Improving crop yield and storing carbon

Biochar in conservation farming in Zambia

Phase 2 report 4

15 October 2014

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Project

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Summary

The main aim of the project is to investigate the potential of organic waste biochar to sequester carbon and improve the fertility of weathered, sandy and/or acidic Zambian soils. Biochar amendment is exclusively combined with Conservation Farming (CF). In CF, only 10-12 % of the land is tilled. This means that CF and biochar are a favorable combination, since less biochar is needed to obtain the same effectiveness as with conventional tillage.

This report describes the following:

i) Agronomy: We started testing a protocol to avoid excessive biochar losses: opening basins only the first year, administering biochar and fertilizer, and then mixing followed by basin closing and planting. During harvesting a small part of the stems must remain in the soil in order to identify the location of the biochar (i.e. stems need to be cut instead of uprooted). In the second season, however, the basins do not need to be reopened (to avoid biochar losses), but instead a small hole needs to be made with a stick to introduce the seed and fertilizer. In the first season after biochar administration, in Kaoma, yield increased by about 30% in the presence of biochar (6 farms). In Mkushi, yield increases of 15-30% were observed for the 2013 plots, and also for plots where biochar was administered in 2011. In Mongu, a yield increase of 20% was observed for one farmer in the second season following biochar application in 2012. We thus obtained tentative indications that the new protocol for biochar application resulted in prolonged crop yield effects of biochar.

ii) Providing enough feedstock for biochar production is a challenge. Pigeon peas proved to be the most promising alternative. Kaoma was the only site where pigeon pea intercropping worked well. Here pigeon pea intercropping had no negative effect on maize yields (3.4 t/ha with intercropping vs. 2.9 t/ha without intercropping), in addition as much as 5.9 ± 3.6 ton/ha (n=6) dry weight pigeon pea biomass could be harvested from the intercropped plots. This particular pigeon pea variety only yielded biomass for biochar, no peas. In Mkushi, maize growth was so extensive that the intercropped pigeon peas were completely overwhelmed. Here separate stands of pigeon pea were necessary, and generated 17 tons/ha dry weight in the first year and 77 tons/ha dry weight in the second year (generating around 25 tons/ha biochar after two years' growth, or 12.5 tons biochar per ha per year). In addition, the shedding of nitrogen-containing leaves will further amount to the resilience of the maize-pigeon pea biochar system.

iii) Quantification of biochar leaching to the subsoil in Kaoma and Mkushi: Plots were established in March 2013, and soil profiles were taken in March 2014. Additional column tests using the same soils will be carried out in the course of autumn 2014. First results indicate the vertical washing-out of biochar particles is limited.

iv) Effect on soil physical properties: Biochar improved soil physical properties and the improvements were greatest with higher biochar doses.

Aggregate stability, porosity, water infiltration and plant available water increased, and bulk density decreased. Increase in plant available water, which otherwise is low in the studied soil, is important for crop growth especially in the areas of unreliable rainfall patterns in Zambia. Increase in soil porosity and reduction in bulk density means the soil structure is more open and this allows root growth. Increase in soil aggregate stability reduces the risk of erosion. In short, biochar could increase the soil's resilience to shocks such as drought, soil compaction and erosional impact of rain.

v) Root analyses: Visual imaging of maize root systems at two sites in Kaoma and two sites in Mkushi revealed that, even for plants of equal size, the root systems of biochar-amended plants were better developed and had larger root surface area than those of non-amended ones.

vi) Biochar production technology: the retort kiln built in Chisamba (Agroforestry Field Station) yielded high-quality biochar of both pigeon pea stems and corn cobs (both with carbon contents around 70%). The main disadvantage of the retort kiln is that it is far too costly for farmers in Zambia. Thus brick kilns or other simple technology such as a covered hole in the ground, are tentatively postulated as the best possibility for implementation currently, even though they are less clean with respect to exhaust gases. Another alternative is a so-called "double drum" which is simple but still has a retort possibility. This type of kiln will be tested in autumn 2014.

Implementation and further plans:

i) Testing the best "recipe" for biochar implementation in Mongu, Kaoma and Mkushi (see under "agronomy" above)
ii) Quantification of biochar leaching to the subsoil in Kaoma and Mkushi.
iii) Intercropping with another variety of pigeon peas that also yields some pigeon pea harvest.
iv) Further testing of the feasibility and gas emissions of simple but clean technologies such as described above.
v) Measuring the effect of biochar on soil humidity: does biochar application result in a delay in soil drying in sandy soils such as in Mongu and Kaoma?

The next full report (Phase 2 Final Repost) will be delivered in June 2015.

Contents

1 Aim

The main aim of the project is to:

Investigate the potential of organic waste biochar to sequester carbon and improve the quality of weathered and/or acidic Zambian soils.

The following aspects are described in this report:

i) Effect of biochar on crop yield: Field trials with maize, with farmers in Mongu, Mkushi and Kaoma. Report of a new season where new biochar from pigeon peas and maize cobs was added.
ii) Feedstock: Pigeon peas were tried as intercrops and separate plots.
iii) Biochar loss by leaching to the subsoil.
iv) Shovelomics: The effect of biochar on the maize root system.
v) Infiltration: the effect of biochar on water infiltration rates and soil physics.

This report is the 6th report in a series on biochar implementation in Zambia. It describes the results of activities performed in 2014 building on field trials started in 2010.

2 Agronomy

Generally, we put in practice the following mode of biochar implementation:

- Place around 4 ton/ha biochar in basins (around 350 g biochar per basin)
- Mix biochar well with fertilizer and soil, backfill the basin
- During harvest, cut maize stems instead of uprooting whole plants
- Do not open basins between seasons since this will spread out too much biochar – put new seed and fertilizer in a stick hole

In season 2013-2014, pigeon pea and maize cob biochar were compared, and intercropping of maize and pigeon peas was also tested. All farmers in this work followed the new “recipe”.

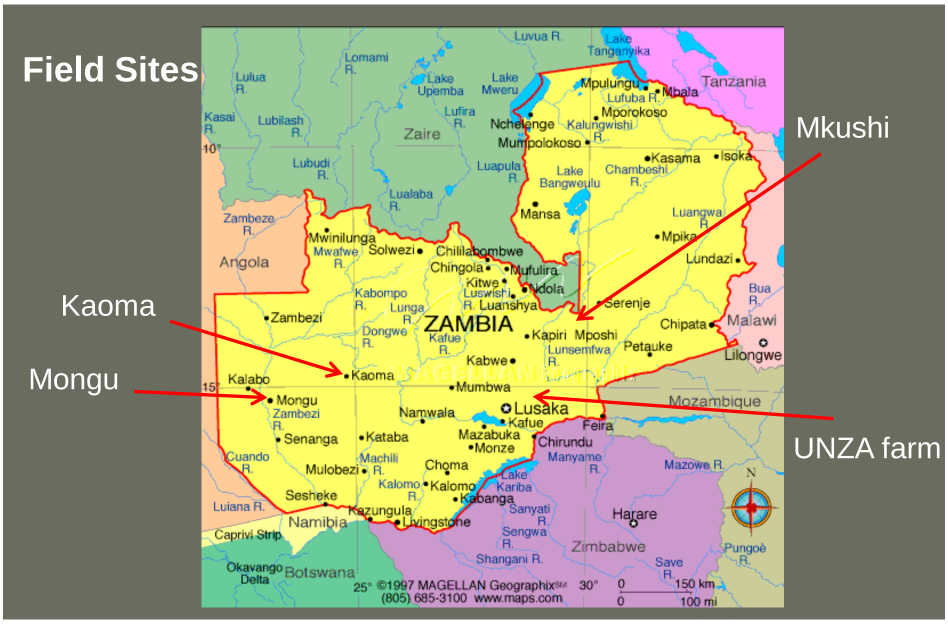


Figure 1. *Field trials sites in Zambia.*

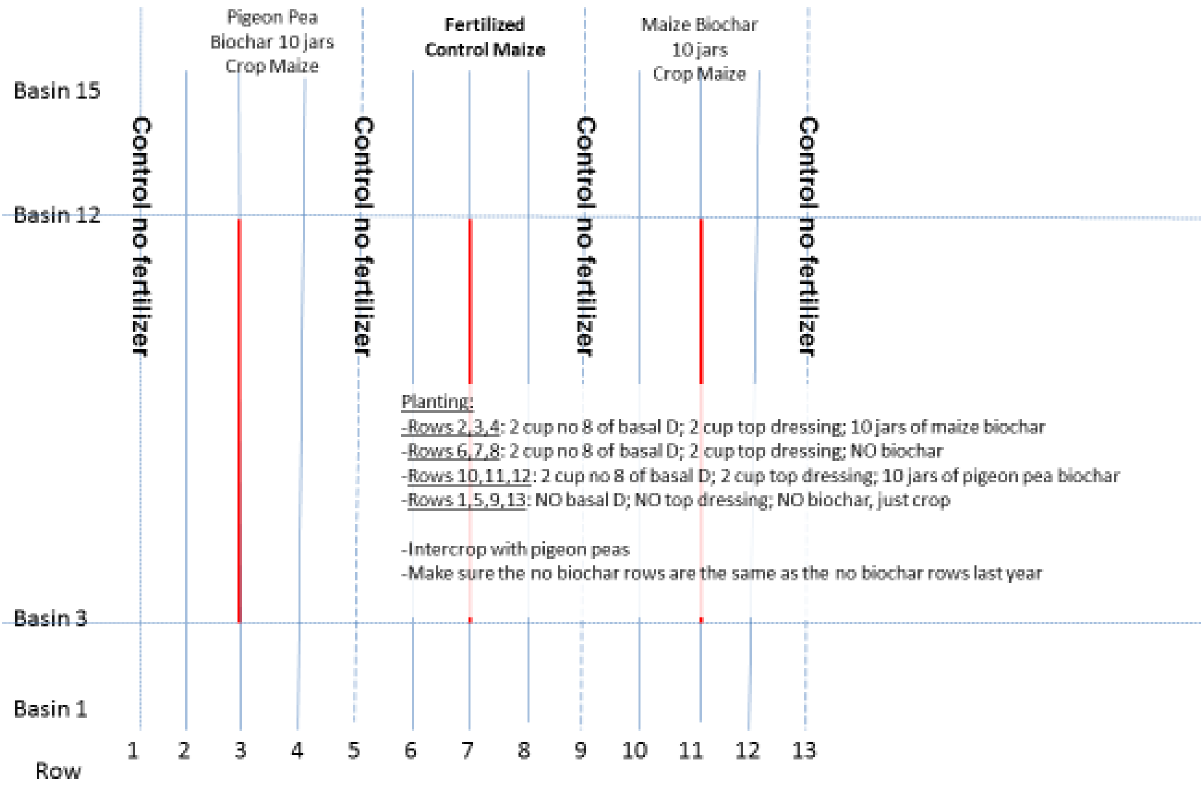
General conditions for all trials:

- Maize cob and pigeon pea biochar, prepared by CFU
- Test fields of 15 basins x 3 rows per treatment, with one row with zero fertilizer in between the treatments

Farmer sites are described in Appendix A.

