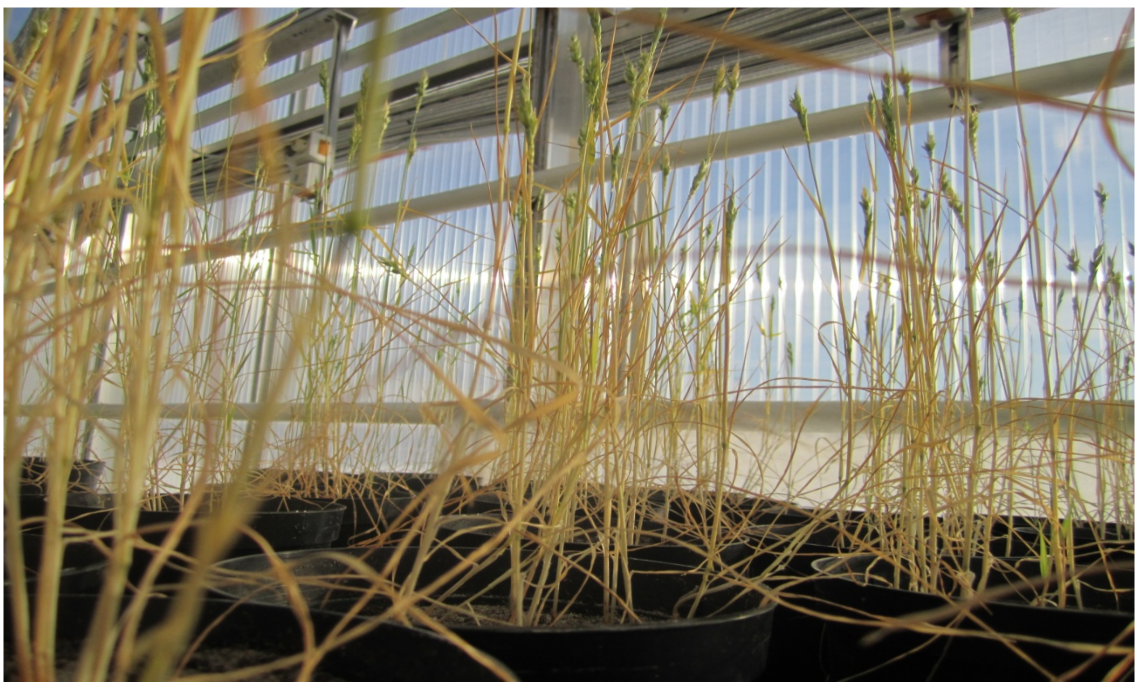

Figure number 13 plants in maturity stage

Stem/Root ratio:

Dividing stem mass to root mass shows different results in different treatments according to Fig.14 and These changes are not increase of decrease according to amount of charcoal usage.

The highest stem/root ratio in group A that is lowest amount of charcoal between treatments. The highest number of variation among the observations according to (Fig.15) is in Control group.

