The Effect of Biochar and Trichoderma Harzianum (T77) on Forage Sorghum (Sorghum Bicolor) Yield in Semi-Arid Regions in Southern Zimbabwe

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Abstract:- A field research experiment was conducted in the 2020/2021 rain season at St. Joseph Secondary School in Beitbridge to evaluate the effect of Biochar and *trichoderma* on forage sorghum yield in semi-arid regions of Southern Zimbabwe. The trial was a factorial experiment in a Randomised Complete Block Design (RCBD) and were replicated three times. Germination percentage, plant height, stem girth, leaf area as well as yield (Wet and dry mass) of forage sorghum were the parameters measured and the data was analysed using Genstat, (Analysis of Variance at P<0.05). The results showed that T. *harzianum* significantly improved germination percentage of forage sorghum by 3.92% at P<0.05, that is Control recorded 86.26% and 1gm/m^2 recorded 90.18% and biochar levels did not improve germination of forage sorghum. T. *harzianum* did not show any increase in growth in relation to plant height, however, it promoted growth of stem girth from 2.096cm to 2.412cm (on week 3) and 6.07cm to 6.69cm (on week 7) at P<0.01 and P0<05 respectively. T. *harzianum* increase growth of leaf area by 34cm^2 from 272.8cm^2 (control) to 306.8cm^2 (on week 5) at P<0.01. The interaction between biochar and T. *harzianum* also resulted in a significant growth on stem girth on the third week which recorded the highest stem girth of 2.749cm against 2.013cm from the control treatment at P<0.01 and at 7th week, stem girth increased by 2.22cm at P<0.05. Biochar also resulted in increase in growth of leaf area of forage sorghum at P<0.05 on week 5, (Control treatment recorded 268.2cm^2, 3tha^{-1} produced a leaf area of 292.2cm^2 and 5ha^{-1} yielded 308.9cm^2) and P<0.01 on week 7. The interaction between biochar and T. *harzianum* also showed a significant increase in growth of stem girth on the third week and seventh week at P<0.01 and P<0.05 respectively. Biochar increased the height of forage sorghum between biochar application rates, that is between control (No biochar) at 20.6cm and 3tha^{-1} levels (24.22cm) at P<0.01 at 2 weeks, P<0.01 at 5th week (No biochar-64.4cm, 3tha^{-1}- 72cm and 5tha^{-1}-78.7cm) and P<0.01 at week 7. There was an increase in wet mass yield by 4.8tha^{-1} on 3tha^{-1} biochar and 9.8tha^{-1} on 5tha^{-1} biochar at P<0.01. Dry matter yield increased by 1.1tha^{-1} on 3tha^{-1} biochar and 3.06tha^{-1} on 5tha^{-1} biochar. Farmers are therefore recommended to make use of T. *harzianum* to enhance seed germination as well as make use of available forestry waste to make biochar such that they will improve forage sorghum yields as well as livestock productivity.

Keywords:- *Biochar, Trichoderma harzianum, forage sorghum.*

I. INRODUCTION

The southern parts of Zimbabwe are mainly characterised by an irregular distribution of rainfall with greater variability within the same seasons as well as between years and higher evapotranspiration. This makes it relatively unfavorable to produce forage crops for livestock production for which livestock production is one of the enterprises that thrive in those regions. In 2018-2019 season, the grazing conditions was fair except for Beitbridge, Buhera and Bulilima districts where the conditions were relatively fair to poor, (ZimVAC, 2020) The available grazing conditions are usually expected to last up to 8 months in most parts of the country except in the Southern regions of the country where they can last up to June and livestock will be requiring some other feed sources such as hay and supplementary feeds. The national beef herd had declined by 5.7%, that is from 5 774 525 cattle in 2018 to 5 443 770, (ZimVAC, 2020) and an increment in average mortality rate from 5% to 9% respectively was witnessed at national scale. This was mainly caused by feed and health related factors.

More than 75% of smallholder farmers' livelihoods in Zimbabwe depend on crop- livestock farming. Growing forage sorghum may enhance a market oriented crop-livestock integration whereby it can be used to supplement feed preserved forage, hay or silage and crop residues together with high protein, drought tolerant fodder legume crops such as *Mucuna* in dry season of the year when grazing conditions are poor. Different varieties of sorghum are used as stock feed worldwide as either grain or hay. Sorghum is the 5th worldwide cereal crop behind maize, rice, wheat and barley, (OECD, 2017), (FAOSTAT, 2017) and is mainly grown for livestock feed and forage production in most parts of the world as it is a lower cost alternative to maize and requires less water to grow, (Hancock, 2000). Forage sorghum is widely adapted species which is capable of growing in semi-arid conditions, subtropical, tropical and temperate climates. Its adaptability is guaranteed by its extensive root system and ability to become dormant during water stress making it drought tolerant typically requiring only half of two thirds of the amount of rainfall as maize, (Hancock, 2000). Forage sorghum is widely adaptable and is characterised by an accelerated growth rate, high biomass accumulation and dry matter content. The forage sorghum variety (Sugar graze) has a high digestibility of 56- 64% and crude protein content or 12-18%, and its dry matter production can range from 5-25 tonnes per hectare depending on region as well as agronomic practices that may have employed (https://www.seedmarketing.co.za/docs/FORAGESORGHUM).

In order to improve forage production in semi-arid regions of southern Zimbabwe, the research seeks to evaluate the effect of Biochar and *Trichoderma harzianum* on growth and yield of forage sorghum. Biochar is a charcoal like substance that is made by burning organic material from agriculture and forestry waste in a controlled process known as pyrolysis whereby the organic material is exposed to high temperature in the absence of oxygen. Adoption of Biochar in Agriculture is a promising technology in mitigating climate change and improving soil quality. It is a black, highly porous, light weight, fine-grained material which has a large surface area. Approximately 70% of its composition is carbon and the other 30% is Nitrogen, H+ and oxygen, (Spears, 2018).Soil degradation is the major cause of concern in most arable lands due to soil erosion, leaching, soil pollution amongst other factors due to poor soil management practices. Biochar can enhance soil structure thereby increasing water retention and aggregation. Research work conducted by (Cayuela, et al., 2014) has shown that biochar decreases soil acidity, reduce nitrous oxide emissions and improve soil porosity. Biochar is also known for regulating electrical conductivity and microbial properties. It contributes to climate change mitigation by enriching soils and reducing the need for chemical fertilisers which in turn will lower greenhouse gas emissions. Improved soil fertility also stimulates plant growth which consumes carbon dioxide. The many benefits of biochar for both climate and agricultural systems make it promising for regenerative agriculture. Given the abundant forestry by-products of forestry and timber manufacturing industry in Zimbabwe, adopting Biochar technology may go a long way in value adding such forestry by- products which might be of lower value in advancing towards climate smart agriculture.

Trichoderma harzianum (T77) is a bio- control agent isolate produced by Kutsaga Research Station in Zimbabwe. *Trichoderma spp.* are free living fungi that are highly interactive in root, soil and foliar environments, (Harman, Howell, Viterbo, Chet, & Lorito, 2004) *Trichoderma spp.* are widely reported as plant growth promoters. Increased root/ or shoot biomass is the most common expression of growth promotion but changes in plant morphology and development have been also reported, (Stewart & Robert, 2014). However, growth promotion may be highly variable due to several limiting factors as crop type, growing conditions, inoculum rate and formulation type. Various reported mechanisms have been proposed to explain growth promotion include direct myco-parasitism where the *Trichoderma spp.* strains limits the effect of plant pathogens. It also enhances the production of anti-microbial compounds, (Qualhato T. , et al., 2013), (Atanasova, et al., 2013), and (Naher & Yusuf, 2018). They are also involved in solubilisation of mineral nutrients, for example, *Trichoderma harzianum spp.* were shown to increase the availability of plant nutrients by solubilizing organic and inorganic phosphates, Fe2O3, CuO, metallic zinc and mnO2, (Saravanakumar, et al., 2017), and (Stewart & Robert, 2014). *T. harzianum* is also known to induce systemic resistance in the plant and tolerance against abiotic stresses such as drought, and salinity through increasing root growth, nutritional uptake and inducing protection against oxidative stresses, (Hidangmayum & Padmanabh, 2018). Thus this research aims at unearthing effects of bio-char amended fertilisers and *trichoderma spp.* on forage sorghum growth and yield as a potential climate smart agricultural practice that can sustainably alleviate food and nutrition insecurity through soil fertility improvement, climate change mitigation and environmental reclamation, (Mia, S; Dijkstra, F.A; Singh, B, 2017).

II. STATEMENT OF THE PROBLEM

Semi-arid regions of Southern Zimbabwe experience higher livestock mortality rate and lower productivity which are mainly attributed to poor grazing conditions mainly due to drought, soil fertility and soil salinity. The region receives erratic rainfall associated with high evapotranspiration rate which cannot substantially support establishment of natural grasslands for grazing throughout the year. The grazing conditions usually last for four months which results in starvation and drought related mortality of livestock mainly cattle. Most of the farmers in these regions cannot afford to purchase supplementary feed which sustain their livestock sustainably throughout the year. As a copping strategy, farmers will resort in selling their livestock so as to maintain a smaller number of livestock mainly for breeding purposes. This will however expose them to food insecurity and instability as distribution of sales will not be equally distributed across the year. Thus, adoption of forage sorghum production and soil quality enhancement using biochar and *T. harzianum* may be a breakthrough in mitigating the effects of drought and abiotic stresses as forage sorghum is more resilient to harsh climatic conditions giving the farmers an opportunity to harvest and preserve hay for feeding during the dry season.

A. *Objectives*

➢ *Main objective*

- To evaluate the response of forage sorghum to bio-char based fertilisers and *trichoderma harzianum (T77).*

➢ *Specific Objectives*

- To determine
  - ✓ The effect of biochar and Trichoderma harzianum on growth of forage sorghum
  - ✓ The effect of Biochar and Trichoderma harzianum on yield of forage sorghum
  - ✓ The effect of interaction between Trichoderma harzianum (T77) and bio-char on growth and yield of forage sorghum.

B. Research questions

The research seeks to answer the following questions;

- Does soil enhancement using bio-char have an influence on the productivity of forage sorghum?
- Does application of *trichoderma harzianum* (T77) to forage sorghum have a bearing on improved performance of the crop in relation to growth and yield?
- Does the interaction between *Trichoderma harzianum* (T77) and bio-char have an effect on growth and yield of forage sorghum?

C. Hypothesis

- H1: Biochar based fertiliser and Trichoderma harzianum (T77) have an effect on growth of forage sorghum
- H1: Biochar based fertiliser and Trichoderma harzianum (T77) have an effect on yield of forage sorghum

D. Justification

The experiment is aimed at investigating if bio char and *Trichoderma harzianum* can improve livelihoods of semi-arid communities who are mostly marginalized through enhancing and improving soil quality as well as fostering tolerance of the forage sorghum to drought stresses thereby improving livestock productivity in such communities. Most of the soils in these regions has deteriorated in terms of soil fertility resulting in very poor yields. Thus, biochar and trichoderma is a promising technology that if embraced, may increase soil quality and fertility and provide protection against some foliar and soil borne diseases.

