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The potential of anthill soils in smallholder maize production under conservation based agricultural systems in southern Zambia

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THE POTENTIAL OF ANTHILL SOILS IN SMALLHOLDER MAIZE PRODUCTION UNDER CONSERVATION BASED AGRICULTURAL SYSTEMS IN SOUTHERN ZAMBIA

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Soil fertility is one of the fundamental challenges faced by cash constrained smallholder farmers across sub-Saharan Africa. In an effort to ward off this hurdle, some smallholder farmers in southern Zambia opt to use anthill soil as alternative fertilizer to enhance soil fertility and mitigate against exorbitant fertilizer costs. This study investigated the potential of using anthill soil as fertilizer for enhancing crop productivity under conventional (CONV) and conservation agriculture (CA) tillage systems with two principals involving minimum tillage and soil cover. The study was conducted in Pemba and Choma districts of southern Zambia where the practice of anthill soil utilization is widespread. Qualitative and quantitative approaches were employed to gather data for the surveys using open data kit (ODK) tool. Pot and on-farm experiments were set in Complete Randomized and Randomized Complete Block Designs to assess growth parameters; plant height, girth, dry matter yield, plant uptake, leaflet length, width and area, grain, stover and core yield of test crop under anthill soil, mineral fertilizer, manure and their combinations. All data recorded were analyzed using Statistical Package for Social Sciences (SPSS) 22, STATISTICA 2010 Programme, GEN STAT 15th edition and Origin Pro 9.0. Results from the survey revealed that key barriers to the application of anthill soils in agriculture production lay in biophysical, technological, land, institutional and agro-climatic issues. The study also found that elevated macro and micro nutrients were more pronounced in top segments of the anthills. Significant (*$p<0.05$)* growth parameter yields were observed in sole anthill soil (5 000 kg/ha) and in combination with manure (10 000 kg/ha) or half rate mineral fertilizer (100 kg/ha; 10% N: 20% P_20_5: 10% K_2O: 6% S and 46% NH_4NO_3) under both pot and field conditions. Phosphatase enzyme activity across the study districts was lower in comparison to arylsulphatase. Moisture retention capacity was consistent in both CONV and CA plots and only in Pemba site. Financial benefits were accrued more in treatments involving sole anthill and in combination with manure. To attain optimal benefits from the practice of anthill soil utilization under CA systems, there is a need for capacity building amongst users on appropriate application techniques.

DECLARATION

I, **Kafula Chisanga,** do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology (NM-AIST) that this Thesis is my own original work and it has not been submitted for consideration of a similar degree award in any other University.

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Name and Signature of Candidate Date

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Dr. Ernest R. Mbega

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CERTIFICATION

The Undersigned Certify that have read and hereby accept the Thesis titled **"The Potential of Anthill Soils in Smallholder Maize Production Under Conservation Based Agricultural Systems in Southern Zambia"** in fulfillment of the requirements for the Degree of Doctor of Philosophy in Life Sciences (Sustainable Agriculture) at the Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, Tanzania.

Prof. Patrick A. Ndakidemi

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DEDICATION

I would like to dedicate this work to my late father and brother, Messrs Julius Tanasho Chisanga and John Chanda Chisanga.

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LIST OF ABBREVIATIONS AND SYMBOLS

AE	Agronomic Efficiency
AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of Variance
BAP	Best Agriculture Practice
Ca	Calcium
CA	Conservation Agriculture
CBA	Cost Benefit Analysis
CHNSO	Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen
cm	Centimeter
cmol	Centimole
CRD	Complete Randomized Design
Cu	Copper
DTPA	Diethylenetriamine Pentaacetic Acid
FAO	Food and Agriculture Organization
Fe	Iron
g	Gram
GPS	Geographic Position System
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIRR	International Institute of Rice Research
ISFM	Integrated Soil Fertility Management
m^3	Meter Cubed
mg	Miligram
Mg	Magnesium
Mn	Manganese
N	Nitrogen
NMAIST	Nelson Mandela African Institution of Science and Technology
OC	Organic Carbon
ODK	Open Data Kit

P	Phosphorous
pH	Potential Hydrogen
K	Potassium
Kg	Kilogram
RCBD	Randomized Complete Block Design
S	Sulphur
SSA	Sub Saharan Africa
T	Treatment
USD	United States Dollar
WaPOR	Water Productivity Open Access Portal
WP	Water Productivity
WWI	World Watch Institute
ZARI	Zambia Agriculture Research Institute
Zn	Zinc

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

In sub-Saharan Africa (SSA), soil fertility constraints are reported to reduce crop yield by 15-25 percent annually and exacerbate food insecurity. This is attributed to farmers' failure to sustain soil fertility management practices. Consequently, farmers are very much optimistic that in less than five years their crop productivity will shrink by 50 percent and already some communities are relying on food aid for their survival. One system that farmers are adopting to enhance soil fertility and crop yield, however, is the use of anthill soils also known as termiteria soil in crop production (World-Watch-Institute, 2011).

In Zambia for example, the technology of conservation agriculture (CA) is highly embraced by the smallholders in the country with a view to enhancing soil productivity. It is estimated that about 180 000 farmers are involved in some kind of CA (Neubet *et al.,* 2011). This translates to 15% of smallholder farmers. Apparently, adoption of CA is strongly appreciated in semi-arid areas of the country to which southern province of Zambia is a part, with annual rainfall ranging between 650 and 1000 mm. Farmers in this part of the country are involved in mixed crop-livestock systems and cultivate mostly cotton, sorghum, groundnuts and maize.

Recently, the agricultural base of southern province has been affected by poor rainfall patterns mostly induced by frequent dry spells during land preparation and peak growing periods. Furthermore, low investments in the agricultural sector due to unfavorable economic policies have resulted in reduced smallholder farmer access to non-collateral agricultural input loans which were once the lifeline of agriculture in the province. It is also in the domain that the staple crop, maize's productivity has been reducing during the past years (estimated at 1.3 t/ha) due to among other factors sub-optimal soil fertility management practices, increase in input costs (fertilizer and seed), poor extension services on best agriculture practices (BAPs) among other factors (Chisanga, Mbega & Ndakidemi, 2019).

Against this background, this research work therefore attempted to study the potential of using anthill soils alone or in combination with other methods for improving maize crop yields under conservation basin tillage systems in semi-arid areas of southern Zambia. The aim was to determine the constraints and opportunities of anthill soil utilization in conservation agriculture (CA) systems; explore the macro and micro nutrients of anthill soils;

assess the effect of anthill soil application on growth and yield parameters of test crop; enumerate phosphatase and arylsulphatase soil enzyme activity and residual nutrient dynamics after anthill soil application; find out the additive effects of anthill soil application on moisture retention and water productivity and also ascertain potential net economic benefits of maize crop supplied with anthill soils and other organic and inorganic NPK sources.

1.2 Statement of the Problem

Farmers in some parts of Africa, have been applying the technique of using anthill soil as an organic fertilizer in order to counteract the challenge of input cost, especially fertilizer. For example, in Malawi, farmers plant bananas on the verge of anthills. Coincidentally, in Niger, Zimbabwe and Uganda, farmers grow fruits and vegetables on top of anthills while farmers in southern Zambia dig and collect soil from anthills and use it as an option to improve their soil fertility at the farm level (World-Watch-Institute, 2011). However, there is isolated scientific evidence to show the performance and quantities of anthill soil needed to be applied in a hectare in order to attain optimum maize yields at the farm level. The practice of anthill soil utilization is common amongst the financially challenged smallholder farmers involved in conservation agriculture and other tillage systems.

Research elsewhere has also indicated that once anthill soil is applied on sandy soils, it is known to act as a form of manure which helps to improve the soil texture and clay content thereby providing the necessary macro and micro nutrients to the crop hence improving production and productivity (Africa Farm News, 2014). This view is also supported by Nyamangara and Nyagumbo (2010) who reported that anthill which represents resources that can be accessed by resource constrained farmers have a positive effect on the soil chemical environment.

A rapid rural appraisal conducted by Zambia Agriculture Research Institute (2010) amongst the anthill soil users in southern Zambia indicated that once this resource is applied in the agriculture lands, the fields do not require fertilizer to be applied for at-least 2 years. Such suggestions by farmers needed to be investigated experimentally, to know the actual nutrient status of the anthill soil, its mineral nutritional value and the contribution to maize yield in conservation agriculture based systems in relation with other integrated soil fertility management (ISFM) options such as manure application or commercially recommended fertilizer.

1.3 Rationale of the Study

In southern part of Zambia, anthills are in great quantity and some cash constrained smallholder farmers in rural areas take advantage of their availability to use part of the soil as a substitute fertilizer. This is implemented to boost the organic content of the poor sandy soils which are extremely exhausted and has consequently led to a situation where benefits of commercially available NPKS compound and urea fertilizers not being amassed attributable to reduced nutrient use efficiency (Nezomba, Mtambanegwe, Tittonell & Mapfumo, 2015). Further, the use of anthill soil by smallholder farmers is due to their inability to purchase commercially available inorganic fertilizers which are sold at exorbitant prices. To avert this challenge, financially constrained smallholder farmers opt to look for ways of maintaining soil fertility using organic resources accessible at their disposal and hence the use of the anthill soil as part of a low cost integrated soil fertility management (ISFM) tactic at the farm level. From the standpoint of soil science, the fertility of the anthills is attributed to termites. They process substantial amount of materials in their anthill building activities, which has a significant effect on soil properties compared with those of neighbouring soils.

Some scientists have reported soil physical and chemical characteristics alterations by termites attributed to their bioturbation activities, with top sections of the anthills reported to have superior levels of macro and micronutrients. For example, it was reported that anthills of African and South American areas built by grass-feeding termites demonstrated higher levels of phosphorus in the inner parts compared with the surrounding soils (López-Hernández, Brossard, Fardeau & Lepage, 2005). Bruno, Johannes and Maike (2001) also confirmed that anthills have low Zn but higher concentrations of Na and Cu. Because of this enrichment in the anthill material, the resource has been used as fertilizer in African smallholder agriculture particularly in soils with low fertility (Siame, 2005). On the other hand, there are limited studies that have focused on the potential of anthill soil utilization in crop production to enhance both soil fertility and crop productivity (Fageria & Baligar, 2005). Additionally, other researchers such as Mukherjee and Lal (2015) have claimed that there is almost no data currently available on the effects of tillage systems on organic soil, particularly under smallholder farming systems. It is against this background that the present study was undertaken to investigate the potential and mineral nutrition status of anthill soil in smallholder maize production under basin conservation agriculture tillage systems. Practical implications of this study relates to filling up the knowledge gap with regard to efficient anthill soil utilization in smallholder farming systems and how this can be integrated in conservation agriculture programmes.