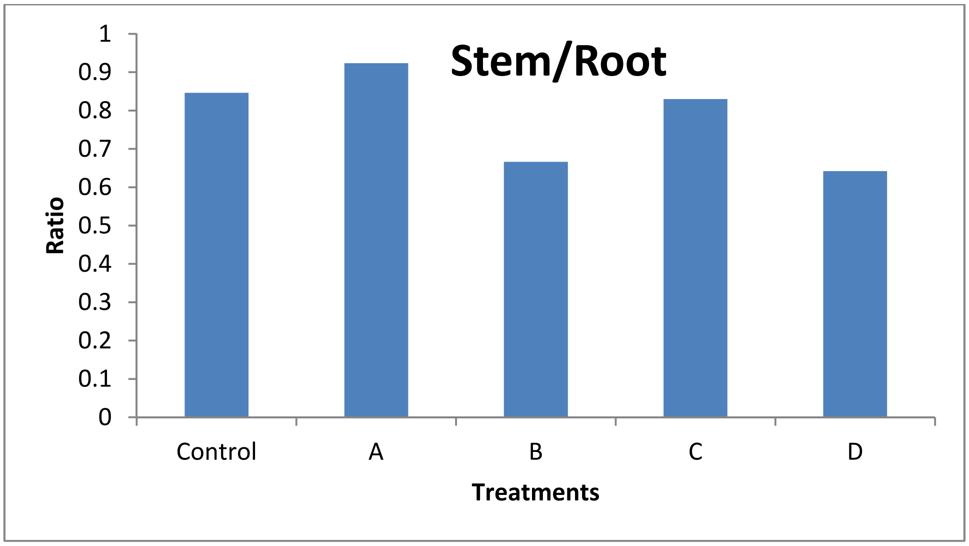

Figure number 14 Stem/root ratio

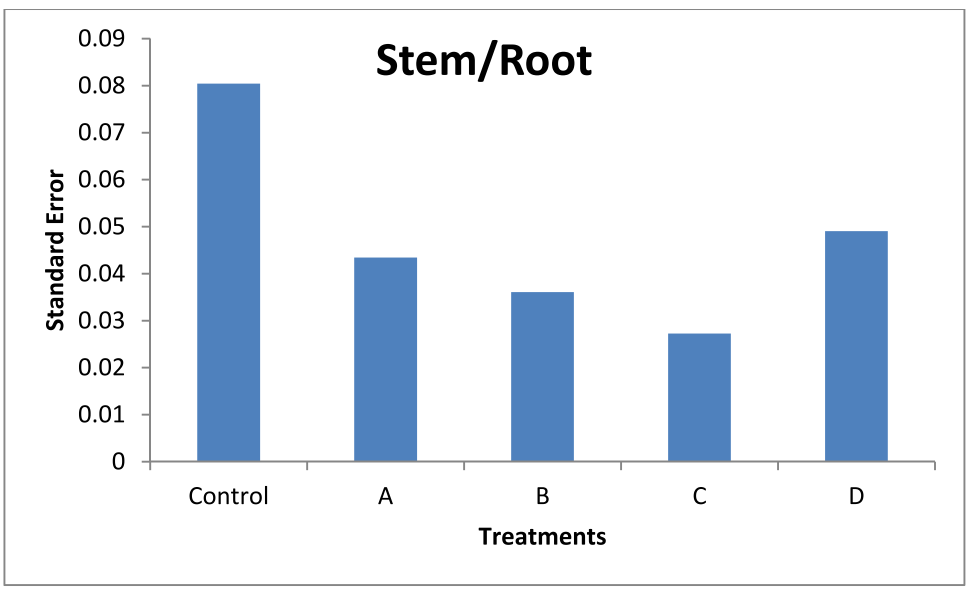

Figure number 15 Stem/Root Standard Error

As you can in ANOVA table below P-value is smaller than 0.05 and I have significant difference amount data in stem/root ratio.

ANOVA Stem/Root						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.892	4	0.223	5.806	0.0004	2.502
Within Groups	2.689	70	0.038			
Total	3.581	74				

Table5 Leaf Mass standard error

Leaf/Root ratio:

The chart below shows dividing leaf mass to root mass gave different results for different treatments (Fig.16). The increase and decrease in these numbers are not according to charcoal usage and the highest amount of leaf/root ratio is in treatment C. The highest variation among the observations was in Control group. (Fig.17)

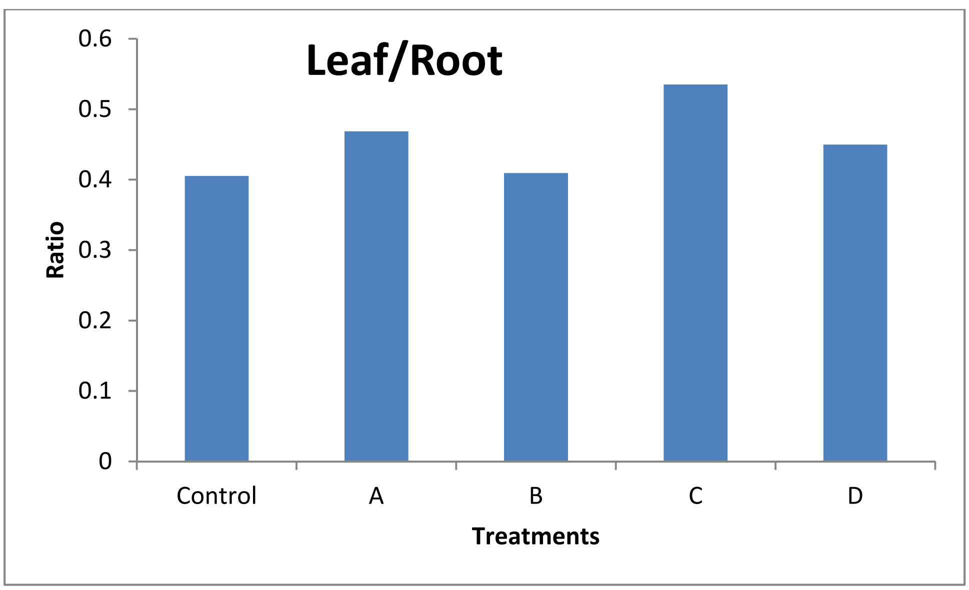

Figure number 16 Leaf/Root Ratio

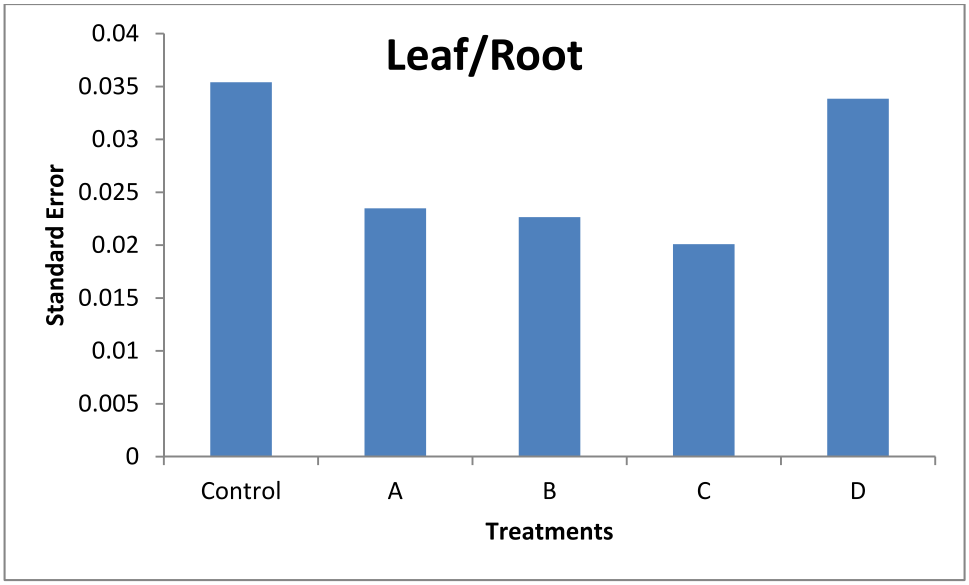

Figure number 17 Leaf/Root Standard Error

According to ANOVA table below and P-value<0.05 I have significant difference amount data in this part.

