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Availability of plant nutrients under conventional farming and conservation farming with and without biochar

- A field study of maize on acidic, sandy loam in Zambia

Tilgjengelighet av næringsstoffer ved konvesjonelt jordbruk og
«conservation» jordbruk med og uten biokull

- Et feltforsøk av mais på sur, sandig-silt jord i Zambia

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Preface and acknowledgement

This thesis was submitted in fulfilment of the requirements for the degree of Master of Science (MSc) in Environment and Natural Resources, with specialisation in Limnology and Water Resources.

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Abstract

Conservation farming (CF) has been promoted as an alternative and sustainable agricultural practice for many small-scale farmers in Sub-Saharan Africa (SSA) as a means to improve acid, degraded soil. Conservation farming involves minimum soil disturbance, retention of crop residues and crop rotation. In addition to CF, biochar (BC) has been advocated as a soil amendment for further soil improvement. Recent studies suggest that BC improves soil fertility, in particular through an increase in soil pH. BC in combination with conservation farming may have a positive impact on crop growth. Little is known about the dynamics of plant available nutrients in response to CF with and without BC and how this relates to systems under conventional farming (CV). The main objective of this study is to investigate the effects of CF, CF in combination with BC and CV on plant available nutrients.

The study was conducted at an experimental site (established in October 2015) on an acidic, sandy loam Acrisol at Mkushi, Zambia. Soil and soil water was sampled taken and analysed to investigate solute concentrations in soil water, plant available NH_4^+ and NO_3^- , and general soil quality parameters including pH, total organic carbon (TOC) and nitrogen (TOT-N), cation exchange capacity (CEC) and exchangeable base cations.

The soils investigated in this study have a land-use history of 7 years of CF with planting basins. Background data indicated a significantly greater pH and TOC content in basins than in-between basins. This effect was still visible after the first year of conversion of CF to CV. Most of the results in this study are due to this legacy of CF, where soil under CV is a mix of (predominantly) in-between basin soil and (minor amounts of) basin soil. Results showed that CV had significantly lower pH soil and CEC, than CF, which could be explained by the mix of soil under CV. Soils under CF in combination with BC (CF+BC) had significantly higher TOC content, CEC and C to N ratio, than CF without BC. CF+BC did not give significantly higher soil extractable phosphorus (P) and pH in soil than just CF. Potassium (K^+), but not calcium (Ca^{2+}) and (Mg^{2+}) concentrations in soil water, was not significantly higher in CF+BC than in CF. The respective plant available nutrients in soil water were significantly lower in CV than in CF probably due to the fact that CV soils primarily derives from the previous in-between basins. Most likely, these in-between basin soils (in contrast to the basin soils) have never received any dolomite and thus the concentrations of at least Ca^{2+} and Mg^{2+} are likely to be smaller in CV.

CF in combination with BC did not result in higher concentrations of plant available nutrients, except for K^+ , than CF alone. CF+BC gave significantly higher content of TOC due to addition of biochar. CF gave significantly higher concentrations of plant available nutrients than CV.

Sammendrag

Conservation farming (CF) er en landbruksmetode der redusert jordbearbeiding ved vekselbruk og retensjon av planterester er i hovedfokus. Denne metoden er blitt promotert som en alternativ og bærekraftig landbruksmetode til mange småskala-bønder i Afrika sør for Sahara (SSA). Formålet med dette er å forbedre sur, forringet jord. I tillegg til CF, har biokull blitt foreslått for ytterligere jordforbedringer. Nylig forskning viser at biokull kan forbedre jordas fruktbarhet, spesielt ved å øke pH i jord. Biokull i kombinasjon med CF kan ha positiv effekt på plantevekst. Det er blitt gjort lite forskning på tilgjengelighet av næringsstoffer ved CF med og uten biokull, og hvordan dette er relatert til CV. Formålet med denne oppgaven er å undersøke effekter på tilgjengelighet av næringsstoffer ved CF med og uten biokull, og ved CV.

Feltforsøket ble gjort på sur, sandholdig siltjord (Acrisol) som har blitt brukt til forskning på biokull og CF siden oktober 2015, i Mkushi, Zambia. Jord- og jordvannsprøver ble tatt og analyser for videre undersøkelser på konsentrasjoner i jordvann, plantetilgjengelig NH_4^+ og NO_3^- , og jordkvalitetsparametere som pH, total organisk karbon (TOC) og total organisk nitrogen (TOT-N), kationbytterkapasitet (CEC) og utbyttbare basekationer.

Landbruksfeltet har blitt brukt til CF med plantebasseng i 7 år før eksperimentet startet. Bakgrunnsdata indikerte en høyere pH og TOC mengde i plantebassengene, enn utenfor bassengene. Effekten av dette er fortsatt synlig i jord brukt til CV etter et år med dette eksperimentet. Meste parten av resultatene er derfor basert på CF ettersom jorda ved CV er en miks av jord fra plantebasseng og jord utenfor plantebasseng. Våre tall viste at jord ved CV hadde en signifikant lavere pH og CEC enn jord brukt til CF. Dette kan være en årsak av den mikset jorda i CV. Jord ved CF med biokull viste en signifikant høyere TOC mengde, CEC og carbon:nitrogen forhold enn jord ved CF. CF med biokull gav derimot ikke signifikant høyere konsentrasjoner av ekstrahert fosfor (P) og pH i jord enn ved CF. Kalium (K^+), bortsett fra calcium (Ca^{2+}) og magnesium (Mg^{2+}), konsentrasjoner i jordvann var ikke signifikant høyere i CF med biokull enn jord ved CF. De respektive næringsstoffene var signifikant lavere i jord ved CV, enn ved CF. Dette er mest sannsynlig forklart ved at CV jord, som inneholdt mer jord fra utenfor bassengene, ikke har blitt tilsatt dolomitt, og dermed vil i det minste konsentrasjoner av Ca^{2+} and Mg^{2+} være lavere ved CV.

Jord ved CF i tillegg til biokull hadde ikke høyere konsentrasjoner av næringsstoffer, bortsett fra i K^+ , enn jord ved bare CF. CF med biokull gav signifikant mer TOC på grunn av tilsetning av biokull. Jord ved CF hadde signifikant høyere konsentrasjoner av næringsstoffer en jord ved CV.

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List of abbreviations:

- BC biochar
- CF conservation farming
- CA conservation agriculture
- CV conventional farming
- CF+BC conservation farming with addition of biochar
- CFU conservation farming unit
- NMBU Norwegian University of Life Science
- UNZA University of Zambia
- NGI Norwegian Geotechnical Institute
- NORAD Norwegian Agency for Development Cooperation
- SOM soil organic matter
- SOC soil organic carbon
- CEC cation exchange capacity
- TOC total organic carbon
- TOT-N total of nitrogen
- TOT-C total of carbon
- KCl potassium chloride
- C/N carbon:nitrogen ratio
- NPK nitrogen:phosphorus:potassium ratio
- PP pigeon pea
- CC corn cobs
- NOB not opening basins

1. Introduction

1.1 Background

One of the major global challenges is to increase food production for a growing population, so that the current state of self-sufficiency at the global scale can be maintained. The challenge of sufficient food production is particularly large in Sub-Saharan Africa (SSA), where 2/3 of the population depends on subsistence farming on marginal, often degraded land (Lal, 2015)

High enough food production requires good quality soils. A good quality soil has good soil tilth, small population of pathogens and insect pests, low weed pressure, good soil drainage, large population of beneficial organisms, resilience to degradation and sufficient plant nutrient supply.

Essential plant nutrients are the macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulphur (S) and magnesium (Mg). Plants need other nutrients but in small amounts such as chlorine (Cl), boron (B), iron (Fe), copper (Cu), zinc (Zn), molybdenum (Mo) and manganese (Mn). The nutrients can be absorbed by plant roots, leached from the soil or adsorbed to the surfaces of negatively or positively charged soil particles. The physical, chemical and biological properties of soils are important to plant growth.

Soil pH is a description of the soil's acid/alkaline reaction. Soils generally range from pH 4 (acid) to pH 8 (alkaline). A soil pH of 6.5 in soil is ideal for plants. Right pH can increase the capacity to bind nutrient cations, increase phosphorus availability and decrease mobility of aluminium (Al), which can reach toxic levels in very acidic soil (Osman, 2012). The Cation Exchange Capacity (CEC), which is an expression of the soil's ability to hold and exchange cations, is dependent on pH. As pH decreases, more H^+ ions are attached to the colloid. They have pushed the other cations from the colloids, which makes CEC lower (Osman, 2012). Sand has very low CEC because sand particles are large, with a low surface-to-volume ratio and hence fewer negative sites, compared to humus and clay minerals.

SOM (soil organic matter) supplies the available nutrient pool via mineralisation and desorption and binds nutrients via immobilisation and adsorption reactions. SOM increases water-holding capacity. This is because the addition of organic matter increases the number of micropores and macropores in the soil either by "gluing" soil particles together or by creating favourable living conditions for soil organisms. Sandy soils have low water-holding capacity, compared to clayey soil. The fate of nutrients in SOM is dependent on processes affecting organic matter decomposition and formation. The carbon/nitrogen (C/N) ratio is a factor determining how easily microorganisms are able to decompose an organic matter. Generally low C/N indicates well-decomposed SOM. The more decomposed, the lower the C/N ratio. Organic carbon compounds (TOC) can be used for assessment of C/N (Jiménez and García, 1991). TOC bind mineral particles together into microaggregates. The soil structure will be stabilised making soil resistant to erosion, but porous enough to allow air, water and plant roots to move through the soil. TOC leads to greater biological diversity in the soil, thus increasing biological control of plant diseases and pests (Bot and Bernites, 2005).

Calcium (Ca^{2+}), Mg^{2+} , K^+ and Na^+ are electrostatically bound as an outer-sphere complex to the surface of clay minerals and humic substances. Calcium and Mg^{2+} are divalent cations,

and K^+ and Na^+ are monovalent cations. Calcium is held in an exchangeable form against the negative charge on soil clay and organic matter particles more tightly than $Mg^{2+} > K^+ > Na^+$. Calcium and Mg^{2+} retention in soil are dependent on high pH, where low pH has little exchangeable Ca^{2+} and Mg^{2+} high CEC, and presence of organic matter (Osman, 2012). The degree of K^+ retention depends on the concentration of competing cations, pH of the soil solution, but also the clay's charge density. At low pH, the lack of K^+ retention is due to large concentrations of H_3O^+ and their ability to replace exchangeable K^+ (competition effect). The retention increases in least weathered materials. Phosphate (PO_4^{-3}) is strongly bound to iron- and aluminium-oxides, and the attraction increases at lower pH. But if the pH is higher than 7.5, PO_4^{-3} will start to form insoluble compounds with Ca^{2+} , which makes it less available (Osman, 2012). Organic nitrogen in residues is converted to inorganic nitrogen through mineralisation. In this process, microorganisms digest SOM and release ammonium-N (NH_4^+ -N). Formation of NH_4^+ -N increases as microbial activity increases which is directly related to soil temperature and water content. NH_4^+ -N has a positive charge and is electrostatically bound to negatively charged soil and soil organic matter. The nitrification process is the conversion of ammonium-N to nitrate-N (NO_3^- -N). Nitrate-N is water-soluble and can leach in soils, due to its negatively charged ion (Osman, 2012).

Africa is expected to dry out faster as the temperature increases, according to the Intergovernmental Panel on Climate Change (Niang et al., 2014). Increased air temperature can affect plants that have a specific temperature requirement for their photosynthesis. Drought is also an effect of climate change in SSA. 95 % of agriculture in SSA is rainfed, which aggravates the drought (Lal, 2015). Rainfall patterns also tend to become more erratic. The impacts are felt particularly by those who directly depend on reliable weather patterns for a livelihood, and where crop cultivation is already on the threshold, small variations will be more noticeable (Lal, 2015).

African farmers have traditionally cleared land by slash and burn methods and grown crops for a limited number of years before moving on to clear more land. When the loss of a nutrient becomes greater than input, the nutrient content in soil reduces. Poor farming practice have affected 24% of the land in SSA. Deforestation has been widely practiced (27 % of land) for production of fuel, wood and charcoal. Without tree roots and with increased exposure to sun, soil can dry out. Increased run-off, drought, soil compaction and reduction of soil nutrients make many of the soils in SSA fragile, relatively infertile and prone to rapid deterioration when farmed, compared with temperate soil (Oldeman et al., 1991).

1.2 Conventional farming

Many countries in SSA have introduced full conventional tillage (CT), using mechanical or animal-draft ploughs (ADP), harrows, hoes, and ridgers on many small-scale farms. Conventional tillage helps mineralizing soil organic matter and thus liberating nutrients into the soil and making them available for plant uptake. Soil tillage also increases oxygen in the soil, which speeds up decomposition and makes more oxygen available for plant roots. Tillage can break up weed roots and disrupt weeds from growing, and by that decrease use of herbicides often used to control the weeds (Bot and Bernites, 2005). Despite the advantages of tillage practice, research has shown that continuous and unnecessary overall soil disturbance by conventional practices (CV) in Africa has resulted in widespread soil degradation and loss in soil productivity (Lal, 2015). Erosion is the primary cause of soil degradation. Erosion is loss of nutrients in or attached to soil particles that are removed from field by wind or water movement. Due to deep ploughing, which breaks up soil into finer particles, the amount of

soil available for transport by water erosion is higher. Wind can pick up soil by dehydrating it and breaking it up into smaller particles. Loss of plant nutrients in topsoil, loss of SOM, and decreased water-holding capacity are all effects of erosion (Annabi et al., 2011).



Figure 1: Conventional farming – animal ploughing in Zambia 2010 (leonie.photoshelter.com).

1.3 Conservation farming

In the hopes of improvement of acid, degraded soil associated with conventional practices, scientists and farmers are working together to improve the production and the sustainability of farming systems (Aagard, 2005). Conservation farming (CF) involves minimal or no mechanical soil disturbance (10-12 % tillage), permanent soil cover and crop rotation, thus minimizing the loss of soil carbon and erosion (Corsi et al., 2012). For the past 20 years the Conservation Farming Unit (CFU), an independent organisation registered under the Societies Act of Zambia, has promoted CF as a sustainable practice to many small-scale farmers in SSA. CFU's goal is to improve farmers' agricultural methods, which will increase yield, reduce cost and labour input, while improving soil quality. Farmers will gain access to services and inputs they require to do the right practices regarding protection of the soil and the surrounding environment (Aagard, 2005).

According to Chivenge et al. (2007), CV induces potential loss of TOC from the soil, while CF promotes TOC stabilisation. According to Busari et al. (2015), TOC content has been significantly improved under long-term continuous CF with maximum residue retention. However, Lal and Bruce (1999) cautioned that increasing TOC content of soil with CF is difficult and may lead to modest increases (0.05 Mg/ha/yr TOC). Mloza-Banda et al. (2016) collected data from fields with land use conversion from CV to CF also in Malawi. They concluded that fields with CF showed greater values of TOC, total N (Tot-N), PO_4^{3-} and CEC compared to CV, while CV appeared to sustain better soil aggregation and root-zone aeration. Huang et al., 2016 also concluded that CF results in higher plant nutrient uptake (N, P, K) than under CV. The addition of plant residues with CF could help to reduce water loss from the soil by evaporation and also help to moderate soil temperature. More moderate soil temperature and wetter soils promote biological activity and are likely to enhance nitrogen mineralisation (Hobbs et al., 2007). Regarding the CF practice with permanent soil cover, it is observed that plant residue in SSA often is removed after a couple of weeks by termites and by roaming cattle. Although the residue improves infiltration initially, the soil cover is lost too

quickly to provide effective protection against surface runoff (Giller et al., 2009). According to Prof. Umar (2012), improvements in soil fertility resulting from CF are not yet evident.