1.4 Objectives

1.4.1 General Objective

The main objective of this study was to evaluate the potential of supplying anthill soil alone or in combination with organic and inorganic methods in smallholder maize production under conservation based agricultural systems in southern Zambia.

1.4.2 Specific Objectives

This study was thus designed to answer the following six fold specific objectives:

(i) To investigate the constraints and opportunities of anthill soil utilization in conservation agriculture (CA) systems.

(ii) To characterize the macro and micro nutrient content of anthill soils for sustained crop growth

(iii) To establish the effect of anthill soil application on growth and yield parameters of maize.

(iv) To quantify phosphatase and arylsulphatase soil enzyme activity and residual nutrient dynamics after anthill soil application.

(v) To determine the additive effects of anthill soil application on moisture retention and water productivity.

(vi) To establish potential net economic benefits of maize crop supplied with anthill soils and other organic and inorganic NPK sources.

1.5 Research Questions

(i) What are the push - pull factors that motivate farmers to engage in using anthill soil as a fertilizer for crop production?

(ii) What are the characteristics of anthill soils that affect plant growth?

(iii) How does anthill soil application affect growth and yield parameters of maize?

(iv) How does anthill soil application influence phosphatase and arylsulphatase soil enzyme activity and residual nutrient dynamics?

(v) What is the effect of anthill soil application on moisture retention and water productivity of maize plant?

(vi) What are the benefits (socio-economic and bio-physical) of anti-hill soil utilization compared with conventional soil fertility management practices?

1.6 Significance of the Study

The significance (s) of the study is briefly described below:

(i) Anthill Soil Application Levels per Hectare: Information has been provided on the efficient approach of anti-hill soil application for small-scale farmers to use on their fields in order to optimize their production and productivity of the maize crop at the farm level. The information has been churned out through results from pot and field experiments that were established in this study.

(ii) Factors influencing yield improvement through conservation farming under varying environmental conditions in the plateau areas of southern Zambia have been identified.

(iii) Improved Soil Nutrient Availability: The potential of improving nutrient availability by anthill soil additions in conservation farming based farming systems has been established. This was done through soil analyses carried out in this study.

(iv) Economic Benefits: The Economic Benefits of anthill soil utilization in relation to other integrated soil fertility management options under conservation-based farming systems with farmer management conditions have been determined. This will abundantly clearly provide smallholder farmers and other interested parties with an array of choices for the best soil fertility management option with more economic benefits in the agriculture production value chain.

(v) Based on the experiences in this study, it is also envisaged that the information generated will be useful for policy makers, academicians and institutions involved in the promotion of conservation agriculture in Zambia and beyond for nutrient availability and climate change mitigation strategy.

1.7 Delineation of the Study

The delineations of the present study are as follows:

(i) The study carried out soil sampling 10 m away from the anthill which was meant to indicate the changes in soil properties with distance. It would have been prudent to extend the soil sampling to a distance of 50 m. Further, the study deemed it fit to narrow the sampling to only active anthills used in crop production by smallholder farmers while non-used anthills were not considered in the study due to the limited time and resources.

(ii) This study was confined to two enzymes that were considered critical and these were arylsulphatase and phosphatase soil enzymes that are responsible for the hydrolysis of sulphates and phosphates. Phosphorous is one of the limiting nutrients in the soils of southern Zambia. Estimation of other enzyme activities would have given a broader picture with regard to soil fertility status as enzyme activities are used as indicator of soil health and productivity.

(iii) Estimation of financial benefits in the present study focussed only on the input costs involving fertilizer, seed, land preparation, planting, weeding and harvesting operations. The labour costs involved in digging and transportation of the anthill soil to the field was not estimated considering the limited time available for the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil Fertility and Anthills

Ajayi (2007) claimed that low soil fertility is one of the greatest biophysical constraints to agricultural production in sub-Saharan Africa (SSA) and is associated with several simultaneous degradation processes which feed on each other to produce a downward spiral in productivity and environmental quality. For instance, the resultant effects of tillage and insufficient applications of nutrient and organic matter unavoidably cause a decline in organic matter of the soil. This affects retention of essential plant nutrients, the breakdown of soil physical structure and diminished water infiltration and storage capacity of the soil. Beyond this, most small-scale farmers face other degradation processes including erosion, salinization and acidification. The decline of soil fertility is also dependent on physical and biological degradation of soils and agronomic practices. A strong relationship exists between poverty and land degradation, national policies and institutional failures. The degradation of soil fertility is linked to other human and environmental problems too, of which malnutrition is a good example.

Chooye (2010) in his personal communication indicated that to avert the challenge of soil fertility, farmers in southern Zambia, use anthill soil to enhance their crop productivity. Anthill soils are known to minimize nutrient losses and act as a form of manure which helps to retain soil moisture and texture (Africa Farm News, 2014). The practice of anthill soil utilization involves digging, heaping and spreading the soil on to the field. Anectodal evidence in some parts of Malawi and Zambia have revealed that maize crop grown and fertilized with anthill soil has been observed to be with high vigor and relatively gives a high yield. One of the factors that may have prompted farmers to use anthill soil in their agriculture production could be high costs associated with inorganic fertilizer which is beyond their reach including the availability of nutrients like nitrogen. Lopez-Hernandez (2001) found that African farmers collect termite mound soils or anthill soil and apply to cropped fields as the resource could be rich in available nitrogen, total phosphorous and organic carbon than adjacent soil. However, there is little information regarding the quantities required per hectare to enhance crop productivity.

The use of anthill soil (Fig. 1) in crop production by farmers has been reported by scholars in Zambia (Siame, 2005), Uganda (Okwakol & Sekamatte, 2007), Zimbabwe (Bellon *et al.*, 1999; Nyamapfene, 1986), Sierra Leone (Ettema, 1994) and Niger (Brouwer, Fussell & Herman, 1993). Nyamapfene (1986) and Logan (1992) reported that farmers either plant specific crops on anthills or spread soil from anthills in their fields. An example of agriculture production around anthill is the *chitemene* system of agriculture cited in southwestern Tanzania (Mielke & Mielke, 1982). Malawi farmers have also been reported to plant various crops that include bananas (*Musa* spp.) near anthills. In Uganda, the scenario is quite different as farmers' plant onions (*Allium* spp.), tomatoes (*Solanum* spp.), pumpkins (*Cucurbita* spp.) and maize beside anthills (Okwakol & Sekamatte, 2007). In Zimbabwe, okra (*Abelmoschus esculentus*), pumpkins, sweet sorghum (*Sorghum* spp.), and late-season planted maize, that requires good water and nutrients supply, are cultivated practically on anthills (Nyamapfene, 1986). Brouwer *et al.* (1993) also indicated that in Niger, the smallholder farmers prefer to grow sorghum on anthills than the surrounding soils.

In some areas, farmers break anthill and spread the soil in their field. For example, in southern Zambia, farmers remove portions of the anthill and make sure that the base and colony are not destroyed. This soil is then taken to the field and mixed with the top soil before the rains begin. In areas where conservation farming is practiced, soil from anthills is put in planting basins (Siame, 2005) and in ripped lines. In South Africa, some patches of excellent well-cared for sugarcane, known as "isiduli", are prominent characteristics sugarcane fields grown on sandy soils. These correspond to some anthills normally evened by ploughing (Cadet, Guichaoua & Spaull, 2004). Similarly, in Zimbabwe, farmers are reported to utilize soil from anthill to enhance soil fertility (Bellon *et al.*, 1999; Nyamapfene, 1986).

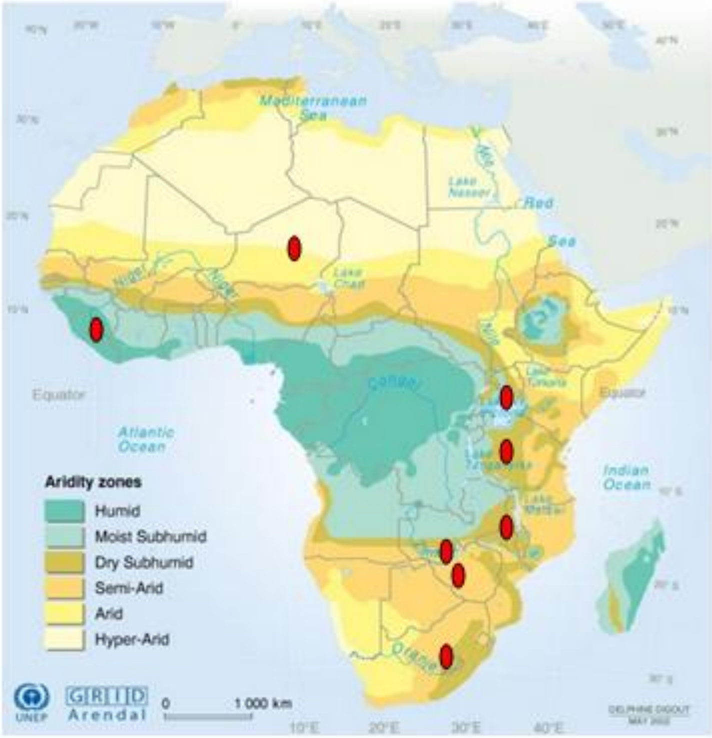


Figure 1: Showing the countries in sub-Saharan Africa, red dots (Malawi, Niger, Sierra Leone, South Africa, Tanzania, Uganda, Zambia and Zimbabwe) placed on the Africa aridity map reportedly where anthill soils are used in agricultural production. Map source: World Meteorological Organization and United Nations Environment Programme (2001)

The farmers' practices of utilizing anthill soil in agriculture have been reported and scientific explanations are available for most of them (Watson, 1977; Nyamapfene, 1986). For instance, some studies have indicated that sugar cane yield is five times greater if the "isiduli" is applied somewhere in the field (Cadet *et al.*, 2004). Similarly, plant biomass and grass growth have been reported to be significantly higher around anthills in comparison with the open veld found in Eastern Cape of South Africa (Steinke & Nell, 1989). Research shows that increase in growth of grass surrounding anthill is attributed to the accumulation of runoff water at the base thereby leading to increased productivity in dry seasons, making it possible for plants to survive worst drought conditions (Steinke & Nell, 1989). Researchers have also experimented on the mineral composition of anthills and the adjacent soils (Watson, 1977; Steinke & Nell, 1989; Holt & Lepage, 2000; Cadet *et al.*, 2004; Masanori & Tooru, 2004; Brossard, Lopez-Hernandez, Lepage & Leprun, 2007; Chikuvire, Mpepereki & Foti, 2007).