E. Scope /delimitations

- The study focused on the performance of forage sorghum under biochar and *trichoderma spp.* as soil fertility enhancers in the semi-arid Southern region of Zimbabwe.
- The study seeks to foster livestock-crop integration where resilient crop varieties and sustainable agronomic practices are employed so as to promote production of fodder crops to support livestock that are vulnerable to drought for the betterment of the communities' livelihoods.

F. Limitations of the Study

- Covid 19 lock down related logistical challenges has hampered smooth flow of execution of some project activities and has caused delays in sending soil samples for analysis.
- Inadequate financial resources have limited the need to replicate the research trials in space that is in other districts within Southern dry regions of Zimbabwe.

III. LITERATURE REVIEW

A. Introduction

The chapter reviews the relevant information relating to the performance of biochar and *T. harzianum* on enhancing soil quality as well as improving forage sorghum so that livestock productivity and human livelihoods can be improved based on work done by other researchers. The chapter reviews the effects of biochar to soil as a soil amendment as well as crop productivity, performance of *T. harzianum* on crop productivity as well as climatic conditions, livestock production and forage production status in Zimbabwe.

B. Semi -Arid Southern region of Zimbabwe

Zimbabwe is a landlocked country that is situated in the Central Southern Africa, where most of its land lies on a plateau between 1200m and 1600m above sea level, (Tawonezvi, 2004). It is divided into two main seasons, which are summer and winter. The country is divided into five main Natural regions (Natural Regions 1-5) where high rainfall (700mm to 1000mm) is received in region 1 and 2 mainly in the Eastern and Northern parts of the country and the least rains are received in Natural farming region 4 and 5. Semi -Arid regions of Zimbabwe falls under Natural farming regions 4 and 5 which is characterised by low rainfall which is below 650mm per annum and severe dry spells during the rainy seasons, (Ncube, 2007). About 64% of Zimbabwe falls in region 4 and 5 for which rainfall is too erratic and unreliable for consistent and viable crop production except where water for irrigation is available, (FAO, NEPAD, GoZ, 2004). The region is suitable for livestock, wildlife management, bee keeping, and non-timber forestry products. Communities in those semi- arid regions are vulnerable to food insecurity and poverty. The semi-arid regions of Southern Zimbabwe are dominated by cereal production mainly maize, sorghum and pearl millet. However, maize usually fails totally when the rainfall season is bad, (Ncube, 2007).

Soils in the Southern Zimbabwe are pre-dominantly sandy and have a limited ability to store organic matter and nutrients resulting in decline of fertility under cultivation. The areas are characterised by higher atmospheric evaporation and highly variable spatial and temporal precipitation that makes rain fed farming a risky economic activity.

C. Livestock production in Semi-Arid regions of Southern Zimbabwe

Livestock production is an important component of agricultural systems in most countries in Southern Africa. (Powell, 2010), noted that livestock production compliments cropping activities, draught power, transport as well as cash and food. According to (Bossio and Deborah, 2009), livestock offer opportunities for risky cropping, farm diversification and provide significant livelihoods benefits thereby improving food security of marginalized communities. Livestock production is one of the agricultural enterprises that contribute a significant percentage in Gross Domestic Product (GDP) of the country which is about 19%, (AEDS, 2020). Recently there had been a decline in number of beef cattle throughout the country. Beef cattle population reduced from 5 773 525 cattle in 2018 to 5 443 770 in 2019 due to drought, diseases related deaths and forced sales and which might have mainly attributed to diseases or drought related destocking. Drought related mortality rate in Matabeleland south only was 5% in 2019/ 2020 season which were amounting to 25 758 herd of cattle, (ZimVAC, 2020).

Livestock production systems in Zimbabwe are dependent on Agro-ecological region and type of farming sector, (Ncube et al, 2013).The main production system in Semi-arid regions 4 and 5 and part of region three is extensive grazing on natural rangelands and wildlife. Although in some districts grazing conditions will be very poor thus, the need for adoption of different mitigation measures such as production of drought tolerant grasses for hay as well as legume forage crops to supplement these natural grazing lands. The major livestock species are cattle, goats and sheep. However, cattle are predominant species followed by sheep and goats. Semi-arid areas of Southern Zimbabwe are characterized by erratic rainfall that is usually below 650mm per annum. The occurrence mid-season dry spells results in poor establishment of natural grazing lands. (Masikati et al, 2012). outlines that livestock in communal areas in Sub Saharan Africa are constrained by a variety of factor for which feed shortages is one the major challenge in terms of quantity and quality. This is as a result of little rainfall received in such areas as is the case of some parts of the Matebeleland South, a semi-arid region in the Southern Zimbabwe. Most vulnerable farmers in this region are usually affected by seasonal deficiencies of quantity and quality of feed during the second half of the dry season, (Masikati et al, 2012).

Recurrent droughts, which temporarily affects veld forage quantity and quality results in less crop residue to supplement livestock feed. This necessitates the need to come up with drought mitigation measures. Some of the mitigation activities that was conducted in Matebeleland South, Matebeleland North and Masvingo to avert losses were relief grazing, destocking, and use of bought in stock feed and hay. However, destocking may expose the farmers to food insecurity as they will be left with limited numbers of livestock which may be used as breeding stock. Supplementing feed with stock further depress food insecure communities due to increased feed costs, hence the need to come up with sustainable and resilient strategies to combat challenges of poor grazing conditions and grazing availability in times of recurrent droughts.

According to the Crop and livestock assessment carried out in 2019/2020 season, the condition of cattle in Beitbridge, Chiredzi, Matobo, Mberengwa, Bubi and Umguza were generally fair. These areas fall under region 4 and 5 which forms part of semi-arid Southern Zimbabwe. The assessment report also outlines that the grazing conditions were poor in that same year. In the 2019/2020 season. The Southern districts had also grazing challenges as grazing availability was expected to last for about three months up to the month of June that same year, and there was need for farmers to come up with alternative feed sources such as browse, hay and supplementary feeds, which can only be sustainably achieved through adoption of drought resilient forage crops such as forage sorghum for making both silage and hay, and some leguminous forage crops such as mucuna/Velvet been.

D. Sorghum production Overview

Sorghum (*Sorghum bicolor)* is a major crop in many parts of Africa and is noted for its versatility diversity. The crop is fifth most important cereal globally and the dietary staple food behind maize, rice, wheat and barley, (FAOSTAT, 2017). (Hancock, 2000) Outlines that nearly all sorghum grown in Western Hemisphere is for livestock feed and forage production because it is a lower cost alternative to maize and require less water to grow. The crop is adapted over a wide range of precipitation and temperature levels, that is, it is able to tolerate relative to other cereal crops to adverse growing conditions. The crop is efficient in photosynthesis, nutrient as well as water use. The species of sorghum are genetically very diverse with preferred cultivars for different uses. The crop thrives well on altitude above two thousand metres above sea level. Sorghum is considered as a primary crop for resource poor, small scale farmers and is typically produced under adverse conditions such as low input use and marginal lands. However, in Zimbabwe, the level of production is quite diverse ranging from commercial to small scale - subsistence farming. This signifies the importance of the crop in Zimbabwe for both human consumption and livestock feed. Sorghum can be categorized into two groups depend on its use.

These major two groups are grain sorghum and forage sorghum. Grain sorghum is the one which is mainly produced across the world for its grain which can be used either for human consumption as well as stock feeds. Secondly, forage sorghum can be harvested for its stalks which can be used for stock feed either as silage or hay depending with farmer’s preference and some can be grown for sugars and some can be used for ethanol production sorghum area production substantially increased main reason being the Presidential input scheme where communal farmers were given seed. The yield for grain sorghum increased by 158% from 40 125mt in 2018/2019 season to 103 684mt in 2019/2020 season (ZimVAC, 2020). Much if the sorghum production is dominated by small holder communal farmers who contribute 78% of the total area although yields are still low compared to Commercial farmers. Sorghum has gained popularity due to its extensive root system and ability to become dormant during water stress making it drought tolerant typically requiring only one half to two thirds of the amount of rainfall as maize (Hancock, 2000).

E. Forage sorghum

Forage sorghum is a member of the sorghum family and is closely related to grain sorghum, broomcorn, sweet sorghum-sweet sorghum, sorghum-sudan grass, and Sudan grass. It is best adapted to warm regions and is particularly noted for its drought tolerance compared to corn. Sorghum will become dormant until the stress is relieved if moisture stress becomes severe. The maturity of the crop is delayed by severe drought stress or cool, late season temperatures. Forage sorghum is best utilized as a silage crop, although it can be grazed or cut for hay if managed appropriately (Corredor, 2009).

Forage sorghum is usually associated with prussic acid poisoning or nitrate toxicity, but these problems are not normally of concern if harvested for silage. Prussic acid occurs mostly in young plants or plants harvested shortly after a frost or drought-ending rain. The regrowth from plants killed by frost are usually high in prussic acid. Prussic acid (hydrocyanic acid" (HCN) is volatile, thus its ability to dissipate during the harvesting and ensiling process and is rarely a problem in sorghum silage. If plants are damaged, as by freezing, chewing, or trampling, then the enzyme emulsion which is found in the leaves can play a role in easily freeing larger quantities of the poison; thus the hazard (Vough, 1978). Various species of animals react differently when fed plants containing these glycosides. These differences are caused by different anatomical structures and different detoxifying abilities of various animals. Cattle and sheep, both being ruminants, are known to be subject to poisoning by cyano-genetic glucosides.

In Zimbabwe, most livestock are reared by smallholder farmers, who live in marginal areas with low rainfall and hence poor forage production, (Allan and Sebata, 2018). As a result, livestock productivity is low as a result of recurring droughts leading to animal mortalities. In low rainfall areas, forage crops have been widely promoted to provide feed resources to livestock, particularly during the dry season and in years of low precipitation. However, production of forage crops among the smallholder farmers remains low, especially in areas that receive low rainfall less than 600 mm per annum, (Sebata, 2018). The most widely grown forage crops in Zimbabwe were leguminous forage herbaceous crops for their fast growth rate and their ability to perform well in unfertile sandy soils due to their ability to fix Nitrogen. The widely grown forage grasses were Napier, Bana grass as well as Star grass. Forage sorghum has not been widely grown in the country hence the need to widely promote the crop as it can be successfully grown in marginalized areas. Forage sorghum (*Sorghum vulgare*) was bred specifically for feeding livestock. Some varieties have sweet thin stems, are leafy and have good tillering ability. More so, forage sorghum has comparable water-soluble carbohydrates to maize (180–250 vs. 280–510 g/kg dry matter). Water-soluble carbohydrates are essential for successful ensilaging. Forage sorghum silage has metabolisable energy of 9.5 MJ/kg dry- matter compared to 10.2 MJ/kg dry- matter for maize silage. The sorghum silage was found to be of good fermentable quality, with a crude protein content of 12.0% of dry matter, when intercropped with lablab. In addition, forage sorghum has been found to be adaptable to low rainfall producing high biomass yields.