1.4 Conservation farming and biochar

The Norwegian Government has been supporting CFU since 1996, and there are close collaborations between organisations in Norway and CFU. Since 2010, the Norwegian Geotechnical Institute (NGI) and the Norwegian University of Life Science (NMBU) have been working together with the University of Zambia (UNZA) and CFU on a NORAD funded project called “Biochar in Conservation Agriculture” in Zambia (Cornelissen et al., 2011). The research fields are in Mkushi (Central Province), Chisamba (Central Province) and Kaoma (Western Province) (Cornelissen et al., 2011; Cornelissen et al., 2013a)

In addition to CF, biochar (BC) has been suggested to be used as a soil amendment to enhance soil quality and improve crop productivity in weathered and eroded soil (Biederman and Harpole, 2013). BC is a heterogeneous, stable substance rich in aromatic carbon (80-90%) and minerals. It has a high specific surface area and is not easy to decompose. Some studies show that addition of BC has lasting effects on soil quality such as increased TOC, increased water holding capacity, increased CEC (Liang et al., 2006), reduced nutrient leaching, decreased soil acidity and reduced green house gas (GHG) emissions to the atmosphere (Obia et al., 2015). Liming effect due to addition of BC is also well documented (Chan et al., 2007, Novak et al., 2009; Cornelissen et al., 2013b; Martinsen et al., 2015). The addition of BC to soil has also been suggested to improve microbial growth (Rondon et al., 2007) and this could be important in the realm of nitrification and denitrification processes (Alling et al., 2014). Evidence for increase of nitrification activity upon the addition of BC to soil has been presented (DeLuca et al 2006; Clough and Condron 2010). In a sandy loam, Acrisol, biochar was found to slightly increase PO_4^{3-} and Ca^{2+} concentration (Hale et al., 2013; Martinsen et al., 2014). Alling et al. (2014) did observe a higher concentration of Mg^{2+} and K^+ in the same soil type with addition of BC, although this is highly dependent on the quality of BC (Cao and Harris 2010).

1.5 Production of biochar

BC is produced by pyrolysis of sustainably obtained biomass under controlled conditions. Traditional ways to produce charcoal exist, but it is in most cases produced for cooking or for export. Most small-scale farmers are not very familiar with the production of BC for agriculture (Cornelissen et al., 2016). BC can be produced from organic waste as maize cobs (CC), pigeon pea (PP) wood and ground nut shells. Maize cobs are available throughout Zambia, but it does not give an adequate amount of BC itself. PP is promising regarding production of adequate amounts of biomass, and both stem and twigs are used for BC production (Martinsen, personal communication, 10th of November). There are no big difference in quality of CC and PP biomass (table 2). BC can be produced in a Kon-Tiki kiln, which is a modern and clean technology that can be made easily by farmers themselves. Traditional kiln technologies, mainly for charcoal production from wood, are slow and without treatment of pyrolysis gases, it results in toxic emissions of gases and aerosols that contribute to greenhouse gas emissions (Sparrevik et al., 2014). Retort kiln is complicated to operate and can reduce emissions, but is costly and consumes valuable biomass during start-up (Schmidt and Taylor, 2014). Kon-Tiki flame curtain kiln is much simpler than a retort kiln, with the combustion of pyrolysis gases in the flame curtain. It also avoids use of external fuel for start-up, and works both as a dryer and a pyrolyzer. (Cornelissen et al., 2016). The

biomass does not need to be homogenized or chopped. However, compared to an automated installation, Kon-Tiki kiln must be hand-fed during the entire period of operation. But on a working day, a person can produce 1-1,5 tons BC with two to four kilns. This corresponds to the daily capacity of a medium sized industrial pyrolysis plant. Overall, this production is a simple, robust and inexpensive solution for small and medium-scale farmers who want to create their own high-quality BC with high carbon content, low ash content, high alkalinity, and high stability in soil. (Schmidt and Taylor, 2014).



Figure 2: PP BC made in flame curtain kiln in Mkushi, Spring 2015. Picture taken by Vegard Martinsen.

1.6 Problem statement

According to the research conducted over the past years, both through laboratory and field studies, findings demonstrate that BC improves soil fertility (Beesly et al., 2011; Cabrera et al., 2011). Other findings by Martinsen et al. (2014) suggest that BC in combination with conservation farming may have a positive impact on crop growth. Regarding the project “Biochar in Conservation Agriculture” in Zambia, there has been done research on several physical and chemical soil properties, but not specifically on the plant available nutrients throughout the growing season (e.g. as determined by their concentration in soil water). Is there a positive effect of essential plant available nutrients with CF in addition of BC (CF+BC) which can support other findings? This investigation will help further research on whether or not Conservation management with addition of BC can improve soil quality and crop growth. By field experiment this was further investigated.

1.7 Objectives and research questions

The study was conducted at Mkushi, Zambia from February to May 2016 on an experimental site established in October 2015. The site is located on an acidic, sandy loam Acrisol where CF with crop rotation has been practised for the last 7 year. The site was managed with a maize-groundnut rotation with maize planted in the season 2015-2016. Lysimeters were installed in the field to allow soil water sampling. Soil water was analysed for different solutes. In addition, soil samples were taken and analysed with respect to the most important plant nutrients and other soil quality parameters (pH, TOC, TOT-N, NH_3^- , NH_4^+ , CEC, and

exchangeable base cations). The main objective of this study is to investigate the effects of CF with or without BC (CF+BC), and CV on plant available nutrients.

The main parameters investigated include:

- Solute concentrations in soil water (lysimeter water)
- Plant available NH_4^+ and NO_3^- (determined in soil KCl extracts)
- Other soil quality parameters, including pH, TOC, TOT-N, CEC and exchangeable base cations

The following are the research questions of this study:

- How does CF, either alone, or in combination with BC affect the availability of important plant nutrients like calcium, magnesium, potassium, phosphorus, and nitrogen in an Acrisol under maize in Central Zambia throughout the growing season? How does this compare with CV?
- How do CF, with and without addition of 4 tonnes/ha of BC affect important soil quality parameters, including organic C content, pH, CEC and exchangeable cations, relative to CV?

The following are the hypotheses of this study:

- CF in combination with BC significantly increases pH, organic C content and CEC of soil compared with CF and CV.
- CF in combination with BC significantly increases the availability of plant nutrients calcium, magnesium, potassium, phosphorus and nitrogen compared with CF and CV, due to higher pH, organic C content and CEC.
- Soil under CF have a significantly greater CEC than under CV.

2. Material and methods

2.1 Biochar production

BC was produced in a flame curtain kiln. Dry PP and CC, after removing the grains, were used as feedstock for BC production. PP and CC were produced in separate batches in November 2015 at a temperature of $\sim 350^{\circ}\text{C}$ and a residence time of 2 days (during residence time, temperature was $300\text{-}350^{\circ}\text{C}$) (Martinsen, personal communication, 9th of November).



Figure 3: Test of Flame curtain kiln. Picture taken by Vegard Martinsen in Mkushi, Spring 2015.

2.2 Experimental approach

2.2.1 Experimental site

The field experiment was established on a private farm, in October 2015, in Mkushi. Prior to the establishment of the experiment, the site had been used for CF, including the use of permanent planting basins (i.e reduced tillage), maize-groundnut rotation and residue retention for the last 7 years. The CF practice included preparation of rows of permanent basins ($\sim 0.05\text{ m}^2$), each with a spacing of 90 cm between rows and 70 cm between basins within rows. Fertilizer and lime was added to basins only, while residues were retained in rows between basins. The soil is characterised as a sandy loam Acrisol. The topsoil is light-textured, acidic and has low CEC (Table 1).

2.2.2 Experimental set up

Eleven different treatments were set up in plots in four blocks, with each block having eleven plots (one for each treatment) (figure 4). The location of the plots was random and differed from block to block. Each plot had four planting rows with 6 basins each (figure 5). Thus, there were 24 basins in total per plot. Four of the treatments were under Conservation Farming with biochar (CF+BC), six treatments were under Conservation Farming without biochar (CF), and one was under Conventional Farming (CV).

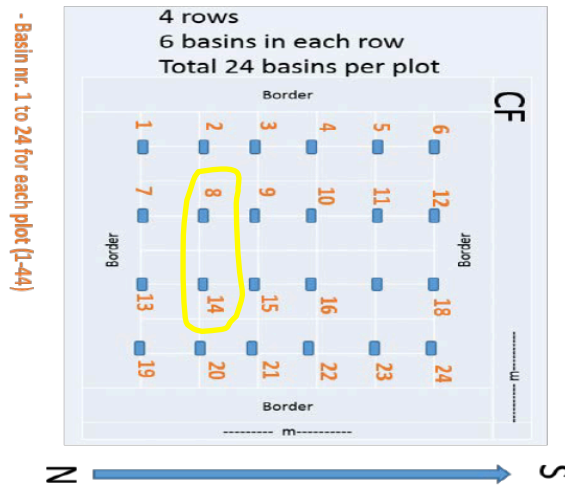


Figure 5: Overview of each plot. Each plot had four rows with 6 basins in each row. Total of 24 basins per plot. Yellow area indicates the basins where lysimeters were installed. The layout is done by Vegard Martinsen.

2.2.3 Description of each treatment

CF: The basins were 20 cm deep, 30 cm long, 16,7 cm wide and in total a volume of ~10 litre. The basins are fully opened after each growing season as a preparation for planting the subsequent crop. The basins are at exactly same place as in the previous seven years. Three maize seeds were planted in each basin on 20/11-15. Prior to planting, 10 cm of soil was backfilled into the basins. Inorganic fertiliser (basal D, NPK (10:20:10), which corresponded to 280 kg/ha, was added on top, and covered by a thin layer of soil. Then sowing was done and the seeds were covered by a thin layer of soil, leaving a small local depression in the soil. Local depression in soil is believed to be an advantage for water harvesting due to more water channelled to the planting basin. In addition, two top-dressings of urea was added. 2 cups of urea (additional input of $92 \text{ N ha}^{-1} \text{ yr}^{-1}$) was added first on 21/12-15 and the second 3 weeks after (exact date not available). Insecticide was sprayed on the soil for weed control. Termidine was sprayed on the soil for prevention of termites. ~5 t/ha additional residue of maize was added on top of the soil. The organic residues were of last year's harvest.

CF+BC: Same procedure as with CF, with the only difference in BC addition and in not opened basins (NOB). BC was mixed into the soil of the deeper half of the basins, on top of which the fertiliser was added.

CV: Established on previous CF field. Shallow soil preparation. Overall digging was done with a hoe, 10-15 cm deep. After shallow digging of the whole plot, the planting stations were located in the rows where there had not been previous CF basins (in the previous seven years, these positions were in-between basins). The same amount of fertiliser, as in CF, was added after emergence. Urea was added with the same amount and at the same time, as with CF. After harvesting, no residues were put on top of the soil, as a common practice for CV. Note that these plots were localised on fields previously used for CF.

Under CF treatment, there were six treatments:

CF burning: the same procedure as CF, but with burned residues.

CF normal: the normal CF procedure.

CF mixed residue in basins: biomass mixed with soil in basin.

CF different basin depths: basin depth at 30 cm.

CF no residue: no residue was put on top of the soil.

CF not opening basin (NOB): basin is not open between the crop seasons.

Under CF+BC treatment, there were four treatments:

Hot charged PP BC: hot charged pigeon pea biochar was mixed with fertiliser.

Cold charged PP BC: cold charged pigeon pea biochar was mixed with fertilier.

Hot charged CC BC: hot charged corn cob biochar was mixed with fertiliser.

PP BC: cold charged pigeon pea biochar was put in soil, and not mixed with fertiliser.

“Not opening basins” means that the basins are not opened for planting the next crop, but seeds will be added using a dibble stick (in this way the soil is little disturbed). Not opening basins may be important to preserve the biochar in the soil. Since 2015/2016 is only the first planting season there is no difference between NOB and “fully opened basins”. There is also no difference between CF treatments <<CF no residue>>, <<CF normal>> and <<CF not opening basins>>. Therefore, the treatments are categorized in three main groups: CF, CF+BC and CV and these groups will be presented and discussed, and not the 11 treatments. The individual results from the 11 treatments are shown in appendix.

2.3 Meteorological data

A weather station was located at the experimental site. Precipitation and temperature were measured from the end of February 2016 until beginning of May 2016. The equipment used: Pyranometer for total solar radiation; Rain-Gauge; sensor for measuring air temperature, relative humidity and barometric pressure; Sonic anemometer for measuring wind speed.

Soil moisture was also measured in the soil with TDR (Time Domain Reflectometry) probes, which was installed by Obia in February 2016.

2.4 Field and laboratory methods

All the soil water samples taken by lysimeters, soil potassium-chloride (KCl) extracts and soil samples by auger, were transported from Zambia to Norway by the team from NMBU, for further analysis.

2.4.1 Soil water sampling and field method

Macro rhizons lysimeters are sampling devices for soil water in the field. Macro rhizons have a porous part of 9 cm, with an outer diameter of 4.5 mm and a pore size of 0.15 μm . It has a strong coating with filled glass fiber epoxy rod and with acrylonitrile-butadiene-styrene (ABS) (Eijkelkamp, 2003).

Macro rhizons lysimeters were installed in basins nr. 8 and nr.14 (figure 5) in each plot under a angle of about 45 degrees, and at a depth of ~6 cm. A total of 88 lysimeters were used. The upper 3-5 of soil was removed and the lysimeters inserted into the middle of the basins. Vacuum was created using syringes. The installation was conducted on 24/02-16 by Obia and Martinsen from NMBU.

Jeremy Selby, the owner of the private farm, did the collections of soil water. The water collected from the two lysimeters in each plot was bulked into one sample prior to analysis.

The first collection of lysimeter water was on 28/02-16 after the first significant rain event, the second collection on 23/03-16 and the last collection on 15/04-16. The samples were stored in deep freezer at UNZA until May 2016. The NMBU team removed the lysimeters in May 2016.

There were less soil water samples from the second collection in March, and especially from the third collection in April, due to less water to extract from the soil. The ones that were collected contained less water than the samples from the first collection in February. Not all elements in soil water from March and April could be analysed. The results of analyses of soil water from February are therefore represented in the result section, as they contained enough water for all analyses. The results from all three periods are presented in the appendix.



Figure 6: Lysimeters collected from the topsoil, in May 2016.

2.4.2 Soil sampling and field method

Soil was sampled with an auger and collected in 1litre bags from each basin where lysimeters were installed, by Obia on 21/04-16. The soil samples were kept refrigerate at 5°C at UNZA until May 2016 when transport to Norway took place.

Only soil samples from 6 treatments were selected for soil analysis. Four CF+BC treatments, two CF treatments and the CV treatment were analysed. The specific treatments included: CF (nob) + 4 t/ha PP BC (CF+BC), CF + hot charged PP BC (CF+BC), CF + cold charged PP BC (CF+BC), CF normal (CF), CF mixing residue (CF) and Conventional (CV).

2.4.3 Soil KCl sampling and field method

Soil for soil KCl extraction was collected from the already sampled soil (8 g soil) by Obia on 21/04-16. The soil samples were kept refrigerated at 5°C after sampling and extracted at UNZA.

2.4.4 Observations during fieldtrip in May 2016

Lumps of dolomite (insoluble) were observed in the basins of the field. Dolomite (CaMg-carbonate) is used for liming the acidic, sandy loam Acrisol during previous CF practice. Termite activity was also observed on wooden sticks between the plots.