There is however scanty information on the characteristics of suitable anthills for use in agriculture production.

Most studies have revealed that anthills consist of significantly higher concentrations of total nitrogen (N) and exchangeable cations than the surrounding soils (Watson, 1977; Steinke & Nell, 1989; Jones, 1990; Holt & Lepage, 2000; Chikuvire *et al.,* 2007). In tropical wet–dry climates, downslope erosion is reported to enhance soil fertility more around anthill than with leached soils away from it (Malaisse, 1978). In addition, soil from anthills has other positive effects on crops which include weeds suppression. For instance, *Cubitermes* soil was revealed to suppress the weed, *Striga* infestation on sorghum crops in West African country of Burkina Faso (Andrianjaka *et al.*, 2007).

This review aimed at bringing together farmers' knowledge and evidence from soil science and field experiences on anthill soil utilization and how this could be integrated into conservation agriculture for achieving sustainable agriculture goals. To this end, a comprehensive review of the potential of anthill soils in agriculture production was undertaken by describing anthill formation, opportunities and constraints of using the resource in agriculture, characteristics for suitability in crop production, type of microbiota organisms found in the soil, nutrient dynamics, water productivity and soil moisture retention. Finally, a description of the potential economic benefits financially constrained farmers across (SSA) would accrue by using anthill soils in crop production practices has also been discussed.

2.2 Formation of Anthills

According to various scholars, they have indicated that termites and other fauna species in the soil play a very important role in anthill formation. This process involves anthill building ants which collect woody debris for their nests and forage for large quantities of insect prey and honeydew as food for their colonies. Active anthills are reportedly enriched with soil organic matter and inorganic nutrient elements, comprising Ca, K, Mg, Na and P, in comparison with surrounding soils (Folgarait, 1998; Kristiansen, Amelung & Zech, 2001; Lobry de Bruyn & Conacher, 1990). Ant activities effectively contribute to transforming; (a) physical soil properties, such as infiltration and porosity (Wang *et al.,* 1995), (b) soil microbial community and faunal biomass (Laakso & Setaelae, 1997) and (c) rates of decomposition of organic matter (Petal & Kusisnka, 1994).

Soil activities of ground-dwelling ants are evident during the construction of anthills. Ants' building activities alter underneath soil into nutrient-rich pockets that favors seed sprouting (Levey & Byrne, 1993; Andersen & Morrison, 1998). Scientists have related changes to soil physical - chemical properties with anthill building by ants (Nkem, Lobry de Bruyn, Grant & Hulugalle, 2000; Lenoir, Persson & Bengtsson, ,2001; Lafleur, Bradley & Francoeur, 2002), while others have linked these activities with plant distribution patterns (Culver & Beattie, 1983; Dean, Milton & Klotz, 1997; Garrettson *et al.*, 1998) and vegetation succession (King, 1977; Farji-Brener & Silva, 1995). Few scholars have associated this soil enrichment to plant growth. Therefore, there is a greater need to take appropriate actions to characterize anthills formed in different localities if they have to be used in soil fertility programs because the nutrient content of the anthills may be related to the locality of an area.

2.3 Opportunities and Constraints of Utilizing Anthill Soils in Crop Production

The opportunities of using anthill soil as an amendment in crop production have been described by various researchers. For instance, Mavehangama and Mapanda (2012) studied the nutrient status of organic soil amendments from selected wards of Chivi district in Zimbabwe and found that use of organic amendments such as anthill soil was a common practice with the goal of improving soil productivity in the communal farmlands of Zimbabwe. These scientists further observed that the differences in the nutrient supply potential of other types of animal manure and among other various types of soil amendments that include anthill soil have not been fully investigated. These differences according to Mavehangama and Mapanda would affect the optimum amounts of each type of amendment that may be needed to achieve a targeted crop yield.

Nyamangara and Nyagumbo (2010) analyzed the interactive effects of selected nutrient resources and tied-ridging on plant growth performance in a semi-arid smallholder farming environment in central Zimbabwe and found that anthill soil and leaf litter are worthwhile investments for financially constrained farmers as they could improve the soil chemical and possibly physical properties. Nyamangara, Gotosa and Mpofu (2001) observed that organic fertilizers such as anthill soil buffer soils from acidification better than mineral fertilizers and suggested that farmers who use it would benefit from the potential hydrogen (pH) moderation effect which in turn would ensure availability of nutrients like phosphorus that usually becomes locked up in acidic soils.

Find Your Feet (2011) carried out a study recognizing the unrecognized: farmer innovation in northern Malawi and found that some farmers rather than planting crops directly on to the anthills as other farmers had been doing decided to take the soil from the anthill and mix it with goat manure in the ratio of 1:1 before applying it, thereby enhancing the plant nutrient content properties of the anthill soil and also reducing the amount of manure required. This innovation was reported to have good potential for scaling up to other resource-poor farmers, as this offers a low-cost alternative to inorganic fertilizers. In addition, significant yields were reported without scientific inquiry.

Other cases, according to Find Your Feet (2011) have also been observed in the central region of Malawi where some smallholder farmers engage in spreading the anthill soil in their farms combined with compost and goat manure. This indicates a viable low input that would counteract the impact of high inorganic fertilizer prices. However, little has been documented and researched to ascertain the use of anthill soil as a source of nutrients for maize production despite convincing literature on the nutrient status of anthill soils. In view of this, there is a need to establish viable and environmentally sound optimum rates of anthill soil application as part of the integrated soil fertility management (ISFM) component in sustainable agriculture.

Results from work by ZARI (2014) in Zambia found that anthill soil can achieve yield results beyond 1000 kg/ha if well applied in agriculture fields. However, the technology requires further investigation on soil management practices, application rates and crop response in medium to high rainfall environments.

In terms of constraints, however, some farmers do not level anthills despite scientists believing that soil from anthill could provide an option to inorganic fertilizers (Logan *et al.*, 1990). Scientists have also highlighted the reasons as to why farmers do not prefer leveling anthills in order to make full use of the land and allow mechanized tillage operations (Nyamapfene, 1986). Such issues have been reported to ignore the spiritual (Geissler, 2000; Copeland, 2007) and economic importance (Nkunika, 1998) that farmers perceive of anthills. The recommendation of scientists also leaves out the fact that leveling anthills may not be sustainable in the long span. Brossard *et al.* (2007), reports that excessive use of anthill soil can affect termite abundance apart from mining nutrients. Some farmers have also expressed labour demands of the practice, especially during digging (ZARI, 2014).

It is also indicated that the problem related to the use of anthill soil in agriculture production has often hinged on how to get the suitable quantities required to satisfy the nutritional needs of crops. The issues of transportation and handling costs are normally beyond the farmer's capacity (Lal, 1988). A study by Lee and Wood (1971) revealed that the rates of production of the anthills are too little to be utilized for annual seasonal crop production and by commercial farmers. Understanding the constraints of utilizing anthill soils in crop production would enable scientists to find solutions and find other methods of inducing faster development of anthills for agriculture production.

2.4 Characteristics of a Suitable Anthill for Crop Production

2.4.1 Chemical Properties

In soil science, chemical properties of soils encompass measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of certain potential contaminants that may include heavy metals, radioactive compounds, etc. or those required for plant growth and development. Soil's chemical condition influences soil-plant relations, water quality, buffering capacities, nutrients and water availability to plants and other organisms, contaminants mobility including other physical conditions, such as crusting (Kheyrodin, 2014). Eneji, Sha'Ato and Ejembi (2015), carried out a comparative analysis of anthill soil and surrounding soil properties in the University of Agriculture, Makurdi, Nigeria, and found that differences in the chemical properties of the anthill and the surrounding soils was as a result of ecosystem services from termites which included among others bioturbation and soil formation, nutrient transportation and cycling, litter decomposition, soil animal and microbial diversity, amendment and remediation. In a similar study Joseph, Seymour, Cumming, Cumming and Mahlangu (2013) who evaluated termite mounds as islands: woody plant assemblages relative to *termitarium* size and soil properties found that anthills are habitat of high socio-economic importance, the *termitaria* which are richer in minerals like Ca, Mg, K, Na and also the accumulation of all these bases increase the pH value of the soil. Other studies by Kaschuk, Santos and Almeida (2006) during the assessment of termite's activity in relation to natural grassland soil attributes showed that soil samples collected from the top, middle and bottom of termite mounds or anthills and from adjacent areas exhibited more content of K, P, Mg, O.C and lowered pH. Ekakitie and Osakwe (2014) analyzed determination of Fe_2O_3, SiO_3, K_2O, CaO, Al_2O_3 and Mg in anthill soil samples in Nigeria and found different concentrations of oxides which were due to parent materials in the soil, vegetation around, fertilizer use and bush burning. The oxides play an important function of providing the solid shape and resistance to water.

Literature also reports that anthill soils have high levels of calcium, phosphorus and organic matter, which is also useful for better crop development. Plants also take up nutrients very easily from anthill soil. This soil has proved a good alternative to local farmers who cannot afford to buy expensive inorganic fertilizers. The anthill soil density is very low but soil may be collected, crushed and mixed with top soil for subsistence farming (Dhembare, 2013).

Sarcinelli *et al.* (2008) also found that the pH and contents of organic C and N, P, Ca and Mg were significantly higher in anthill soils than adjacent areas, with an inverse trend for Al content. Significant differences in pH and exchangeable Al were observed between soil and anthill across the slopes. It is however, observed that there are few studies on chemical properties of anthill soils and most have focused on macro nutrients and little is reported on the nutrient levels of micro nutrients that include Fe, Mn, Zn and Cu etc. Therefore, it becomes imperative that chemical characterization of anthill soils is done. This would facilitate proper planning and utilization of this natural resource base in integrated soil fertility management programs.