F. Biochar

Biochar is a charcoal-like substance that is made by burning organic material from agricultural and forestry wastes (also called biomass) in a controlled process called pyrolysis, (Spears, 2018). It is a black highly porous, light in weight, fine grained and has a large surface area. Approximately 70% of its composition is carbon and the other 30% is in Nitrogen, Hydrogen irons and oxygen, (Spears, 2018). The pyrolysis temperature is strongly correlated with changes in the structure of bio char and physiochemical properties of bio char, ((Asadullah, et al., 2007); (Chen, Dandan, & Lizhong, 2008); (Jindo, Mizumoto, Sawada, Sanchez-Monedero, & Sonoki, 2014). (Kannan, Krishnaveni, & Ponmani, 2020), states that biochar has become increasingly recognized to address multiple contemporary concerns such as agricultural productivity and contaminated ecosystems, amelioration primarily by removing carbon dioxide from the atmosphere and improving soil health. Multiple sources has reviewed that biochar has the potential to adsorb and degrade heavy metals accumulated in the industrial contaminant sites, (Lehmann & Joseph, 2015). This means that it is promising in mitigating climate change and improving soil quality. In most of the research work that have been conducted worldwide, it is reported that application of biochar have both positive and negative effects on crop yield dynamics under changing climate depending on the source of biochar as well as their application graded levels, (Meenambigai, Vijayaraghavan, Gowri, Rajarajeswari, & Prabhavathi, 2016). Thus the current and future researches on biochar will focus on sustainable crop and environmental management.

- *Physiochemical Properties of biochar*

(Chia, Downie, & Munroe, 2015) Outlined that biochar may improve bulk density, particle density particle size, macro and micro- porosity, surface area as well as hydrophobicity. These physical properties may help to improve crop productivity. These properties subsequently have an effect on the air and water movement in the soil layers thereby implicating the soil’s ability to function. Bio char contains nutrients and organic matter, thus its addition has been reported to increase soil pH, electrical conductivity (EC), organic carbon (C), total nitrogen (N),available phosphorous (P), and cation exchange capacity (CEC), (Rawat, Saxena, & Sanwal, 2019). Such properties are key when amending soils thereby improving absorption of nutrients by plants. It has also been reported that biochar is beneficial to agriculture due to its properties that include presence of minerilisable organic compounds, (Tomczyk, Sokołowska, & Boguta, 2020). Some of these organic compounds in biochar triggers growth of beneficial organisms, enhancement of mineral weathering and have growth regulatory effects.

- *How does Biochar improve/ enhance soil structure and aggregation*

Soil structure can be defined as the spatial arrangement of soil particles and soil voids (soil pores), which is the spatial distribution of soil properties. It is comprised of the physical habitat of soil living organisms, and controls many important physical, chemical and biological soil functions and associated ecosystem service, (Jindo, K; Mizumoto, H; Sawada, Y; Sanchez-Monedero, M.A; Sonoki, T., 2014). (NEIRA, J. et al, 2015), assets that soil structure is a main soil property since it regulates soil water content, aeration and temperature of soils. This important property has a positive influence on plant germination and root growth, thus a good soil structure enhances plant growth and productivity. Nevertheless, soil structure is more than only the physical arrangement of particles and pores. It includes structural stability that is the ability to resist endogenous factors or stresses and structural resilience, which is the ability of soil to recover upon stress removal, (Kay & Angers, 2001).

Soil aggregation is responsible for soil structure and it is fundamental for soil to function as well as agricultural productivity. Thus, application of Biochar can influence the different mechanisms of soil aggregation namely hierarchical theory of aggregation (Edwards & Bremner, 1967), the centric theory, (Santos et al, 1997) .The precipitation of hydroxides, oxides, phosphates and carbonates also enhances aggregation (Bronick & Lal, 2005), cations also form bridges between clay and soil organic matter particles resulting in aggregation, (Moghimi et al, 2012), or it is possible that aggregates form through a combination of these processes (Bronick & Lal, 2005). Given this potential of Biochar, it is very noble to promote its adoption especially in Semi-arid regions of Zimbabwe. These regions are usually found in the marginal areas where soils are usually exhausted and characterised by poor soil structures. Poor soil structures have a greater influence on soil productivity. Applied biochar may be combined with minerals in the soil to become part of soil aggregates. Some reported literature also indicates that the cations contained in the Biochar can be joined by the means of cationic bridges with clay and organic particles, (Rajkovich, et al., 2012), (Bronick & Lal, 2005). These create a favorable soil structure conditions. (Mukome, Zhang, Silva, Six, & Parikh, 2013) and (Feng-Peng, Xiang-Hong, & Xing-Chang, 2012) reported that multivalent ions associated with biochar may have a positive effect through interactions with negative charged surface functional groups on SOM (Soil organic matter), (e.g., R-COO−) and soil minerals (e.g., Al-O−, Si-O−). The bridging effects of multivalent ions, such as Fe^{3+} can enhance sorption of SOM to clay minerals. Other reported mechanisms that influence aggregation of soil can be explained through base cations. These can act as a bond between the mineral particles of the soil and bio char particles, (Lin, Munroe, Joseph, & Henderson, 2012) (Joseph, et al., 2016). Biochar particles can also be connected with water stable aggregates, as it cannot only be found as free particles. However, the effects on individual fraction of aggregates may differ as what was found in the study of (Šimanský V., Horák, Igaz, Balashov, & Jonczak, 2018).

- *Effect of Biochar on microbial properties*

Soil amendment with biochar can modify soil microbial abundance, activity and community structure. However, (Hardy et al, 2019), asserts that the long-term evolution of these effects is unknown and of critical importance because biochar persists in soil for centuries. (Gałązka, A. et al, 2020), assessed the change in biological activity and microbial diversity. It was found that an increase in 10% to 20% of biochar depending on the initial carbon content in the soil significantly increased biological activity and functional diversity. The optimal dose for enhancement of soil biological activity was 10 to 20%. This significantly induced increase in the total carbon content in the microbial mass, enzymatic activity and the overall content of total and easily extractable glomalins. Conditioning soil with biochar has a positive effect on soil microorganisms, which contributes a key role in soil structure and function. (Schloter et al, 2018), confirmed the assertion that microorganisms are good indicators of soil quality due to their participation in many biochemical processes. Microbial activities of several microorganisms, which are important to agriculture, was supported by biochar application. The main attribute of biochar, which is important, is its porous structure, which serves as a suitable habitat for many microorganisms. The highly porous structure and large surface area of biochar provide refuge for beneficial soil microorganisms such as mycorrhiza or bacteria (Thies & Rillig, 2012).; (Deal, Brewer, Brown, Okure, & Amoding, 2012), agrees that this would be positive on microbial processes involved in nutrient cycling, decomposition of organic matter, and greenhouse gas emission. In some instances, bacterial growth and its abundance may be associated with the sorption surfaces of biochar and bacteria can be attached to biochar particles. In a separate research work, (Woolf, 2008), demonstrated biochar exerts a positive effect on the mycorrhiza and production of mycorrhizal glomalins that is a glycoprotein stabilizing soil structure.

- *How does biochar reduce Nitrous oxide emissions?*

One of the major benefits of biochar is reduction of nitrous oxide emissions. Nitrous oxide is reported to have 298 times potential to cause global warming than Carbon dioxide, (Martin et al, 2015). Biochar also changes soil's chemical composition and activity of microorganisms in such a way that it reduces the soil's nitrous oxide emissions by up to 55%, according to (Aisosa et al, 2019). About 60% of all nitrous oxide is emitted by agriculture in developed countries, and half of agricultural greenhouse gas emissions are nitrous oxide, (Smith et al, 2007). This signifies the need for adoption of biochar in Agriculture to correct the detrimental effects caused by excess use of inorganic fertilisers and pesticides.

(Wang, Zheng, Deng, Herbert, & Xing, 2013); (Wilson, Ghosh, & Ow, 2015) suggested that nitrous emissions, a potent greenhouse gas, is linked to a large component of agriculture's carbon footprint, which is a potent greenhouse gas. Greenhouse gas emissions (GHG) need to be reduced so as to minimise the impact of Agriculture on the environment at the same time enhancing Nitrogen fertiliser efficiency, (McDonald, et al., 2015). This can be achieved by incorporation of traditional farming approaches such as reducing the tillage intensity, reducing N fertilizer additions, adopting techniques, such as cover crops, that improve nutrient recycling and splitting the N application although they some of them may be labour intensive and increase production costs. Amongst these traditional approaches, biochar could be one of the climate smart agricultural practices that can effectively reduce GHG emissions. Among other aspects, biochar allows the carbon dioxide immobilization in soil and, in consequence, a reduction of its emission to the atmosphere (Conte, 2014); (Šimanský V, Horák, Dušan, Eugen, & Jerzy, 2018).

- *The effect of biochar on bulk density of the soil.*

Soil bulk density is one of the most studied properties following biochar application. There are two mechanisms that were suggested to be responsible for the reduction in bulk density after biochar application, that is, through the mixing or dilution effect. The extent of this effect can be particularly large when the difference in density between the materials is large. The second mechanism could by interacting with soil particles and improving aggregation and porosity which may happen in the long term. Studies conducted by (Omondi et al, 2016) reviewed that biochar application reduced bulk density by 3 to 31% in 19 out of 22 soils, indicating that bulk density generally decreases with increase biochar application. On average, bulk density decreased by 12%. The significant decrease in bulk density agrees with, (Omondi et al, 2016) who reported that biochar application could reduce bulk density by 7.6%. In that same report, bulk density gradually decreased with an increase in the amount of biochar applied. On a separate research, (Głąb, Palmowska, Zaleski, & Gondek, 2016) and (Liu, 2017)) reported that bulk density decreased linearly with the increase in amount of biochar, however (Rogovska, 2016) argues that in a few cases, it decreased quadratically. His studies found out that biochar application rates above 60 Mg ha -1 had a smaller effect on reducing bulk density than application rates below 60 Mg ha-1. This literature review also shows that, in a few cases, biochar application at rates less than 10 Mg ha-1 may not significantly reduce bulk density, (Xiao, et al., 2016). While application of large amounts of biochar generally reduces bulk density. (Shinogi, 2016), found that biochar application even at rates as high as 2% by weight (which is equivalent to about 50 Mg ha-1of biochar) did not change bulk density thereby suggesting that biochar effects should be evaluated on a site-specific basis.

Liu et al.'s (2016), work indicates that biochar application can reduce bulk density in coarse textured soils more than in fine-textured soils. It reduced bulk density by 14.2% in coarse-textured soils and 9.2% in fine-textured soils and the largest decrease (31%) of bulk density was for sand.

- *Effect of biochar on particle density*

Soil particle density can be defined as mass soil per unit volume. It is an important soil property that affects many other soil properties and processes (porosity, particle sedimentation, specific surface area, thermal properties, and others) and most importantly, particle density affects soil porosity. Biochar have particle density which ranges from 1.5 to about 2 g cm-3, (Brewer, Klaus, Satrio, & Brown., 2009), whereas the particle density of the soil could range from 2.4 to 2.8 g cm-3, depending on the textural class. In practice, particle density of the soil is often assumed to be constant (2.65g cm-3) when computing soil porosity. However, changes in soil Carbon concentration could significantly reduce this soil property (Blanco-Canqui, 2020). Thus the addition of biochar (>60% C) could induce changes in particle density and thereby affect soil porosity. In a field study, application of 30 Mg ha-1 of wood biochar reduced soil particle density from 2.55 to 2.20 g cm-3(14% decrease) compared with <10 Mg ha-1of wood biochar on a fallow land, but it had no effect on soil particle density on a grassland (Usowicz, et al., 2020). Similar to the effect on soil bulk density, the decrease in soil particle density with the addition of biochar is attributed to the low particle density of biochar particles although there are few studies indicate that biochar application can reduce the particle density of the soil.