2.4.5 Laboratory methods

Samples with 3-5 blanks for determination of ions on Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Flow Injection Analyser (FIA), Ionic Chromatography (IC), Carbon- and nitrogen Elemental Determinator, Spectrophotometry were sent to the laboratory at the Institute of environmental science (IMV) at NMBU.

ICP-MS is an analytical technique used for determination of solute concentrations. An ICP-MS combines a high-temperature ICP (Inductively Coupled Plasma) source with a mass spectrometer. The ICP source converts the atoms of the elements in the sample to ions. These ions are then separated and detected by the mass spectrometer (Wolf, 2005).

IC is an ion chromatography where ions are chromatographically separated by means of a separating column. A low capacity anion exchanger is used as the stationary phase, and an aqueous solution of salt of weak monobasic acids is used as eluent. Detection by a conductivity detector in combination with a suppressor device decrease the conductivity of the eluent and convert the separated anions into their corresponding acids (Bruckner, n.d).

FIA is a flow injection analyser where samples are injected into the flowing carrier stream. The samples are supplied with chemicals (NaOH-solution for $\text{NH}_4^+\text{-N}$, buffer-solution for $\text{NO}_3^-\text{-N}$) and colour reactions occur. The concentrations are determined by automatic spectrophotometry (FIALab, (no date)).

ICP-OES is an analytical technique used for determination of solute concentrations as ICP-MS, but the analyte species are detected by optical emission spectrometer, which measures the density of radiation emitted at the element-specific, characteristic wavelength from thermally excited analyte atoms or ions. Intensity measurements are converted to elemental concentration by comparison with calibrated standards (EAG, 2016).

Carbon- and nitrogen Elemental Determinator is an analyser in which the material is burned at 1050°C and carbon (C) converts to CO_2 by oxidation. The concentration of CO_2 gas is measured by infrared light (IR cell). The principle behind measurement of tot-N is the same as with tot-C, but during the analysis, the nitrogen oxide (NO_x) is reduced to nitrogen gas (N_2) by copper (Cu). The concentration is measured by thermal conductivity (TC cell) (Yeomans and Bremner, 2008).

Spectrophotometry is an instrument that measures how much a chemical substance absorbs light by measuring the intensity of light as the beam of light passes through sample solution. UV-visible spectrophotometer uses light over ultraviolet range (185-400 nm) and visible range (400-700 nm) of electromagnetic radiation spectrum (Caprette, 1996).

2.4.5.1 Soil water

Measurement of cations (Ca²⁺, Mg²⁺, K⁺, Na⁺, Al³⁺, Tot-P and Tot-S):

Soil water samples were analysed on ICP-MS Agilent 8800 for determining the concentration of the cations Ca²⁺; Mg²⁺; K⁺; Na⁺; Al³⁺; Tot-P; Tot-S. Limits of detection (LD): 0.007 mg/l Ca²⁺; 0.001 mg/l Mg²⁺; 0.004 mg/l K⁺; 0.002 mg/l Na⁺-0.0008 mg/l Al³⁺; 0.0002 mg/l Tot-P; 0.001 mg/l Tot-S.

Measurement of anions (SO₄²⁻, Cl⁻):

5 ml of each soil water sample were analysed on IC 5000 Ion Chromatograph, Zelweger analytics, Lachat instrument for determining the concentration of the anions sulphate (SO₄²⁻) and chloride (Cl⁻) concentrations according to ISO 10304-1. LD: 0.009 mg/l.

Measurement of nitrogen (NO₃⁻-N, NH₄⁺-N):

5 ml of each soil water samples were analysed with FIA Star 5010 analyzer for determining the concentration of the anion NO₃⁻-N and the cation NH₄⁺-N. LD: 0,0016 mg/l NO₃⁻-N; 0,0058 mg/l NH₄⁺-N.

Measurement of pH:

2 ml of each soil water sample was measured on Orion pH electrode. The pH electrode was calibrated at pH 4 and pH 7 before measuring pH in soil water.

Measurement of total organic carbon (TOC):

10 ml of each soil water sample was analysed on ICP-MS for determination of total organic carbon concentration. LD: 0,05 mg/l TOC.

2.4.5.2 Soil

Preparation:

The samples were put in a heating cabinet at 40°C, and were dried after 5 days. The samples were sieved at <2 mm using a steel screen with pestle according to Krogstad (1992). For total C and N analyses, approximately one teaspoon of soil from each sample was crushed with agar mortar in 3 minutes. Krogstad (1992).

pH in soil:

pH was determined with 1 g:2,5 dl soil:deionized water suspension according to Krogstad (1992).

Cation exchange capacity (CEC) in soil:

According to Schollenberger and Simon (1945), 3 g soil from each sample was put into each 100 ml Erlenmeyer flask. 25 ml 1M ammonium acetate solution was added and the solution was shaken. The suspension stayed overnight. The solution was filtered through a filter paper (blue ribbon) with a small portion of ammonium acetate solution into 250 ml Erlenmeyer flask to the marking point. 10-15 ml of extract solution was used for ICP-OES determination (mg/l) of Ca²⁺, K⁺, Mg²⁺, Na⁺ and 20 ml for H⁺ determination. The concentrations were then recalculated to amount per kg soil. The sum of these cations was the CEC. LD: 0.019 cmol/kg Ca²⁺; 0.128 cmol/kg K⁺; 0.016 cmol/kg Mg²⁺; 0.046 cmol/kg Na⁺; 0.36 cmol/kg H⁺. For H⁺ determination, pH was measured of the 20 ml solution and titrated with 0,05M NaOH to pH

7,00+/-0,02 of a unit under stirring. Volume of sodium hydroxide was recorded. pH meter was calibrated with extraction ammonium acetate solution 15 min before measurements.

Total carbon (Tot-C):

According to Nelson and Sommers (1982), the analysis was done by “dry combustion” method. 0,2 g of each sample was weighted in tin foil. The samples were analysed on the Carbon- and nitrogen Elemental Determinator Truspec CHN analyser. LD: 0,05 % Tot-C.

Total nitrogen (Tot-N):

According to Bremner & Mulvaney (1982), the analysis was done by “Dumas” method. Truspec CHN analyser was used. LD: 0,05 % Tot-N.

Volumetric weight:

Volumetric weight was determined according to Krogstad (1992).

Loss of ignition (LOI):

LOI was determined in percentage of dry matter content according to Krogstad (1992). LOI was corrected for water associated with clay minerals.

Particulate phosphate (PO_4^{3-} -P):

Plant available phosphorus was measured colorimetrically according to the Norwegian Standard methods 5721, respectively using the photometer Gilford Instruments. Soil was extracted with ammoniumacetat-lactate (AL-method), according to Krogstad (1992). LD:1.5 mg/kg.

2.4.5.3 Soil KCl extracts

Extraction:

The soil was extracted by Obia at UNZA. Moisture content of all soil samples was determined. 8 g dry weight equivalents of soil was taken out from each soil samples, and homogenized. The 8 g dry weight equivalent was placed in 100 ml plastic bottles and 40 ml of 2 M KCl solution was added. The soil:solution ratio was 1:5. The mixture was shaken for 30 minutes and then filtered. ~30 ml filtrated solution from each sample was collected in 100 ml plastic bottles.

NO_3^- and NH_4^+ measurement:

5 ml of each KCl extracts was analysed with FIA Star 5010 analyzer for determining the concentration of the anion NO_3^- -N and the cation NH_4^+ -N. LD: 0,013 mg/l NO_3^- ; 0,1 mg/l NH_4^+ .

pH measurement:

2 ml of each KCl extract was measured on pH electrode ORION modell SA720.

2.5 Statistics

Results were checked for statistical significance using the two-way analysis (ANOVA) of variance at the 0.05 confidence level. CF+BC, CF and CV were compared to each other. Regression analysis was done for estimating relationships between selected elements with a respective p-value. All statistical analyses were carried out using Microsoft Excel.

3. Results

3.1 Soil background

Table 1: Soil properties (background data). Measured pH, TOC, NH_4^+ -acetate extractable Ca^{2+} , Mg^{2+} , K^+ , Na^+ , CEC, CEC/TOC and PO_4^{3-} in basin and in-between basin. Soil samples from October 2015.

| Block | In/in-between basin | pH (0.01M CaCl2) | | Tot_C (%) | | Ca cmol/kg | | Mg cmol/kg | | K cmol/kg | | Na cmol/kg | | CEC | | CEC cmolc/ g TOC | | PO4-P mg/kg | |
|-------|---------------------|------------------|-----|-----------|------|------------|------|------------|------|-----------|------|------------|------|------|------|------------------|------|-------------|-------|
| | | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd |
| 1 | In basin | 6,4 | 0,1 | 0,73 | 0,08 | 2,77 | 0,59 | 1,10 | 0,18 | 0,20 | 0,02 | 0,20 | 0,02 | 4,26 | 0,75 | 0,55 | 0,05 | 176,33 | 31,34 |
| 2 | In basin | 6,3 | 0,2 | 0,68 | 0,04 | 2,67 | 0,21 | 1,06 | 0,21 | 0,19 | 0,05 | 0,03 | 0,02 | 3,95 | 0,40 | 0,55 | 0,05 | 185,00 | 32,08 |
| 3 | In basin | 6,4 | 0,1 | 0,68 | 0,11 | 2,77 | 0,50 | 1,10 | 0,21 | 0,20 | 0,04 | 0,02 | 0,00 | 4,09 | 0,70 | 0,57 | 0,05 | 181,33 | 23,80 |
| 4 | In basin | 6,2 | 0,1 | 0,58 | 0,04 | 1,77 | 0,06 | 0,87 | 0,04 | 0,17 | 0,03 | 0,03 | 0,00 | 2,83 | 0,05 | 0,45 | 0,05 | 136,67 | 15,82 |
| 1 | In-between basin | 5,0 | 0,2 | 0,51 | 0,08 | 0,84 | 0,14 | 0,34 | 0,08 | 0,21 | 0,10 | 0,23 | 0,13 | 1,61 | 0,38 | 0,28 | 0,05 | 171,67 | 17,16 |
| 2 | In-between basin | 4,8 | 0,3 | 0,47 | 0,06 | 0,72 | 0,43 | 0,27 | 0,12 | 0,17 | 0,04 | 0,06 | 0,05 | 1,21 | 0,24 | 0,21 | 0,05 | 179,67 | 8,08 |
| 3 | In-between basin | 5,2 | 0,3 | 0,57 | 0,08 | 1,27 | 0,15 | 0,48 | 0,05 | 0,21 | 0,00 | 0,03 | 0,01 | 1,99 | 0,16 | 0,31 | 0,05 | 167,00 | 12,29 |
| 4 | In-between basin | 5,1 | 0,2 | 0,48 | 0,05 | 0,61 | 0,27 | 0,29 | 0,10 | 0,19 | 0,03 | 0,07 | NA | 1,16 | 0,41 | 0,20 | 0,05 | 134,67 | 14,84 |

Soil samples were taken in basins and in-between basins on soil with previous CF practice. The land use history resulted in differences in soil characteristics between in-between basins as compared to within basins (table 1). Since the planting stations at the CV treatment established in October 2015, were located in the rows, which previously were in-between basins and thus without additions of fertilizer and lime for the last 7 years, the chemical and physical soil parameters from this treatment are to a large extent determined by the land use history, as seen in table 1. Background data indicated a greater pH and TOC content and CEC in basins than in-between basins. Concentrations of Ca^{2+} and Mg^{2+} were also higher in basins than in-between basins.

Table 2: BC properties. Measured pH, TOC, Tot-H, Tot-N, C/N, Ca^{2+} , Mg^{2+} , K^+ , Na^+ and CEC in PP BC and CC BC.

| Description | pH (0.01M CaCl2) | | Tot-C (%) | | Tot-H (%) | | Tot-N (%) | | C/N | | Ca cmol/kg | | Mg cmol/kg | | K cmol/kg | | Na cmol/kg | | CEC | |
|-----------------|------------------|-----|-----------|------|-----------|------|-----------|------|------|-----|------------|------|------------|------|-----------|------|------------|------|-------|------|
| | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd |
| PP normal | 9,2 | 0,1 | 55,52 | 7,99 | 1,08 | 0,15 | 0,69 | 0,13 | 80,3 | 5,0 | 6,97 | 0,38 | 6,80 | 0,26 | 24,67 | 1,53 | 0,17 | 0,09 | 38,60 | 2,21 |
| cold charged PP | 9,4 | 0,0 | 33,43 | 4,25 | 0,88 | 0,08 | 0,92 | 0,16 | 36,7 | 1,5 | 7,90 | 0,44 | 5,83 | 0,40 | 17,00 | 2,00 | 0,11 | | 30,84 | 2,79 |
| hot charged PP | 9,5 | 0,1 | 48,77 | 1,90 | 0,89 | 0,03 | 1,51 | 0,01 | 32,0 | 1,0 | 15,33 | 1,53 | 9,37 | 0,60 | 36,00 | 1,00 | 0,21 | 0,01 | 61,00 | 0,95 |
| hot charged CC | 8,5 | | 84,00 | | 1,49 | | 0,89 | | 94,0 | | 0,26 | | 0,23 | | 34,02 | | | | 34,50 | |

Table 2 shows the properties of hot/cold PP biochar and hot CC biochar. There is no large difference between PP and CC in quality in soil (Martinsen 2016, personal communication, 9th of November). Table 2 shows that PP biochar has higher pH, higher concentration of Ca^{2+} and Mg^{2+} than CC biochar. The concentration of K^+ and CEC and the amount of Tot-N are about the same for PP BC and CC BC. The C/N ratio is higher in CC biochar than in PP biochar.

3.2 Meteorological data

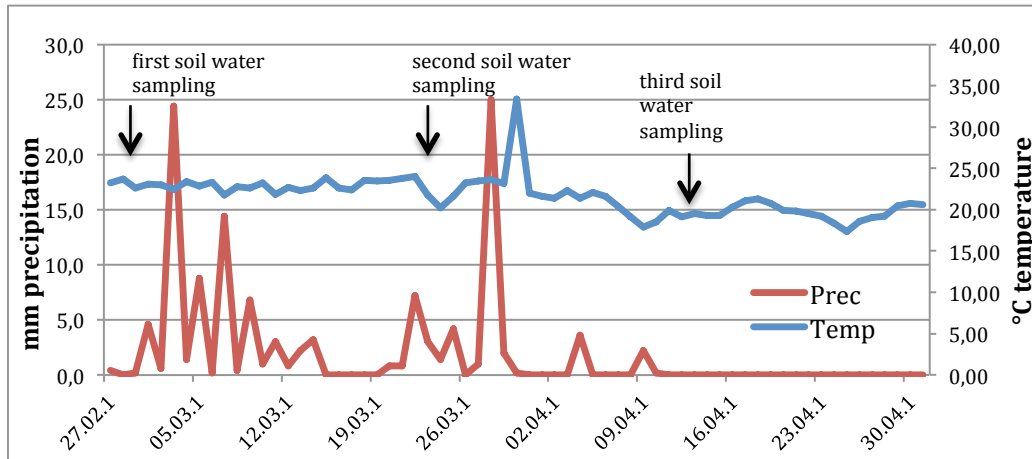


Figure 7: Measured precipitation and temperature on the experiment site from end of February until end of April. The date of first, second and third soil water sampling is indicated.

In March, the temperature was $\sim 18^{\circ}\text{C}$ and stable, except $\sim 15^{\circ}\text{C}$ on 24/03-16 and $\sim 25^{\circ}\text{C}$ on 30/03-16. In April, the temperature gradually stagnated towards $\sim 14^{\circ}\text{C}$ (figure 7).