2.5 Physical Properties

Physical properties of the soil relate to the arrangement of solid particles and pores. Examples may include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. These essentially are indicators of limitations to root growth, seedling emergence, infiltration, or water movement along the soil profile (Kheyrodin, 2014). Cammeraat, Willott, Compton and Incoll (2002). Dashtban and Schraftwensheng (2009) indicated that ants play a big role in determining the physical soil properties of anthills soil during construction due to their burrowing habit and their ability to change physical characteristics, which include infiltration, water retaining capability, etc., of their anthills. These scholars further reported that there are a number of studies conducted on the effects of ants on soil characteristics that include bulk density, organic matter content and porosity within the anthill area. Decreased bulk density and increased soil porosity within the anthills have been reported to accelerate aeration, change temperature gradient and changes soil pH (Dean *et al.*, 1997).

Shakesby *et al.* (2003) also indicated that water infiltration rate in anthill soil and that of adjacent area is increased by ants. These creatures tend to create large macropores (biopores) and mix organic matter with mineral soil during anthill formation. Lobry de Bruyn and Conacher (1994) stressed that the cortex which act as a cover around the anthills is assumed to play an important role in absorbing the impact of the rain drops and in ensuring that water is infiltrated inside the anthills. The impact of ants on water infiltration and erosion is crucial in agricultural soils, where heavy machinery and herbicide use are reported to reduce soil porosity and organic matter (Cerda & Jurgensen, 2008).

Schaefer (2001), remarked that the results of aggregate fractioning indicated that a greater portion of anthill walls is composed of large aggregates which are cemented by termite body fluids (fraction N 2.00 mm), that are rapidly disintegrated into smaller particles, thereby increasing the aggregate fractions to less than 0.500 mm. This constitutes the main fraction of the stable micro-aggregates in Latosols. In the upper slope and hill top, larger organo-mineral aggregates, are formed from organic matter incorporation, which are only present at the surface, with decreasing values depending on depth (B horizon) and where minute micro-aggregates can be found. This point to the fact that fresh anthill materials are made by welded aggregates and form larger cemented clods (N 1.00 mm). These are further eroded by erosion and weathering processes after abandonment of anthills. Without much reliance on statistics, micro morphological observations strongly support this hypothesis and thin sections of anthill walls and adjacent soils clearly show smaller aggregates partially held together, when observed at microscopic level.

In the larger aggregates, mica particles, charcoal and charred materials are observed as being randomly scattered within the clay plasma, indicating the deep turnover of soil material in the anthills, since mica is virtually absent on the surface of Latosols. The landscape stability of these top positions supports a greater degree of weathering, relatively to lower and steep positions, and thus, accelerates micro-aggregation and Latosols formation. Other researchers have shown evidence of the formation of organo-mineral micro-aggregates and their stabilization through electrochemical and hydrogen bonding via exchangeable cations and organic compounds, as a result of the passage of mineral particles along the intestinal tract of the insects during humus digestion (Garnier-Sillam, Villemin, Toutain & Renoux & 1985; Garnier-Sillam & Harry, 1995).

Grassé (1984) and Jungerius, Van den Ancker and Mucher (1999) also reported that soil materials which are reworked in mandibles of insects with the addition of saliva has also been classified as a process of aggregate production. However, the understanding of the action of the body fluids and digestive processes on the formation of the aggregates and their mineralogy is constrained by the lack of information on chemical composition of those fluids and insect biology (Grassé, 1984). Considerable number of researchers have reported the concentration of nutrients in termite anthills and surrounding soil (Watson, 1962; Pomeroy, 1983; Anderson & Wood, 1984; Coventry, Holt & Sinclair, 1988; Hullugale and Ndi, 1993; Lobry de Bruyn & Conacher, 1995), while other scholars also reported results on soil porosity transformations and particle size sorting (Anderson & Wood, 1984; Lobry de Bruyn & Conacher, 1990; Garnier-Sillam *et al.,* 1991).

In the lower slope, greater amounts of large aggregates in horizon A and B show that these kind of soils have a quite contrasting framework and field observations confirm that mildly podzolized Latosols (transitional between Oxisols and Ultisols) occur at that lower position, related to a moderate and medium sized blocky structure. This is associated to the greater intensity of wetting and drying cycles on these colluvial foot slopes, for oxic Ultisols found in that landscape position, as opinionated by Carvalho Filho (1989). With regard to Latosols, Sarcinelli *et al.* (2008) reported that the microstructure, of these soils in anthills could be compared to a “coffee powder” which confirms that indeed the termite's activity plays a key role on such soils. In this respect, they should be considered as a factor on Latosols genesis. However, there is need for further research in order to have conclusive scientific evidence on the matter. The microstructure of the anthills should be known as this affects the physical properties such as bulk density, porosity, infiltration rate and water retention capacity in general among others.

2.6 Biological Community in Anthill Soils

2.6.1 Bacteria, Fungi, Fauna Biomass and other Microbiota Organisms

Sleptzovaa and Reznikovab (2006) reported that besides ants, there are a number of other organisms like bacteria, fungi, actinomycetes, microarthropod, centipedes and millipedes which are inhabitants of anthills. Kotova *et al.* (2013) studied the bacterial complex associated with several species of ants, the inhabiting soil and their anthills and found that more than 80% of the majority of anthills were dominated by *Bacillus* whereas the anthill of

Formica was characterized by the Flavobacterium – Bacteroides – Cytophaga group. Further, actinomycetes were found to be widespread in the anthills of *Formica* sp and *Lasius* sp.

Numerous staphylococci (20%) were also found in the *L. flavus* anthills, but the major dominants of the bacterial community were Streptomyces bacteria (68.5%) while many Bacteroides (28%) were found in the anthills of Tetramorium. Actinomycetes from the genus Streptomyces were observed in the bacterial complexes of all studied ants, apart from *F. cunicularia*. Pokarzhevskij (1981), concluded that the abundant bacteria, actinomycetes and fungi in anthill induce many small soil invertebrates to come up, including springtails. In these anthills, ants play the role of ensuring a stable microclimatic environment (Horstmann and Schmid, 1986), which determines to a considerable extent the specific structure of a microarthropod community.

Springtails abundance and diversity depends on the growth and development of anthills. The abundance of springtails in large old domes with relatively constant humidity may significantly exceed their abundance in the surrounding soil and litter. Similarly, Stoev and Gjonova (2005) reported a diversity of Myriapods, a subphylum of Arthropoda containing millipedes and centipedes from anthills of *Formica sp., Camponatus sp. and Myrmica sp*. in the European country of Bulgaria. These Myriapods found dwelling in anthills encompasses *Brachydesmus sp., Polyxenus legurus, Megaphyllum sp.* and *Lithobius microps*. Schultz (2000) also opinionated that ants develop well in various environments including the anthills and constitute about 15-20% of the terrestrial animal biomass and this is more than that of the vertebrates. Future studies should nevertheless, consider the temperature requirements under which the fungi and ants as microbes thrive well because this may have an effect on biological community in anthills.

2.7 Soil Enzymes in Anthill Soils

Soil enzymes play key biochemical functions in organic matter decomposition in the soil system (Burns, 1983; Sinsabaugh, Antibus & Linkins, 1991). They act as important catalyst in several important chemical reactions needed for the life processes of micro-organisms in soils and provides stability to soil structure, decomposition of organic wastes, organic matter formation and nutrient cycling (Dick, Sandor & Eash 1994). Enzymes are continously being synthesised, accumulated, inactivated and/or decomposed in the soil, thereby playing an important role in agriculture and mostly in nutrients cycling (Tabatabai, 1994; Dick, 1997). Activities of enzymes in soils pass through complex biochemical processes accompanied by integrated and ecologically-linked processes for ensuring enzyme immobilisation and stability (Khaziyev & Gulke, 1991). In this respect, any soil type is composed of a number of enzymes that influence soil metabolism activities (McLaren, 1975) which, rely, on the physical, chemical, microbiological and biochemical properties.

The enzyme levels in soil systems vary in amounts owing to the fact that each soil type has different quantities of organic matter content, type of living organisms and the rate at which biological processes occur. In practice, the biochemical reactions are as a result of the catalytic contribution of enzymes and different substrates that serve as energy sources for micro-organisms (Kiss, Dragan-Bularda & Radulescu, 1978). Major enzymes in the soil may include amylase, arylsulphatases, β-glucosidase, cellulose, chitinase, dehydrogenase, phosphatase, protease and urease released from plants (Miwa, Ceng, Fujisaki & Toishi 1937), animals (Kanfer, Mumford, Raghavan & Byrd, 1974), micro-organisms and organic compounds (Dick & Tabatabai, 1984; James, Russel & Mitrick, 1991; Richmond, 1991; Hans & Snivasan, 1969; Shawale & Sadana, 1981) and soils (Cooper, 1972; Gupta, Farrell & Germida, 1993).

Knowledge of the role of soil enzymes activity in the ecosystem is critical as this would provide a unique opportunity for an integrated biological assessment of soils due to their crucial role in several soil biological activities, their ease of measurement and their rapid response to changes in soil management practices (Dick, 1994; Dick, 1997; Bandick & Dick, 1999). Other studies by scholars reveal that high enzyme activity is an indicator of mineral element limitation in the ecosystem (Sinsabaugh *et al.*, 1993; Makoi & Ndakidemi, 2008). Although there have been extensive studies on soil enzymes (Lizararo, Jorda, Juarez & Sanchez-Andreu, 2005; Mungai, Motavalli, Kremer & Nelson, 2005; Wirth & Wolf, 1992; Ross, 1976; Perucci, Scarponi & Businnelli, 1984), there is still scanty information on their roles in agricultural development. To better understand the roles of these enzymes' activity and efficiency, studying their presence in anthill soils are critical to know for contribution to nutrients availability such as nitrogen, phosphorous and potassium etc.

2.8 Nutrient Dynamics in Anthill Soils

Although initial work of Darwin on the effects of earthworms on soil formation (Darwin, 1881), influenced later research developments, soil chemical, physical and mineralogical properties have still received much more little attention than soil fauna by pedologists or geomorphologists. However, many soil organisms transform the environment in which they live, through physical and biotic conditioning, in both absolute and relative terms to resources availability. Since the early days of pedology, Dokuchaev remarked that "soil animals were not merely soil inhabitants, but played a vital role in most soil reactions". Termites (Isoptera) are social insects numbering about 3000 known species, from which an estimated 75% are classified as soil-feeding termites. The diet of soil-feeding termites consists of no cellular organic material mixed with clay minerals. Their gut is formed by five compartments that present rising scales of pH, up to 12.5, and different status of oxygen and hydrogen (Brune, Miambi & Breznak, 1995; Brune & Kühl, 1996; Donavan, Eggleton & Bignell, 2001). These attributes are surely important and could effectively be described as contributors to anthill soil chemical and physical alterations.