ANOVA Leaf/Root						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.167	4	0.041	3.617	0.009	2.502
Within Groups	0.811	70	0.011			
Total	0.979	74				

Table6 Leaf Mass standard error

Spike/Root ratio:

After dividing spike mass to root mass the results in (Fig.18) founded. It shows the highest number of spike/root ratio in group B and according to standard error chart (Fig.19) the highest variation among the observations is in group B and D.

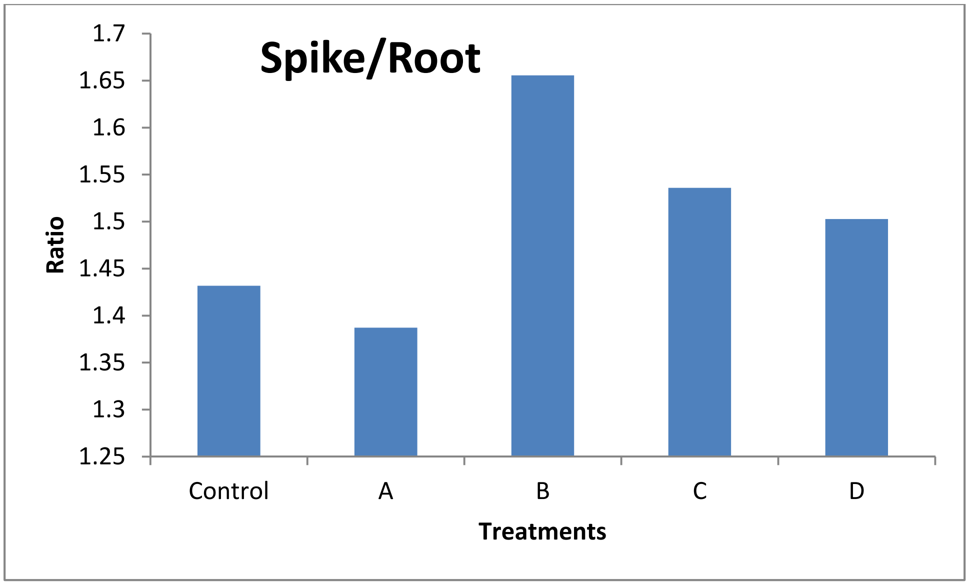

Figure number 18 Spike/Root Ratio

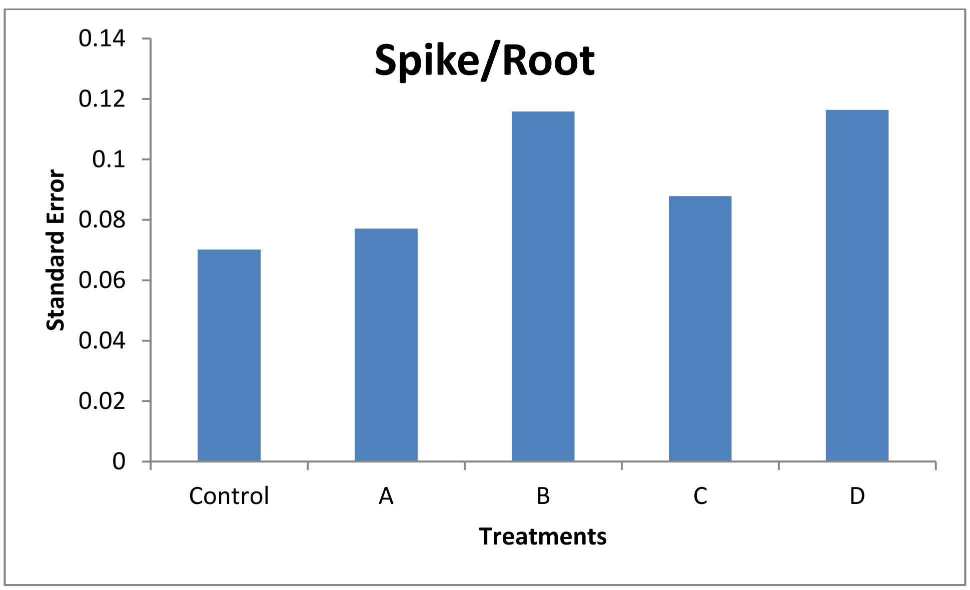

Figure number 19 Spike/Root Standard Error

According to ANOVA table below P-value>0.05 so there is no significant deference in the results.

ANOVA Spike/root						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.642	4	0.160	1.175	0.329	2.502
Within Groups	9.565	70	0.136			
Total	10.207	74				

Table7 Leaf Mass standard error

Spike/Leaf ratio:

According to (Fig.20) in spike/leaf ratio the highest amount in group C and it looks the increase and decrease in these numbers are not relevant to charcoal proportion. According to standard error chart (Fig.21) the highest variation among the observations is in control group.