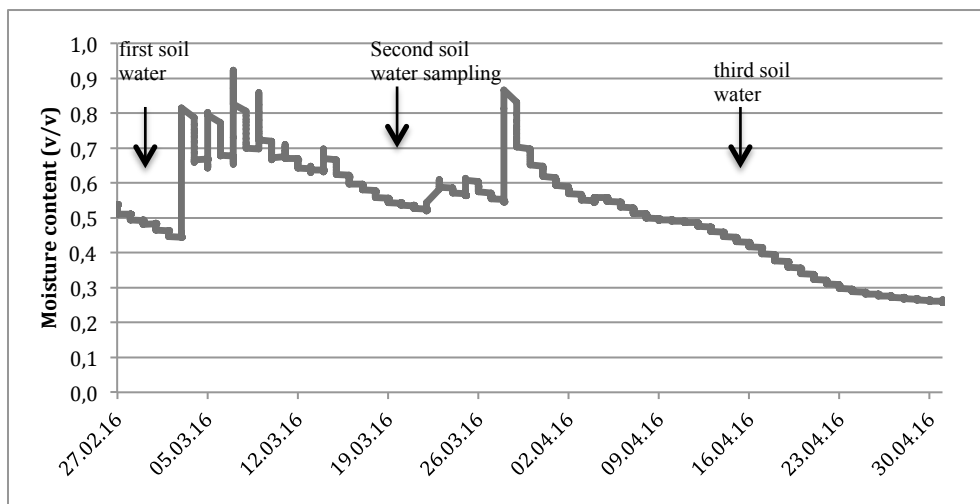


Figure 8: Measured moisture content in soil on the experimental site from end of February until end of April. The date of first, second and third soil water sampling is indicated.

The moisture content in soil is moist, with two peak periods of higher soil moisture due to two rain events. The moisture content was highest when the second soil water sampling was done, and lowest when the third soil water sampling was done (figure 8). The moisture content gradually decreased in April (Obia 2016, personal communication, 10th of August).

3.3 Soil

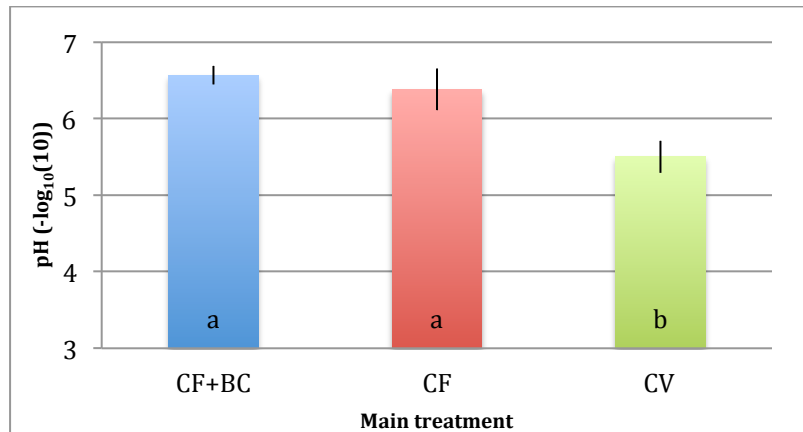


Figure 9: Measured pH in soil. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil collected on 21/04-16 in Mkushi.

The pH-value of 5.5 in CV treatment (figure 9) was significantly smaller compared to the pH-values from 6.5-6.6 in CF+BC ($p < 0.05$) and from 6.3-6.4 in CF ($p < 0.05$). The soil pH in CF+BC was not significantly higher than in CF ($p > 0.05$).

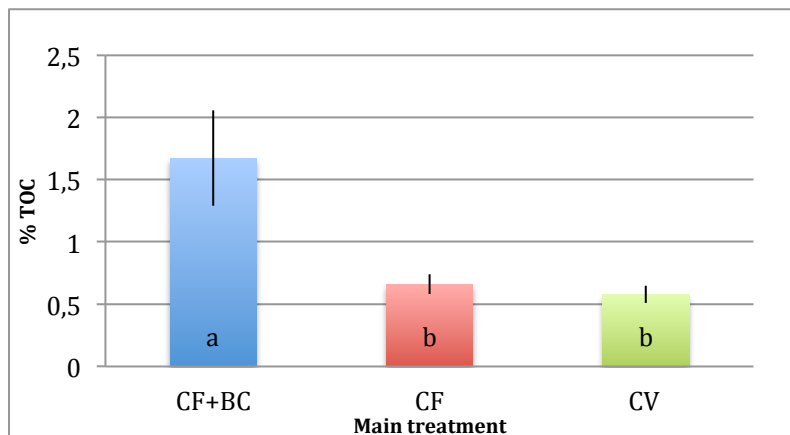


Figure 10: Measured % TOC in soil. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil collected on 21/04-16 in Mkushi.

In figure 10, CF+BC had ~1.5 % TOC, compared to in CF with ~0.5 % TOC ($p < 0.05$). There was no significant difference between CF and CV ($p > 0.05$).

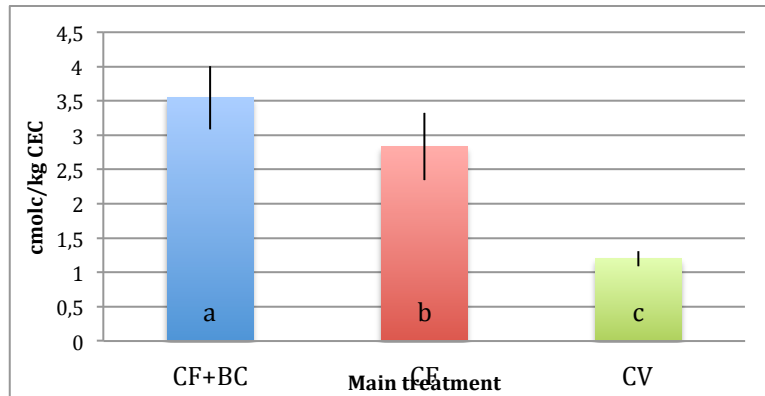


Figure 11: CEC in soil. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil collected on 21/04-16 in Mkushi.

CV had a CEC of 1.2 cmolc/kg (figure 11) and was very low compared to in CF+BC ($p < 0.05$) and in CF ($p < 0.05$). CF+BC had a CEC of ~3.5 cmolc/kg, and was significantly higher than CEC in CF of ~3 cmolc/kg ($p < 0.05$).

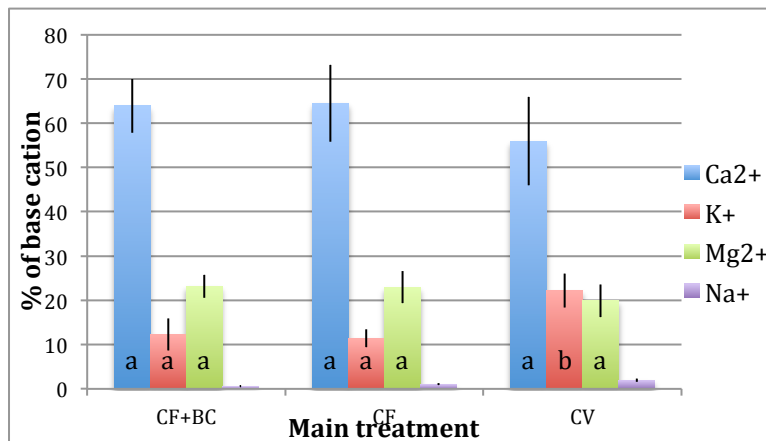


Figure 12: Calculated NH_4^+ -acetate extractable calcium, potassium, magnesium and sodium in soil. Values are means and standard deviations. Significant differences in each cation are indicated by different letters: a; b; c. Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil sampled on 21/04-16.

The amount of base cations in soil was measured in filtrated NH_4^+ -acetate solution. Figure 12 shows the percentage of the CEC of the NH_4^+ -acetate extractable cations in soil. The sum of the percentage of exchangeable base cations is 100 %. The % of NH_4^+ -acetate extractable Ca^{2+} did not significantly differ between the main treatments ($p > 0.05$). The % of K^+ did not differ between CF+BC and CF ($p > 0.05$). The % of K^+ was significantly higher in CV than in CF+BC ($p < 0.05$) and in CF ($p < 0.05$). Regarding % of Mg^{2+} , there was no significant difference between the main treatments ($p > 0.05$). The % of Na^+ was below ~1 % in the main treatments. The amount of H^+ was excluded in the calculation due to results of unreasonable high values from the H^+ determination with NH_4^+ -acetate.

Table 3: Calculated C/N ratio and measured PO_4^{3-} -P mg/kg in soil. Values are means and standard deviations. Significant differences are indicated by different letters a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil sampled on 21/04-16.

| Main treatment | C/N | | | PO_4^{3-} -P | | |
|----------------|------|------|-----------|----------------|------|-----------|
| | mean | sd | sign diff | mean | sd | Sign diff |
| CF+BC | 22 | 3.5 | a | 137 | 83 | a |
| CF | 11 | 1.16 | b | 97.5 | 37.5 | a |
| CV | 12 | 0.76 | b | 17 | 7 | b |

Table 3 shows that the soil C/N ratio in CF+BC was higher than in CF ($p < 0.05$) and in CV ($p < 0.05$). The concentration of extractable P in CF+BC was high (106-204 mg/kg) compared than in CV with a value of 17 mg/kg ($p < 0.05$).

3.4 Soil KCl extracts

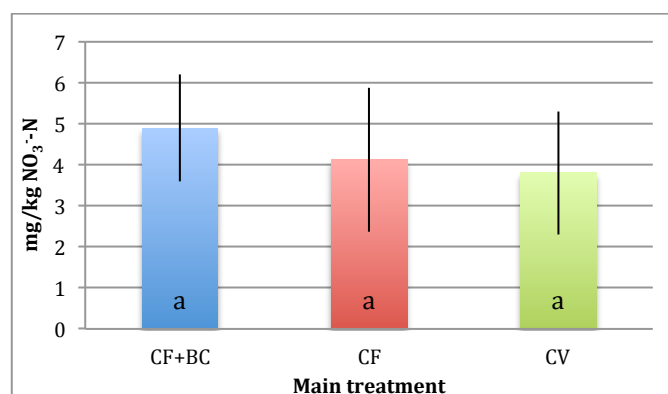


Figure 13: Concentration of NO_3^- -N in mg/kg measured in soil KCl extract. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil collected in April 2016 in Mkushi.

The concentration of NO_3^- -N measured from soil KCl extracts (figure 13) was highest in CF+BC (~5 mg/kg), but not significantly higher than in CF ($p > 0.05$) and CV ($p > 0.05$).

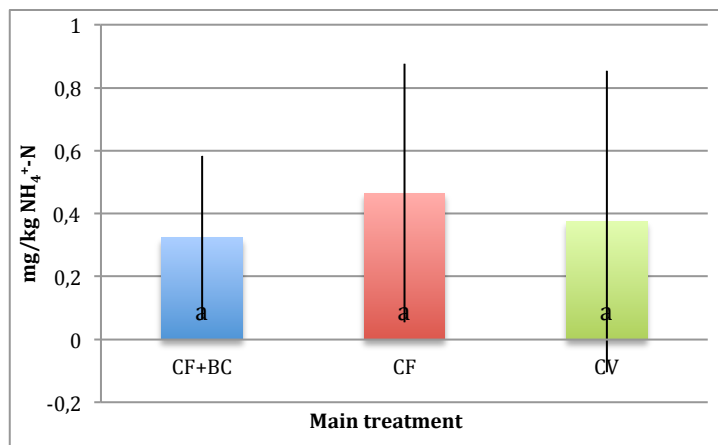


Figure 14: Concentration of $\text{NH}_4^+\text{-N}$ in mg/kg measured in soil KCl extract. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil collected in April 2016 in Mkushi.

Figure 14 shows a very small content of $\text{NH}_4^+\text{-N}$ compared with $\text{NO}_3^-\text{-N}$ (figure 13). The concentration of $\text{NH}_4^+\text{-N}$ measured from soil KCl extracts (figure 14) was higher in CF (~0.4 mg/kg), but was not significantly higher than in CF+BC ($p>0.05$) and CV ($p>0.05$). The concentration in CF+BC was lowest (~0.3 mg/kg). The concentration of $\text{NH}_4^+\text{-N}$ (mg/kg) in blanks was high, and so were the concentrations of $\text{NH}_4^+\text{-N}$ in all the KCl extracts. The concentration in blanks was deducted from the measured concentration in all samples.

3.5 Soil water

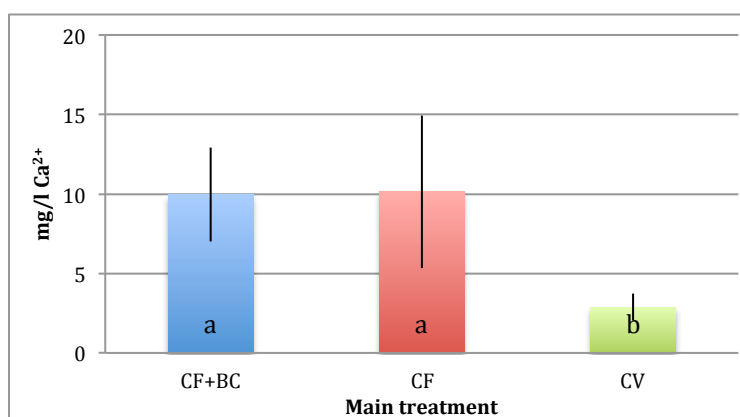


Figure 15: Concentration of calcium in mg/l measured in soil water. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil water collected on 28/02-16 in Mkushi.

Figure 15 shows that Ca^{2+} concentration in CV of 3 mg/l was significantly smaller than in CF+BC ($p<0.05$). Ca^{2+} concentration in CF+BC and in CF was ranging from 7 mg/l to 12 mg/l; values did not differ significantly ($p>0.05$).

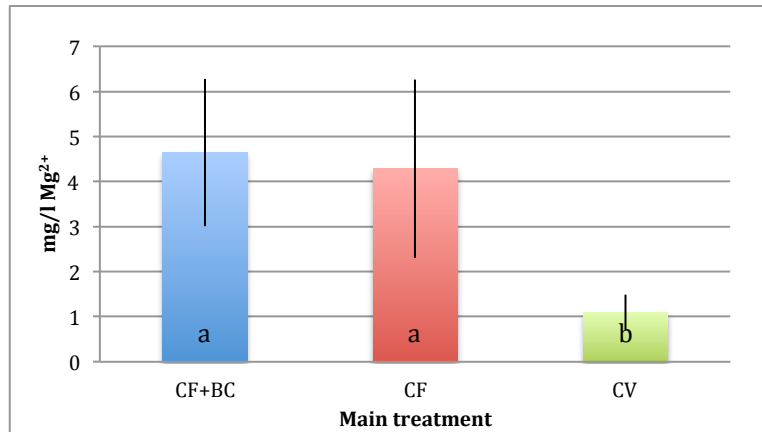


Figure 16: Concentration of magnesium in mg/l measured in soil water. Values are means and standard deviations. Significant differences: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil water collected on 28/02-16 in Mkushi.

Figure 16 shows that in CV with the lowest value of 1 mg/l Mg²⁺, was lower than in CF (p<0.05) and in CF+BC (p<0.05). The Mg²⁺ concentration in CF+BC was ranging from 3.2-6 mg/l. The Mg²⁺ concentration in CF was ranging from 2.8-5.8 mg/l.