Termites are also referred to as "ecosystem engineers" (Dangerfield, McCarthy & Ellery, 1998) as they enhance soil changes by disturbance processes. Termites collect organic matter and mineral particles from different depths and deposit them in anthills, thereby accelerating the content of organic C, clay and nutrients. Also, pH and microbial population is reported higher in anthills than in surrounding soils (Lal, 1988; Black & Okwakol, 1997; Holt, Coventry & Sinclair, 1998). The material accumulated is redistributed by erosion, affecting soil micro-structure and fertility (Lee & Wood, 1971; Black & Okwakol, 1997; Dangerfield *et al.*, 1998; Jungerius *et al.*, 1999; Schaefer, 2001). Termites also participate in construction of galleries that increase soil porosity and water infiltration (Mando & Stroosnijder, 1999; Leonard & Rajot, 2001) and these galleries are filled up with top soil materials. Rainfall contributes to the process of formation of deep, uniform Latosols (correlated to the Oxisols in the Soil Taxonomy) (Schaefer, 2001).

The composition of clay in anthills is normally 20% higher than in surrounding soils, but it is not known whether termites choose particles, or soil undergoes a physical fractioning through their guts (Lee & Wood, 1971; Donovan *et al.*, 2001; Jouquet, Lepage & Velde, 2002). It is also true to opinionate that clay minerals are transformed as soil particles are handled in their mouths or pass through their guts. In this regard, Schaefer (2001) reported that kaolinite become less crystalline after passing through termite guts, due to high pH levels. Although literature reports the role of termites in anthill soil transportation, particle size sorting, nutrient concentration, organic matter turnover, greater porosity, organo-mineral micro aggregation, aggregate stabilization, erosion effects, among others, there is still very little information concerning pedogenesis, landscape evolution and nutrient dynamics in agricultural systems involving Anthills.

2.9 Water Productivity and Soil Moisture Retention in Anthill Soils

Ali and Talukder (2008) indicated that in crop production system, water productivity (WP) is used to define the relationship between crop produced and the amount of water involved in crop production, expressed as crop production per unit volume of water. Crop production may be expressed in terms of total dry-matter yield or seed (or grain) yield (kg) or, when dealing with different crops, yield may be changed to monetary units (e.g USD or any other legal tender in a given situation). More options are available to define the amount of water. Different water productivity indices are from various alternatives as shown below in the following equations:

WP_1= Grain or seed yield/ Water applied to the field (kg/ha/cm) [Equation1]

WP_2 = Total dry matter yield/ Water applied to the field (kg/ha/cm) [Equation 2]

WP_3 = Total monetary value/ Water applied to the field ($\$/m^{-3}$) [Equation 3]

With effectiveness of water use in a single crop being described, Equations [1] or [2] is appropriate. However, if comparison is being done at regional level, or the effectiveness of water use by different ethnic groups or under scarce water situations without land limitations is studied, then we can use Equation [3] (Ali & Talukder, 2008).

Soil moisture retention is one of the key factors that affect water productivity in agriculture production. Loss of water from the soil surface through evaporation influences plant growth during germination and seedling establishment, including other growing periods. The texture of the soil and organic matter content determine the water storage and release properties. When the soil dries rapidly, it does not provide osmosis process and thus affects yield and water productivity. The nutritional condition of upcoming crops, especially nitrogen, can significantly influence the speed of development of leaf area thereby causing evaporation losses from the soil. Organic matter in soil environment undergoes chemical processes involving microbial activities and nutrients present.

In terms of water productivity and soil retention of anthill soils, there is little information reported on this aspect. However, other literature reveals that anthill soils generally have high clay content and this enhances water storage capacity (Jouquet *et al.*, 2002). When soils with low water retention capacity are common and anthill soil is spread on these soils it results in a higher soil moisture content and improved crop growth. This implies that anthill soils could have high water productivity. Further research is nevertheless needed to prove the effectiveness and efficiency under agricultural production conditions.

2.10 The Potential of Anthill Soils in Integrated Soil Fertility Management (ISFM)

Place, Barrett, Freeman, Ramisch and Vanlauwe (2003) defined integrated soil fertility management (ISFM) as a set of best cultural practices, preferably used in combination, including the use of appropriate germplasm, fertilizer and of organic resources coupled with best agricultural practices (BAPs). This aspect is seemingly becoming acceptable to development organizations in sub Saharan Africa (SSA), and to a large extent, to the small-holder farmers. ISFM entails widening the choice set of farmers by enhancing their awareness of the variety of options available and how they may complement or substitute for one another. Vanlauwe (2015) noted that ISFM can act as a conduit for enhancing crop productivity while maximizing the agronomic efficiency (AE) of applied inputs, thereby contributing to sustainable intensification. The degree of variability in soil fertility conditions and the soil challenges which are beyond those addressed by fertilizer and organic inputs such as anthill soils are considered within ISFM amongst the smallholder farms.

Different biophysical environments that are common amongst smallholder farming systems affect crop productivity and the associated AE. In this regard, targeted application of inputs including management practices is critical for enhancing AE. Further, decisions for management squarely depend upon the farmer's capacity and production objectives. Soil fertility restoration in SSA is seen as extremely important towards contributing to the efforts of poverty alleviation. Soil fertility is crucial because poverty in Africa affects mostly the rural people where the per capita arable land has reported reduced from the initial 0.530 to 0.350 hectares during the period 1970 and 2000 (Food and Agriculture Organization Statistical Database, 2002).

Accelerated and sustainable agricultural intensification is required. However, intensification, increased agricultural productivity and improved rural livelihoods relies on investment in soil fertility. African soils demonstrate numerous constraints that encompass physical soil loss from erosion, nutrient deficiency, low organic matter, aluminum and iron toxicity, acidity, crusting, and moisture stress. Some of these constraints occur naturally in tropical soils, but degradation processes related to land management exacerbate them. Estimates suggest that about two-thirds of agricultural land is degraded, with 85% caused by wind and water erosion (Oldeman, Hakkeling & Sombroek, 1991). Limited use of nutrient inputs among smallholder farmers exacerbates soil nutrient deficiency.

In the late 1990s, it was reported that fertilizer use in Africa was averaging about 9 kg per hectare and that this scenario does not seem to have changed (Henao & Baanante, 2001). The estimated losses, due to erosion, leaching, and crop harvests are over 60 – 100 kg of N, P, and K per hectare each year in Western and Eastern Africa (e.g. Stoorvogel & Smaling, 1990; de Jager, Kariuku, Matiri, Odendo & Wanyama, 1998). Promotion and use of locally available organic resources such as anthill soils for improving soil fertility as alternative for the cash constrained farmers who cannot afford to buy inorganic fertilizer could hold the key. However, there is less information regarding the application rates of anthill soils and/or in combination with other soil amendments for optimum crop productivity. This calls for research on combining appropriate soil amendments practices such as organic and inorganic fertilizers with anthill soil and come up with useful ISFM program for use by small scale farmers where these resources are available.

2.11 Effect of Anthill Soils on Plant Growth

The ISFM concept acknowledges the need for both organic (e.g anthill soils, cattle manure) and mineral inputs for maintaining soil health and crop production as they interact and complement each other (Buresh, Sanchez & Calhoun, 1997; Vanlauwe, Diels, Sanginga & Merckx, 2002a) which accelerates plant growth. The most common organically based soil nutrient practices by smallholder farmers include; cattle manure, compost, crop residue incorporation, fallowing (natural and improved), intercropping of legumes and biomass transfer. Although our focus is on soil nutrient management practices, there are a number of other management practices that contribute to soil fertility, which include soil conservation and tillage techniques, weed management and cropping strategies. The old thinking has been that organic resources are sources of major soil nutrients such as nitrogen (N). Palm, Gachengo, Delve, Cadisch and Giller (2001) indicated that research by other scholars has been done on quantifying the availability of N from organic resources influenced by their resource quality and the physical environment. More recently, other contributions of organics extending beyond fertilizer substitution have been emphasized in research, such as the provision of other macro and micro-nutrients, reduction of phosphorus sorption capacity, enhancing carbon/organic matter, decreasing soil borne pest and disease through crop rotations and increment of soil moisture status (Vanlauwe *et al.,* 2002a).

There are some key differences in the way that the organic systems contribute to soil fertility. Agriculture practices involving nitrogen-fixing species add extra quantities of nitrogen without depleting the nutrients from the soils. Organic sources will differ in terms of nutrient content and how the organic compounds are made available to the crop including the provision of other soil fertility benefits (e.g. weed reduction). Agronomic practices also determine the effectiveness

of organics. Other organics like anthill soils where available at farm level could also play a significant role in enhancing crop productivity owing to the fact that they have higher N content which is crucial in plant development.

It is however known that organic and mineral inputs cannot be substituted entirely by one another and are both required for sustainable crop production (Buresh *et al.*, 1997; Vanlauwe *et al.,* 2002a), due in part to (a) practical reasons fertilizer or organic resources alone may not provide sufficient amounts or may be unsuitable for alleviating specific constraints to crop growth (Sanchez & Jama, 2002), (b) the potential for enhanced benefits created via positive interactions between organic and inorganic inputs in the short-term and (c) the several roles each of these inputs play in the longer range. Where these are used in combination, they help to reduce the costs of crop production.

One key complementarity is that organic resources such as anthill soil enhance organic matter status and the functions it supports, while mineral inputs can be targeted to key limiting nutrients. There have been efforts made focusing on quantifying the amount of accrued including the systems responsible for creating them. Vanlauwe *et al.* (2002b) indicated clear interactions involving urea and use of organic applications such as crop residues while Nhamo (2001) reported extra benefits from manure and ammonium nitrate combinations. Although the above list of observed strong interactions between organic and mineral inputs is not exhaustive, very often these inputs are demonstrated to have only additive effects. But because of declining marginal increases from one single type of input, the additive effects are often superior in terms of overall yields and net financial returns, as shown by Rommelse (2001) on maize in Kenya. Negative interactions are never observed.