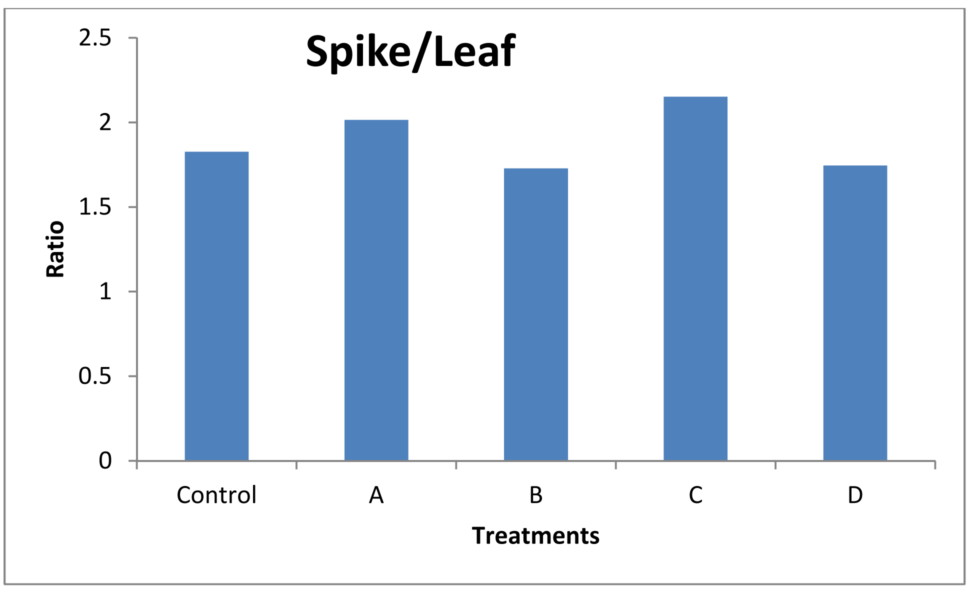

Figure number 20 Spike/Leaf Ratio

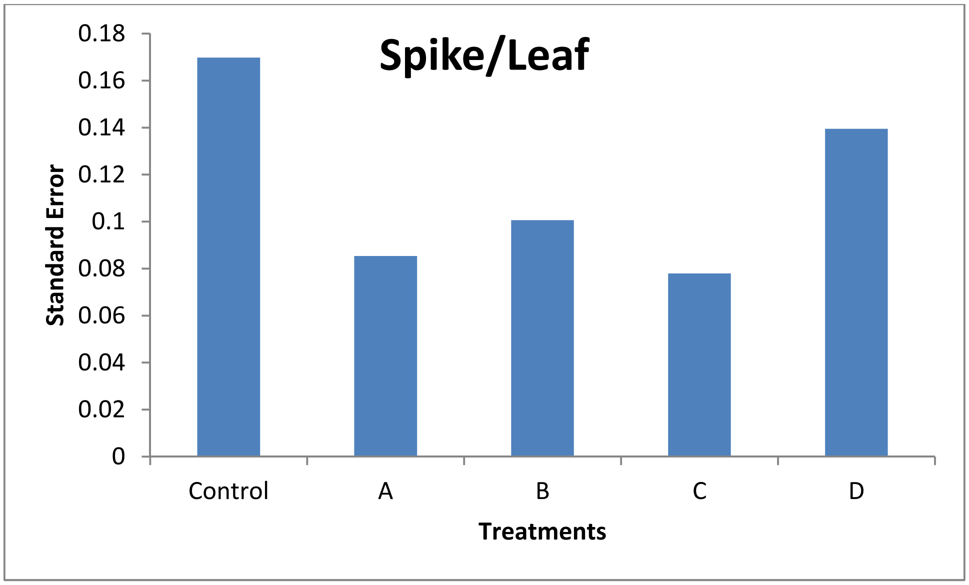

Figure number 21 Spike/Leaf Standard Error

According to ANOVA table below since the P-value is only slightly larger than 0.05 there is a tendency for a significant difference in spike/leaf ratio data

ANOVA Spike/Leaf						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.024	4	0.506	2.350	0.062	2.502
Within Groups	15.071	70	0.215			
Total	17.095	74				

Table8 Leaf Mass standard error

Total net growth:

The total net growth is increase according to charcoal use (Fig.22). The highest amount of total net growth is in group C. In general increase in total net growth is according to charcoal usage and according to standard error chart (Fig.23) the highest variation among the observations is in group B.