2.1 Kaoma

The setup for Kaoma is as given below:



In Kaoma, new plots were established in November 2013, with fresh biochar produced from either corncobs or pigeon peas. In contrast to previous seasons, there was only one application rate of the biochars (10 cups per basin, i.e. 4 t/ha). The average maize grain yield was greatest for the treatment with 4 t/ha corn cob biochar combined with fertilizer and pigeon pea intercropping (Table 1). However, despite a nicely replicated design (six farmers with no missing yield values); only slight and non-significant positive effects of biochar on maize yield were observed (Fig. 2), in contrast to the earlier seasons. As previously observed in the biochar trials, the importance of fertilizer addition on crop growth was clearly demonstrated. The average maize grain yield at plots receiving no fertilizer were significantly ($p<0.05$) smaller as compared to sites receiving the recommended amounts (Fig. 2). Pigeon pea intercropping had no significant effect on maize yields (3.4 t/ha with intercropping vs. 2.9 t/ha without intercropping) even though 5.9 ± 3.6 ton/ha dry weight pigeon pea biomass could be harvested from the intercropped plots (see next section). No significant pea yields were obtained for this particular pigeon pea variety.

Table 1: Kaoma: Average (± sd) maize yields for the new plots established Nov. 2013. The average maize grain yield is based on an average of six farmers and the average stover (and total) maize yield is based on two farmers (Kasanga and Muneku).

Treatment	Grain (t ha^{-1})	Stover (t ha^{-1})	Tot. Biomass (t ha^{-1})
Control no fertilizer	1.1 ± 0.7	0.6 ± 0.0	1.3 ± 0.1
Control with fertilizer; no intercrop (regular CF)	2.9 ± 1.6	0.8 ± 0.3	2.5 ± 0.5
Control with fertilizer; p.p intercrop	3.4 ± 1.6	1.5 ± 0.1	3.8 ± 0.3
Pigeon Pea Biochar 4 ton/ha + fertilizer; p.p intercrop	3.5 ± 1.9	1.5 ± 0.0	4.0 ± 0.6
Maize Biochar 4 ton/ha + fertilizer; p.p intercrop	4.2 ± 1.9	1.6 ± 0.2	4.8 ± 0.3

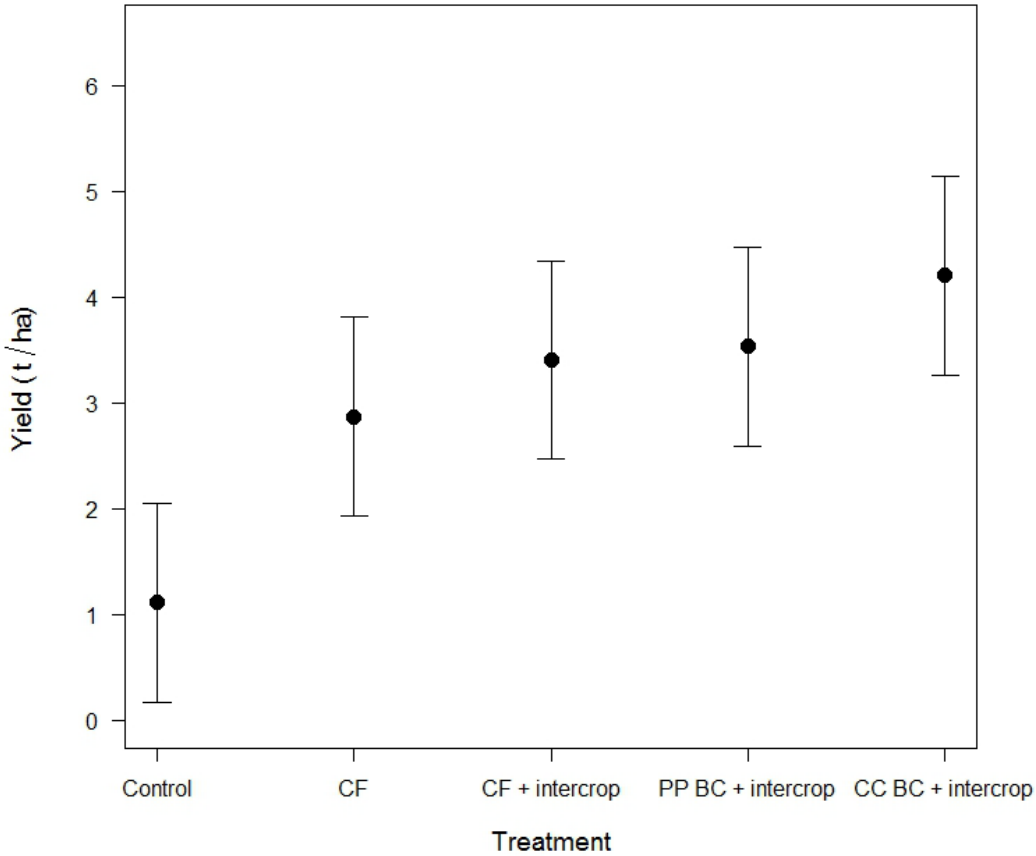


*Figure 2. Average maize grain yields for the season 2013-2014 in Kaoma (PP BC= pigeon pea biochar; CC BC = Corn Cob Biochar). The error bars shows the least significant difference (LSD, 1.88 t ha^{-1}). Overlapping bars indicate a difference less than 1.88 t ha^{-1} and non-overlapping bars indicate a difference greater than 1.88 t ha^{-1} at a level of significance <0.05. The LSD ($t_{(0.975,25)}$ *sqrt(2.497*2/6)), is calculated based on a one way ANOVA model: Yield ~ treatment (five levels), p= 0.03, R^2=0.34.*

2.2 Mkushi

The setup in Mkushi is as given below:

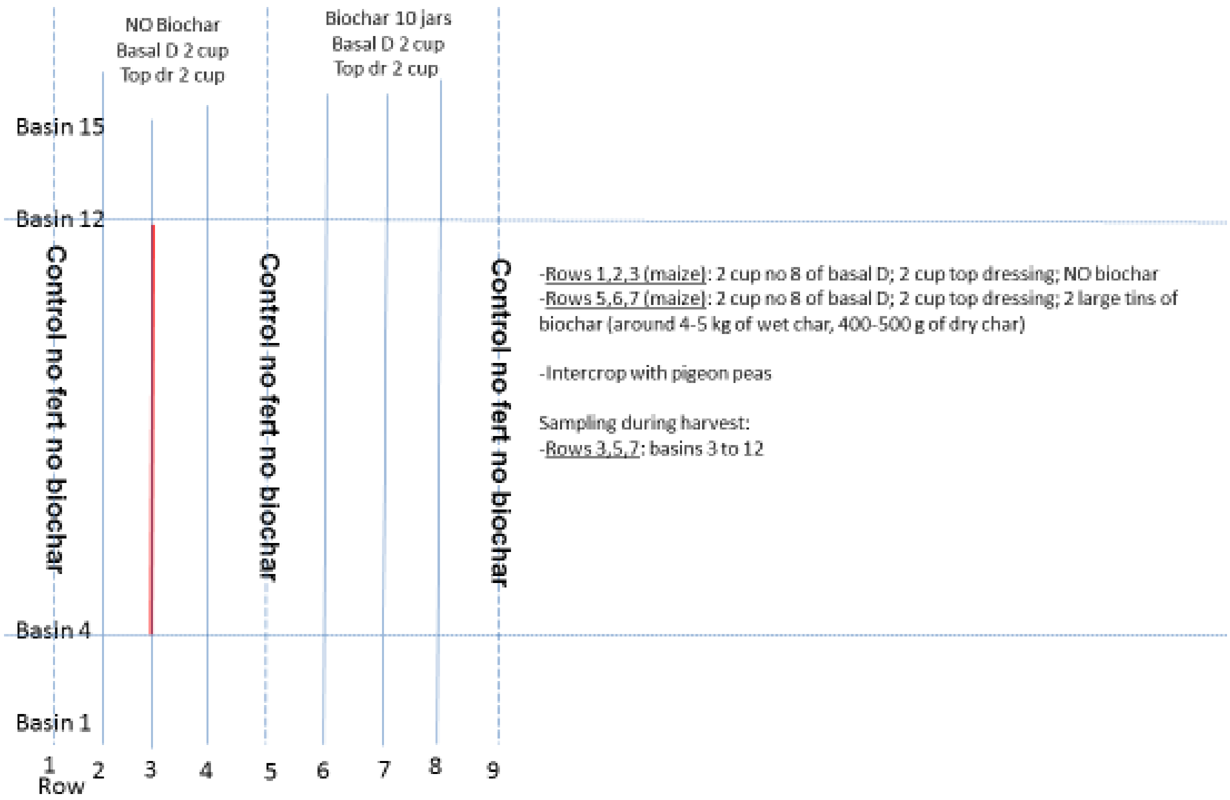


Table 2: Mkushi: Average (± sd) maize yield for the new plots established Nov. 2013 (five farmers) and for the old plots (three farmers) established Nov. 2011. Stover and total biomass yield for the new plots derive from farm Mk4 (Isabelle Upper) and stover and total biomass yield for the old plots derive from farm Mk7 (Ngambi).