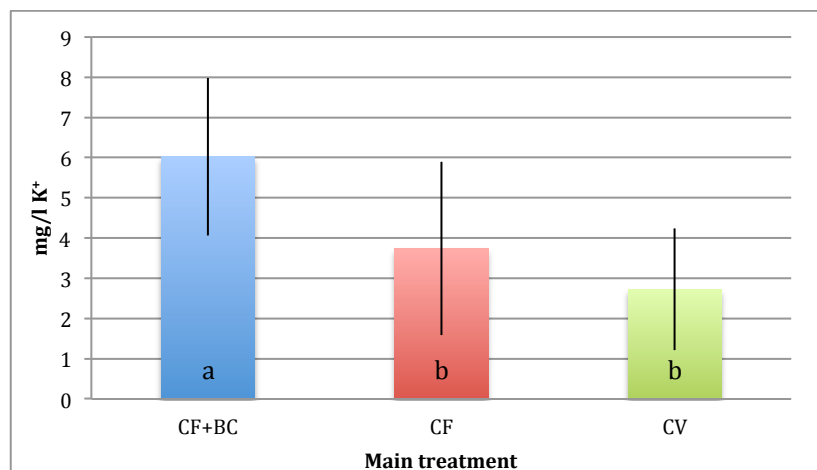


Figure 17: Concentration of potassium measured in soil water. Values are means and standard deviations. Significant differences: a; b; c. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil water collected on 28/02-16 in Mkushi.

Figure 17 shows that the concentration of K⁺ was lowest in CV (2.5 mg/l). CF+BC was significantly higher than in CF (p<0.05) and in CV (p<0.05).

4. DISCUSSION

The retention of plant available nutrients is dependent on chemical soil properties as pH, CEC and SOM in soil.

The pH was ~6.4 inside old basins and ~5 in-between old basins, before the experiment was established (table 1). After the experiment was established, measured pH in soil in February was ~6.5 in CF+BC, ~6.3 in CF, and 5.5 in CV. The stations in CV were established in-between old rows where the pH was ~5. The low pH in CV is mostly due to mixing of soils from the old in-between basins and the old basins. Studies show that pH increases due to BC's liming effect on acidic soil (Glaser et al., 2001; Chan et al., 2007; Novak et al., 2009). Studies of pH affect by BC addition by Alling et al. (2014) also resulted in a pH of 6.5 in an acidic, sandy loam Acrisol. The pH did not significantly differ between CF+BC and CF and the pH was fairly stable from October 2015 to February 2016. It could be an effect of large amounts of dolomite used for liming.

Table 4: Calculation of expected increase of TOC in soil with addition of BC.

| |
|---|
| Volume of basin (d=20 cm, l=30 cm, w=16.7 cm) = 10020 cm ³ |
| Soil per volume = 1.2 g/cm ³ |
| Soil per basin = 12.2 kg |
| Amount of biochar added = 4 t/ha |
| Amount of basins = 16 000 |
| Carbon content of biochar = 45.90 % |
| |
| 4 t/ha / 16 000 basins = 0.25 kg |
| 0.25 kg * 45.90 % / 100 = 0.11 kg |
| 0.11 kg / 12.2 kg * 100 = 0.95 % |
| |
| This shows an expected increase of ~1 % TOC in soil. |

The soil TOC content before the experiment was established, was ~0.5% (table 1), and there has been an increase in 1% TOC with addition of BC (figure 10), as expected (table 4). This also indicates that soil samples taken from CF+BC, included the BC addition, and was significantly higher than in CF and CV ($p < 0.05$). Between CF and CV, there was expected a higher TOC in CF than in CV due to residue retention which would improve the build-up of SOM in CF soil, also because the background data show that basins have more TOC than in-between basins (table 1). Use of tillage in CV would increase SOM decomposition due to soil disturbance (Six et al., 2002). In this study, the planting stations in CV were also strongly affected by soil from old in-between basins, but the soil was mixed with soil from CF. Therefore, the amount of TOC in CV seems to be affected by TOC content in basins. This could also be confirmed by that the C/N ratio (table 3) did not differ between CF and CV either, as TOC determination is traditionally used for the assessment of the C/N ratio. CF+BC soil had a lot of extra carbon (figure 10), which was not accompanied by much nitrogen. Therefore, CF+BC had larger C/N ratios than CF and CV soils. The low C/N ratio in CF and in CV could indicate a high decomposition rate of SOM by microorganisms or termites.

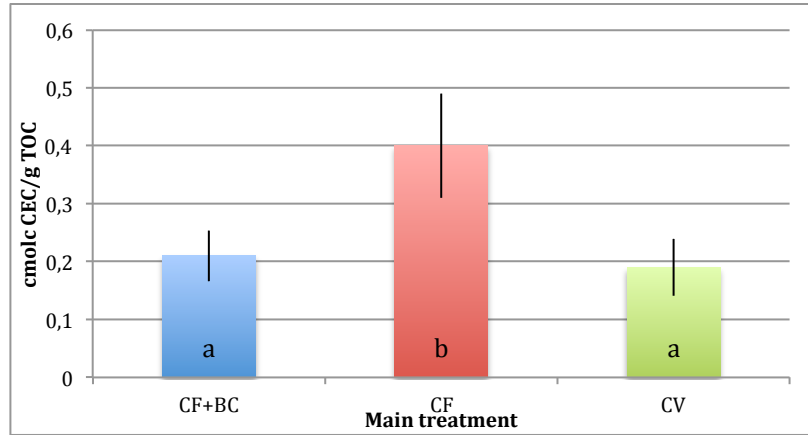


Figure 18: Cmolc CEC/g TOC ratio in soil. Values are means and standard deviations. Significant differences are indicated by different letters: a; b; c.. CF+BC: Conservation farming with biochar. CF: Conservation farming without biochar. CV: Conventional farming. Soil collected in April 2016.

SOM is responsible for a large portion of CEC. Thus, a strong relationship between carbon and CEC was expected (Gruba and Mulder, 2015). It was therefore surprising that the cmolc CEC/g TOC was significantly higher in CF rather than in CF+BC and CV (figure 18). The cmolc CEC/g TOC ratios in background data were higher in basins than in-between basins (table 1). The highest ratios were ranging from 0.45-0.57 cmolc/g in basins, while the lowest ratios were ranging from 0.2-0.31 cmolc/g. Insoluble dolomite was observed on the field during fieldwork in May 2016, as mentioned. Dolomite, which contains a fair amount of Ca^{2+} , Mg^{2+} and some K^+ (Haas, 1992), most likely explains the high content of Ca^{2+} and Mg^{2+} , in previous basins (table 1). During the CEC determination of our data, the insoluble dolomite did possibly extract in NH_4^+ -acetate solution, and did result in higher Ca^{2+} , Mg^{2+} and K^+ concentration in our CF soil data. The calculated CEC in previous basins were higher than the calculated CEC in CF+BC and CF soil from our data (table 1; figure 11), and the difference could be explained by that NH_4NO_3 solution was used for determination of CEC in background soil and not NH_4^+ -acetate solution.

Correlation between Ca^{2+} ; Mg^{2+} ; K^+ ; Na^+ in soil water and in soil.

The soil/soil solution ratio is the relationship between the fraction of exchangeable cation on exchange sites and the fraction of cationic charge in soil water contributed by the cation. Gaines-Thomas equation describes soil-soil solution exchange (Gaines and Thomas, 1953). K_{gt} is the Gaines-Thomas selectivity coefficient, a constant.

$$(\text{Mg}^{2+})[\text{Ca}^{2+}] / (\text{Ca}^{2+})[\text{Mg}^{2+}] = K_{gt} \quad (1)$$

Rearranging yields:

$$[\text{Ca}^{2+}] / [\text{Mg}^{2+}] = K_{gt} * (\text{Ca}^{2+}) / (\text{Mg}^{2+}) \quad (2)$$

From the equation 2 the ratio of Ca^{2+} to Mg^{2+} in solution (specifically $[\text{Ca}^{2+}] / [\text{Mg}^{2+}]$) is defined by the ratio of these ions on the exchange sites $[(\text{Ca}^{2+}) / (\text{Mg}^{2+})]$ rather than the ratio of the absolute amounts. The same principles apply to all other major cations.

The concentration of Ca^{2+} in soil water was not significantly higher in CF+BC as expected (figure 15). As BC is added, Ca^{2+} should become increasingly available in the soil solution for plant uptake. BC, with its negative surface charge, is supposed to attract more positively charged ions to its surface (Liang et al., 2006; Xiao et al., 2016).

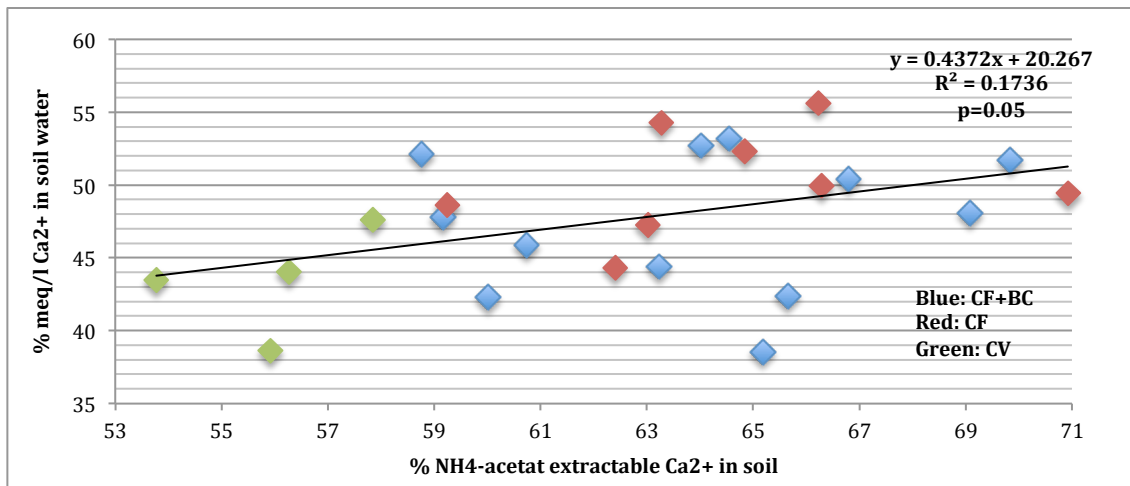


Figure 19: Relation between % NH_4^+ -acetate extractable Ca^{2+} in soil and % meq/l Ca^{2+} in soil water. Blue: CF+BC. Red: CF. Green: CV.

Figure 19 shows a correlation between calculated % NH_4^+ -acetate extractable Ca^{2+} in soil and % meq/l Ca^{2+} in soil water ($p < 0.05$). That the percentage of Ca^{2+} in soil did result in increased percentage of Ca^{2+} in water seems only true for CV soil. Regarding CEC/TOC relation (figure 18), CF soil samples contained most likely dolomite and would therefore result in higher concentration of Ca^{2+} in our data. Regarding CF+BC, which did not correlate ($p > 0.05$), Ca^{2+} could be less exchangeable in BC. It could also be extracted from BC-associated ashes in a form of lime (Munéra 2016, personal communication, 28th of November), when using NH_4^+ -acetate in the CEC determination. Some BC-associated ashes could be included in the determination.

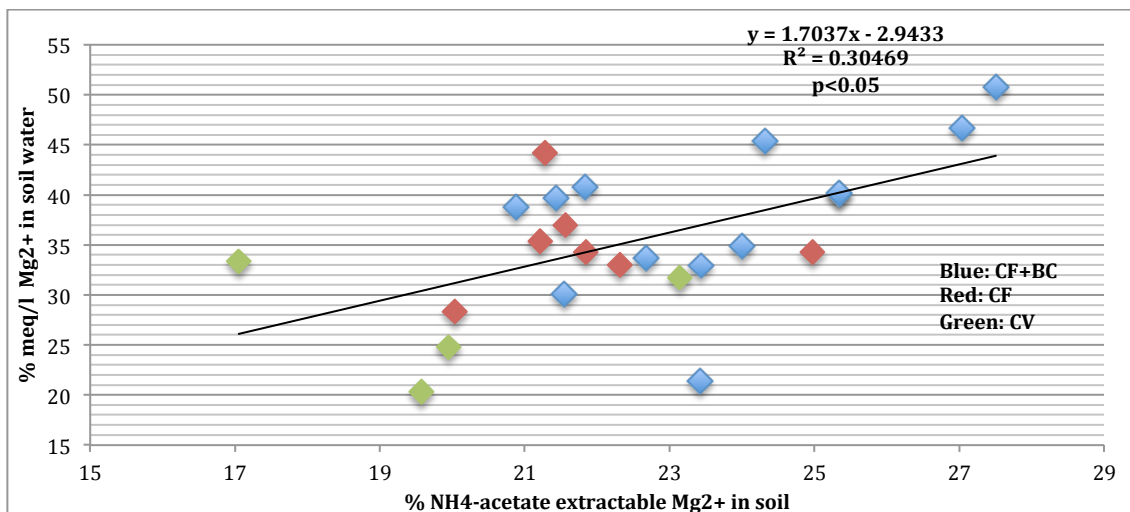


Figure 20: Correlation between % NH_4^+ -acetate extractable Mg^{2+} in soil and % meq/l Mg^{2+} in soil water. Blue: CF+BC. Red: CF. Green: CV.

Regarding concentration of magnesium in soil water, it follows the same trend as the concentration of calcium in the different treatments. The concentration was significantly lower in CV than in CF+BC and CF, and there was no significant difference between CF+BC and CF (figure 16). That was also a bit unexpected due to suggested Mg^{2+} increase in BC amended soil (Alling et al., 2014), although it is highly dependent on BC's quality.

Figure 20 shows a correlation between calculated % NH_4^+ -acetate extractable Mg^{2+} in soil and % meq/l Mg^{2+} in soil water ($p < 0.05$), but there was no difference in the amount of NH_4^+ -

acetate extractable Mg^{2+} between CF+BC and CF ($p>0.05$) (blue and red symbols). The non-difference could be explained by that Mg^{2+} presented in BC could exist in varying forms and may not be instantly available (Alling et al., 2014). The insoluble dolomite in CF soil could also increase the Mg^{2+} concentration in CF, and explain the non-significant difference between CF+BC and CF.

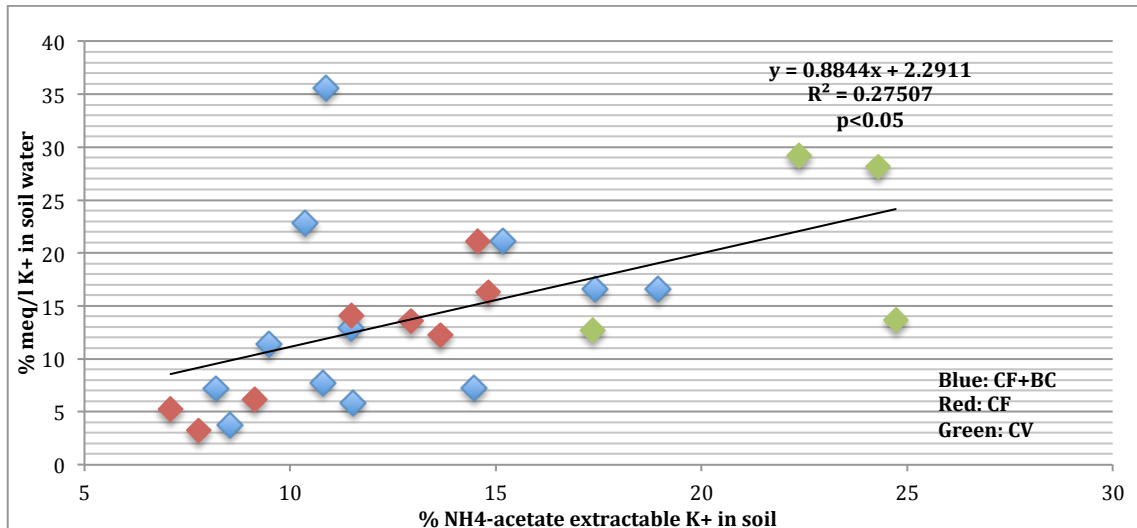


Figure 21: Correlation between % NH_4^+ -acetate extractable K^+ in soil and % meq/l K^+ in soil water. Blue: CF+BC. Red: CF. Green: CV.