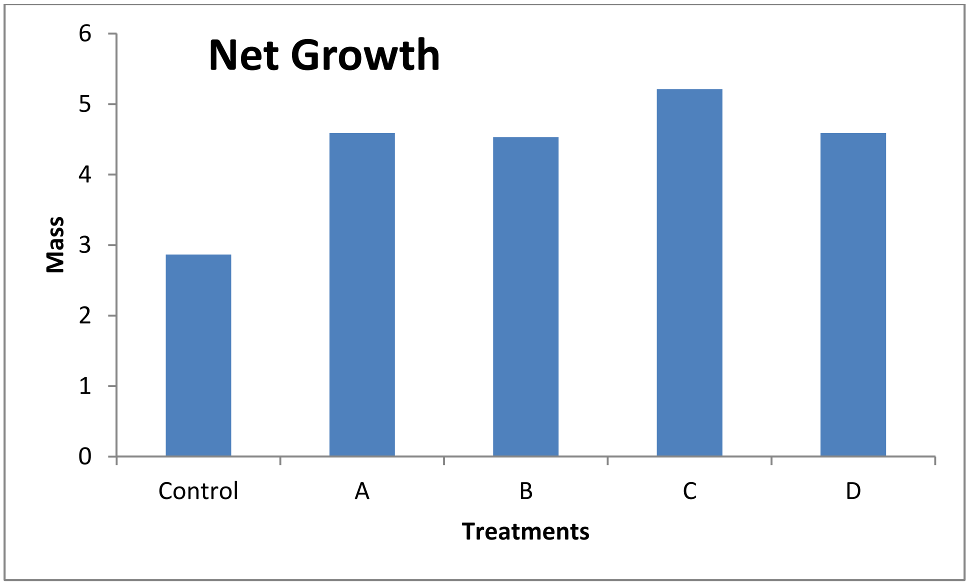

Figure number 22 Net Growth mass

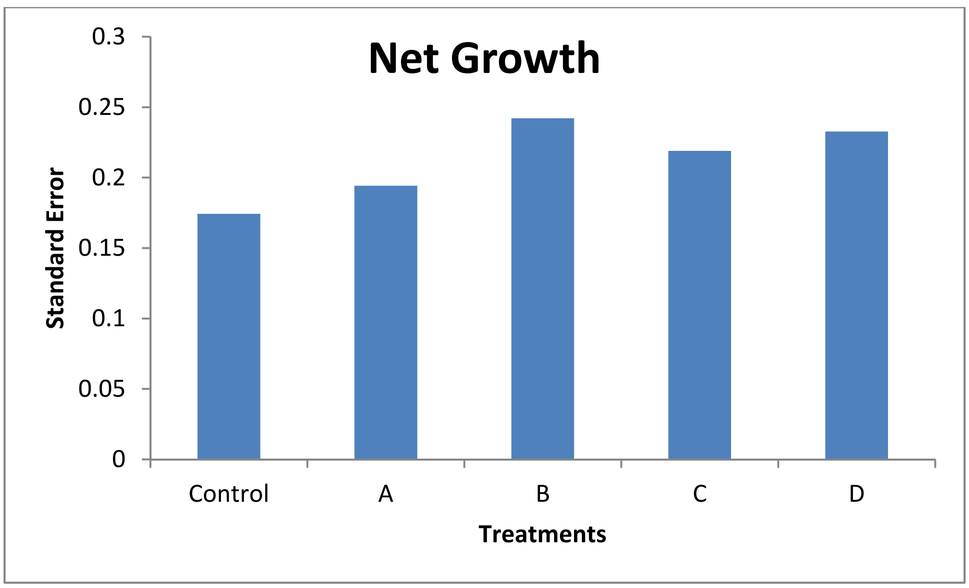

Figure number 23 Net Growth Standard Error

According to the ANOVA table, the P-value is much lower than 0.05 and there is a clearly significant difference in the results.

ANOVA Net Growth						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	46.458	4	11.614	16.915	<0.001	2.502
Within Groups	48.063	70	0.686			
Total	94.521	74				

Table 9 Leaf Mass standard error

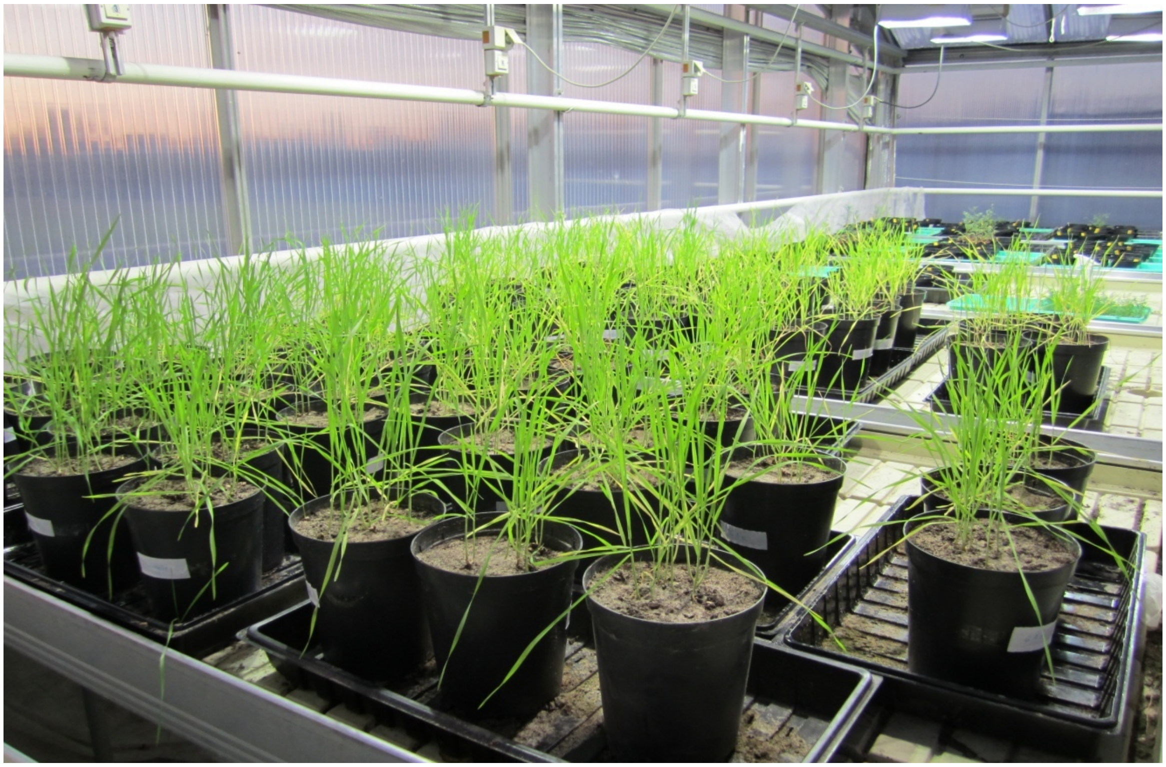

Figure number 24 pots after removing weakest plants.