Treatment	Grain (t ha^{-1})	Stover (t ha^{-1})	Tot. Biomass (t ha^{-1})
New plots established Nov. 2013:			
Control no fertilizer; p.p intercrop	4.3 ± 1.1	5.8 ± na	9.1 ± na
Control with fertilizer; p.p intercrop	7.9 ± 2.6	9.7 ± na	15.7 ± na
Maize Biochar 4 ton/ha + fertilizer; p.p intercrop	9.6 ± 2.1	13.1 ± na	22.2 ± na
Old plots established Nov. 2011 (MK3, MK4, MK7):			
Control no fertilizer	2.5 ± 0.8	5.6 ± na	7.2 ± na
Control with fertilizer	6.8 ± 1.8	8.7 ± na	13.6 ± na
Maize Biochar 2 ton/ha + fertilizer	6.9 ± 0.8	10.2 ± na	16.2 ± na
Maize Biochar 6 ton/ha + fertilizer	7.7 ± 0.5	11.6 ± na	18.8 ± na

The average grain yields of maize in Mkushi were significantly smaller ($p<0.05$) at sites receiving no fertilizer as compared to fertilized sites with or without biochar addition (Table 2, Figure 3). An increase in grain yield due to maize biochar was observed in Mkushi (9.6 vs 7.9 t/ha; average for five farmers), even though it was not statistically significant due to the variability in harvest yield among the five farmers. Yields in Mkushi were generally very good with biochar, on average almost 10 t/ha at the new sites (established Nov. 2013) with biochar and fertilizer. Interestingly, there was still a positive effect of the biochar applied Nov. 2011 (Table 2). The grain yields were greater at sites with 6 t/ha maize biochar as compared to controls with added fertilizer (7.7 ± 0.5 and 6.8 ± 1.8 t /ha).

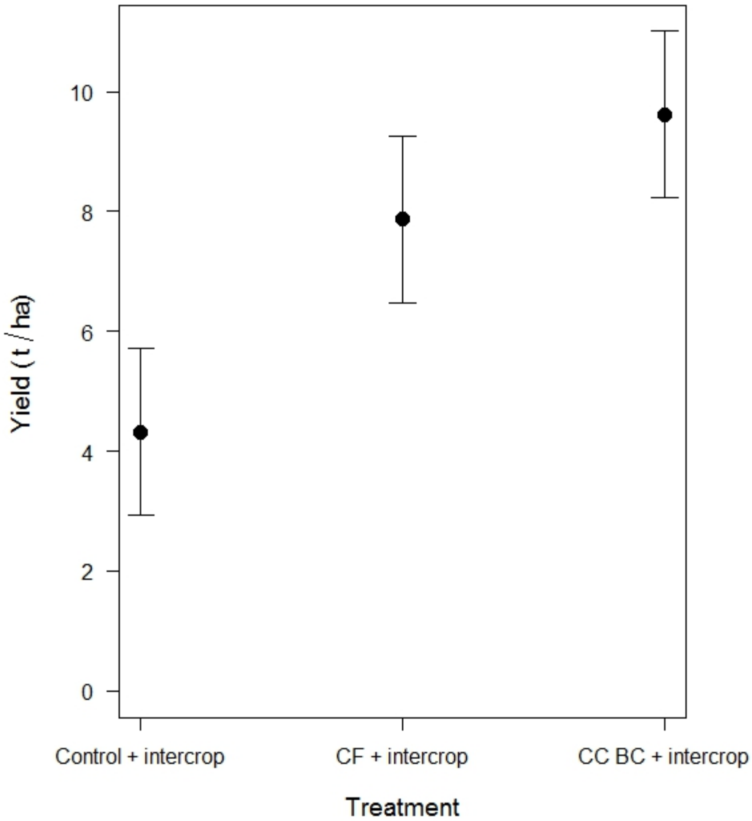
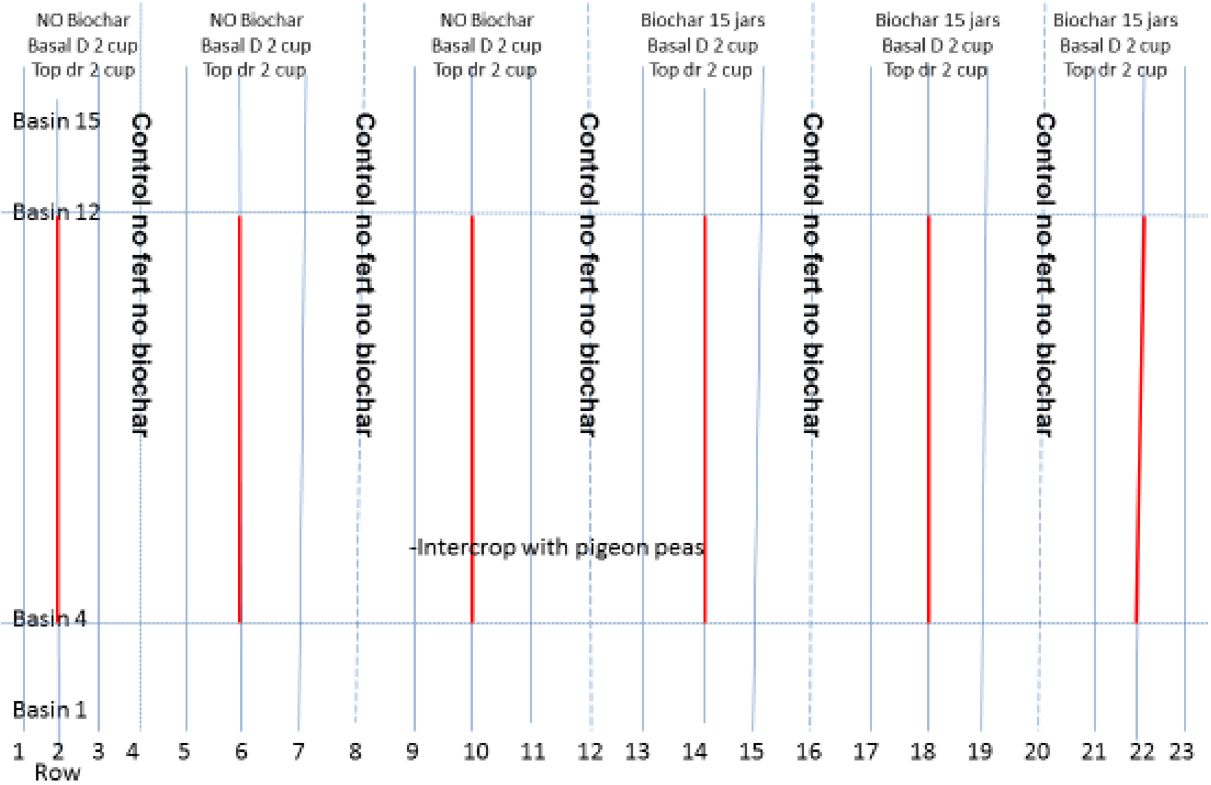


Figure 3. *Average maize grain yields for the season 2013-2014 in Mkushi for the new plots established Nov. 2013. The error bars shows the least significant difference (LSD, 2.78 t ha^{-1}). Overlapping bars indicate a difference less than 2.78 t ha^{-1} and non-overlapping bars indicate a difference greater than 2.78 t ha^{-1} at a level of significance <0.05. The LSD ($t_{(0.975,12)}$ *sqrt(4.06*2/5)), is calculated based on a one way ANOVA model: Yield ~ treatment (three levels), p= 0.004, R^2=0.59. For treatment name specification, see Table 2.*

Figure 4: Plot MK4 in Mkushi.Left the biochar rows, in the middle an unfertilized control plot, to the right the non-biochar fertilized plot rows.

2.3 Mongu

In Mongu, proper results were only obtained for one farm (M12; Mwanamuke Wamundila). However, the experiment here was especially relevant and interesting for two reasons; i) it was the second season with the same biochar and the “biochar recipe” suggested above (no basin opening, stem cutting) was followed; and ii) the plot was so extensive that triplicate samples with and without biochar could be taken. The plot design was as follows:



Yields for the biochar plots were around 30% higher than for the fertilized control plots. This is very encouraging since it was the first time the "recipe" with no stem cutting and no basin opening was tested. However, actual yields were very low on this extremely sandy site, at around 1 t/ha.

Table 3: Mongu: grain yields for plots at farmer M12 established Nov. 2012 (second season; three plots per treatment).

Treatment	Average maize grain yield (t/ha; five farmers)
Control with fertilizer	0.70 ± 0.04
Maize Biochar 6 ton/ha with fertilizer	1.04 ± 0.26

An interesting side observation at Mongu from season 2012-2013 (three farms) was that fertilizer (basal D + urea administered in various amounts) has no effect since the poor sand with almost zero cation exchange capacity was not able to retain the nutrients. The addition of biochar however alleviated this problem and resulted in effectiveness of the fertilizer (3 ton/ha with NPK vs. 1.5 ton/ha without; Figure 5).

n/ha without; Figure 2).

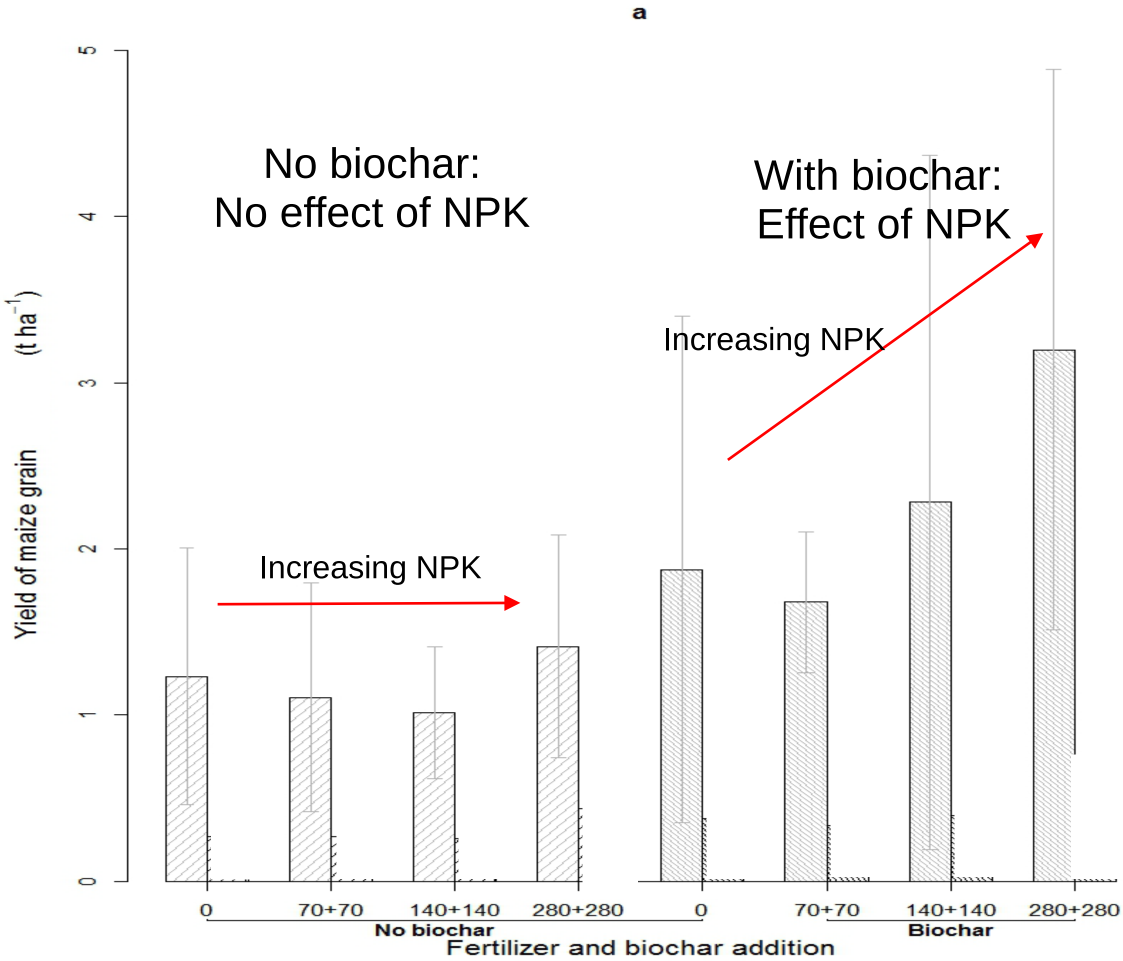


Figure 5: Yield in Mkushi with and without biochar, at various amounts of NPK fertilizer (0.5+0.5 cup, 1+1 cup, 2+2 cups). Results for three farms.