- *Biochar and saline soils*

Soil salinization and sodification are two commonly occurring major threats to soil productivity in arable croplands resulting in food insecurity, and are distributed extensively in the semi-arid 17 areas across the world (El-Mouhamady, 2020), states that salt stress usually alters crop growth through the effect of chloride and Na ions on the plant by specific ion toxicity, which occurs when these components in the soil water are absorbed by the roots and accumulate in plant stems or leaves. High concentrations of Na and chloride are often synonymous of a high salinity level, (Tester, 2008). There are various inorganic and organic amendments that are used to reclaim the salt-affected lands, but biochar has attracted considerable attention as a soil amendment. An emerging pool of knowledge shows that biochar addition is effective in improving physical, chemical and biological properties of salt-affected soils.

Biochar has been reported to amend saline soils, which is one of the limitations of crop productivity, (Wassmann, et al., 2009). Biochar application also increases the growth, physiological and biochemical characteristics of plants under saline conditions. Organic amendments have reported to mitigated salt stress in plants by improving anti- oxidant enzyme synthesis, (Tartoura, Youssef, & El-Sayed, 2014). However, a few studies have described the impact of biochar on oxidative stress and anti- oxidant enzyme activity in plants that are grown under salt stress. For example, (Kim, et al., 2016), reported that biochar application reduced ascorbate peroxidase (APX) activity in maize exposed to salinity compared to control. However, some studies have revealed adverse effects of bio-char on crop productivity where bio char was applied, (Liu, 2017); (Yu, et al., 2019). Some studies have also found an increase in soil salinity and sodicity with biochar application at high rates (Saifullah, 2018). One of the major challenges is that there is relatively limited information on the long-term behavior of salt-affected soils subjected to biochar applications.

Research work that was carried out by (Ibrahim, et al., 2020), confirmed that the 12.6 dS m-1 salinity rate, 5% biochar increased plant height, leaf area, fresh weight, DM yields, A, gs, and E by 20.1%, 16.5%, 26.2%, 27.4%, 14.5%, 31.1%, and 26.7%, respectively. At the 12.6 dS m-1 salinity rate, 5% biochar decreased CAT, POD, and SOD by 56.8%, 44.8%, and 18.9%, respectively on forage sorghum. Furthermore, among all biochar rates used in this investigation, the 5% rate had a better result for forage sorghum production. These findings suggest that the lowest biochar soil amendment application could alleviate the harmful impact of salinity whilst a high biochar application rate can have a negative influence.

- *Biochar as a fertiliser and its response to crop yield*

Biochar can be used alone as a fertiliser or can be used in combination with in-organic fertilisers. In a research work done by (Ye, et al., 2020) reported an increase in yield in sorghum by 15% indicating that biochar was effective as a

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fertiliser when used in combination with inorganic fertilisers in a short term field responses. Biochar has also have liming effect supported by Lili Ye *et al*, (2019), which may be a short term response but however, results recorded from the same work over time (>3 years) exhibited a 31% increase in yields which may be attributed by bio-char properties as improved cat-ion exchange capacity other than liming in course textured soils. Thus, the applicability of biochar in agriculture as a sustainable climate smart agriculture may go a long way in improving the livelihoods of vulnerable marginal communities when fully embraced in Zimbabwe. The higher rates of biochar that is greater than 30tha-1did not significantly affect the crop yield, however, (Mia, S; Dijkstra, F.A.; Singh, B, 2017), concluded that 1-10tha-1was the most effective application rates which significantly improved grain yield.

G. Trichordema harzianum (T77)

Trichoderma spp. are fungi that in nearly all soils and other diverse habitats. The *spp*. includes *T. harzianum, T. viridi, T. kaninjii, T. hanatum* and other *spp*. Trichoderma *spp*. Are well known for their competence in colonizing rhizosphere, that is they are able to colonise and grow on roots as they grow. It is a filamentous fungus antagonist of plant pathogens, used in the biological control of diseases caused by phyto-pathogenic fungi. It is widely used in agriculture due to its properties as a bio fungicide, bio fertilizer and bio stimulant, (DanayI i., 2019). The scientific interest generated by this species is related to the control mechanisms against phyto-pathogenic fungi. It acts through different mechanisms such as competition for nutrients and space, myco-parasitism and antibiosis, and these are biological control mechanisms. Trichoderma *spp.* evolved different mechanisms for which they attack some other strains of fungi as well as enhancement of plant growth. Such mechanisms has drawn much attention from researchers to find out how they can be exploited in sustainable agriculture as well as environmental management so as to reduce poverty and food insecurity to vulnerable communities. Trichoderma harzianum (T77), is a strain that was invented and patented in Zimbabwe by Tobacco Research Board on commercial scale. The process comprises loading receptacles with culture medium; sterilisation of the medium in situ; inoculation with spores of T77; incubation for 21 days at 29 degrees centigrade; cooling and packaging in ambient conditions, (Zimbabwe Patent No. 104/89, 1989). (Jeyarajan & Nakkeeran, 2000), suggested that to develop a successful Trichoderma formulation, Trichoderma should possess high rhizosphere competence, high competitive saprophytic ability, enhanced plant growth, ease for mass multiplication, broad spectrum of action, excellent and reliable control, safe to environment, compatible with other bio-agents and should tolerate desiccation, heat, oxidizing agents and UV radiations.

➢ *Trichoderma spp. on myco-parasitism and antibiosis*

Bio-control of fungal plant pathogens through the use of myco-parasitic fungi is an environmentally sustainable approach to management of plant diseases. *Trichoderma spp*. are capable to recognize and attack plant-pathogenic fungi of distinct phyla like *Rhizoctonia solani* (*Basidiomycete*), *Botrytis cinerea*, *Fusarium graminearum* (both *Ascomycetes*), *Phytophthora spp*., and *Pythium spp.* (both Oomycetes), (Barbara & Alfredo, 2010). Myco-parasitism by *Trichoderma spp.* primarily involves production of cell-wall degrading enzyme. *Trichoderma spp*. currently consist of one third of all fungal bio-control preparations produced and sold for control of diseases of horticultural crops (Chernin, Viterbo, Ramot, & Chet, 2002). Myco-parasitism is the direct attack of one fungus on another, and in the case of *Trichoderma spp*. It involves the production of cell wall lytic enzymes. (J. M. Steyaert, 2003), reported to involve four sequential steps which are chemotropism, recognition, attachment and coiling, and cell wall penetration as well as digestion of host cell content. The scope of action involving recognition, secretion on cell wall lysing enzymes, secretion of secondary metabolites, formation of penetration structures, and lysis of the host fungus.

Trichoderma *spp.* possesses a bright variety of bio trophic and saprophic lifestyles. The fungi's ability to kill and/or parasitise other fungi is the one of the mechanisms that is being exploited for plant protection against soil borne fungal diseases. Various research work reported that there are genes that are responsible for production of secondary metabolites (GH16β-glucanases, proteases and small secreted cysteine rich proteins), as well as those which influence interaction between trichoderma and plants. Different spp. of trichoderma has shown varying levels/ strength in antagonizing, parasitizing or even killing of different fungal pathogens, ((Qualhato T. F., et al., 2013) and (Naher & Yusuf, 2018)). This poses a great potential when incorporated in farming practices in Zimbabwe in harmony with nature. 2.6.2 Trichoderma spp. on tolerance to stress and induced resistance to crops.

Trichoderma spp. is well known for its ability to offer a symbiotic relationship with plants. They are able to induce defense related genes and protect plants from microbial infections. Trichoderma spp. produces different bio active compounds and elicitors which through its interaction with roots, increase plant growth and tolerance to abiotic stresses. (Akash & Padmanabh, 2018) Outlines that trichoderma in known for inducing systemic resistance and tolerance against abiotic stresses such as drought and salinity through root growth, nutritional uptake and inducing protection against oxidative stress. Trichoderma spp. has shown positive results on drought tolerance on tomatoes, (Alwahibi, et al., 2017). This alone shows that much of the effort should be put on how best this characteristic should be exploited on field experimental studies since much of the work done was under controlled environments. Characterization of Trichoderma from Theobroma cacao revealed changes in gene expression patterns, which imply the possibility that Trichoderma sp. could induce tolerance to abiotic stresses, possibly including drought, in cacao((Bailey, 2006).

➢ *Biochar and trichoderma spp.*

As the focus of much of the modern research work focuses on climate smart farming technologies, incorporation of biochar and trichoderma is one of the potential farming practices that can be used to re-address the negative effects that were as a result of Agricultural revolution which aimed at improving agricultural productivity through intensive use of in-organic fertilisers and pesticides. There is little research work that was conducted to evaluate the performance of forage sorghum on soils amended with combined biochar and trichoderma spp. However, biochar can act as a carrier of beneficial organisms such as trichoderma spp. These which in turn can protect the crop from fungal pathogens such as Fusarium (wilts), Rhizoctonia (root rot), Sclerotinia (blight), and Pythium and Phytophthora (damping off), (George, 2019), as well as enhancing crop growth due to secondary metabolites that are produced when the trichoderma engulf other micro- organism that are pathogenic to the crop. The incorporation of the plant growth promoting microorganisms with biochar was referred as the best combination for growth and yield of French beans on research work that was done by (Saxena, Rana, & Pandey, 2013). Also, addition of biochar and trichoderma spp. was reported to have increased maize growth and straw derived bio-char supported the survival of *Trichoderma spp*., (Muter, et al., 2017). All these evidence supports the fact that adoption of biochar and *trichoderma spp*. in Zimbabwe may have a positive result in improving both crop and livestock productivity in marginal areas of Zimbabwe. This reflects the gaps and potential research areas that needs to be worked on especially on the field to come up with the best technics that can be employed in semi-arid regions to boost both crop and livestock production.

IV. METHODOLOGY

A. *Introduction*

The chapter outlines the procedures that were undertaken in laying out the experiment, brief description of the study area, design of the experiment, sampling procedures, and data collection procedures.

B. *Brief description of the study area/ sites*

The experiment was conducted at St Joseph Government Secondary School in Beitbridge Urban, GPS coordinates -22.187460, 29.985035. The soils of the area are sandy loam soils with lower organic matter content. The vegetation of the area is mainly characterised by Mopane trees (*Colophospermum mopane*) which is prevalent in salt rich soils, Baobab, Marula and various species of *combretum* and *acacia* and sparse grass cover mainly *sporoborous spp*. (love grass) and *Cynodon dactylon* grasses. The mean annual rainfall for the District is 300mm to 600mm and most of the rainfall is experienced October to March. The mean annual temperature is between 25oC to 27.5oC, (Matsa and Dzawanda, 2018). The slope of the area is less than 2%. Soils in the District are varied, depending on the parent materials and age. On sedimentary formations, soils that occur in younger deposits are deep and often stratified. On levee deposits, soils are relatively light-textured with a high proportion of coarse sand of granite origin. Basin areas have heavy-textured soils derived from fine materials deposited during floods.