Discussion:

Increased crop yield is a commonly reported benefit of adding charcoal to soils in many agricultural experiments. However, experimental results are variable and dependent on the experimental set-up; soil properties, conditions and kind of charcoal or biochar that is used (Lehmann et al 2010, Rajkovich2012). As much as different kind of material (wood, plant waist, animal manure, and paper sludge or food waist) for preparing charcoal can make differences in results (Rajkovich2012), some other elements in preparing charcoal like temperature (Rajkovich2012) may also have some effects on final results. But one thing is obvious from most of the research around the world, and it is that a use of charcoal or biochar generally seems to improve crops yields. This increasing in yield appears because of ability of charcoal for improving soil condition from increasing water holding capacity **(**Jeffery 2012) to increasing number of useful soil microorganisms. There is much research, both in the field and in the laboratory that shows that there is significant difference in results in treatments with charcoal and control treatments lacking charcoal. The amount of charcoal in use in each treatment of this research has a very important role for the results. Mostly, the treatments are starting with 0% usage of charcoal and increasing to the upper levels. For example in one of the studies done by Rajkovich et al. (year), they used 0.0%, 0.2%, 0.5%, 2.0%, and 7.0%, which were (*w/w)* equivalent to 0.0, 2.6, 6.5, 26, and 91 t biochar ha^{-1}. Interestingly, Rajkovich et al. (year) used biochar that originated from different material, andthey have these results: animal manure biochars increased yield by up to 43% and wood charcoal by up to 30%, while food waste biochar decreased biomass by up to 92%. In another research done in Zambia with these amounts of charcoal 0.0, 0.8, 4 ton s of charcoal ha^{-1} in two different type of soil yield increased up to 30% after using of charcoal in both acidic and normal soil (Cornelissen2010) and in another research on durum wheat in the Mediterranean climate condition, with usage of charcoal was 30 and 60 t ha^{-1} the results was almost the same as results in Zambia and yield increased up to 30% (Vaccari2011). These researches show no matter which part of world and which type of soil used for researches in the results most of the times there is significant difference between control and other treatments.

In my experiment according to charts and tables there is significant difference in the results too. In some part of plants these differences much more clear than other parts. Two parts that in my opinion are the most important results are Root Mass and Net growth.

There is a fact that plants in the absent or shortage of nutrition are making more roots. With more roots it is possible for plants to searching for nutrition in far distances. Due to this fact the same thing happened for my treatment. In the control treatment I had just poor nutrition sandy soil with certain amount of organic matter, and the wheat plants were making more roots to search for nutrition. The order in Root Mass chart (Fig.1) is according to increasing amount of charcoal it means by increasing amount of charcoal from Control treatment to treatment D Root mass decreased.

According to the data of ANOVA table for net growth, there is significant difference between the charcoal treatments, which indicate that the spring wheat yield was improved by charcoal addition. However, I had the highest yield in the group C, and not in group D that represented the highest charcoal addition. This was not expected and one possible explanation for why the highest amount of net growth belongs to group C and not D is that the proportion of organic matter may be too low to handle the high amount of charcoal in group D.

My results also show that the lowest charcoal dose treatment (i.e. group A) had a significant and positive effect on the wheat yield. While in the third treatment (i.e. group C), where the charcoal addition dose was doubled, the results did not change much. From a commercial point of view, and if we want to use charcoal in agriculture to improve soil properties, the best amount of charcoal to use that has economic justification is the group A treatment with 0.63 gram charcoal per pot. Interestingly, this amount corresponds to approximately 150 g m^{-2} (equally to 150 kg ha^{-1}), which in turn is about the same amount as the average size of the charcoal pool in the boreal forest soil, see Ohlson et al. (2009). general, a use of charcoal in agricultural systems may reduce the need for using commercial fertilizers and have positive carbon sequestration effects, which in turn will help our environment and increase crop yields simultaneously.

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Appendix:

Root mass	*Control*	*A*	*B*	*C*	*D*
Mean	0.156104974	0.109965333	0.146584667	0.101888481	0.131148963
Standard Error	0.016899149	0.006283222	0.009570644	0.007560672	0.01082047
Median	0.13401	0.10662	0.14805	0.0897	0.13415
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.065450122	0.024334815	0.037066943	0.029282355	0.041907501
Sample Variance	0.004283719	0.000592183	0.001373958	0.000857456	0.001756239
Kurtosis	-1.021780739	7.417150658	-0.475674807	1.912303464	-0.763022484
Skewness	0.606114489	2.436216843	0.07001083	1.528259623	-0.348321023
Range	0.192268333	0.10164	0.13488	0.10479	0.1335
Minimum	0.081491667	0.08517	0.08224	0.06944	0.05901
Maximum	0.27376	0.18681	0.21712	0.17423	0.19251
Sum	2.341574604	1.64948	2.19877	1.528327222	1.967234444
Count	15	15	15	15	15
Confidence Level(95,0%)	0.036245069	0.013476172	0.020526989	0.016216028	0.023207601