3 Biochar Feedstock

Providing enough feedstock to actually produce biochar is a challenge for biochar implementation. To address this concern, four solutions were investigated in Mkushi, Mongu and Kaoma: i) pigeon peas intercropping; ii) Gliricidia windbreaks; iii) the use of some of the maize stems as feedstock; iv) bamboo planting.

Pigeon peas proved to be the most promising alternative as described. In Kaoma, the stems of the pigeon peas provided 3-9 tons/ha dry weight of feedstock in the first year, possibly generating 1-3 tons/ha biochar per year.

In Mkushi, growth was even better, and around 17 tons/ha dry weight in the first year (2012-2013; generating around 5 ton/ha biochar per year) and 77 tons/ha dry weight in the second year (2013-2014; generating around 25 tons/ha biochar after two years' growth, or 12.5 tons per ha per year, biochar picture in Fig 9) were obtained. In addition, the shedding of nitrogen-containing leaves will further amount to the resilience of the maize-pigeon pea system (see Fig 6).

Kaoma was the only site where pigeon pea intercropping worked well. Here pigeon pea intercropping had no significant effect on maize yields (3.4 t/ha with intercropping vs. 2.9 t/ha without intercropping). As much as 5.9 ± 3.6 ton/ha dry weight pigeon pea biomass (average for six farmers) could be harvested from the intercropped plots in 2013-2014 (more or less the same as for the separate stands in 2012-2013). No significant pea yields were obtained for this particular pigeon pea variety. We propose to use a pea-yielding variety for the next seasons.

In Mkushi, maize growth was so extensive that the intercropped pigeon peas were completely overwhelmed. Here separate plots of pigeon pea are probably necessary.

In Mongu, pigeon peas did not grow well at all and bamboo plots could be an alternative. The bamboo seedlings did grow to man's height in the first season after planting (2013-2014), however, more time is needed to reach its full potential.

Figure 6: Pigeon pea "grove" in Mkushi planted Nov 2012 after the first growth season (October 2013), giving around 17 tons/ha dry-weight of biomass already in the first year, and as much as 77 tons/ha dry weight in the second year. A nice litter layer of N-rich leaves is visible.

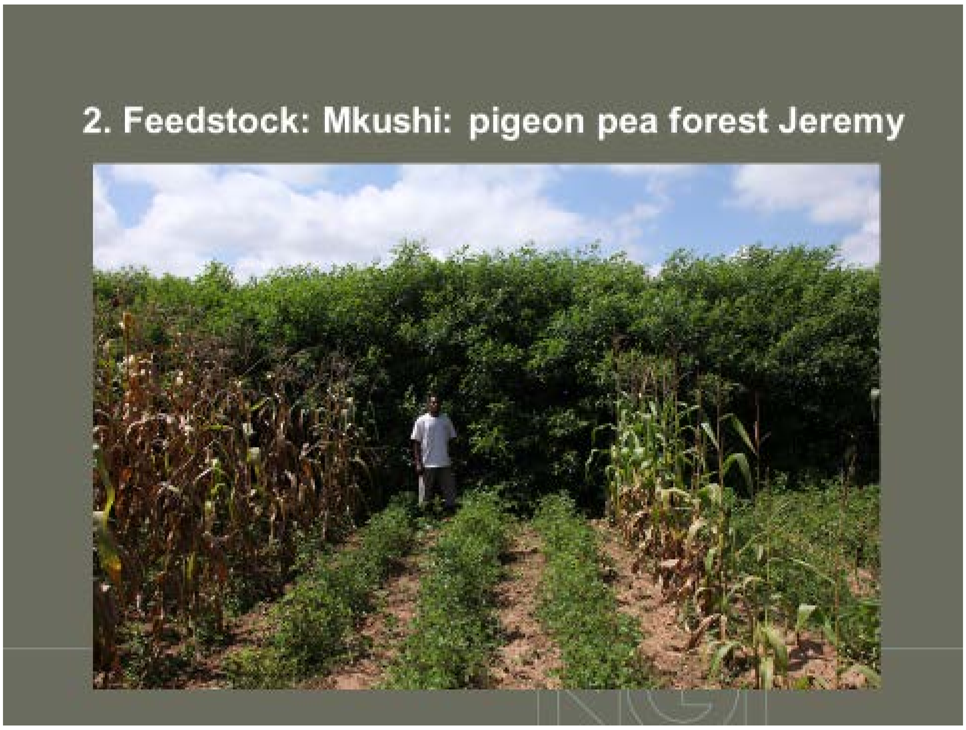


Figure 7: *Pigeon pea "grove" in Mkushi in the second growth season (March 2014), giving as much as 77 tons/ha dry biomass in the second year.*

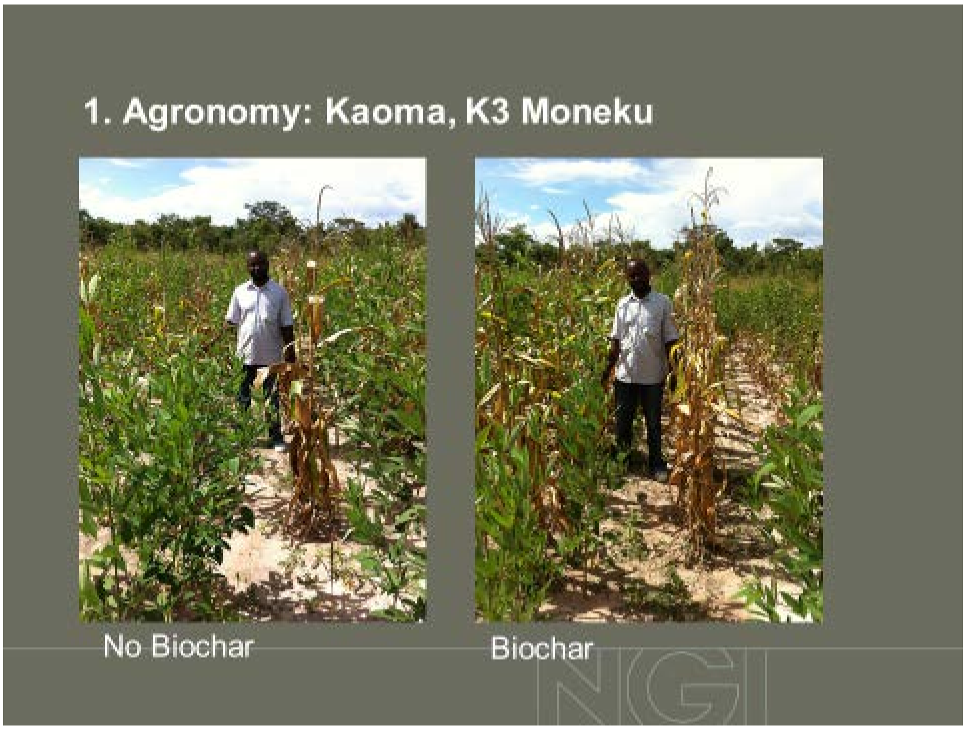


Figure 8: *Kaoma, pigeon pea intercropping working well and giving 5.9 ± 3.6 ton/ha feedstock without compromising maize harvest.*

Figure 9: Biochar generated from pigeon pea stems. The agronomic effectiveness of this biochar is reported in the chapter "Agronomy".

4 Biochar leaching into the subsoil

Plots were established in Mkushi and Kaoma with both rice husk biochar and maize biochar, to quantify the amount of biochar leached to the subsoil. Rice husk biochar was selected since rice, in contrast to maize, is a C3-plant and therefore rice husk biochar can be distinguished from maize-derived organic matter in a soil. First results indicate that leaching of biochar mixed into the top 0-5 cm layer was limited, and did not extend beyond 6 cm depth. Proper quantification of the carbon amounts in the depth profile samples will be done in the course of autumn 2014, and discussed in the next report.

Figure 10: Soil profiles to quantify biochar leaching into the subsoil.

5 The effect of biochar on the physical properties of soil

Here, we present the results from field trials showing how biochar affects physical properties of soil, which is a topic that has received little research attention.

5.1 Field experiment established 2011 – MK3 farm, Mkushi

Maize cob biochar produced at approx. 350°C in the brick kiln was applied once in the planting basins at the rate of 0, 2 and 6 ton/ha. The experimental layout consisted of two part: nine rows planted with maize and the other nine rows planted with soya.

The soil was sampled in April 2013, 18 months after application of biochar, taking six samples randomly from each treatment. The samples were taken only from the planting basins where the crops had been growing, at the harvest time of the second season.

The soil samples were analysed for aggregate stability using rainfall simulation methods, water retention using sand box and pressure plate apparatus, texture and total carbon.

5.2 Field experiments established 2013 – MK5 farm, Mkushi and K4 farm Kaoma

Two field experimental sites were established in April 2013, one in Mkushi (MK5) and the other in Kaoma (K4) as illustrated in figure 11. Biochar of different particle sizes (≤0.5mm, 0.5-1mm and 1-5mm) were applied to small plots of 50cm x 50cm at doses of 0%, 2.5% and 5% dry weight basis.

Figure 11. Establishment of field site in Mkushi (left) and Kaoma (right) in April 2013

The plots were arranged in a split plot experimental design. Fertilizer was added at recommended application rate at the time of planting maize. One maize plant was planted at the centre of each small plot.