Figure 21 shows a significant correlation between of K^+ in soil and K^+ in soil water ($p<0.05$). The figure indicates that the fraction of NH_4^+ -acetate extractable K^+ changed, and so did the fraction of K^+ in soil water. The concentration of K^+ was significant higher in CF+BC (figure 17), than in CF and CV. The BC used, contains high concentration of K^+ (~27 cmol/kg K^+) (table 2). This is not a surprise as BC has been shown to be a source of potassium (Atland and Locke, 2013).

These results on Ca^{2+} and Mg^{2+} indicate that our data of determined CEC (with NH_4^+ -acetate solution) in CF+BC and CF soil are not trustworthy. Since divalent cations Ca^{2+} and Mg^{2+} are preferred at the replacing site more than monovalent cations K^+ and Na^+ , the relations between amount NH_4^+ -acetate extractable Ca^{2+} , K^+ , Mg^{2+} and Na^+ in soil (figure 12) is only trustworthy for CV. That also explains the high values of CV compared with CF+BC and CF shown in figure 21.

Measured PO_4^{3-} -P in CF+BC was 137 mg/kg, compared to 97.5 mg/kg in CF and 17 mg/kg in CV (table 3). Hale et al. (2013) observed an addition and a slow release of PO_4^{3-} of 172 mg/kg by use of CC BC. This observation can explain the high concentration of PO_4^{3-} -P in CF+BC. Atland and Locke (2013) did experiments on retention and release of phosphate with different BC amendment. Their experiment resulted in variable phosphate retention and suggested that it was necessary to do more study to determine what other factors might affect the phosphate retention in soil with addition of BC. Measured PO_4^{3-} -P in soil in CV was very low (7 mg/kg). The very low PO_4^{3-} -P in CV did not seem to be affected by that CV was a mix of previous basins and in-between basins, and the background data do not show any significant difference in PO_4^{3-} -P between basins and in-between basins (table 3). Previous research has observed a lower concentration of PO_4^{3-} -P in CV compared to in CF (Mloza-Blanda et al., 2016). The very low concentration could be explained by the low pH in soil of 5.5. If pH is lower than 6, phosphorus will start to form insoluble compound with Fe and Al (Richardson, 2001).

According to Zaman and Nguyen (2010), the lime effect by BC addition can result in increase in NO_3^- concentration in soil. However, no difference in concentration of NO_3^- -N was observed between CF+BC, CF and CV in soil KCl extracts (figure 13). Our data do not confirm this probably due to observed very low NO_3^- -N concentration in February. The temperature used during pyrolysis of PP BC and CC BC was $350^\circ\text{C} \pm 50^\circ\text{C}$, and Yao et al. (2012) suggested that increase in pyrolysis temperature might improve the sorption ability of BC to aqueous nitrate. Maybe an increase in pyrolysis temperature could improve the nitrate sorption by BC in this experiment. The concentration of NO_3^- -N in all main treatments (figure 13) was high compared to the measured NH_4^+ -N concentration (figure 14) in soil KCl extracts. Note that the KCl extraction was not done in the field, and the high values in the blanks is mostly likely due to contamination in the KCl solution. However, the total concentration of NH_4^+ -N was very low, as seen in soil water too (see appendix). The difference between NO_3^- -N and NH_4^+ -N from soil KCl extractions do indicate that there has been a nitrification process where NH_4^+ -N is converted to NO_3^- -N. Cornelissen et al. (2011) reported a higher nitrification rate in Zambian soil with BC. In this experiment, CF+BC soil had the lowest concentration of NH_4^+ and the highest concentration of NO_3^- (figure 13; figure 14). This could indicate a higher nitrification rate in addition of BC (DeLuca et al 2006; Clough and Condron 2010).

Affect on soil moisture, precipitation and air temperature:

It is difficult to observe any affect of soil moisture in concentration of nutrients measured in soil water extracted in February (figure 8). This is due to no accessible data on soil moisture from December 2015 to early February 2016. The air temperature has been stable from February to April. There were a few rain events in the beginning of March (figure 7), and the moisture content increased that period (figure 8). The moisture content did decrease gradually throughout April. There has been observed a general increase in concentration on plant available nutrients in the soil water from February to April (see appendix). The decrease in moisture content could explain the dynamics.

Further investigation:

For further investigation on plant available nutrients in these treatments, soil water should be collected during the whole cropping season. Determination of CEC and exchangeable base cations in soil should be determined by soil KCl extracts in the field or only 1-2 days after soil sampling. Microbial activity should be measured for further investigation on effects of residues in CF.

5. CONCLUSION

The soils used in this study have a land-use history of 7 years of CF with basins. Background data indicated a significant greater pH and TOC content in basins than in-between basins. This effect was still visible after the first year of conversion of CF to CV. Most of the results in this study are due to this legacy of CF, where soil under CV is a mix of (predominantly) in-between basin soil and (minor amounts of) basin soil. Results showed that CV had significantly lower pH and CEC in soil than CF alone, and could be explained by the mix of soil under CV. Soils under CF in combination with BC had significantly higher TOC content, CEC and carbon:nitrogen ratio, than CF alone. CF+BC did not give significantly higher PO_4^{3-}P and pH in soil than CF. Ca^{2+} and Mg^{2+} concentrations in soil water were not significantly higher in CF+BC than in CF, except of K^+ . The reason for not observing significant differences in Ca^{2+} and Mg^{2+} is assumed caused by NH_4^+ -acetate extraction of Ca^{2+} and Mg^{2+} from insoluble dolomite, which was present in CF soil. It was also believed that NH_4^+ -acetate solution did extract Ca^{2+} and Mg^{2+} from BC-associated ashes. The calculated CEC per gr TOC was significantly higher in CF than in both CF+BC and CV. This indicates that our data on soil in CF is an affect of the overestimation of exchangeable Ca^{2+} and Mg^{2+} by the NH_4^+ -acetate extract (due to the presence of dolomite in the basins). Both CF and CF+BC have this (and not CV). However, CF+BC also has more TOC than CF, but this extra TOC is from BC, which does not have so much charge per gram TOC (Munéra, personal communication, 9^h of December). The respective plant available nutrients in soil water were significantly lower in CV than in CF, and is most likely explained by that this soil has not had any dolomite in 7 years of CF. For extractable. P, the lower amount in CV may be due to the lower pH, which is again due to the lower amount of dolomite applied to the in-between basin soil. The difference between concentrations of NO_3^- and NH_4^+ indicated a high nitrification rate in soil in all treatments.

Based on the results of CEC and exchangeable cations, use of NH_4^+ -acetate solution for the analysis is not a good option in soil with addition of biochar and/or dolomite.

CF in combination with BC did not result in higher concentrations of plant available nutrients, except for K^+ , than CF alone. CF+BC gave significantly higher content of TOC due to addition of biochar. CF gave significantly higher concentrations of plant available nutrients than CV.

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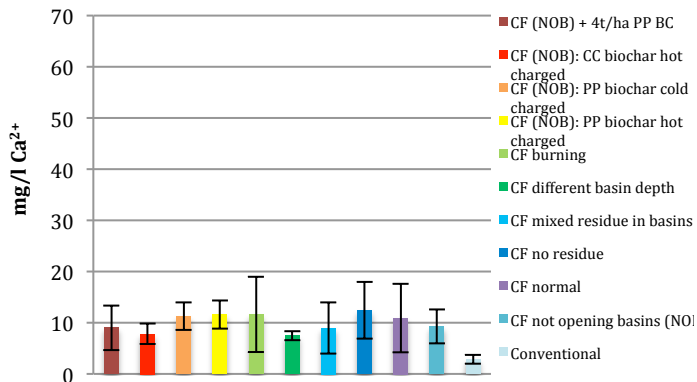
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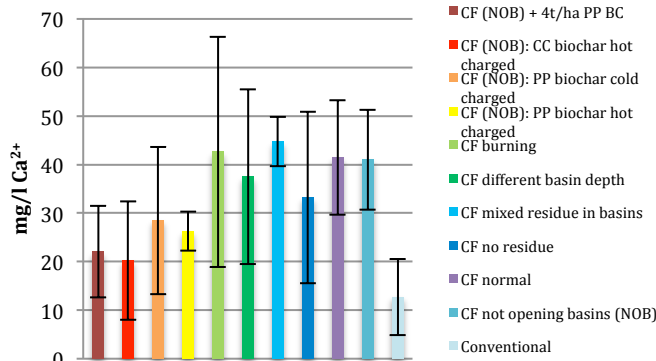
7. Appendices

Analysis of concentration of plant available nutrients and pH in soil water in Mkushi