In brief, it is observed that there is considerable evidence showing the key contributions of organic matter alone to agricultural crop yields. There is little, nevertheless significant proof pointing to the positive short and long term impacts of ISFM technologies integrating organic and mineral nutrient sources. More economic analyses of these systems and evidence from farmer-managed practices are needed. One important aspect to note is that most agronomic research on ISFM has taken place on cereal crops. However, much organic and inorganic fertilizer use by smallholders is focused on higher value crops for which the effects of organics such as anthill soil and ISFM remain under-researched.

2.12 On-farm Integrated Soil Fertility Management (ISFM) Practices by Smallholder Farmers

Various scholars have indicated that a number of smallholder farmers in Africa, use a wide range of ISFM practices and involves legume intercropping (cowpeas, soybeans, common beans, groundnuts, pigeon peas, lablab, bambara nuts etc) and cattle manure which are well established practices. Omiti, Freeman, Kaguongo and Bett (1999) indicated that in Kenya, farmers who utilized manure in semi-arid and semi-humid areas of Nairobi ranged between 86% and 91% respectively. However, only 40% of the farmers used compost, but by few farmers especially in the more arid sites. In severe humid western highlands, 70% of farmers were reportedly used manure and 41% used compost while 20% of them were engaged in using biomass transfer and improved tree fallows (Place *et al.*, 2002a). In a related study by Clay, Kelly, Mpyisi and Reardon (2002) in Rwanda, it was found that 49% of households' plots received organic nutrient inputs. Rotations involving legumes and green manure systems were common in 48 and 23 percent of extension sites in Zimbabwe (Gambara, Machemedze & Mwenye, 2002). Higher practices of alley farming were reported in areas of Nigeria (Adesina & Chinau, 2002) and of *Mucuna* fallows in Benin and Cameroon (Manyong and Houndekon, 2000). Inspite of varying adoption rates between organic and mineral nutrients in terms of area, the use of organic practices such as natural fallowing and animal manure have always been more than the use of inorganic fertilizers.

In Rwanda, the scenario was abit alarming where only 2% of plots received mineral fertilizer. There is however, less information available on the quantities of organic nutrients applied, but it is common knowledge that smallholder farmers often face the challenges of increasing opportunity costs and in this regard, the amounts produced and applied are sparingly limited. Place *et al.* (2002a) indicated that in terms of profitability, evidence of positive returns is reported for biomass transfer and improved fallows including manure (Mekuria & Waddington, 2002). Positive returns are often found for inorganic fertilizer inputs (Kelly, Sylla, Galiba & Weight, 2002; Shapiro & Sanders, 2002) and for integrated inorganic-organic systems (Place *et al.,* 2002a; Mekuria & Waddington, 2002).

Further, Mekuria and Waddington (2002) opinionated that the ISFM practices of manure and fertilizer on maize in Zimbabwe was reported to have labor profitability of about $ 1.350 per day, while the best sole fertilizer or manure treatment produced only $ 0.250. While more economic analyses of farmer-managed ISFM systems are needed, existing evidence suggests that organic or ISFM systems could be profitable where purchased fertilizer alone remains unattractive. Farmers in Kenya are known to practice ISFM on their agriculture fields. Freeman and Coe (2002) found that 37% of farmers in the relatively drier zones of Kenya integrated organic and mineral fertilizers. Additionally, 10% were using other organic sources but without mineral fertilizer. In the western Kenyan highlands, more than 66% of farmers using mineral fertilizer also utilized cattle manure (Place *et al.,* 2002a). Murithi (1998) reported several sources of nutrients used on a number of crops in central Kenya. This is generally true of areas where livestock are important and markets for fertilizer exist. In western Kenya, it was also reported that where ISFM practices have been used, soils have improved and the farmers have increased their yields of maize and legume crops (soybeans, climbing and bush beans) by about 60% and 46% respectively (Alliance for a Green Revolution in Africa & International Institute of Rice Research, 2014). In Uganda, it was found that there is little integration of organics and mineral fertilizer, partly due to poor fertilizer availability.

In Malawi, there is utilization of green manure and mineral fertilizer systems, where farmers use both pigeon pea intercrops and fertilizer (Peters, 2002). As with manure, farmers have shifted promising innovations using integrations of organic and mineral fertilizers onto higher-value commodities such as vegetables (Place *et al.*, 2002a). Organic sources that provide a dual benefit (e.g. food) have a higher preference by farmers. Organic nutrient systems are commonly more affordable to financially constrained farmers than fertilizer options.

Mekuria and Waddington (2002) indicated that because livestock ownership is strongly related to household incomes, wealthier farmers are more likely to use manure than poorer ones. In contrast, (Place *et al.,* 2002c) found that resource constrained farmers use agroforestry-based nutrient systems and compost in western Kenya. However, there is concern that as land sizes continue to shrink, noting niches for producing any type of organic nutrient source will become far-fetched. In brief, evidence from across SSA shows that there is considerable use of organic inputs, normally with less widely used mineral fertilizers. It should be noted here that profitability of alternative nutrient input sources depends largely on yield gains and market scenarios, as emphasized by generally more use on higher valued commodities. However, critical evidence on ISFM profitability is little, leading to a serious research gap which calls for further investigation. In addition, although farmers use organic nutrient inputs such as anthill soil in agriculture production, the rates still remain to be known.

2.13 Economic Benefits of Anthill Soils

Miyagawa *et al.* (2011) in their study of the Indigenous utilization of anthill soils and their sustainability in a rice-growing village of the central plain of Laos, Indo - Chinese peninsula found that if the resource is available in abundance, it could be used as a fertilizer for rice growing to increase rice yield without buying chemical fertilizer. The scholars also observed that none of the farmers sold or gave away anthill soil from their own land. It was essentially meant for self-sufficiency in the farming systems of the local communities. Further, the study concluded that anthills were not only used for soil amendment as a fertilizer but also as beds for vegetable production and construction of charcoal kilns. However, this depended on the architecture of the anthill. There is still little information reported on the economic benefits of using anthill soils in crop production in literature.

2.14 Summary of Literature Review

This review has demonstrated that anthill soils are used in various ways in many parts of Africa for agriculture production. They possess great potential for use as fertilizer as they are rich in macro and micro nutrients such as P, K, Ca, Mg, organic carbon, Fe, Zn and Cu which can substantially contribute to better crop development. Given that the utilization of anthills may not be sustainable at present as most of the farmers who are using the resource in crop production tend to dig up and clear the anthills, subsequently affecting the ants in their construction of the nests, it is therefore incumbent that micro dosing technique in anthill soil application for crop production is taken on board as one of the options to conserve the anthills. In conservation agricultural systems, this can be implemented by applying the anthill soil in specific spots required by the crop for growth such as ripped lines or basin planting structures for ensuring maximum benefit.

The International Centre for Research in Semi-Arid Tropics (ICRISAT) has promoted the efficient utilization of fertilizer at farm level called micro dosing in west, central and southern Africa which is about enhancing crop productivity and production through precision fertilizer use efficiency techniques and involves applying small doses of the fertilizers at planting and or after 4 weeks of planting for ensuring that the root and crop development is fast once the seed accesses the nutrients applied in small dosages (ICRISAT, 2009). This technique could be a solution for enhanced productivity in conservation agriculture tillage systems given the circumstances under which most of the smallholder farmers find themselves in, with respect to their failure to apply precision agriculture techniques and it is believed that this technology could be critical in preserving the anthills from extinction which may not be used sustainably.

Studies regarding suitability of anthill soils in agriculture production and how they influence crop performance together with constraints encountered by smallholder farmers including activity of enzymes such as phosphatase and arylsulphatase in nutrients availability are isolated. Additionally, the additive effects of anthill soil on moisture retention dynamics and water productivity coupled with economic benefits in relation to other organic sources is modestly understood in agricultural crop production conditions.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Location

The study was conducted in Southern Province of Zambia in Pemba (16° 32' 0" South, 27° 22' 0" East) and Choma (Longitudes 26^0 $30^,$ and 27^0 $30^,$ East of Greenwich and Latitudes 16^0 and 17^0 $45^,$ South). Pemba and Choma Districts (Fig 2.) fall in Agro Ecological Zone (AEZ) IIa where maximum rainfall range from 800-1000 mm $yr^{-1}$and the dominant soils are the Lixisols, Regosols, Leptsols and Vertisols. The climate of Pemba is classified as Cwa by the Köppen - Geiger system, characterized by warm and temperate conditions. When compared with winter, the wet seasons have much more rainfall. Mean annual temperature is 19.5 °C while mean annual precipitation is 848 mm. The driest month is July, with 0 mm of rainfall. In December, the precipitation reaches its peak, with an average of 219 mm. The warmest month of the year is November, with a mean temperature of 23.1 °C, the coldest month is July (14.0 °C). Just like Pemba, the climate in Choma is classified as Cwa following the Köppen-Geiger system coupled with warm and temperate weather scenarios. In winter, there is much less rainfall than in wet season.

Annual mean temperature is 18.7 °C while that of rainfall is 805 mm, with July being the driest (0 mm of rain). Most precipitation falls in January (202 mm). November is the warmest month of the year (22.4 °C). In July, the mean temperature is 12.9 °C and is considered the lowest of the whole year. The principal vegetation in Southern Province of Zambia is the Kalahari woodlands, characterized by Mopane with patches of miombo woodland, Munga (*Acacia species*) and Termiteria (Mound vegetation). Southern Province landscape is dominated by three dominant topographic features; (a) The Choma-Kalomo Block located in the centre of the Province; (b) The escarpment and (c) The Zambezi valley (“graben”) in the east and the Kafue Flats in the north; The Choma-Kalomo Block consists of the larger part of Central African Plateau and originates from ancient (Precambrian) basement rock. Elevation range of the undulating surface is from 1200 – 1350 m above sea level.

The study districts are predominantly maize growing coupled with high practice of anthill soil utilization due to poor soils or lack of capacity by some farmers to purchase adequate inorganic fertilizer. Farmers in the two districts characteristically use hand hoes/ox-drawn-maize based farming systems. Predominant crops grown in the districts apart from maize include cowpeas, beans, groundnuts, sunflower and sweet potatoes.