Soil samples were collected in April 2014, one year after biochar application. Aggregate stability and water retention were determined in addition to field measurement of water infiltration using a tension infiltrometer.

5.3 Experiment established 2011 – farm MK3, Mkushi

5.3.1 Aggregate stability

The increase in the dose of biochar applied generally resulted in an increase in stability of soil aggregates (Figure 12). There was a significantly higher percentage of stable aggregates (both 0.6-2 and 2-6mm size) under soya when biochar was added at 2 and 6 t ha^{-1} compared to control. Under maize crop, the increase in percentage of stable aggregates was insignificant but higher doses resulted to more stable aggregates.

The effect of biochar on soil aggregate stability was dependent on the type of crop grown. The percentage of stable aggregates of size 2-6mm was higher under maize than under soya with increasing biochar dosage. For aggregates of size fraction 0.6-2mm, the stability was higher under maize, only for control plots.

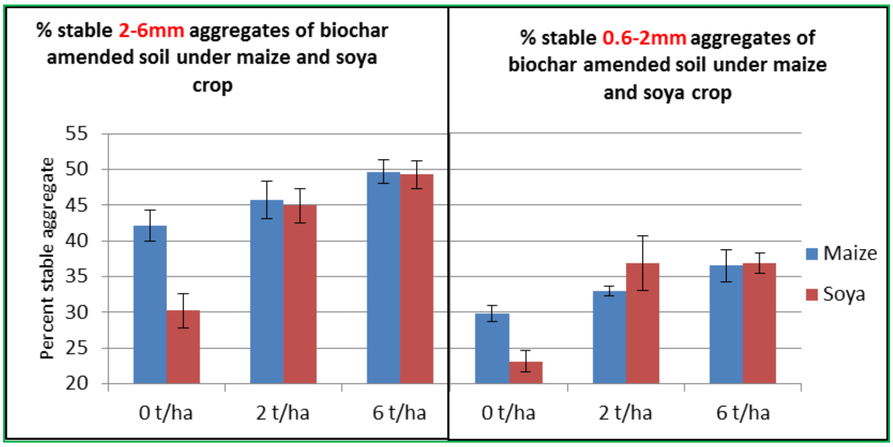


Figure 12. Aggregate stability of biochar amended soil under conservation farming practice in Mkushi.

5.3.2 *Total porosity and bulk density*

Biochar increased soil porosity and decreased bulk density (Figure 13). This effect could be linked to the effect on soil aggregation especially the formation of large aggregates. There was a consistent increasing pattern between the aggregate stability of 2-6mm aggregates and soil total porosity. The weight dilution effect of biochar on soil bulk density could be less important compared to biochar effect on soil aggregation.

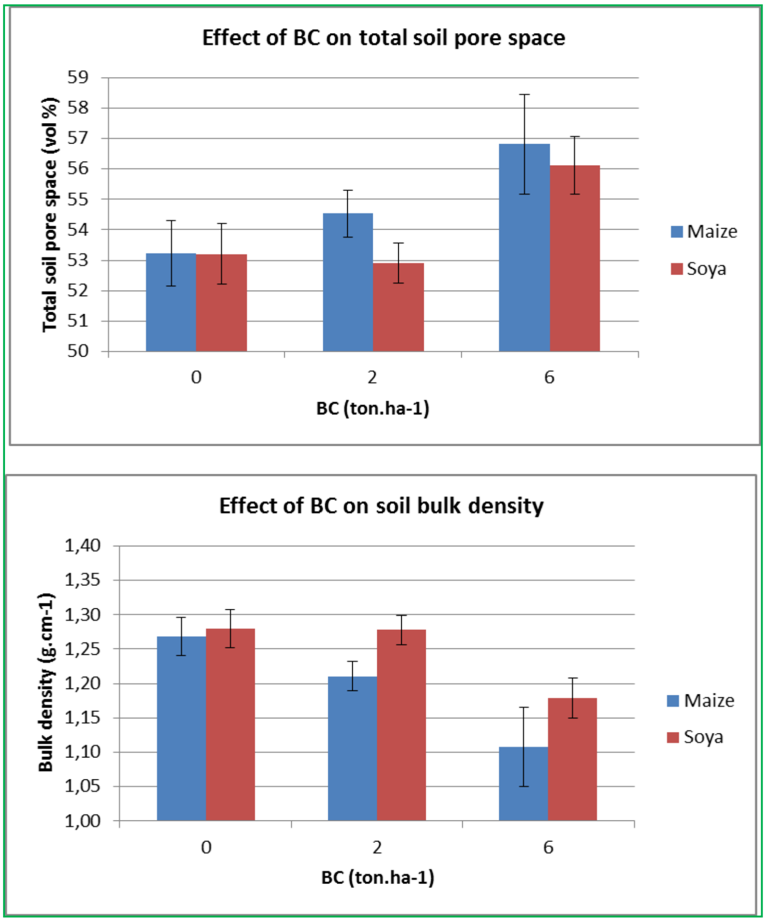


Figure 13. *Soil total porosity and bulk density of biochar amended soil under conservation farming practice in Mkushi.*

5.3.3 Water retention capacities

Biochar increased water retention at low suctions, a suction range in which water is only temporarily available to crops because pores at these suctions are large enough to drain rapidly. At field capacity, biochar also increased water content resulting in an increase in plant available water at the highest dose of biochar applied (Figure 14). The increase in plant available water was approx. 12% for 6t/ha relative to control. Under maize crop with 0 and 2t/ha biochar, more water was retained at all suctions except at permanent wilting point where water content is the same as that under soya crop.

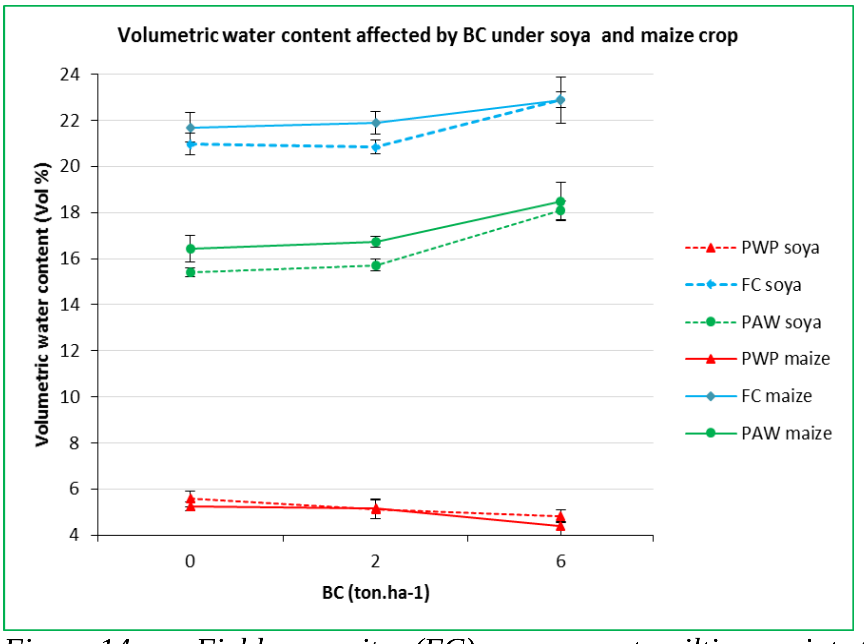


Figure 14. Field capacity (FC), permanent wilting point (PWP) and plant available water (PAW) content of biochar amended soil under conservation farming practice in Mkushi.

5.4 Field experiments established 2013 –farm MK5, Mkushi and K4, Kaoma

5.4.1 Aggregate stability – MK5

The aggregate stability of MK5 soil is presented in figure 15. Percent stable 2-6mm aggregates was higher compared to 0.6-2mm aggregates. ≤0.5 and 0.5-1mm biochar particles increased aggregate stability of 2-6mm aggregates. The effect of biochar on aggregate stability in this soil is lower and less clear compared to farm MK3 probably because of its coarse texture (clay 9%, silt 15.9%, sand 75.1%) and the shorter duration of this experiment.

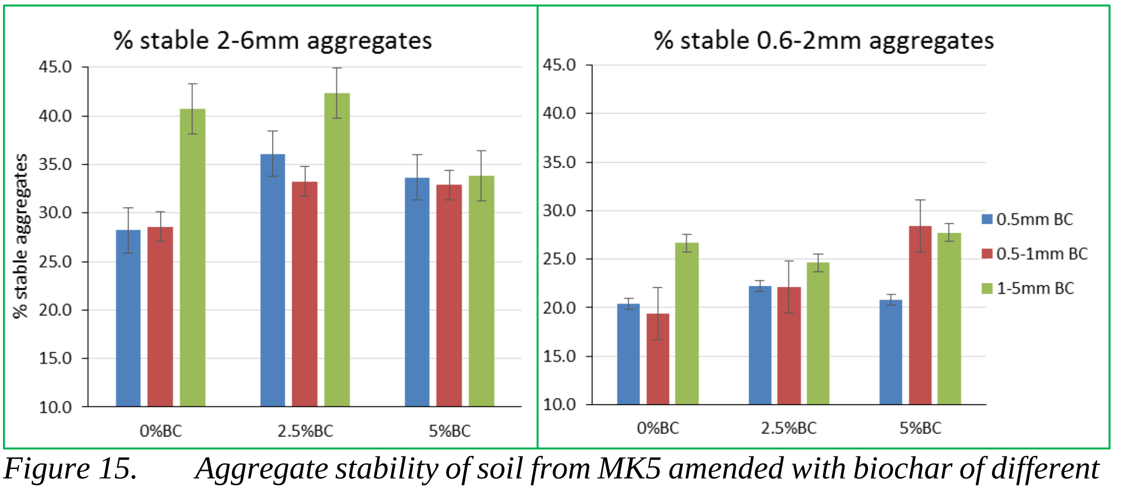


Figure 15. Aggregate stability of soil from MK5 amended with biochar of different particle sizes.

5.4.2 *Total porosity and bulk density*

In Mkushi soil (Figure 16A), only biochar of particle sizes of ≤0.5mm and 1-5mm increased total porosity and decreased porosity with increasing dosage. The overall change in porosity and bulk density brought about by biochar at 5% dose relative to the control ranged from 5-10%. For Kaoma soil (Figure 16B), even the 2.5% biochar dose resulted in noticeable increases in porosity and decrease in bulk density. 2.5% and 5% dose of biochar relative to control resulted to approx. 4 and 8% changes in porosity and bulk density respectively. Since there was no consistent trends between soil aggregate strength in Mkushi soil and changes in total porosity and bulk density, the observed changes in porosity and bulk density are more of a direct biochar effect. The direct effects of biochar are due to its high porosity and low density resulting to increase in soil total porosity and weight dilution respectively.