C. *Research design*

The research was a factorial experiment with two factors, that is Biochar at three levels (3t per ha, and 5t/ha) and trichoderma at two levels (0 and 1g/m2). The experimental design used was a Randomised Complete Block Design (RCBD) on 6 by 2m beds replicated 3 times to give 18 treatments.

Table 1: Experimental treatment

Tr0	**Tr1**	
Bi0	Bi0Tr0	Bi0Tr1
Bi1	Bi1Tr0	Bi1Tr1
Bi2	Bi 2Tr0	Bi2Tr1

Key:
Bi0- No Biochar Application
Bi1- $3tha^{-1}$
Bi2- $5tha^{-1}$
Tr0- No *trichoderma harzianum* to be applied
Tr1- $1g/m^2$
NB: 1g of *T. harzianum contains* 1*109 colony forming units

Table 2: Treatment layout BLOCK 1

BLOCK 1	BLOCK 2	BLOCK 3
Bi2Tr0	Bi2Tr1	Bi0Tr1
Bi0Tr1	Bi0Tr0	Bi0Tr0
Bi2Tr3	Bi1Tr1	Bi1Tr0
Bi0Tr0	Bi1Tr0	Bi2Tr1
Bi1Tr1	Bi0Tr1	Bi2Tr0
Bi1Tr0	Bi2Tr0	Bi1Tr1

- *Land preparation*

Before the land preparation, soil samples were taken for analysis to determine the residual nutrients available in the soil. Conventional tillage was used on land preparation to create a fine tilth seed bed. Compound fertiliser was applied equally on all treatments at a rate of 250kg per Ha. Biochar was applied at a rate of 3t/ha^{-1} and 5t/ha^{-1} respectively on 6 treatments each. The biochar was collected charcoal residues which are locally produced by small holder farmers in Rutenga, Zimbabwe. *Trichoderma harzianum* T77, a bio-control agent from Kutsaga Research Station, was applied at a rate of 1g/m^2 on 12 treatments. The treatments with no either *trichoderma harzianum* or biochar were the control.

- *Planting*

The trial was planted on the 15th of January 2021. The variety of forage sorghum planted was Sugar graze. It was planted at a rate of 10kg per hectare. 40cm (inter-row) and 10cm (in-row) spacing was used. Planting the crop was planted on furrows that were marked to allow capturing of moisture. This was done after basal fertiliser and biochar application was done and trichoderma was drenched at a rate of 2L/m2 (1g/m2). Each 1g of *T. harzianum* contains 1*109 colony forming units.

- *Fertiliser application*

Fertiliser application was done prior to planting (basal fertiliser) at a rate 250kg per ha .Top dressing was applied at a rate of 250kg per ha in two splits.

- *Irrigation*

There was no supplementary irrigation that was done to the crop.

- *Harvesting*

The crop was harvested 60 days after emergency when the crop was in its initial stages of flowering. The crop was cut approximately 15cm above the ground. The wet mass of the harvested crop was recorded and was air dried under the shed for four weeks.

D. *Sampling procedure*

The treatments were randomly allocated and replicated three times. Each replicate block had six treatments and two discard border lines on each side, to make them ten lines per block. Amongst the treatments, parameters measured were done on five randomly selected plants per each treatment.

E. *Data collection*

Parameters measured

- *Germination percentage*

Germination percentage was estimated 7 days after crop emergence using the following formula:

Germination percentage = seeds germinated/Total seeds planted × 100

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Days to emergence were uniform.

- *Plant height*

Plant height was measured on weekly intervals until the crop was prior to harvesting (prior to flowering) as the height of the forage sorghum crop has a positive correlation with yield. Tools used to measure height were sewing tape, clip board, recording sheets and pen. The measurements were taken from the base of the plant (ground) to the last fully developed leaf and last measurement was done up to the flag leaf.

- *Stem girth*

Stem thickness was measured on weekly bases using sewing tape. Tools used to measure the circumference of the stem were sewing tape, pen, recording sheet as well as a clip board. Stem measurements were taken weekly on different heights of the crop for seven weeks.

- *Leaf area*

Leaf area was estimated using the equation LA = L*W* A where LA is Leaf area, L is leaf length, W is leaf maximum width and A is a constant (0.75). Leaf area data was collected on weekly basis. Leaf length and width was measured using a sewing tape.

- *Yield*

Weight of harvested crop was measured through weighing the actual wet (fresh weight). The crop was harvested on the 8th week, the period when flowering was commencing. Harvesting of forage sorghum is done when the crop is prior to flowering up to soft dough stage. The harvested forage stalk was air dried on the shade for four weeks and dry mass of the stalks was measured at approximately 18% moisture level.

F. *Data analysis*

Data was analysed using Analysis of Variance (ANOVA) using Genstat 14th Edition at 5% significant level.

G. *Ethical considerations*

The permission to carry out the experiment at a local school premises was sought and granted from the school authorities. All agreed terms and conditions were also adhered to. Covid 19 regulations were also followed accordingly. The researcher assured that all operations that were implemented were not going against the norms and values of the local people.

H. *Summary*

The chapter detailed all research methodology that was used in data collection and analysis to answer the research questions. It also outlined how the research was laid out and all operations that were undertaken from planting to harvesting.

V. RESULTS AND DISCUSSIONS

The results shows that it is statistically significant that *Trichoderma harzianum* can improve germination of forage sorghum at $P<0.05$.

A. *The effect of trichoderma harzianum on germination of forage sorghum*

The results showed that application of *T. harzianum* in forage sorghum either on planting or before planting have an effect on the germination of forage sorghum. It was statistically significant that application of 1g/m2 of *T. harzianum* resulted in improved seed germination of 90.18% compared to 86.26% of the treatment that was not treated with trichoderma, at P<0.01, This might have been attributed by the fact that *T. harzianum* have an effect on the soil borne pathogens which affect germinating seedlings such as *Pythium*, and *Phytophthora spp. T. harzianum* has been reported to control soil pathogens through myco-parasitism where it is responsible for production of cell wall degrading enzymes, (Gajera et al, 2012). This can be achieved through direct attack of the fungus chemotropism, recognition, attachment and coiling, cell penetration as well as digestion of the cell contents.

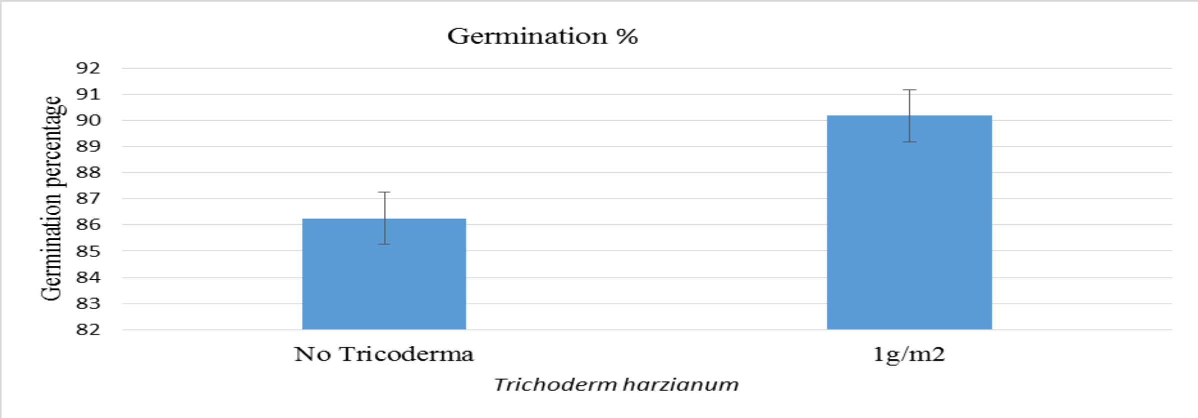

Fig. 1: Trichoderma harzianum can improve germination of forage sorghum at P<0.05.

Some researches that were conducted also suggests that *T. harzianum* can improve seed germination when exposed to different abiotic stresses such as osmotic, salinity, chilling or heat stress. It was also suggested that *T. harzianum* can overcome physiological stress caused by poor seed quality induced by seed aging. This means that farmers can make use of *T. harzianum* to treat their forage sorghum seeds to improve and enhance seed vigour and minimise seed deterioration when the seeds are in storage. This is a potential break-through for most farmers who are marginalized for which majority of them may be financially challenged such that they may not afford to buy treated seeds. Thus, adoption of *T. harzianum* can go a long way in improving seed keeping quality whereby the fungus has a potential to control seed borne diseases when the seed is in storage. More so, incorporation of seed with *T. harzianum* when planting may result in improved crop performance as this can be influenced by quick take-off of the seedlings which assures a vigorous crop as there will be less chances of seedling diseases as damping off and the favourable rhizosphere due to the action of the beneficial fungus as well as their secondary metabolites that can support crop growth and other beneficial micro-organisms.

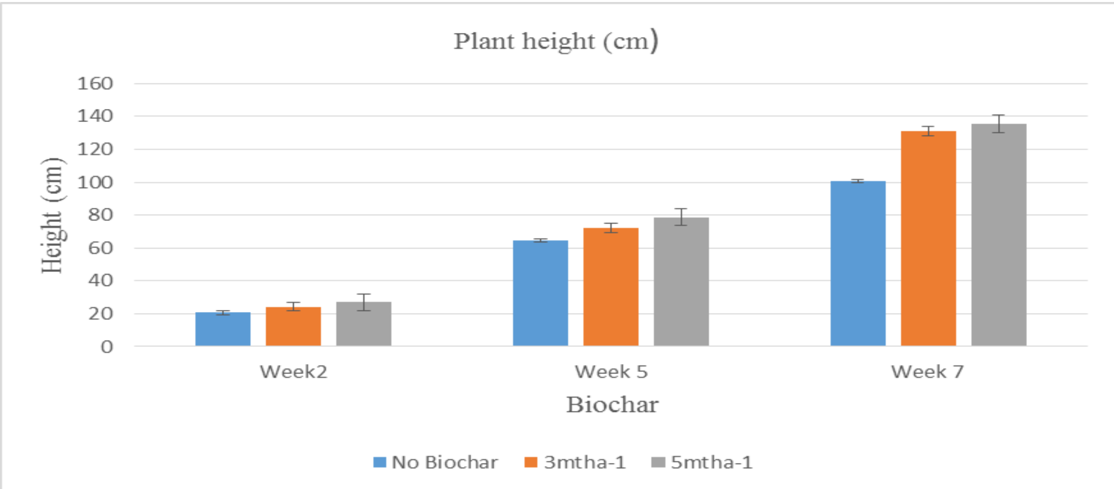

Fig. 2: Plant height

B. The effect of biochar on forage sorghum height

The results shows that biochar statistically increased the growth in height of forage sorghum between biochar application rates, that is between control (No biochar) and 3tha^{-1} levels at P<0.01 at 2 weeks, P<0.01 at 5th week and P<0.01 at week 7. Nevertheless, there was no statistically significant effect on the height of forage sorghum between biochar application rate of 3tha^{-1} and 5ha^{-1}.