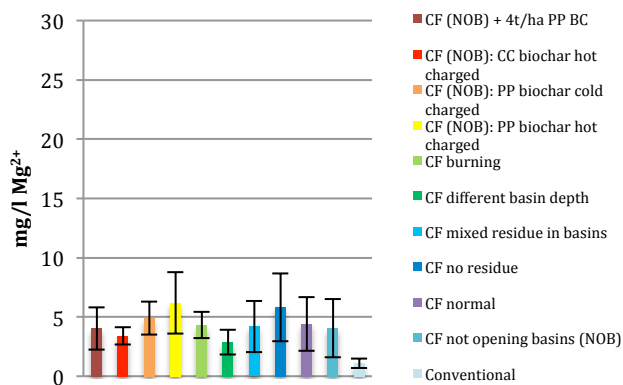
Concentration of calcium in February



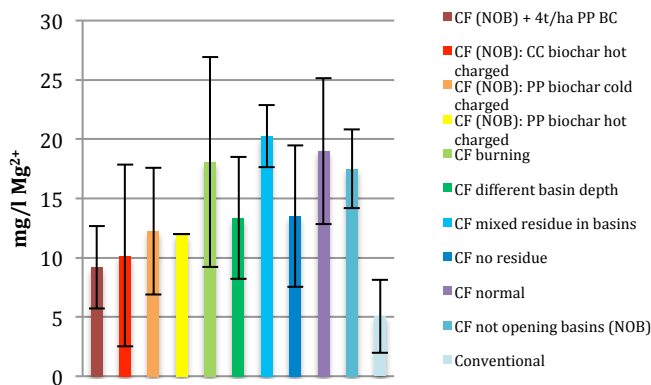
Concentration of calcium in March



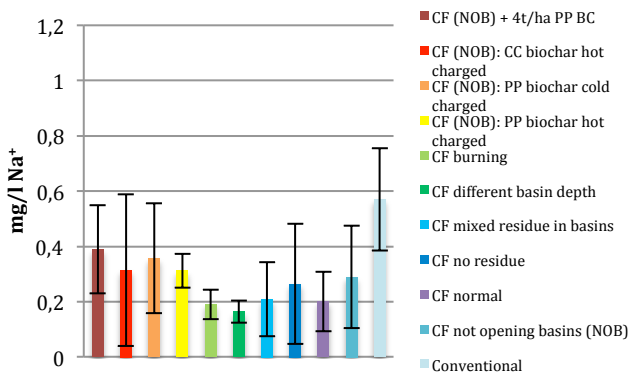
Concentration of magnesium in February



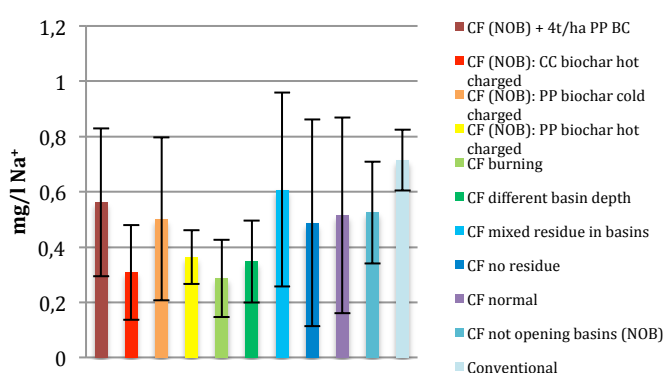
Concentration of magnesium in March



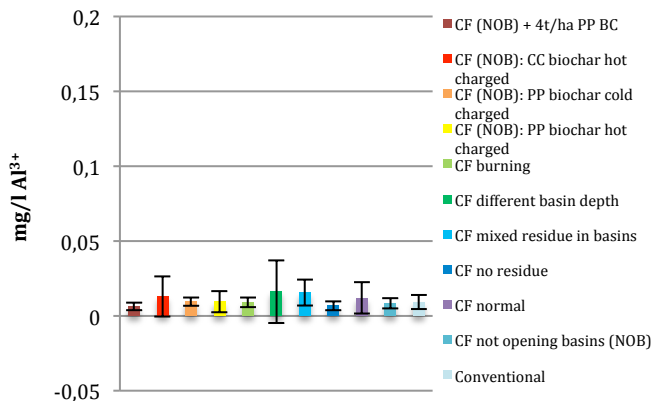
Concentration of sodium in February



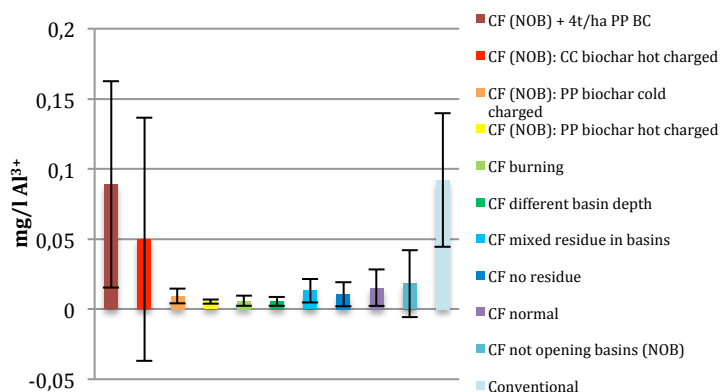
Concentration of sodium in March



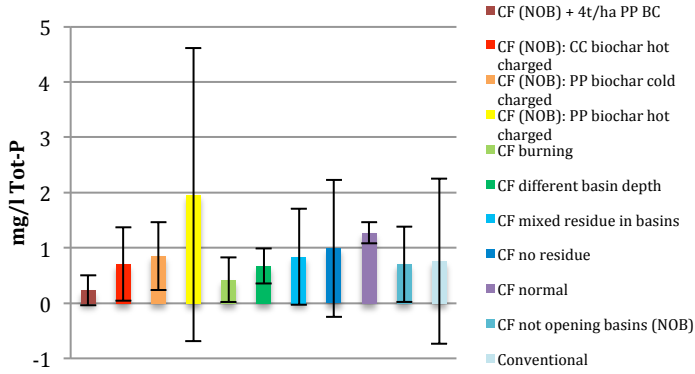
Concentration of aluminium in February



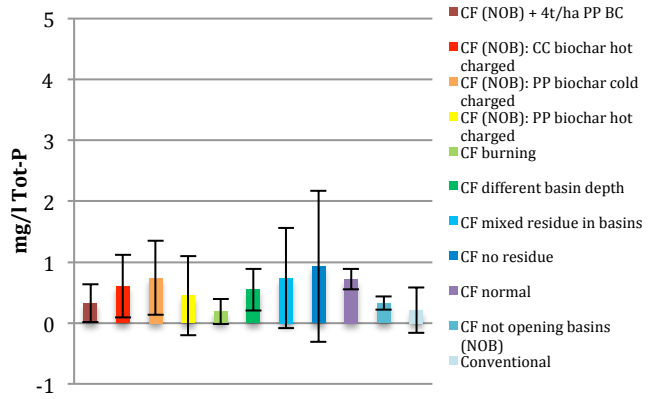
Concentration of aluminium in March



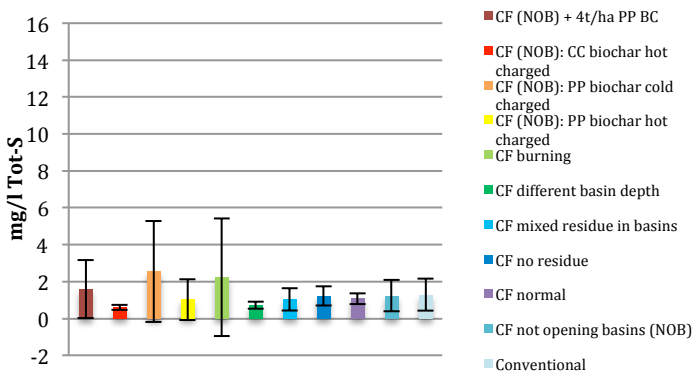
Concentration of TOT-P in February



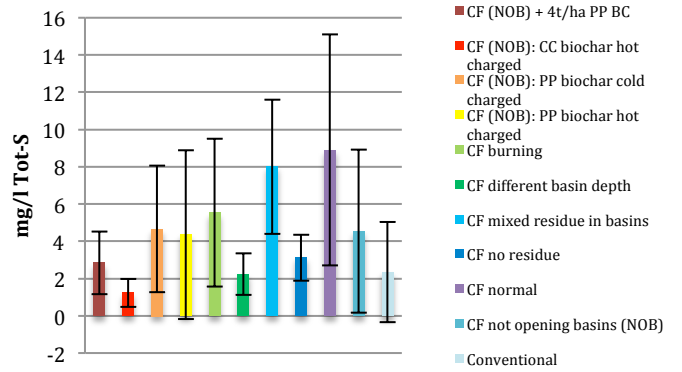
Concentration of TOT-P in March



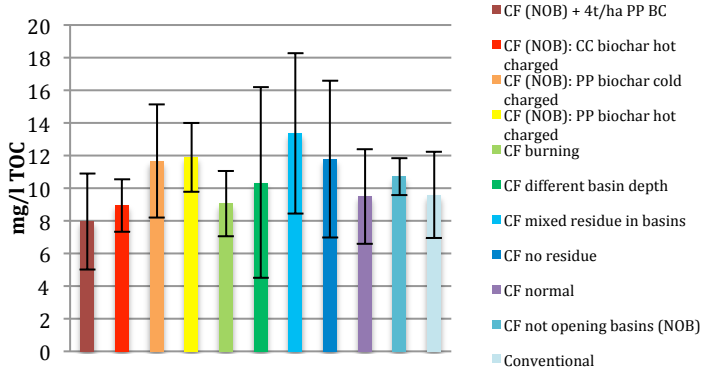
Concentration of TOT-S in February



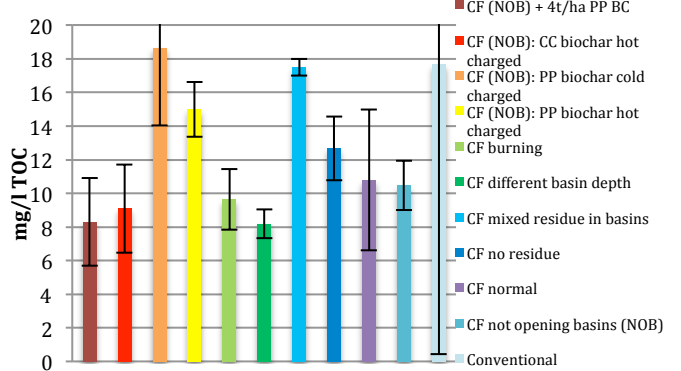
Concentration of TOT-S in March



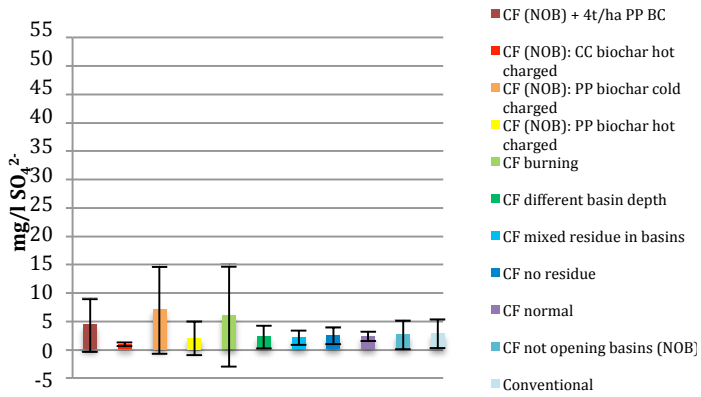
Concentration of TOC in February



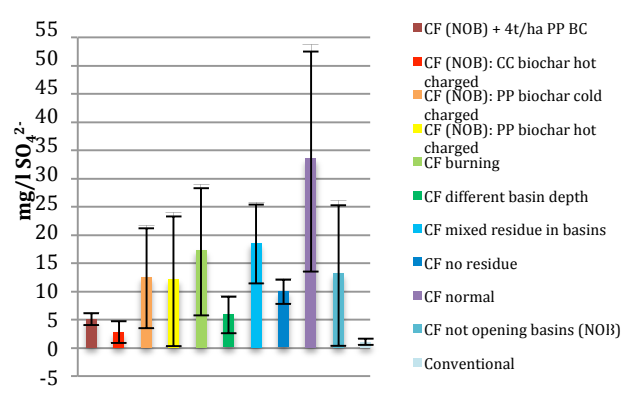
Concentration of TOC March



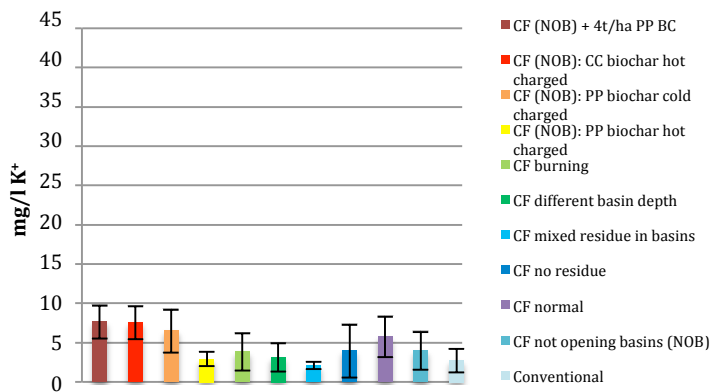
Concentration of sulphate in February



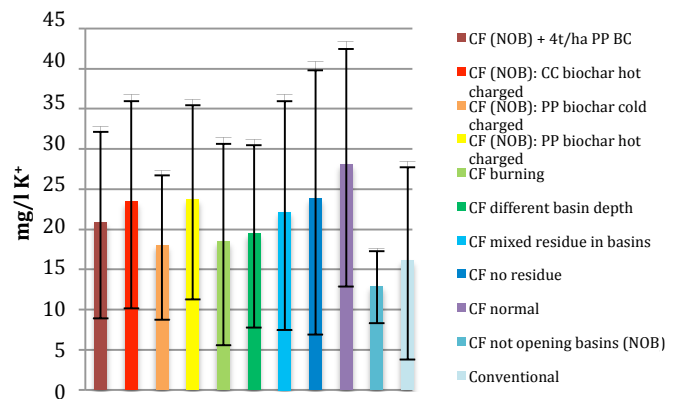
Concentration of sulphate in March



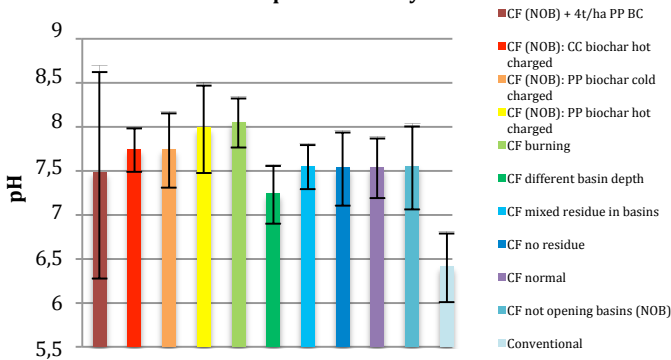
Concentration of potassium in March



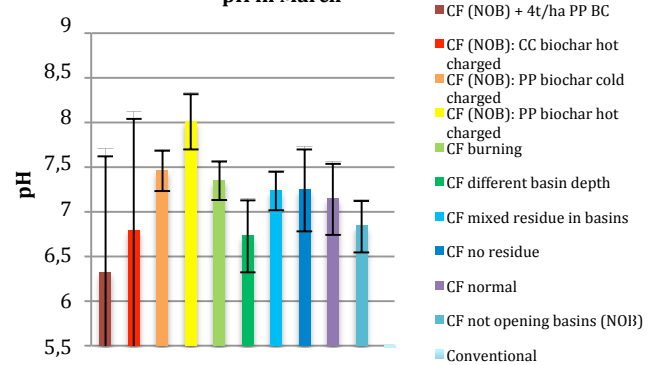
Concentration of potassium in March



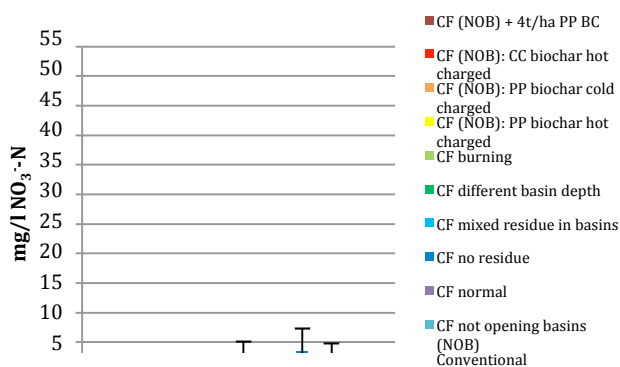
pH in February



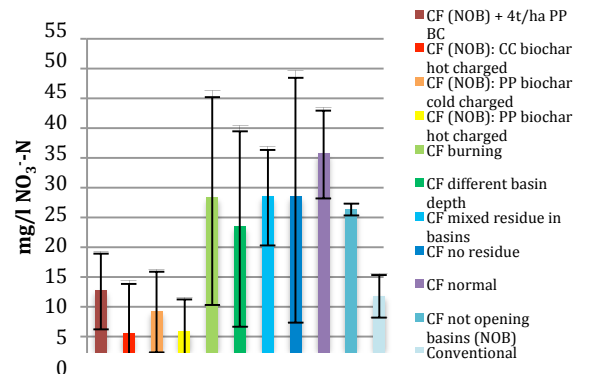
pH in March



Concentration of nitrate-N in February



Concentration of nitrate-N in March



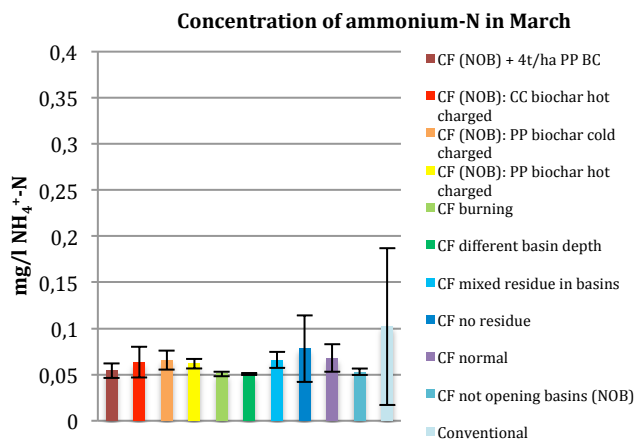
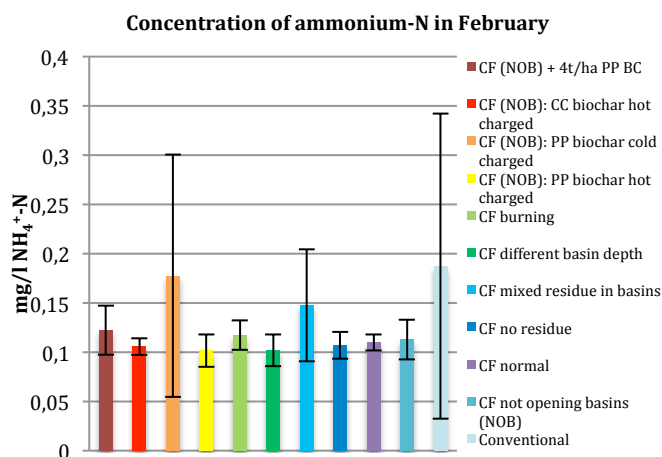
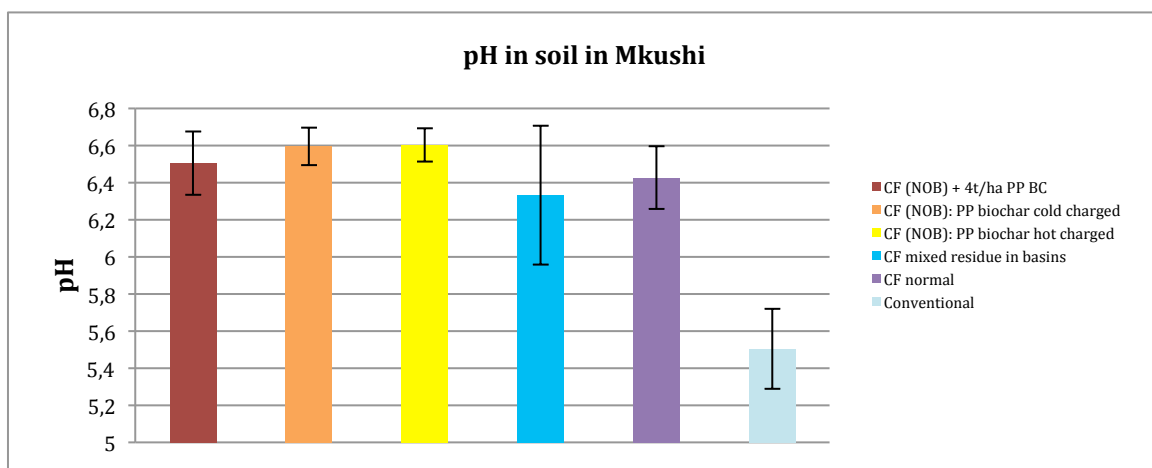
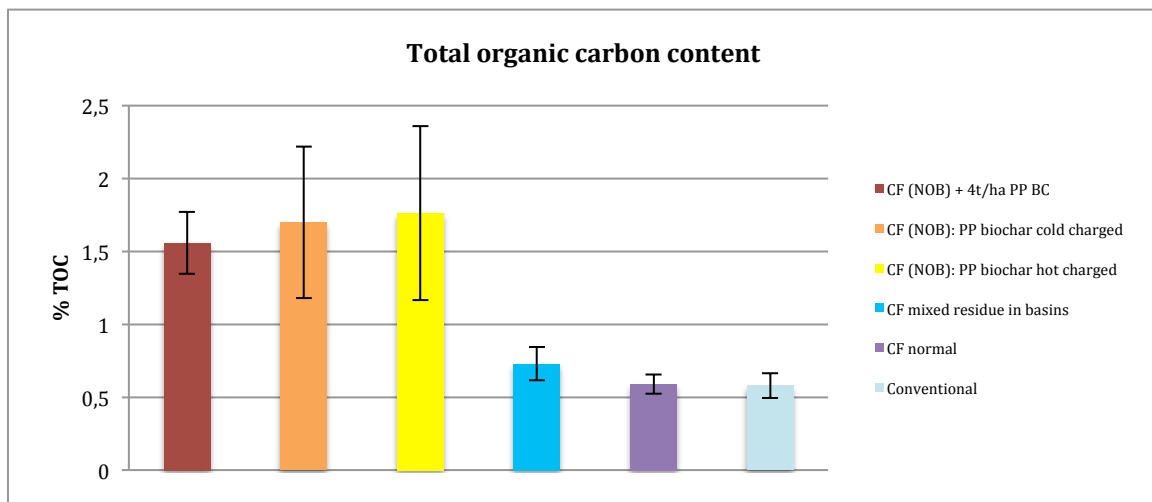
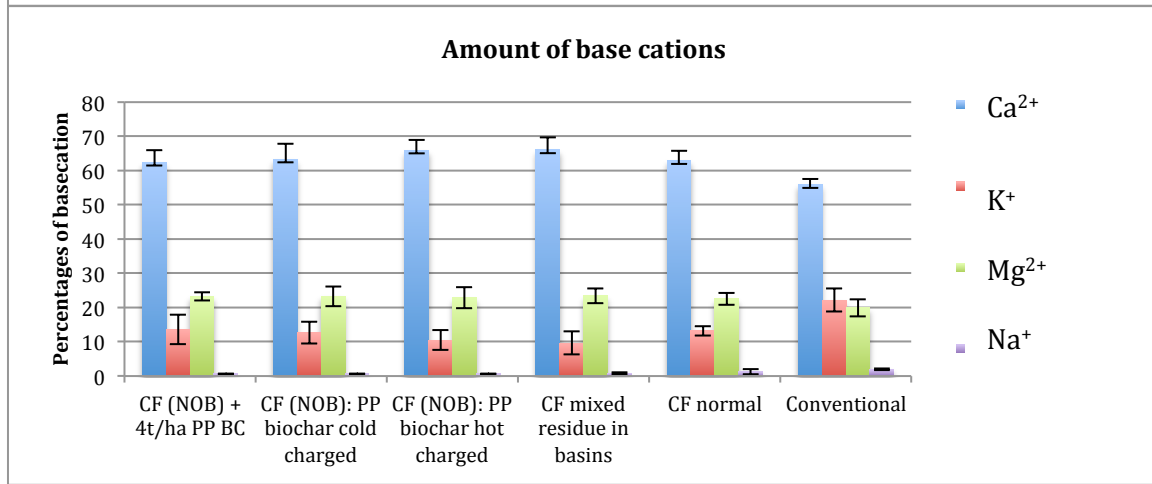
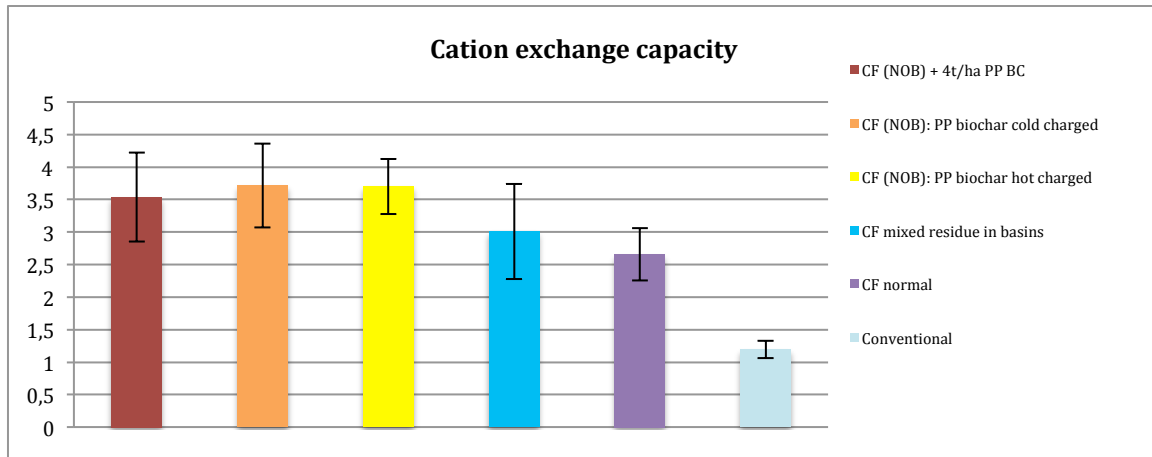