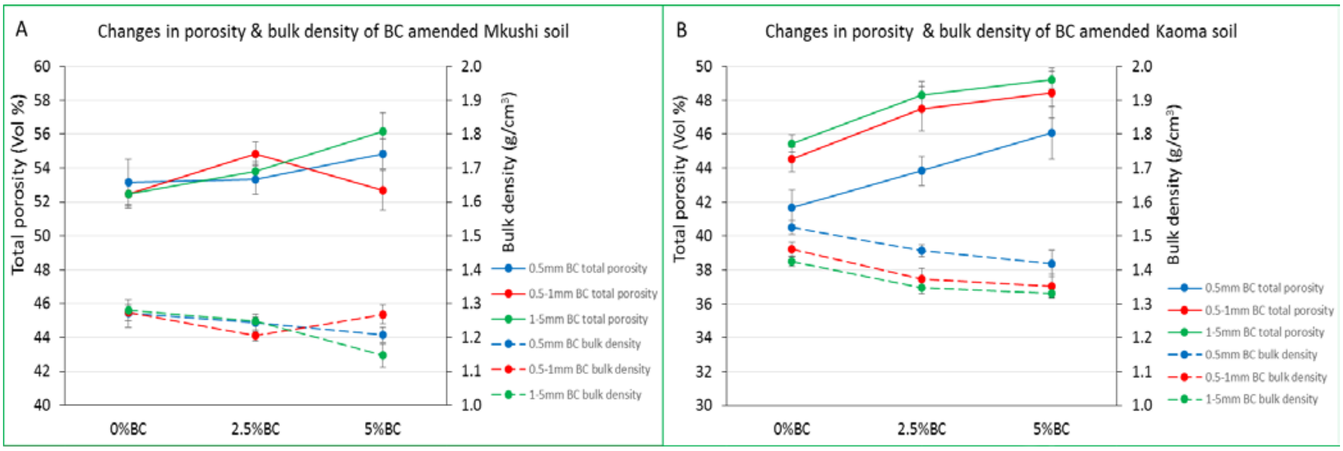


Figure 16A/B. Porosity and bulk density of soil amended with biochar of different particle sizes.

5.4.3 *Water retention capacities*

Biochar increased plant available water content of both Mkushi and Kaoma soils (Figure 17). Plant available water increased by approx. 16% and 27% at 5% biochar dose, relative to control in Mkushi and Kaoma soil respectively for biochar with particle sizes of ≤0.5mm and 1-5mm. 0.5-1mm biochar addition did not affect plant available water.

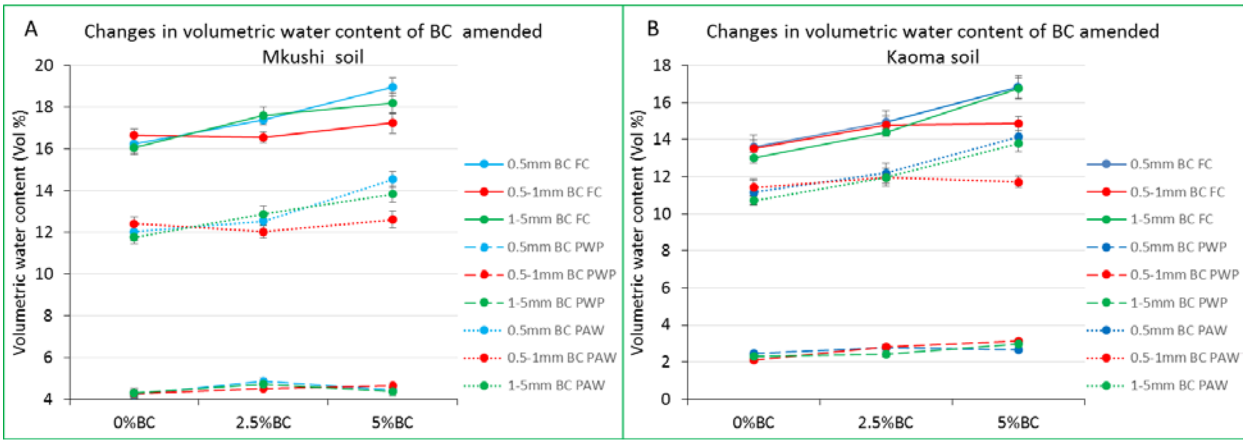


Figure 17. *Field capacity (FC), permanent wilting point (PWP) and plant available water (PAW) content of soil amended with biochar of different particle sizes.*

5.4.4 Water infiltration

Only fine biochar particles resulted in a consistent increase in water infiltration with increasing biochar dosage at -13cm suction pressure (i.e., mimicking modest to heavy downpour) for both Mkushi and Kaoma soils (Figure 18 and 19). The fine biochar particles probably entered between soil particles and between aggregates increasing the proportion of finer pores that conduct water at -13cm suction pressure. At low suction pressure (-3cm; i.e., mimicking extreme and less representative downpour where a water column forms on the soil), the pattern of increasing infiltration with increasing biochar dosages vanished.

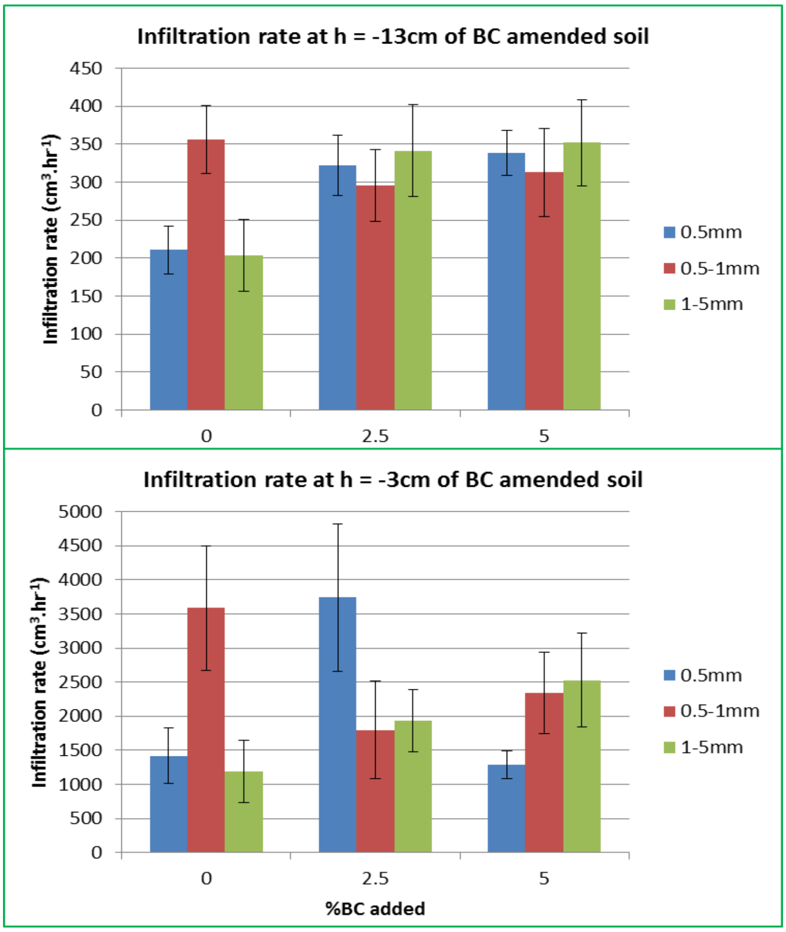


Figure 18. Water flux at two suction pressures in Mkushi soil amended with biochar of different particle sizes.

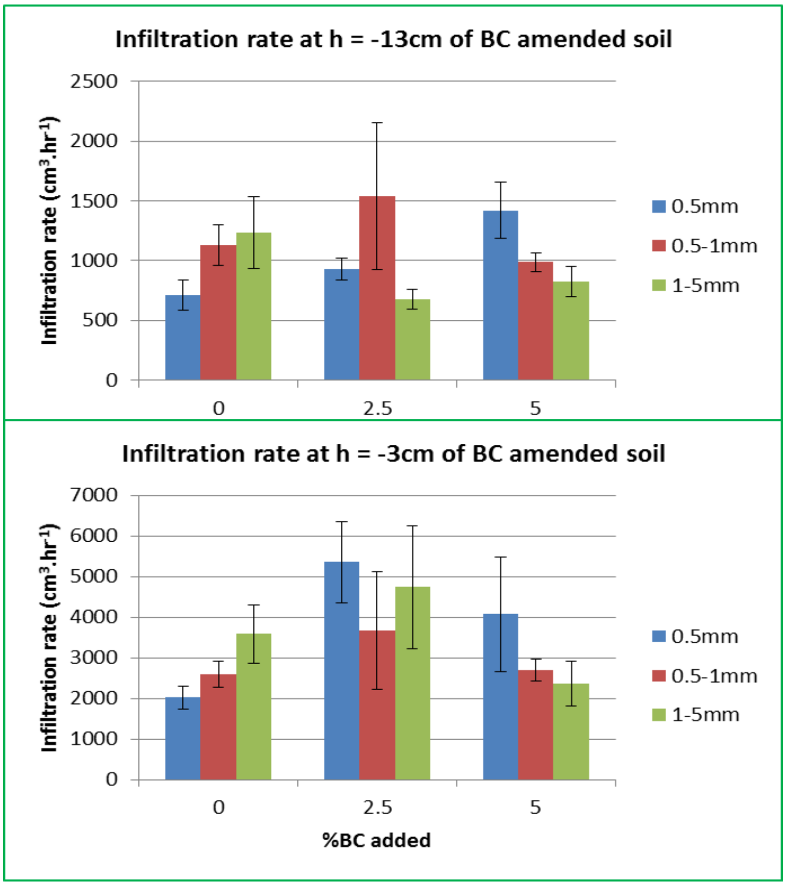


Figure 19. *Water flux at two suction pressures in Kaoma soil amended with biochar of different particle sizes.*

Figure 20: *Measurement of water infiltration rates in Kaoma and Mkushi.The special equipment used provides an upward suction of water from the surface, lowering the pressure of the water column standing on the soil, so that the pressure of the water column is more representative of a gentle rainfall event instead of an extreme downpour (such as in the case of applying a water column without upward suction).*

5.5 Conclusions and implications for agronomy

Biochar improved soil physical properties and the improvements were greatest with higher biochar doses. The changes in physical properties of soil due to biochar depend on the type of crop grown. Increase in plant available water capacity which otherwise is low in the studied soil is important for crop growth especially in this era of unreliable rainfall pattern in Zambia. Increase in soil porosity and reduction in bulk density means the soil structure is more open which thus allows good root growth. In addition, increase in soil aggregate stability reduces the risk of erosion, which washes away the top soil including the nutrients in the top soil. In short, biochar increases soil's resilience to extreme conditions such as drought, soil compaction and erosional impact of rain and thus can contribute towards increase in crop productivity.