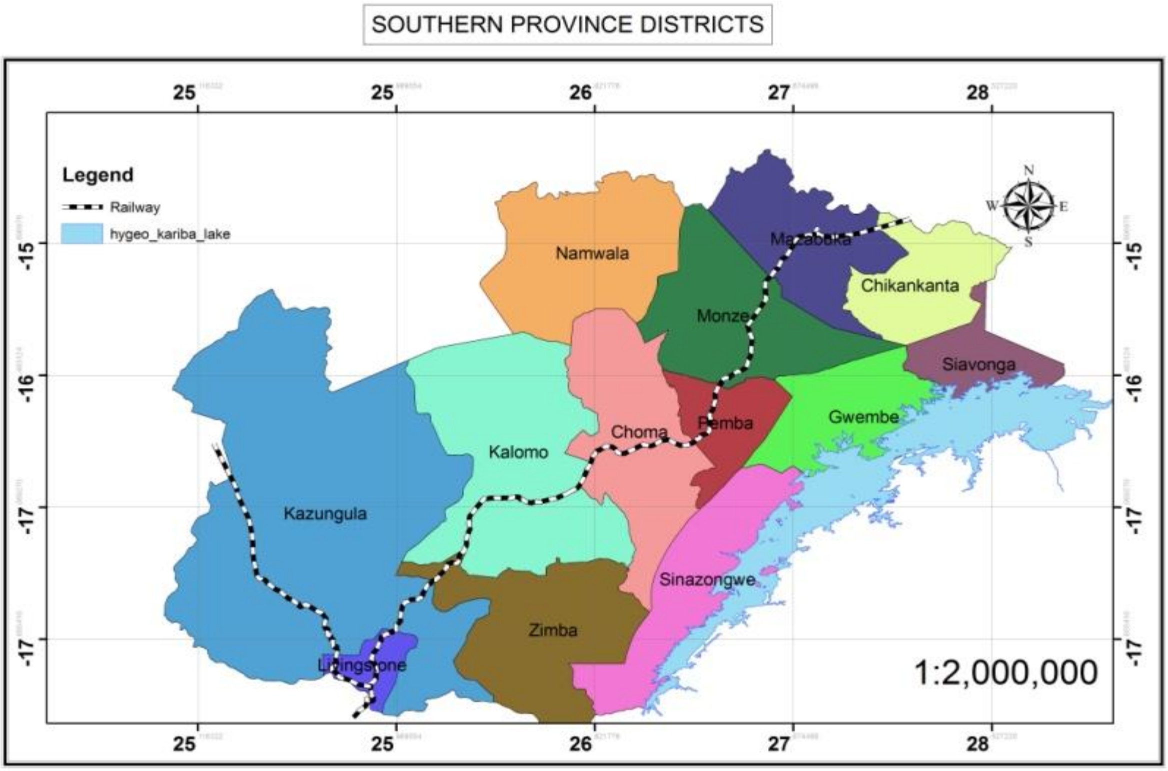


Figure 2: A Map showing study districts, Choma and Pemba of southern Zambia

3.2 Investigation of the Constraints and Opportunities of Anthill Soil Utilization in Conservation Agriculture (CA) systems

3.2.1 Development of Data Collection Tools

The initial step implemented was the development of data collection tools. This involved two stages. Firstly, a qualitative questionnaire was developed for key informants and focus group discussions. Secondly, a quantitative questionnaire was designed for household interviews. The household interview questionnaire was later converted into digital form using the Open Data Kit (ODK) tool. The ODK allowed the researcher to collect data on a mobile device and send collected data to a server which was aggregated and extracted in useful formats for further analysis (De Glanville, 2017). The study was then conducted in three stages in a chronological manner.

Firstly, the research team held key informant interviews in the respective study districts with public and private key decision makers (n=6) from Government departments and Non-Governmental Organizations to get their views regarding their knowledge on the status of anthill soil utilization and reasons for its use. Secondly, focus group discussions (n=4) were held with farmers with a view to hearing their insights on their experiences with anthill soil technology and lastly a quantitative data collection exercise was undertaken from the community (n=390) to get data from variables of interest which formed the basis for data analysis. This mixed method approach (Fig. 3) was adopted as it offered an opportunity to get strong collective views from both quantitative and qualitative research (Johnson & Onwuegbuzie, 2004). The survey questionnaire was organized to cover questions on household demographic characteristics, social assets, physical assets, human assets, natural assets, income sources, site characteristics, integrated soil fertility management practices, anthill soil utilization and management calendar, constraints and benefits to agriculture production and household access to agriculture technology information.

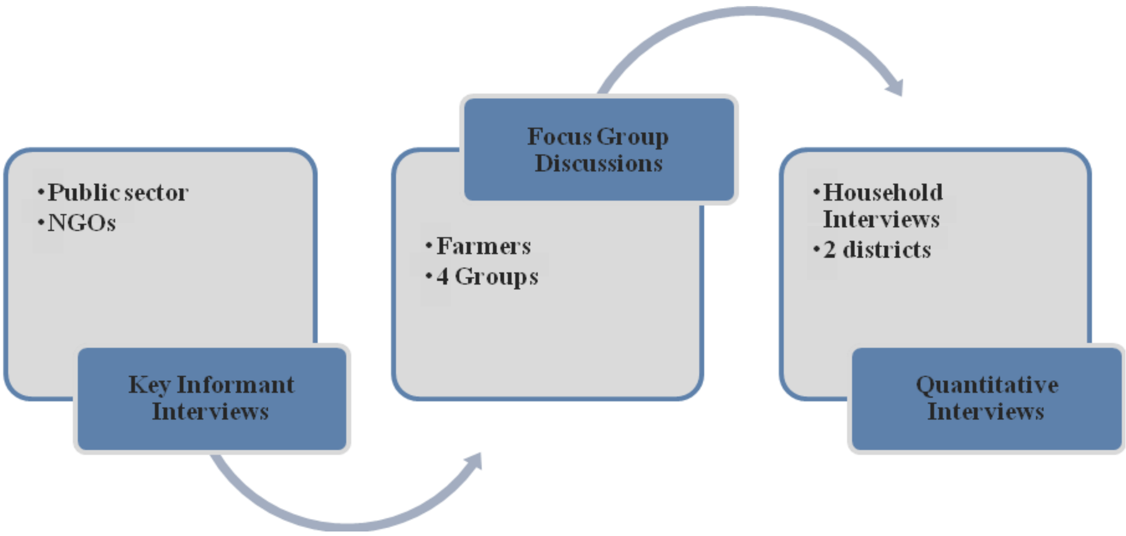


Figure 3: Schematic representation of the research process. Source: Author (2019)

3.2.2 Ethical Considerations

Before commencement of the present study, a verbal informed consent was obtained through the camp agriculture extension officer of the research sites at the time of recruitment of the participants to the study by reading and interpreting the designed consent form. This is in line with Campbell, Marsh, Mpolya, Thumbi and Palmer (2018), who reported that oral consent has an advantage over written consent as it includes all respondents of any literacy scale. The informed consent spelt out the purpose of the study and any likely benefits and disadvantages which were to be accrued. Interestingly, all of the participants welcomed the study and responded positively. The respondents' participation in the study was voluntary and each respondent had equal chance to agree or reject. Further, in recognizing the economic circumstances of participants, compensation for their time and commitment of their contributions to the research was done with drinks and snacks at the time of conducting meetings.

3.2.3 Household Sampling

In this study, a systematic farmer sampling strategy by village based on Agricultural Camp Register was employed with the aid of the Cochran method illustrated in Bartlett, Kotrlik and Higgins (2001), to determine the sample population using the formula; $N = [Z^2 (p) (1-p)/C^2]$; where $Z = 1.96$, $p = 0.5$ (% picking a choice response), c = confidence interval (0.95). This provided ~ 390 respondents across the two study districts whereby 4 Agricultural Camps/district with 48 farmers were interviewed on a structured questionnaire using Open data kit (ODK) Application on a smart phone. This gave a total of 196 surveys per study district. From the sampled population, 30% was reserved for women to engender the research process (NGP 2014). However, this study, only managed to capture 14% of active women involved in anthill soil technology practice.

Prior to data collection, 10 Enumerators were recruited and trained to help with administering the questionnaire using the ODK Application installed on a smart phone. Interviews were conducted in the local dialect, Tonga but the responses were recorded in English. Pre-testing of the digitized questionnaire was done to check for clarity, performance and ensure reliability. The timing of data collection was selected to coincide with the end of the harvest period – a time when most farmers spend less time on agricultural activities in the field.

3.3 Analysis of the Macro and Micro Nutrients of Anthill Soils

3.3.1 Anthill Identification and Testing

The first step for this activity involved anthill identification. This was done through use of indigenous knowledge and conventional means by characterization of the different types of anthills in the target study area in order to determine suitability for crop production. A tree which served as landmark some distance away was selected as basis for sampling areas. An area of 1000 m^2 was paced out from it where the corners were set and bench marked with wooden pegs. All the anthills in the area both used and non-used were counted as described by King (1981) and two anthills were selected at random for sampling as described in Nkem *et al.* (2000). Soil samples were taken at the depth of 0-20 cm from three points; top, base and 10 m away from the centre of the anthill. This was followed by physical and chemical analysis of the anthill soil. The chemical analysis focussed on the macro and micro nutrients i.e N, P, K, S, Mg and Ca and Fe, Mn, Zn and Cu respectively.

3.3.2 Termite Mound Sampling Design

Prior to collection of soil samples from termite mounds, a field research permit was obtained from the IRB (Approval No. 2018-Feb-046). Subsequently, a rapid appraisal of the study areas was undertaken during the cropping season to identify the mounds which were in use for crop production by the smallholder farmers. In an area of 1000 m^2, six plots measuring 50 x 20 m were marked out, with corners set and bench marked using pegs. All the anthills in the area both used and non-used were counted and two anthills were selected at random for sampling (Sarcinelli *et al.*, 2009). Soil samples were taken at the depth of 0-20 cm from three different points; top, base and 10 m away from the centre of the anthills using an augur (Illustration 1). A composite sample made up of three subsamples were collected, thereafter a representative sample of close to one kg of soil was packed in a plastic, labeled and taken to the laboratory. All the collected soils were air dried and sieved through a two milimeters-sieve.