leaf mass	*control*	*Group A*	*Group B*	*Group C*	*Group D*
Mean	0.049717021	0.044767333	0.052443333	0.048433556	0.049300815
Standard Error	0.001408152	0.00272302	0.0026597	0.002350609	0.002532044
Median	0.04869	0.04422	0.0505	0.0462	0.05065
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.005453749	0.01054621	0.010300972	0.009103871	0.009806565
Sample Variance	2.97434E-05	0.000111223	0.00010611	8.28805E-05	9.61687E-05
Kurtosis	0.096071458	0.226670498	0.502976576	2.586131331	-1.11266402
Skewness	0.755043412	0.565577784	1.127573252	1.320265021	-0.001102727
Range	0.01892	0.03931	0.03547	0.03595	0.03113
Minimum	0.0418	0.02839	0.0394	0.03676	0.03334
Maximum	0.06072	0.0677	0.07487	0.07271	0.06447
Sum	0.745755308	0.67151	0.78665	0.726503333	0.739512222
Count	15	15	15	15	15
Confidence Level(95,0%)	0.003020185	0.005840297	0.005704488	0.005041556	0.005430695

Stem Mass	*control*	*A*	*B*	*C*	*D*
Mean	0.101146284	0.086762667	0.08602	0.074749556	0.072277704
Standard Error	0.006238265	0.004869919	0.005540813	0.004087464	0.004738295
Median	0.09802	0.08004	0.08057	0.073783333	0.07172
Mode	#N/A	#N/A	#N/A	#N/A	0.08396
Standard Deviation	0.024160697	0.018861115	0.021459476	0.015830679	0.018351336
Sample Variance	0.000583739	0.000355742	0.000460509	0.00025061	0.000336772
Kurtosis	6.109416989	1.012729226	3.016082876	0.717722906	0.884001388
Skewness	2.13079961	1.260716986	1.648898903	0.885267515	0.546434095
Range	0.10086	0.06587	0.08344	0.0582	0.071684444
Minimum	0.0736	0.06457	0.06114	0.05287	0.043755556
Maximum	0.17446	0.13044	0.14458	0.11107	0.11544
Sum	1.517194266	1.30144	1.2903	1.121243333	1.084165556
Count	15	15	15	15	15
Confidence Level(95,0%)	0.013379748	0.010444937	0.011883862	0.008766738	0.010162631

spike mass	*Control*	*A*	*B*	*C*	*D*
Mean	0.070073598	0.061350667	0.085132667	0.077641222	0.078550667
Standard Error	0.004595993	0.005348329	0.007782875	0.006126174	0.009693829
Median	0.068641667	0.05782	0.07328	0.07152	0.07635
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.017800204	0.02071399	0.030142943	0.02372657	0.037544039
Sample Variance	0.000316847	0.000429069	0.000908597	0.00056295	0.001409555
Kurtosis	2.194500231	1.203030801	-0.716558763	-0.93919877	2.471377959
Skewness	1.320607563	0.891592901	0.661557381	0.524575161	1.488834058
Range	0.0692	0.07802	0.09613	0.07393	0.13959
Minimum	0.04697	0.03435	0.04642	0.04698	0.03859
Maximum	0.11617	0.11237	0.14255	0.12091	0.17818
Sum	1.051103974	0.92026	1.27699	1.164618333	1.17826
Count	15	15	15	15	15
Confidence Level(95,0%)	0.009857424	0.011471025	0.016692606	0.013139337	0.020791196

Stem/Root	*Control*	*A*	*B*	*C*	*D*
Mean	0.846232314	0.92362755	0.666148552	0.830089616	0.64213317
Standard Error	0.080424255	0.043425161	0.036074392	0.027275986	0.04904844
Median	0.77554222	0.902267146	0.645163959	0.831266735	0.600679057
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.311481799	0.168184927	0.139715519	0.105639438	0.189963793
Sample Variance	0.097020911	0.02828617	0.019520426	0.011159691	0.036086243
Kurtosis	-0.083897319	-1.327828429	0.478748159	-0.378379711	1.934442928
Skewness	0.646520042	0.471377961	0.762744796	-0.285292666	1.194820965
Range	1.091574885	0.457715984	0.508662344	0.35716046	0.735167276
Minimum	0.421205652	0.740390187	0.481143277	0.614456051	0.399630537
Maximum	1.512780537	1.198106171	0.989805621	0.971616511	1.134797813
Sum	12.6934847	13.85441326	9.992228284	12.45134424	9.631997549
Count	15	15	15	15	15
Confidence Level(95,0%)	0.17249287	0.093137708	0.077371876	0.058501171	0.105198442