6 Root analysis

Root analysis was performed via so-called shovelomics. The root system of 8 maize plants from four sites at Kaoma and four sites at Mkushi were used as examples and the effect of biochar on root systems was investigated (financed by another NGI-initiated biochar project) by a special digital technique developed by the University of Zurich, Switzerland.

The main effect of biochar was on the area and mass of the root system – these were larger in the presence of biochar, even for equally large plants with similar stem diameter (Figures 21-23). Root mass was larger for biochar-amended plants (Fig. 24), as well as root surface area (Fig. 25). Root depth was increased only for site K4 (Fig 26b), and the width of the root system (diameter in which 95% of the roots fitted) was only significantly increased for site K3 (Fig 26a).

The main conclusion is that biochar improves the root system of maize plants, either by a chemical mechanism (higher plant-available water, lower acidity) or by a biological mechanism (e.g. improved development of mycorrhizae that facilitate nutrient uptake by plant roots).

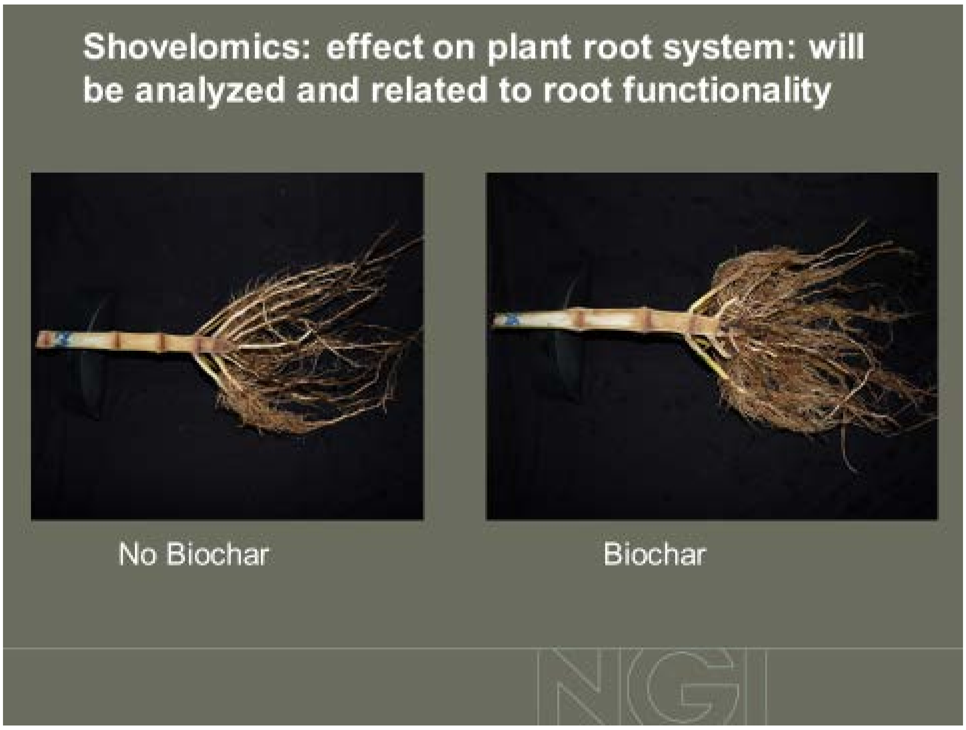


Figure 21: An example of root systems of equally thick maize plants with and without biochar (Kaoma K4).

6.1 Two examples of the image analysis

On the left, the original image. On the right, the processed image, in white the pixels selected, in red the soil surface and the angles of the roots. The blue rectangle represents 95% of root-derived pixels (in order to remove some artefacts from the picture).

Figure 22a: Mkushi MK4 site, No biochar

Figure 22b: MK4 site, with biochar

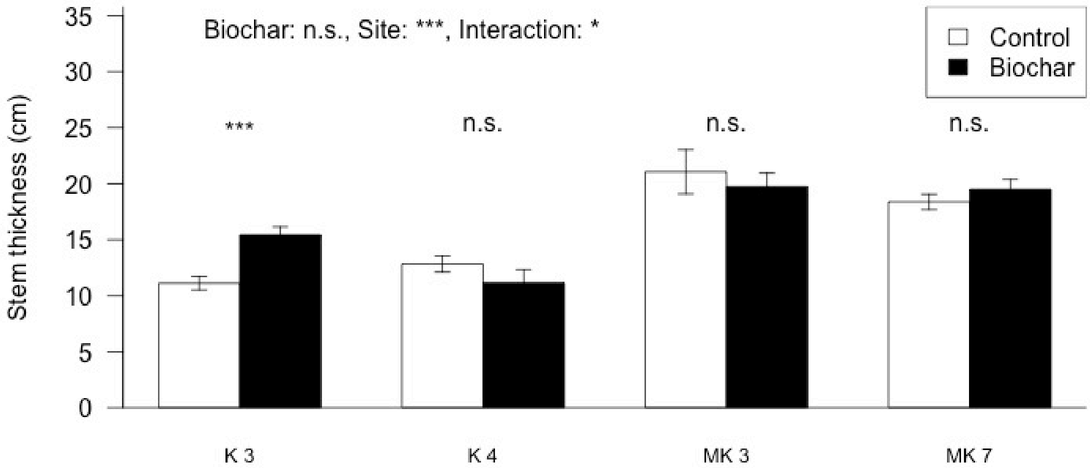


Figure 23: *Stem thickness (cm) measured in the field, 15 cm from the surface. Similar stem thickness with and without biochar except for site K3.*

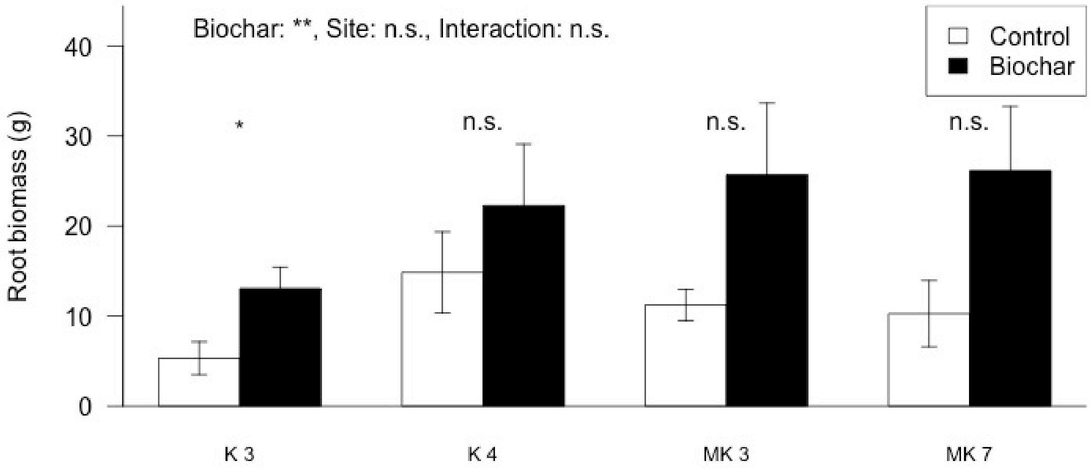


Figure 24: *Root biomass in g dry mass. Overall a biochar effect, but quite a bit of scatter. Strongest effect on the sandy Kaoma soil.*

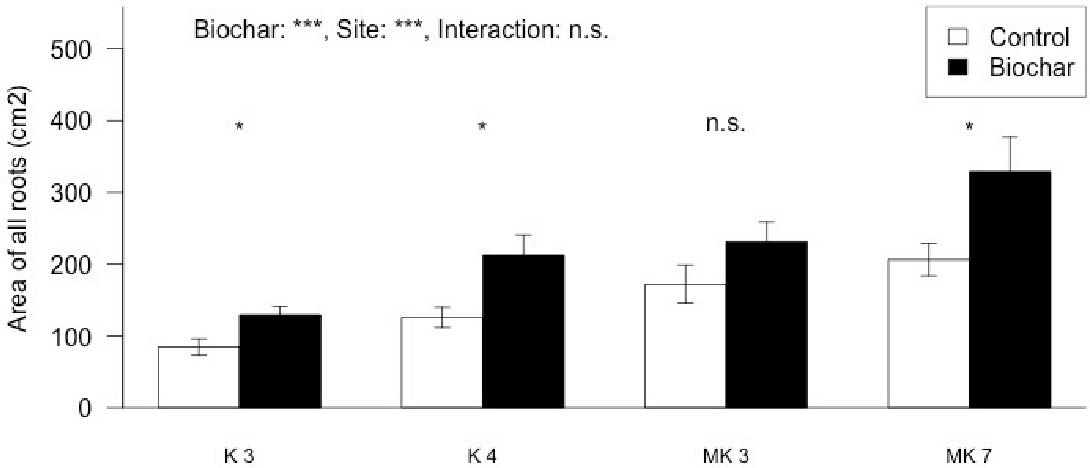


Figure 25: *Area of all root derived pixels in cm^2. Biochar increases the root area of maize in 3 sites, a trend is visible for the 4th site.*