C. The effect of biochar on height of forage sorghum

Biochar application rate had an effect on the plant height of forage sorghum. The results shows that biochar statistically increased the height of forage sorghum between biochar application rates, that is between control (No biochar) at 20.6cm and 3tha-1 levels (24.22cm) at P<0.01 at 2 weeks, P<0.01 at 5th week (No biochar-64.4cm, 3tha^{-1}-72cm and 5tha^{-1}-78.7cm) and P<0.01 at week 7. This

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means that application of biochar in forage sorghum can go a long way as far as yield improvements is concerned as plant height is one of the parameters that determines yield of forage sorghum. This may be attributed to the ability of biochar to influence retention of N, P and S which is associated with the increase in biological activities, (Yang Ding et al, 2016) and it was tested that biochar can improve biological community composition and microbial biomass by 125%, ((Grossman et al, 2010), (Liang et al, 2015).This can influence plant growth through improving organic matter decomposition and humus formation, nutrient recycling, aggregate formation and stabilization, outcompeting micro-organisms that are pathogenic to the crop as well as increasing bio-availability of nutrients. All this will result in increased nutrient availability to the crop hence increased crop growth and development. Nevertheless, there was no statistically significant difference between the height of forage sorghum between biochar application rate of 3tha-1 and 5ha^{-1}. This might be due to the fact that biochar dose has been reported that it has no linear response to crop productivity by (Sun et al, 2015), however some reports argues that there is linear response to biochar application rates, (Laird et al, 2010), hence the need for more research in that area for more clarity.

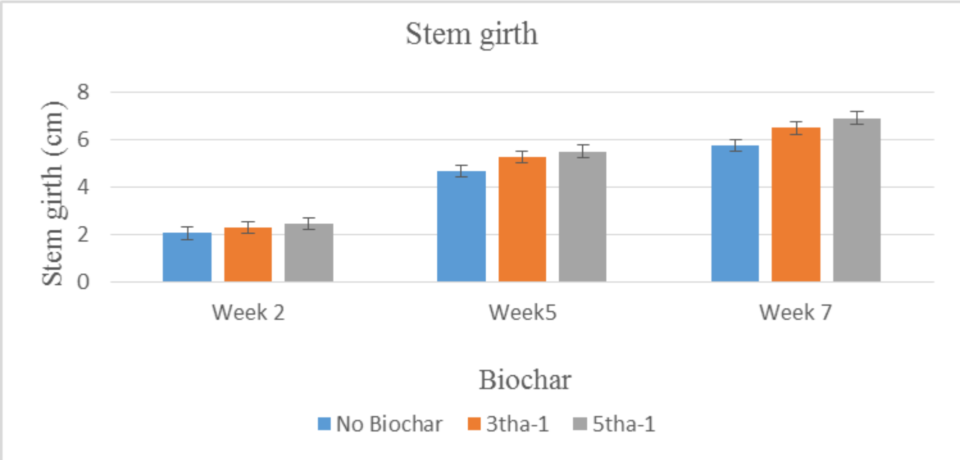

Fig. 3: Stem Girth

The effect of biochar on stem girth of forage sorghum. There was significant difference statistically on the effect of Biochar on stem girth on the third week and 7th week (P<0.01) respectively. On the 5th week, Biochar had statistically no effect on stem girth. However, there was no significance difference between 3tha^{-1} and 5tha^{-1}.

D. The effect biochar on stem girth of forage sorghum

Biochar application on forage sorghum had an effect on stem girth on the third week (2.043cm, 2.283 and 2.435) and seventh week (5.74cm, 6.49cm and 6.90cm) in respect of three levels namely No biochar, 3tha^{-1} and 5tha-1 all (P<0.01). This observation shows that generally, size of the stem girth was increasing with an increase in biochar level although there was no significant difference at week five. This might be as a result of improved nutrient availability and enhanced root development of the crop. The stem girth is an important parameter in forage sorghum production as it affects the stem volume and tolerance to lodging. Thus, from the observations in the figure 4.3, it means that application of biochar may have a positive effect on the final yield of the forage sorghum as its size is relatively linked to dry matter accumulation.

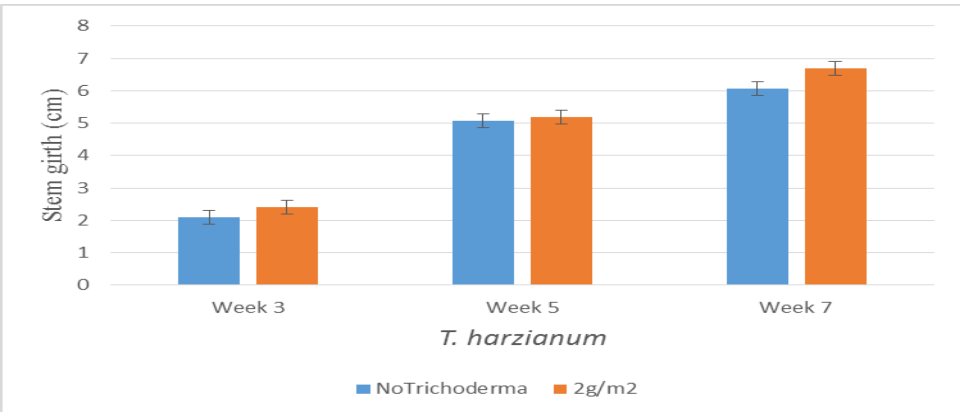

Fig. 4: The effect of *Trichoderma harzianum* on stem girth of forage sorghum

The results shows that statistically, there was significant difference between the control and 1g/m^2 *T. harzianum* on the third week at P<0.01. On the fifth week, there was no significant difference between the control and 1g/m^2 *T. harzianum*. Statistically significant differences between the control and 1g/m^2 *T. harzianum* on stem girth was also observed in the 7th week at P<0.05.

E. The effect of T. harzianum on stem girth

The results observed show that there were significant differences between the control and 1g/m2 *T. harzianum* on stem girth at P<0.01 on the third week and P<0.05 on the seventh week. This might be as a result of plant growth promotion by the *T. harzianum* where it limits the effect of plant pathogens through direct myco-parasitism as well as enhancement of microbial compounds. At week seven, the highest recorded stem girth was 6.69 cm in circumference compared to 6.07cm. This was probably due to increased availability of nutrients through solubilisation of organic and inorganic phosphates, Fe2O3, CuO, metallic zinc and mnO2, (Li et al, 2017). *T. harzianum* is also known to induce systemic resistance in the plant and tolerance against abiotic stresses such as drought, and salinity through increasing root growth, nutritional uptake and inducing protection against oxidative stresses, (Hidangmayu, 2019).As a result, the final yield of the forage sorghum may be influenced due to tolerance to lodging due to firm girth as well reduced population of rhizosphere inhabiting plant pathogenic microorganisms resulting in reduced incidence of diseases.

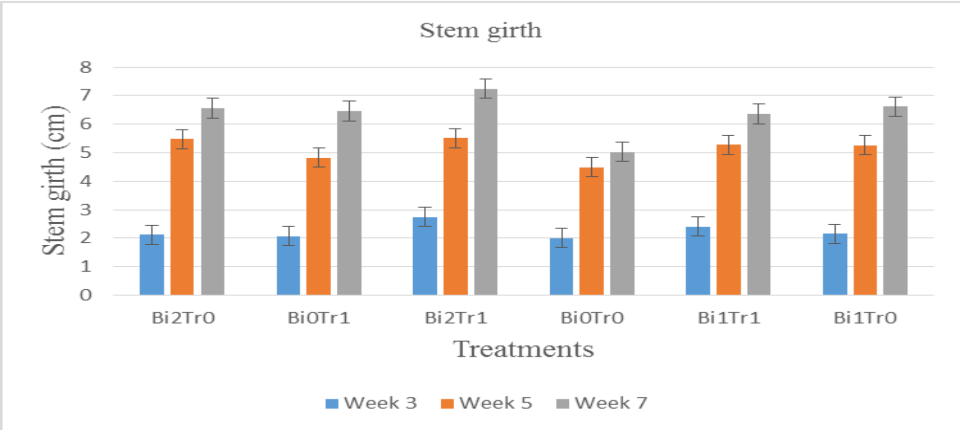

Fig. 5: The graph above shows that there was statistically significant differences between the interaction of *T. harzianum* and biochar on the third and seventh week at P<0.01 and P<0.05 respectively. Week five did not record any significant difference on the interaction between *T. harzianum* and biochar.

F. The effect of interaction between T. harzianum and biochar on stem girth

The interaction between biochar and *T. harzianum* was significant between week 3 (P<0.01) and week 7 (P<0.05. Biochar is known to offer habitat to soil micro-organisms which in turn can protect the crop from pathogenic plant pathogens *Sclerotia spp. Pythium and Phtopthora spp.* George, 2019). The crop may also benefit from the secondary metabolites that are produced when *T. harzianum* engulf pathogenic plant pathogens. On separate research that was conducted by (Grantina et al, 2017)), reported that there was increased maize growth and straw derived bio-char supported the survival of *Trichoderma spp*. Biochar improves physical soil properties such as bulk density, particle density as well as porosity which improves water holding capacity and soil aggregation which modify soil microbial abundance, activity community structures, (Hardy et al, 2019). (Gałązka, 2019), assessed the change in biological activity and microbial diversity. It was found that an increase in 10% to 20% of biochar depending on the initial carbon content in the soil significantly increased biological activity and functional diversity. The optimal dose for enhancement of soil biological activity was 10 to 20%.

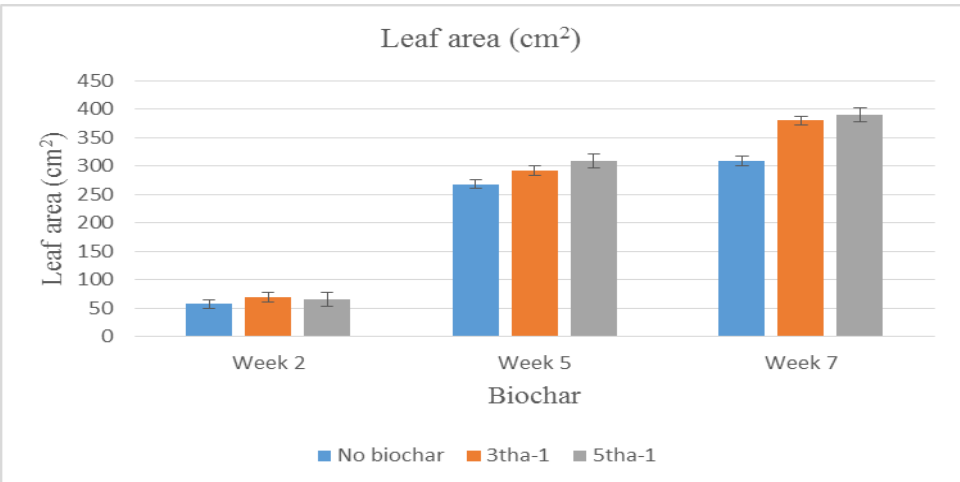

Fig. 6: The effect of biochar on leaf area of forage sorghum

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On week two, there was no significance difference statistically between the three treatments (No biochar, 3tha-1 and 5tha-1. There was a significance difference between the control (no biochar) and other two treatments (3tha^{-1} and 5tha^{-1}) statistically at P< 0.5 (week 5) and P<0.01 (week 7).