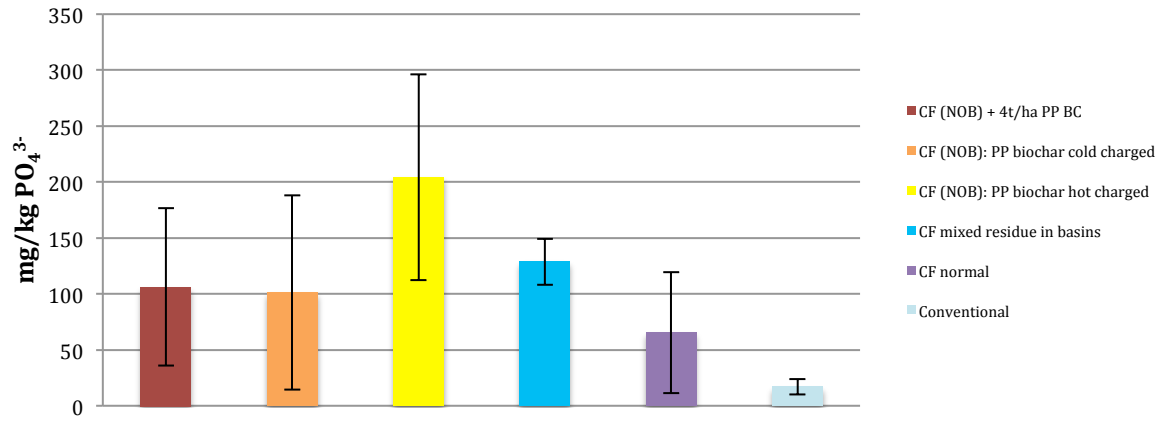
Table: Measured concentrations in April. Not all elements could be analysed due to lack of water.

| Treatment | mg/l Ca ²⁺ | mg/l Na ⁺ | mg/l Mg ²⁺ | mg/l K ⁺ | mg/l Al ³⁺ | mg/l Tot-P | mg/l Tot-S |
|-----------------------------------|-----------------------|----------------------|-----------------------|---------------------|-----------------------|------------|------------|
| CF (NOB) + 4t/ha PP BC | 8,6 | 0,59 | 3,9 | 28 | 0,032 | 0,052 | 3,5 |
| CF (NOB): CC biochar hot charged | 17 | 0,81 | 15 | 18 | 0,037 | 2,2 | 3,3 |
| CF (NOB): PP biochar cold charged | 28 | 0,85 | 14,6 | 23,5 | 0,0615 | 0,445 | 12,6 |
| CF (NOB): PP biochar hot charged | 14 | 0,44 | 6,4 | 81 | 0,01 | 0,057 | 7,8 |
| CF burning | 97 | 0,73 | 29 | 31 | 0,0049 | 0,045 | 15 |
| CF no residue | 56 | 1,325 | 22,5 | 52 | 0,0345 | 1,375 | 8,85 |
| CF normal | 43 | 0,57 | 19 | 15,5 | 0,3745 | 0,805 | 15,75 |
| CF not opening basins (NOB) | 24 | 0,71 | 13 | 17 | 0,02 | 0,066 | 2,5 |

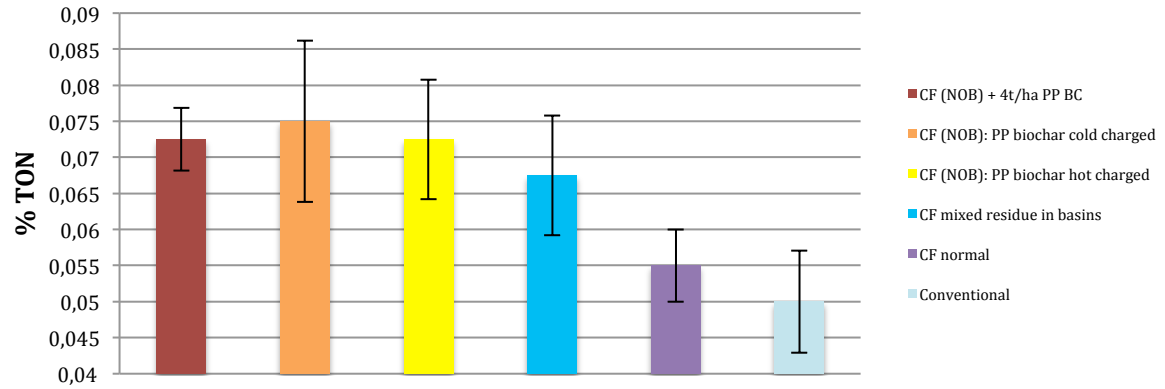
Analysis of concentration of soil parameters in Mkushi



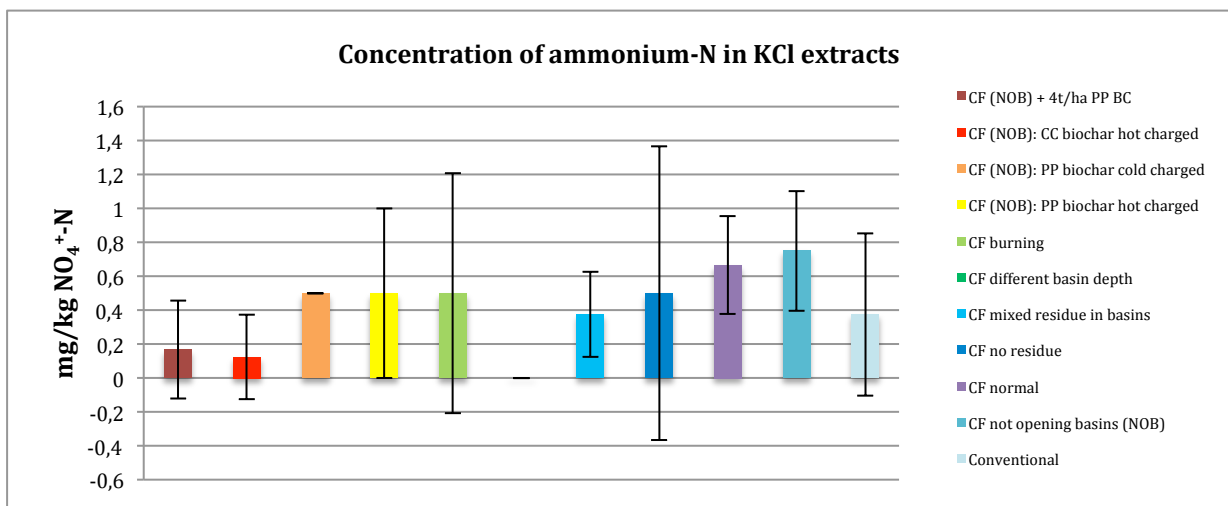
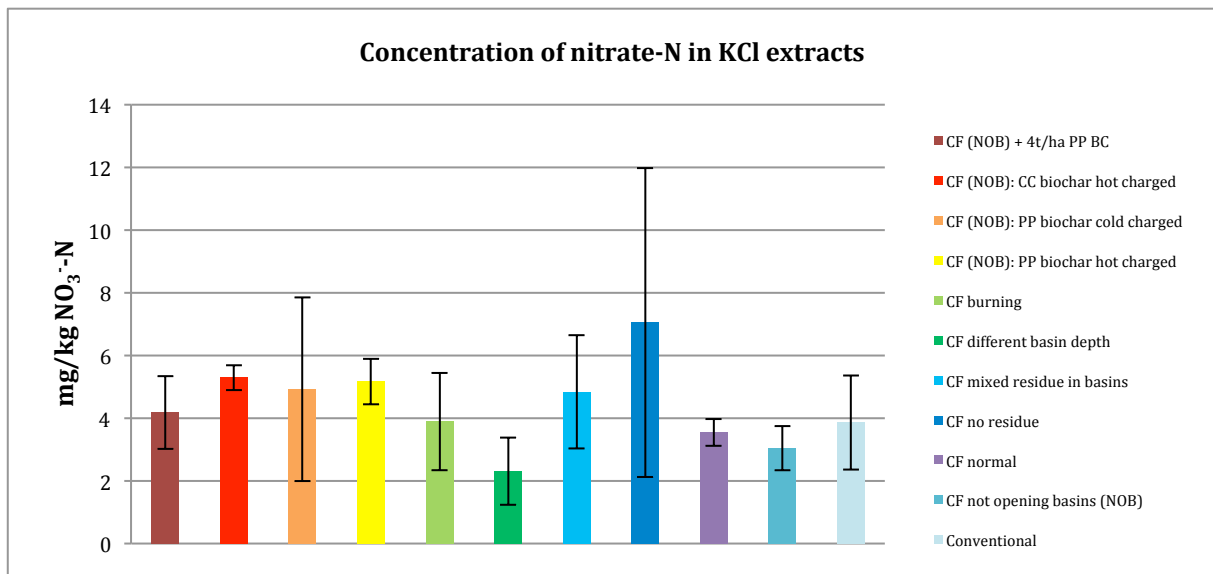
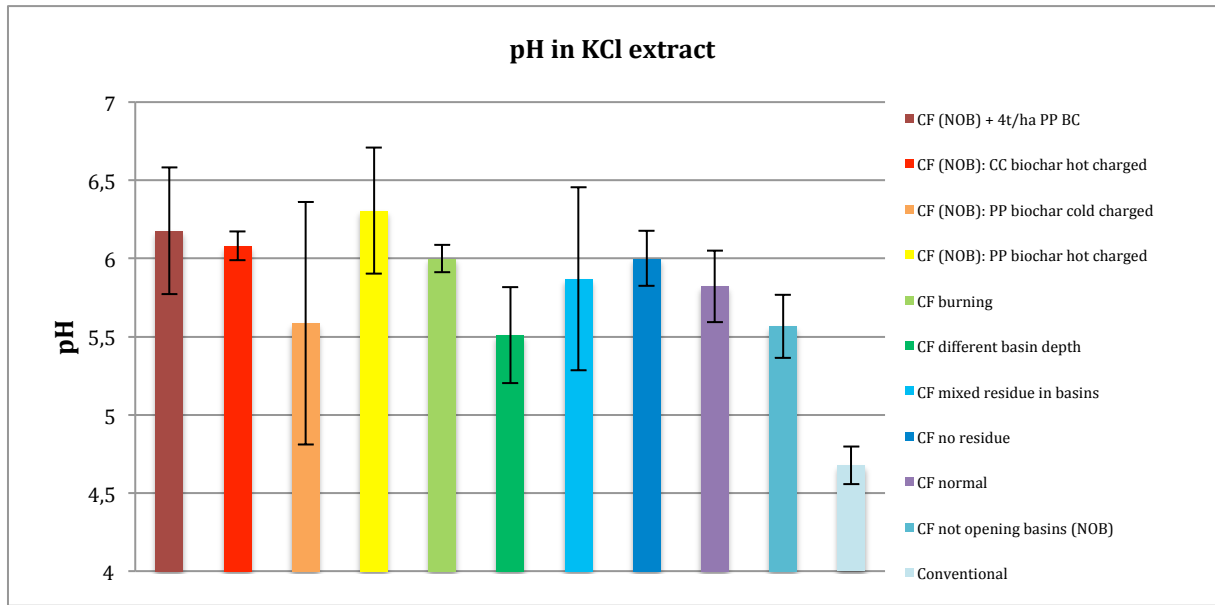
Concentration of plant available phosphate



Amount of nitrogen



Analysis of pH and concentration of ammonium-N and nitrate-N in soil KCl extracts





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