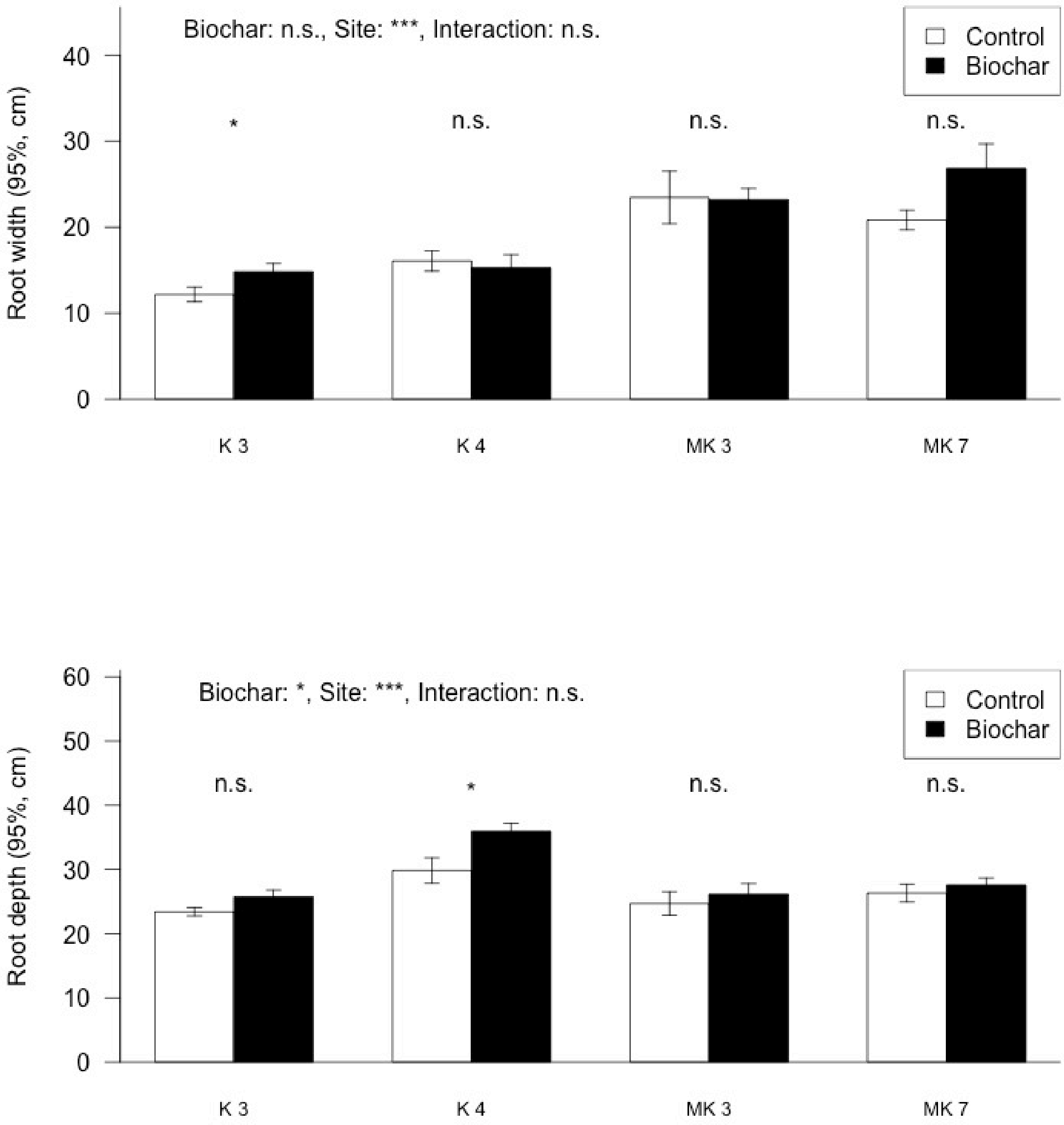


Figure 26: *Width (a) and depth (b) of 95% of root system for the 4 sites (K3, K4 MK3 and MK7), with (black bars) and without (white bars) biochar addition. The bars represent the standard error. The results of the ANOVA are presented above the figure and the comparison between the biochar and the control per site above the bars corresponding to the sites.*

7 Biochar Technology

The retort kiln built in Chisamba (CFU Agroforestry Field Station) yielded high-quality biochar of both pigeon pea stems and corn cobs (both with carbon contents around 70%). Gas emissions were measured for the improved kiln and indeed the kiln generated far lower emissions levels of methane (greenhouse gas), carbon monoxide (toxic gas) and smoke, as compared to traditional non-retort kilns (phase 2 report 3). However, the main disadvantage of the kiln is that it is far too costly for farmers in Zambia.

Thus brick kilns or other simple technology such as a covered hole in the ground, are those solutions that are possibly the best when it comes to implementation, even though they are less clean with respect to exhaust gases than household stoves or retort kilns. Another alternative is a so-called “double drum” which is simple but still has a retort possibility. With the help of Concern in Mongu, such a kiln will be built and tried out during the team visit in October 2014.

Another exciting new development is an open-fire cone kiln “Kon-Tiki” designed by collaboration partner Hans-Peter Schmidt in Ithaka Institute in Switzerland, together with Paul Taylor. This kiln generates 200-300 kg biochar in one round with the low gas emissions of a retort kiln due to convection loops that draw the syngases back into the fire. This kiln has a lower investment need than other retort kilns. This kiln will be tested for the Zambian situation at a later stage. Before this, measurement of gas emissions from this kiln will be carried out in Switzerland.

Figure 27: Open-fire cone kiln with probably low emissions developed by Ithaka Institute.

8 Implementation and further plans

Plans for the season 2014-2015 include:

1. Testing the best “recipe” for prolonged biochar effectiveness in Mongu, Kaoma and Mkushi: opening basins the first year, administering biochar and fertilizer, then mixing and closing and planting. During harvesting a small part of the stems must remain in the soil in order to identify the location of the biochar (i.e., stems need to be cut instead of uprooted). In the second season, however, the basins are not to be reopened (to avoid biochar losses), but instead a small hole needs to be made with a stick to introduce seed and fertilizer.
2. Quantification of biochar leaching to the subsoil in Kaoma and Mkushi. Plots were established in March 2013, and soil profiles will be taken in March 2014. Additional column tests using the same soils will be done in the course of 2014.

3. Intercropping with another variety of pigeon peas that also yields some pigeon pea harvest. In addition, the pigeon pea fields in Kaoma and Mkushi will be further monitored.
4. Further testing of the feasibility and gas emissions of simple but clean technologies such as described above.
5. Measuring the effect of biochar on soil humidity: does biochar cause a longer delay in soil drying in sandy soils such as in Mongu and Kaoma?

Appendix A Overview of field trial locations and setup

Appendix A

Overview of farmer sites

Mongu (list will be updated with new farmers after next field visit)

Name	GPS	pH	Soil	Previous Crops	Fertilizer, how much	Fertilizer, Where from	Can make charcoal?	Food preparation	How long?	Where wood from?	Would you make biochar?	Poverty (1-5)	Innovation (1-5)	Remarks
M1 Sikupa Senga	S 15.20.923 E 23.10.840	3.4	Sand	None	2 + 2	Govt. Late.	Yes	Firewood	3 x 1 h	Family land	Yes	3	5 (Faidherbia)	Saved fertilizer
M2 Lizazi Namayonga	S 15.27.717 E 23.14.107	4.2	Sand	09 Casava 10 Maize	1 + 1	Govt. In time.	No, local people	Firewood, char in rain	2-3 x 45'	Forest	Not sure	3	2	No residues, burnt 2008
M10 Moyowantambe Katambo	S 15.12.244 E 23.08.763		Sand											
M11 Lubasi	S 15.12.827 E 23.09.028		Sand											
M12 Mwanamuke Wamundila	S 15.27.036 E 23.12.892		Sand											

Mkushi

Name	**GPS**	**pH**	**Soil**	**Previous Crops**	**Fertilizer, how much**	**Fertilizer, Where from**	**Can make charcoal?**	**Food preparation**	**How long?**	**Where wood from?**	**Would you make biochar?**	**Poverty (1-5)**	**Innovation (1-5)**	**Remarks**
MK1 Musanji Makondo	S 13.43.706 E 29.03.936	4.0	Acidic Loam	09 Maize 10 Maize	2 + 2	CFU staff	Yes	Charcoal, soon electricity	3 x 45’		Yes	1	3	CFU
MK2 Silanda Brus	S 13.43.851 E 29.03.673	5.0	Loam	10 Maize	2 + 2	Govt. Late.	Yes	Firewood	3 x 30’	Own land	Not sure	3	3	CFU Last year’s farmer
MK3 Michael Selby	S 13.45.420 E 29.03.935	6.2	Loam	09 Maize 10 Gr.nuts	2 + 2	Agro-dealer	Yes	Gas	NA	NA	Yes	1	4	Well limed, lime in groundnut plot 2011
MK4 Michael Selby	S 13.45.684 E 29.03.349	6.5	Loam	10 Maize	2 + 2	Agro-dealer	Yes	Gas	NA	NA	Yes	1	4	Lime in all plots 2011
MK5 Charles	S 13.44.876 E 29.05.868	5.3	Loam	09 GrNuts 10 Maize	2 + 2	Govt	No, local people	Firewood	3 x 30’	Bush	Yes	3	3	
MK6 Robinson Changwe,	S 13.48.007 E 29.32.571	5.4	Sandy Loam	09 Gr nuts 10 Maize	2 + 2	Govt	Yes	Firewood	2 x 1 h	Bush	Yes, make kiln now!	2	4	VTC Miloso, good mulch, good understanding
MK7 Watson Ngambi	S 13.36.264 E 29.29.768	4.1	Loam	09 Maize 10 Maize	2 + 2	Govt	No, local people	Firewood	3 x 45’	Bush	Yes	1	3	Great basins, great mulch

Kaoma

Name	GPS	pH	Soil	Previous Crops	Fertilizer, how much	Fertilizer, Where from	Can make charcoal?	Food preparation	How long?	Where wood from?	Would you make biochar?	Poverty (1-5)	Innovation (1-5)	Remarks
K1 Kangayi Kapoba	S 14°49.571 E 24°52.970	5.1	Sand	09 Fallow 10 Maize	1 + 0	CFU staff	Yes	Charcoal, firewood	3 x 45'	Own land	Yes	4	3	Last year's farmer No new biochar
K2 Mwenya Muhau	S 14.49.665 E 24.55.698		Sand		1 + 1	Govt. Late.	No, but connec-tions	Firewood		Forest	Yes	3	2	CFU
K3 Frederick Moneku	S 14.49.763 E 24.57.394		Sand	Newly opened, but residues	1 + 1	Govt. Late.	Yes	Firewood		3 ha own forest	Yes	2	5	Faidherbia, student will live here
K4 Kebby Kasanga	S 14.50.245 E 25.02.150	4.9	Sand	09 Maize 10 Gr nuts	1 + 1	Govt. Late.	Yes	Firewood		Forest	Yes	3	2	
K5 Evans Chitundu	S 14.50.426 E 25.04.044	5.5	Loamy Sand	08 Maize 09 GrNuts 10 Maize	1 + 1	Govt. Late.	No	Firewood		Bush	Not sure	3	2	
K6 Shishinko Moluwela	S 14.50.464 E 25.05.220	5.1	Sand	09 Maize 10 Gr nuts	1 + 1	Govt. Late.	Yes	Firewood		Bush	Yes	4	3	
K7 Sombo Kavongo														
K8 Dongis Isaya														

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