G. The effect of biochar on leaf area of forage sorghum

The observations made on the figure 4.6 shows that there was no any significant difference onthe leaf sizes of the forage sorghum on week 2 which was 57.8cm2 for No biochar, 69.7cm^2 for 3tha^{-1} and 5tha^{-1}. This was mainly due to the fact that rate of sorghum growth is slow in the first 20-25 days that is up to five leaf stage, (VANDERLIP, 1993). However, as the number of leaves increases, the growth rate will start to increase due to increased photosynthesis. This may also be attributed by the fact that the crop will be still utilizing the nutrients provided by the endosperm as well as the primary roots. Biochar application had an effect on leaf area at week 5 (P<0.05) and week 7 (P<0.01) at week 5, the leaf area of the control was 268.2cm2, 292.2cm2 (3tha-1 biochar) and 308.9cm2 (5tha-1 biochar) and 309.2cm2, 380.7cm2 (3tha-1 biochar) and 390.6cm2 (5tha-1 biochar) at week 7. The larger the surface area, the more the amount of assimilates is produced. Leaf area has got a direct bearing on the canopy of the crop. Increase in sorghum canopy have been shown to contribute to 44 yield increases, (Gaillard, 2020) thereby improving both light interception and light interception efficiency which is essential to meet forage grass requirements for livestock in semi-arid regions of southern Zimbabwe. (Bueno, 1979) agrees with the fact that crop yields may differ due to the variations in the amount of assimilates synthesized thus the study of variations in dry matter accumulation and leaf area development can be quantified by growth functions, which are helpful in explaining the partitioning of synthesized assimilates to different plant organs throughout the life cycle of the plant. On other separate research done by Arunah et al, (2015) on sorghum, concluded that highest contribution towards final yield was leaf area index. This means that adoption of biochar on forage sorghum may result in improved dry matter yield resulting in reduced livestock mortality due to drought and other abiotic stresses.

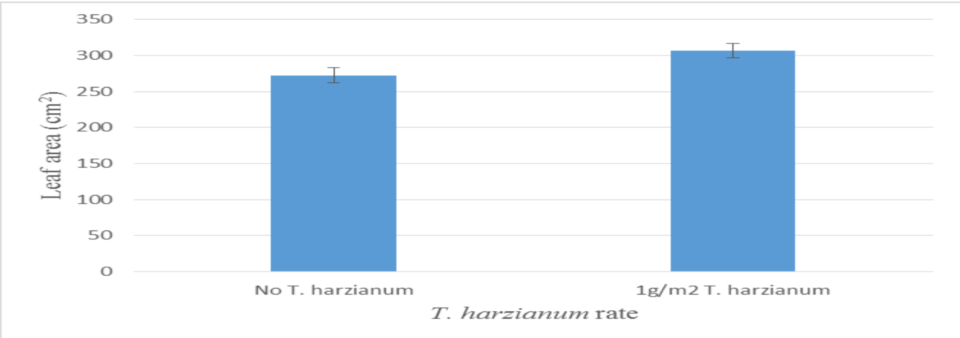

Fig. 7: The effect of T. *harzianum* on leaf area of forage sorghum

There was a significant difference statistically between the control and the one treated with 1g/m2 T. *harzianum* at P<0.01. The leaf area of the crop treated with 1g/m^2 was 306.8cm^2 compared to 272.8 for the treatment with no T. *harzianum* at week five. There was no significant difference between leaf area and T. *harzianum* application at weeks 2 and 7. This means that application of T. *harzianum* does not improve growth of the crop at the early stages of plant growth which may be attributed by low fungal populations that can significantly affect crop growth and at later stages of crop growth, the effect of T. *harzianum* on leaf development may be relatively low as the crop will be reaching senescence.

H. The effect of T. harzianum on forage sorghum leaf area

The results showed that there was statistically significant difference between the control and 1g/m^2 at P<0.01. This means that an application of 1g/m^2 *T. harzianum* increased the growth of forage sorghum's leaf area. The leaf area recorded on control treatment was 272.8cm^2 and 306.8cm^2 for the *T. harzianum* treatment. This might be the result of increased microbial population in the rhizosphere which increase the production of antifungal metabolites, competition for space and nutrients with other micro-organism and enhances induction of defense responses in plants as well as reducing populations of plant pathogenic micro-organisms through myco-parasitism. Increased leaf area of the crop may be as a result of plant symbiotic relationship which exists between plant roots and *T. harzianum*. As a result, symbiotic relationship can induce localized systemic resistance to pathogen attack, (Hidangmayu, 2019). Leaf area is essential in forage crop productivity as it determines the light interception capacity of the crop leading to increase in photosynthetic capacity resulting in high biomass accumulation although it is non-linear and its variability is dependent upon carbon partitioning. Thus, application of *T. harzianum* can help marginalized farmers in semi-arid regions improve biomass accumulation on forage sorghum in attempting to mitigate effects of abiotic stress on forage sorghum in a sustainable manner.

VI. RECOMMENDATIONS

- Seed companies and farmers who use retained seed are encouraged to treat forage sorghum seeds with part of T. harzianum to protect seeds from seed borne diseases as well as enhancing germination
- More research work needs to be done on open fields to ascertain the effects of T.harzianum and biochar of forage sorghum growth parameters.

- Farmers and stakeholders need more training on how to produce biochar and its effects on crop productivity as well as addressing the effects of climate change through climate smart and regenerative agriculture.

VII. CONCLUSION

The results above shows that adoption of both biochar and T. harzianum can go a long way in improving both crop and livestock production as the results demonstrated a significant gain in germination, plant height, leaf area and stem girth. These parameters has a direct effect on biomass accumulation and total yield hence increased productivity in forage as well as livestock productivity in drought prone areas.

REFERENCES

[1.] Moghimi. Mineralogy and aggregate stability of soils in the arid. *African Journal of Agricultural Research Vol. 7(11*, 1639-1649.)2012.

[2.] AEDS. *ZIMBABWE LIVESTOCK PRODUCTION TRENDS (2019-2020).* Harare: Africa Economic Development strategies.2020.

[3.] Aisosa. Significance of biochar application to the environment and economy. *Annals of Agricultural Sciences, 64(2)*, 222-236.2019.

[4.] Akash, H., & Padmanabh, D. Plant Responses to Trichoderma spp. and their. *Journal of Pharmacognosy and Phytochemistry*, *1*(7), 758-766.2018

[5.] Allan and Sebata. An Insight into Current and Future Production of Forage Crops in Zimbabwe. *In New Perspectives in Forage Crops. IntechOpen*.2018.

[6.] Alwahibi, H., AbdAllah, E., Alqarawi, A., Soliman, D., Wirth, S., Egamberdieva, D., & Mona, S. Increased resistance of drought by Trichoderma harzianum fungal treatment correlates with increased secondary metabolites and proline content. *Journal of Integrative Agriculture, 16*, 1751-1757.2017

[7.] Asadullah, M., Rahman, M., Ali, M., Rahman, M., Motin, M., Sultan, M., & Alam, M. Production of bio-oil from fixed bed pyrolysis of bagasse. *Fuel*, *86*(16), 2514-2520.2007

[8.] Bailey, B. A. Fungal and plant gene expression during the colonization of cacao seedlings by endophytic isolates of four Trichoderma species. *Planta*, *224*(6), 1449-1464.2006.

[9.] Barbara, R., & Alfredo. The complexity of Trichoderma atroviride – host interaction: observations on the transcriptome level. *Guanajuato*, *31*(4), 281-291.2010

[10.] Blanco-Canqui, H. Does biochar improve all soil ecosystem services. *GCB Bioenergy*.

[11.] Board, T. R. *Zimbabwe Patent No. 104/89.* 2020.

[12.] Bossio and Deborah. Livestock and water: understanding the context based on the 'Comprehensive Assessment of Water Management in Agriculture'. *The Rangeland Journal 31(2)*.2009.

[13.] Brewer, C. E., Klaus, S.-R., Satrio, J. A., & Brown, R. C. Characterization of biochar from fast pyrolysis and gasification systems. *Environmental Progress & Sustainable Energy: An Official Publication of the American Institute of Chemical Engineers* , *28*(2), 386-396.2009.

[14.] Bronick, C., & Lal, R. Soil structure and management: a review. *GEODERMA*, *124*(1-2), 3-22.2005

[15.] Chen, B., Dandan, Z., & Lizhong, Z. Transitional adsorption and partition of nonpolar and polar aromatic contaminants by biochars of pine needles with different pyrolytic temperatures. *Environmental science & technology*, *42*(14), 5137-5143.2008.

[16.] Chernin, L., Viterbo, A., Ramot, O., & Chet, I. Significance of lytic enzymes from Trichoderma spp. in the biocontrol of fungal plant pathogens. *Antonie Van Leeuwenhoek*, *81*(1), 549-559.2002.

[17.] Chia, C., Downie, A., & Munroe, P. Characteristics of biochar: physical and structural properties. *Biochar for environmental management: Science, technology and implementation*, *1*(1), 89-109.2015.

[18.] Conte, P. iochar, soil fertility, and environment. *Biol Fertil Soils*, *50*(1175).2014.

[19.] Corredor, D. S. Evaluation and characterization of forage sorghum as feedstock for fermentable sugar production. *Applied biochemistry and biotechnology*, *158*(1), 164-179.2009.

[20.] DanayI i., e. a. Mechanisms of action of Trichoderma against phytopathogenic fungi. *Journal of Plant Protection*, *24*(1), 14-21.2019.

[21.] Deal, C., Brewer, C., Brown, R., Okure, M., & Amoding, A. Comparison of kiln-derived and gasifier-derived biochars as soil amendments in the humid tropics. *Biomass and Bioenergy*, *37*(1), 161-168.2012.

[22.] Edwards, A., & Bremner, J. Microaggregates in soils 1. *Journal of Soil Science*, *18*(1), 64-73.1967.

[23.] El-Mouhamady, A. B. Elicitation of salt stress-tolerant mutants in bread wheat (Triticum aestivum L.) by using gamma radiation. . *Bulletin of the National Research Centre, 44(1)*, 1-18.2020.

[24.] FAO, NEPAD, GoZ. *Support to NEPAD-CAADP implementation. Rehabilitation of smallholder irrigation.* Harare: Government of Zimbabwe.2004.

[25.] FAOSTAT. "Production – Crops –Area harvested/yield/production quantity – sorghum – 2014. In *FAO Satistics* (1 ed.). Food and Agriculture Organization.2017.

[26.] Feng-Peng, H., Xiang-Hong, L., & Xing-Chang, Z. Effect of biochar on soil aggregates in the Loess Plateau: results from incubation experiments. *International Journal of Agriculture and Biology*, *14*(6).2012.

[27.] Gałązka, A. et al. Biological activity and functional diversity in soil in different cultivation systems. *Int. J. Environ. Sci. Technol. 17,*, 4189-4204.2020.

[28.] George, H. *TRICHODERMA IMPROVES PLANT GROWTH AND KILLS FUNGAL PATHOGENS.* Califonia: Garderner's path.2019.

[29.] Głąb, T., Palmowska, J., Zaleski, T., & Gondek, K. Effect of biochar application on soil hydrological properties and physical quality of sandy soil. *Geoderma*, *281*(1), 11-20.2016.

[30.] Hancock, J. D. Value of sorghum and sorghum co-products in diets for livestock. *Sorghum Origin*. 2002.