Leaf/Root	*Control*	*A*	*B*	*C*	*D*
Mean	0.405310634	0.468661383	0.40937871	0.53520442	0.449749449
Standard Error	0.035397202	0.023477707	0.022645588	0.020097604	0.033840775
Median	0.392025206	0.460873367	0.416256885	0.557577267	0.395574889
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.137092773	0.090928769	0.087705986	0.077837687	0.131064757
Sample Variance	0.018794428	0.008268041	0.00769234	0.006058706	0.017177971
Kurtosis	0.808070069	-0.552309578	-1.086234157	-0.533705363	-0.780160244
Skewness	0.908395033	0.432334166	0.303678493	-0.608028144	0.559754688
Range	0.516125643	0.316545513	0.290639156	0.255940108	0.426823091
Minimum	0.215285729	0.336730382	0.284167338	0.389095316	0.291929249
Maximum	0.731411372	0.653275895	0.574806494	0.645035424	0.718752341
Sum	6.079659505	7.029920744	6.140680643	8.028066301	6.746241734
Count	15	15	15	15	15
Confidence Level(95,0%)	0.075919447	0.050354674	0.048569956	0.043105074	0.072581243

Spik/Root	Control	A	B	C	D
Mean	1.431811743	1.387193904	1.655517118	1.53587237	1.502788144
Standard Error	0.070151013	0.077090658	0.115858534	0.087857799	0.116370473
Median	1.463238604	1.391401228	1.575052489	1.469531061	1.362272015
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.271693706	0.298570836	0.448718173	0.340271792	0.450700905
Sample Variance	0.07381747	0.089144544	0.201347999	0.115784892	0.203131305
Kurtosis	-0.440476845	0.851044544	-1.233074062	0.081562687	1.490126955
Skewness	0.429469197	0.859541406	0.247160842	0.753778858	1.214881766
Range	0.951279329	1.087072624	1.38164578	1.214573325	1.698909699
Minimum	1.015454211	1.009353776	1.039236521	1.068225543	0.941314238
Maximum	1.96673354	2.096426399	2.420882301	2.282798869	2.640223937
Sum	21.47717614	20.80790856	24.83275677	23.03808556	22.54182216
Count	15	15	15	15	15
Confidence Level(95,0%)	0.150458959	0.165343017	0.248491841	0.188436237	0.249589841

Spike/Leaf	*Control*	*A*	*B*	*C*	*D*
Mean	1.826921263	2.0145683	1.728145245	2.151620121	1.745560572
Standard Error	0.169760344	0.085372312	0.10060526	0.077940793	0.139513399
Median	1.66151022	2.028002843	1.796902617	2.138376192	1.786375556
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.657478987	0.330645542	0.389642496	0.301863393	0.54033307
Sample Variance	0.432278618	0.109326475	0.151821275	0.091121508	0.291959827
Kurtosis	-0.28117118	-1.608027248	-1.126046437	0.131346052	1.010089925
Skewness	0.622035211	0.078544185	0.036785549	0.456297225	0.800764638
Range	2.199523961	0.947832302	1.287928112	1.14936532	2.044651293
Minimum	0.936301965	1.562336628	1.125101989	1.650779012	1.017884635
Maximum	3.135825926	2.51016893	2.413030102	2.800144333	3.062535928
Sum	27.40381894	30.2185245	25.92217867	32.27430181	26.18340858
Count	15	15	15	15	15
Confidence Level(95,0%)	0.364099726	0.183105398	0.215776821	0.167166375	0.29922648

Spike/total mass	*Control*	*A*	*B*	*C*	*D*
Mean	2.905217521	4.62995677	4.570452889	5.25295606	4.631068779
Standard Error	0.174308865	0.194246555	0.242155701	0.21893977	0.232775478
Median	3.061673997	4.638170559	4.683451842	5.069410814	4.41984805
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.67509533	0.752313673	0.937864995	0.847950082	0.901535549
Sample Variance	0.455753705	0.565975862	0.87959075	0.719019341	0.812766347
Kurtosis	-0.416225319	0.269329399	-0.025750114	3.016640477	-0.624401873
Skewness	-0.279393282	-0.025969426	0.263171951	1.435265574	0.150205277
Range	2.408662294	2.697510495	3.357668361	3.40471837	3.007916474
Minimum	1.720921965	3.257475723	3.009857213	4.17045301	3.119229142
Maximum	4.129584259	5.954986218	6.367525574	7.57517138	6.127145616
Sum	43.57826282	69.44935154	68.55679334	78.7943409	69.46603168
Count	15	15	15	15	15
Confidence Level(95,0%)	0.373855332	0.416617424	0.519372321	0.469579102	0.499253745

Net growth	*Control*	*A*	*B*	*C*	*D*
Mean	2.865624521	4.59036377	4.530859889	5.21336306	4.591475779
Standard Error	0.174308865	0.194246555	0.242155701	0.21893977	0.232775478
Median	3.022080997	4.598577559	4.643858842	5.029817814	4.38025505
Mode	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.67509533	0.752313673	0.937864995	0.847950082	0.901535549
Sample Variance	0.455753705	0.565975862	0.87959075	0.719019341	0.812766347
Kurtosis	-0.416225319	0.269329399	-0.025750114	3.016640477	-0.624401873
Skewness	-0.279393282	-0.025969426	0.263171951	1.435265574	0.150205277
Range	2.408662294	2.697510495	3.357668361	3.40471837	3.007916474
Minimum	1.681328965	3.217882723	2.970264213	4.13086001	3.079636142
Maximum	4.089991259	5.915393218	6.327932574	7.53557838	6.087552616
Sum	42.98436782	68.85545654	67.96289834	78.2004459	68.87213668
Count	15	15	15	15	15
Confidence Level(95,0%)	0.373855332	0.416617424	0.519372321	0.469579102	0.499253745