[31.] Hardy et al.The Long-Term Effect of Biochar on Soil Microbial Abundance, Activity and Community Structure Is Overwritten by Land Management. *Long-term Fate and Effects of Black Carbon in Soils: How and What Can We Learn from Centuries-old Black Carbon of Anthropogenic or Natural Origin?* 12.07.2019.

[32.] Ibrahim, M. M., Tong, C., Hu, K., Zhou, B., Xing, S., & Mao, Y. Biochar-fertilizer interaction modifies N-sorption, enzyme activities and microbial functional abundance regulating nitrogen retention in rhizosphere soil. *Science of the Total Environment, 739*, 140065.2020

[33.] J. M. Steyaert, H. J. Genetic basis of mycoparasitism: A mechanism of biological control by species of Trichoderma . *New Zealand Journal of Crop and Horticultural Science*, 14-21.2003.

[34.] Jeyarajan, R., & Nakkeeran, S. Exploitation of microorganisms and viruses as biocontrol agents for crop disease management. *In Biocontrol Potential and its Exploitation in Sustainable Agriculture*, 95-116.2000.

[35.] Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M., & Sonoki, T. Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosciences, 11*(23), 6613-6621.2014.

[36.] Jindo, K; Mizumoto, H; Sawada, Y; Sanchez-Monedero, M.A; Sonoki, T. Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosciences, 11*(23), 6613-6621.2014.

[37.] Joseph, S., Zhang, D. Y., Chen, D., Bian, R., Cheng, K., Li, L., & Zheng, J. Is current biochar research addressing global soil constraints for sustainable agriculture?. *Agriculture, ecosystems & environment, 226*(1), 25-32.2016.

[38.] Kannan, P., Krishnaveni, D., & Ponmani, S. Biochars and Its Implications on Soil Health and Crop Productivity in Semi-Arid Environment. *In Biochar Applications in Agriculture and Environment Management*, 99-122.2020.

[39.] Kay, B., & Angers, D. Soil Structure. *oil physics companion*, 249.2001.

[40.] Kim, H., Kim, K., Yang, J., Ok, Y., Owens, G., Nehls, T., Kim, K. Effect of biochar on reclaimed tidal land soil properties and maize (Zea mays L.) response. *Chemosphere, 142*(1), 153-159.2016.

[41.] Lehmann, J., & Joseph, S. Biochar for environmental management. In J. Lehmam, & S. joseph (Eds.), *science, technology and implementation*. Routledge: Earthscan.2015.

[42.] Lin, Y., Munroe, P., Joseph, S., & Henderson, R. Migration of dissolved organic carbon in biochars and biochar-mineral complexes. *Pesquisa Agropecuaria Brasileira, 47*(5), 677-686.2012.

[43.] Liu, W. H. Effects of biochar on nitrogen transformation and heavy metals in sludge composting. *Bioresource technology, 235*(1), 43-49.2017.

[44.] Martin et al. Biochar-mediated reductions in greenhouse gas emissions from soil amended with anaerobic digestates. *Biomass and Bioenergy Volume 9*, 39-49.2015.

[45.] Masikati et al. Constraints and opportunities for increased livestock production in communal areas: A case study of Simbe, Zimbabwe. *Livestock Research for Rural Development 24(9)*, 561-756.2012.

[46.] McDonald, A., Wei, L., Liang, S., Guho, N., Hanson, A., Smith, M., & Garcia-Perez, M. Production and characterization of bio-oil and biochar from the pyrolysis of residual bacterial biomass from a polyhydroxyalkanoate production process. *Journal of Analytical and Applied Pyrolysis, 115*(1), 268-278.2015.

[47.] Meenambigai, P., Vijayaraghavan, R., Gowri, R., Rajarajeswari, P., & Prabhavathi, P. Meenambigai, P., R. Vijayaraghavan, R. Shyamala Gowri, P. Rajarajeswari, and P. Prabhavathi. "Biodegradation of heavy metals–a Review. *International Journal of Current Microbiology and Applied Sciences, 5*(4), 375-383.2016.

[48.] Mia, S; Dijkstra, F.A.; Singh, B. Long-term aging of biochar: a molecular understanding with agricultural and environmental implications. *Advances in agronomy, 141*(1), 1-51.2017.

[49.] Mukome, F., Zhang, X., Silva, L., Six, J., & Parikh, S. Use of chemical and physical characteristics to investigate trends in biochar feedstocks. *Journal of agricultural and food chemistry,, 61*(9), 2196-2204.2013.

[50.] Muter, O., Lelde, G.-I., Galina, M., Dagnija, V., Silvija, S., Turs, S. Christoph, S. Effect of biochar and Trichoderma application on fungal diversity and growth of Zea mays in a sandy loam soil. *Environmental and Experimental Biology , 15*(4), 289292.2017.

[51.] Naher, L., & Yusuf, U. H. Mycoparasitism activity of Trichoderma harzianum associated with chitinase expression against Ganoderma boninense. *Pak. J. Bot,, 50*(2), 1241-1245.2018.

[52.] Ncube. *Understanding cropping systems in the semi-arid environments of Zimbabwe: Options for soil fertility management*. Wageningen : Wageningen University.2007.

[53.] Ncube et al. Communal cattle production in Zimbabwe: A review. *Livestock Research for Rural Development 25(12),* Article 217.2013.

[54.] NEIRA, J. et al. Oxygen diffusion in soils: Understanding the factors and process needed for modeling. *Journal of Agricultural Research, vol. 75.* 2015.

[55.] Omondi et al. Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data. . *Geoderma, 274,*, 28-34.2016.

[56.] Powell. *REVIEW AND INTERPRETATION Crop-Livestock Interactions in the West African Drylands.* Researchgate.2010.

[57.] Qualhato, T. F., Lopes, F. A., Steindorff, A. S., Brandão, R. S., Jesuino, R. S., & Ulhoa, C. J. Mycoparasitism studies of Trichoderma species against three phytopathogenic fungi: evaluation of antagonism and hydrolytic enzyme production. *Biotechnology letters, 35*(9), 1461–1468.2013.
[58.] Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A., & Lehmann, J. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils,, 48*(3), 271-284. 2012.
[59.] Rawat, J., Saxena, J., & Sanwal, P. Biochar: a sustainable approach for improving plant growth and soil properties. *In Biochar-an imperative amendment for soil and the environment*. 2019.
[60.] Rogovska. A model for mechanistic and system assessments of biochar effects on soils and crops and trade-offs. *Gcb Bioenergy, 8(6)*, 1028-1045.2016.
[61.] Saifullah, S. D. An increase in soil salinity and sodicity with biochar application at high rates, affected soils: Challenges and opportunities. *Sci Total Environ 1;625*, 320-335.2018.
[62.] Santos et al. From neutral oligoanilines to polyanilines: a theoretical investigation of the chain-length dependence of the electronic and optical properties. *Physical Review B, 56(14)*, 8638.1997.
[63.] Saxena, J., Rana, G., & Pandey, M. Impact of addition of biochar along with Bacillus sp. on growth and yield of French beans. *Scientia Horticulturae, 162*, 351-356.2013.
[64.] Schloter et al. Microbial indicators for soil quality. . *Biol Fertil Soils 54*, 1-10.2018.
[65.] Sebata, A. An Insight into Current and Future Production of Forage Crops in Zimbabwe. *n New Perspectives in Forage Crops. IntechOpen,*. 17 January 2018.
[66.] Shinogi, P. Rice husk biochar application to paddy soil and its effects on soil physical properties, plant growth, and methane emission. . *Paddy and water environment, 14(4)*, 521-532.2016.
[67.] Šimanský, V., Horák, J., Dušan, I., Eugen, B., & Jerzy, J. Biochar and biochar with N fertilizer as a potential tool for improving soil sorption of nutrients. *Journal of Soils and Sediments , 18*(4), 1432-1440.2018.
[68.] Šimanský, V., Horák, J., Igaz, D., Balashov, E., & Jonczak, J. Biochar and biochar with N fertilizer as a potential tool for improving soil sorption of nutrients. *Journal of Soils and Sediments, 18*(4), 1432-1440.2018.
[69.] Smith et al. *Agriculture, 2007 Agriculture. In Climate Change: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of theIntergovernmental Panel* . Cambridge: Cambridge UniversityPress. 2007.
[70.] Spears, s. (2018). What is biochar. *Regeneration international, 1*(1), 2018.
[71.] Tartoura, K. A., Youssef, S. A., & El-Sayed, A. T. Compost alleviates the negative effects of salinity via up-regulation of antioxidants in Solanum lycopersicum L. plants. *Plant growth regulation, 74*(3), 299-310.2014.
[72.] Tawonezvi. *Zimbabwe country report on the state of the world's animal genetic resources.* Harare: Agriculture Research Council.2004.
[73.] Tester, M. Mechanisms of salinity tolerance. . *Annu Rev Plant Biol 59*, 651-681.2008.
[74.] Thies, J., & Rillig, M. Characteristics of biochar: biological properties. In *Biochar for Environmental Management* (pp. 117-138). Routledge.2012.
[75.] Tomczyk, A., Sokołowska, Z., & Boguta, P. Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. *Reviews in Environmental Science and Bio/Technology,, 19*(1), 191-215.2020.
[76.] Usowicz, B., Lipiec, J., Łukowski, M., Bis, Z., Usowicz, J., & Latawiec, A. Impact of biochar addition on soil thermal properties: Modelling approach. *Geoderma, 376*, 114574.2020.
[77.] Vough, L. Preventing prussic acid poisoning of livestock [Cyanogenetic plants, glucosides]. *Extension Circular-Oregon State University.* 1978.
[78.] Wang, Z., Zheng, H., Deng, X., Herbert, S., & Xing, B. Impacts of adding biochar on nitrogen retention and bioavailability in agricultural soil. *Geoderma, 206*(1), 32-39.2013.
[79.] Wassmann, R., Jagadish, S., Heuer, S., Ismail, A., Redona, E., Serraj, R. Sumfleth, K. Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. *Advances in agronomy, 101*(1), 59-122.2009.
[80.] Wilson, B., Ghosh, S., & Ow, L. Influence of biochar and compost on soil properties and tree growth in a tropical urban environment. *International journal of environmental science and technology, 12*(4), 1303-1310.2015.
[81.] Woolf, D. *Biochar as a Soil Amendment: A Review of the Environmental Implications.* Swansea: Swansea University , School of the Environment and Society.2008.
[82.] Xiao, B., Laghari, M., Naidu, R., Hu, Z., Mirjat, M., Hu, M., . Abudi, Z. Recent developments in biochar as an effective tool for agricultural soil management: a review. *Journal of the Science of Food and Agriculture, 96*(15), 4840-4849.2016.
[83.] Ye, L., Camps-Arbestain, M, Shen, Q., Lehmann, J., Singh, B., & Sabir, M. Biochar effects on crop yields with and without fertilizer: A meta-analysis of field studies using separate controls. *Soil Use and Management, 36*(1), 2-18.2020.
[84.] Yu, H., Zou, W., Chen, J., Chen, H., Yu, Z., Huang, J., Gao, B. Biochar amendment improves crop production in problem soils: A review. *Journal of environmental management,, 232*(1), 8-21.2019.
[85.] ZimVAC. *Zimbabwe Vulnerability Assessment Committee (ZimVAC) 2020 Rural Livelihoods Assessment.* Harare: Government of Zimbabwe.2020.