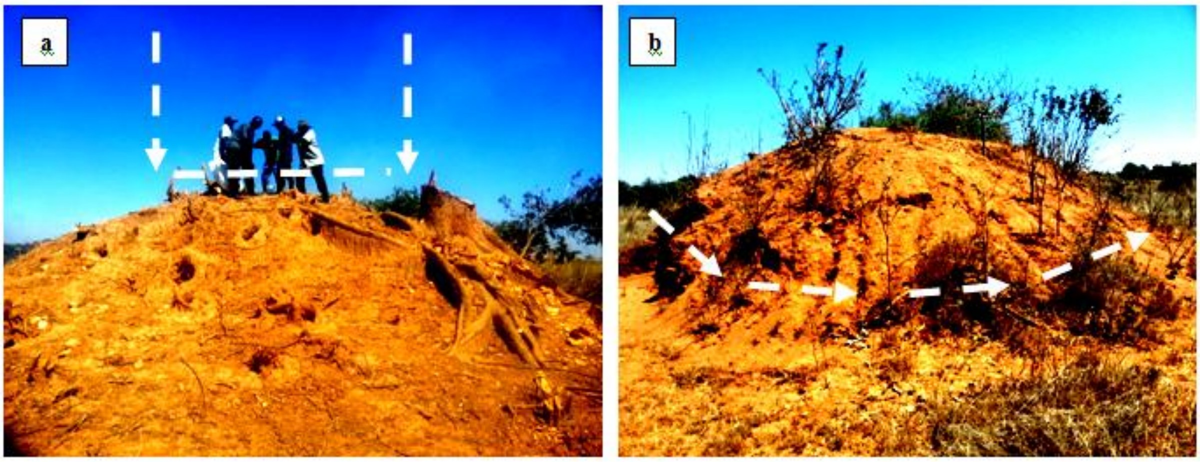


Illustration 1: Photographs of anthill soil sampling points. (a) Soil collection at the top of the anthill (b) Soil collection along the base of the anthill (Photos: K. Chisanga)

3.3.3 Laboratory Analysis

The Soil pH in water was estimated by a pH meter (LASEC, ACCSEN) in a soil water ratio of 1 – 2.5 as described by Van Reeuwijk (1993). Available P was extracted following Bray-1 procedure, for non-calcareous by shaking 1 g of air dried soil in 10 mL of 0.025 M HCl and 0.03 M NH_4F for five minutes. Available P was determined on the filtrate by the molybdate-blue method using ascorbic acid as a reductant. Color development was measured using uv vis spectrophotometer at 884 nm wavelength (Bray & Kurtz, 1945). Organic carbon was determined, following sulfochromic oxidation titration method (Walkley and Black, 1934). Total N was determined by The Tecator standard Kjeldahl method which involved a two-step process. Firstly, the sample in a ratio of one gram of Kjeldahl catalyst mixture to 2 mL of 98% sulfuric acid underwent a sulfuric acid digestion that converted Oxygen and Nitrogen (ON) compounds to NH_4^+. Secondly, the converted NH_4^+, along with any NH_4^+ that was originally present, was further converted to NH_3 in an alkali distillation process.

The NH_3 liberated in this process was then quantified to determine the total N in the original digest. A separately determined value for NH_3 and NH_4^+ was then subtracted from the value obtained by the Kjeldahl method, and the difference was the mineralizable, or potentially plant-available, ON (Page, 1982). The Cation Exchange Capacity (CEC) was extracted with MNH_4OAc solution at pH seven. The soil-solution slurry was shaken for two hours, and the solution was separated from the solid by centrifugation. The addition of NH_4^+ in excess to the soil displaced the rapid exchangeable alkali and alkaline cations from the exchange sites of the soil particles. The NH_4 exchanged soil was subjected to standard Kjeldahl distillation procedure. The exchangeable bases (Ca, Mg, Na and K) were extracted following similar procedure.

The concentrations of Na, K, Ca and Mg were subsequently analysed by Atomic absorption flame spectrophotometer, Version UNICAM 919 (Van Reewijk, 2006). Available metallic micronutrients that included Cu, Zn and Fe were extracted using the flame atomic absorption spectrometry as described by Lindsay and Norvell (1978). The measurement of electrical conductivity (EC) was estimated by weighing out 20 g soil in a 50 mL beaker after adding 40 mL of distilled water using ACCSEN COND8. Later stirring was done intermittently for four times and then left overnight in order to get a clear supernatant solution. The EC was then measured using the conductivity meter (Raina, Sharma & Sharma, 2007). Finally, the mineral part of the soil was separated into various size fractions and the proportions of these fractions were determined by the hydrometer method. The determination comprised all material, that included gravel and coarser material, but the procedure itself was applied to the fine earth (less than two millimeters) only. The pre-treatment of the sample was aimed at complete dispersion of the primary particles. Cementing materials i.e organic matter and calcium carbonate were removed. After this pre-treatment, the sample was shaken with a dispersing agent and sand was separated from clay and silt with a 63-μm sieve (VanReeuwijk, 1993).

3.4 Evaluation of the Effect of Anthill Soil Application on Growth and Yield Parameters of Maize

3.4.1 Screen House Pot Experiment

The initial step involved preliminary determination of the mineral nutritional value of the identified anthill soil types. This was conducted through a screen house pot study for a period of 42 days or 6 weeks (Adamu, Mrema & Msaky, 2015) with treatments set in a Completely Randomized Design (CRD). The number of replications was 6 with 10 treatments, where each substrate from the sampling points had 6 pots, giving a total of 60 pots. Before sowing, 100 kg of soil was homogenized with manure, fertilizer and anthill soil were weighed in portions and placed in each of the pots. Water was applied to the potted soil until field capacity moisture level followed by incubation for a period of one week with three days spacing.

3.4.2 Pot Filling Procedures

Prior to pot filling, fertilizer requirements (Basal fertilizer 20% or 50 kg P/ha and Urea/Top dressing 46% or 100 kg N/ha) were determined following Johnson and Askin (2003) formula as described in the text box below:

STEP: A B C D E

$$\text{g fertilizer/pot} = kg\ element\ /\ ha \times \frac{100}{\text{\% element in the fertilizer}} \times \frac{1}{100\,m \times 100\,m} \times \frac{1000\,g}{1} \times \frac{1}{100\,cm \times 100\,cm} \times \frac{pot\ area\ cm^2}{1}$$

$$= g\ fertilizer\ /\ pot$$

Surface Area of a Pot was determined using the formula; $A = (\text{л}r^2 + \text{л}r^2)/2$, where Top surface Area was = b = 7 cm and Bottom surface Area = d = 4.5 cm. Mean Pot Area was therefore calculated as **108.725 cm^2**

For converting anthill soil (5 t/ha) and manure (10 t/ha) rates to kg/ha to g/pot, the following procedures were performed which culminated in knowing the quantities of anthill soil and manure required per pot for the experiment:

Step 1: Converting kg Anthill Soil/ha or Manure/ha to g /pot

(i) Mass = Density (g/cm^3) x Volume (m^3) = M x V

(ii) Density of soil = 1.1 g/cm^3, Volume of Pot = 1.5 m^3

(iii) Mass of soil to fill Pot = Density x Volume (m^3) = 1.1 x 1.5 =1.65 kg

(iv) Mass = Density x Volume

(v) Mass = Density x (Length x Breadth x Height) = Density x Area x Height

(vi) Area = Length x Breadth = L X B

(vii) Volume = Area x Height

(viii) Volume of Soil/ha = L x B x H; 1 Hectare = 10 000 m^2; H = 0.2 m soil sampling depth

(ix) Volume of Soil/ha = 10 000 x 0.2 m = 2000 m^3

Step 2: Converting kg Anthill Soil/ha or Manure/ha to g /pot

(i) Mass of Soil in a Hectare = Density x Volume; Density = 1.1 g/cm3

(ii) = 1.1 x 2000 m^3 = 2200 g

(iii) Convert density from 1.1 g/cm^3 to kg/m^3

(iv) Therefore, mass of soil in kg/ha = 2.2 x 10^6 kg/ha

(v) Mass of soil/pot = 1.65 kg

Step 3: Application Rate for 5t /ha Anthill Soil and 10t/ha Manure

(i) 5000 kg anthill soil required = 2.2 x 10^6 kg

(ii) Then 1.65 kg mass of soil/pot required the following:

(iii) 5000 kg anthill soil = 2.2 x 10^6 kg soil/ha

(iv) y anthill soil in pot = 1.65 kg/pot

(v) Therefore, y = (1.65 x 5000) divided by 2.2 x 10^6

(vi) = 0.00375 or 3.750 g of anthill soil/pot while for the manure this was doubled to 7.500 g/pot

3.4.3 Seed Sowing

Three maize seeds were sown in each pot measuring 14 cm x 9 cm and 16 cm deep. After germination, maize was thinned to one plant per pot. During the experimental period, data were collected on growth parameters; plant height, girth, dry matter yield, plant uptake, leaflet length, width and area. The plant samples were later subjected to Nitrogen, Phosphorus and Potassium analysis based on the procedures by AgriLASA (2007). Plant uptake of N, P and K in the above ground biomass of the potted maize was estimated by multiplying nutrient concentrations with dry matter (Ndakidemi, 2014). The results of this study were then used for determining rates of anthill soil application on-farm. The proposed treatments for determining the rates were as provided in Table 1.

Table 1: Treatment Structure

Treatments	Description
T1	Anthill soil top
T2	Anthill soil base
T3	Fertilizer (Full rate)
T4	Fertilizer (Half rate) + Anthill soil top
T5	Fertilizer (Half rate) + Anthill soil base
T6	Manure + Anthill soil top
T7	Manure + Anthill soil base
T8	Manure
T9	Top dressing fertilizer + Anthill soil top
T10	Top dressing fertilizer + Anthill soil base

Note: In Zambia, the recommended rates for Basal and Top dressing fertilizer (NPK: 10% N, 20% P_2O_5; 10% K_2O and 6% S) blanket application is 200 kg/ha while for manure under conservation agriculture is 4000 kg/ha. Anthill soil was pegged at 5000 kg/ha

3.4.4 Research Trials Establishment

Field experiments with selected treatments from the pot study and 3 recommended hybrid maize varieties for southern Zambia were evaluated in split plot design generated using Gen Stat software, 15th edition, replicated 3 times and compared under a gradient of climate and soil types. Plot sizes of 5 m long x 4.5 m wide and inter plot distances of 1m apart (Fig. 4) were established in 2 sites, with planting basin structures and conventional tillage systems being tested. Two sites, one conservation agriculture and the other conventional were established side by side in each of the two study districts.

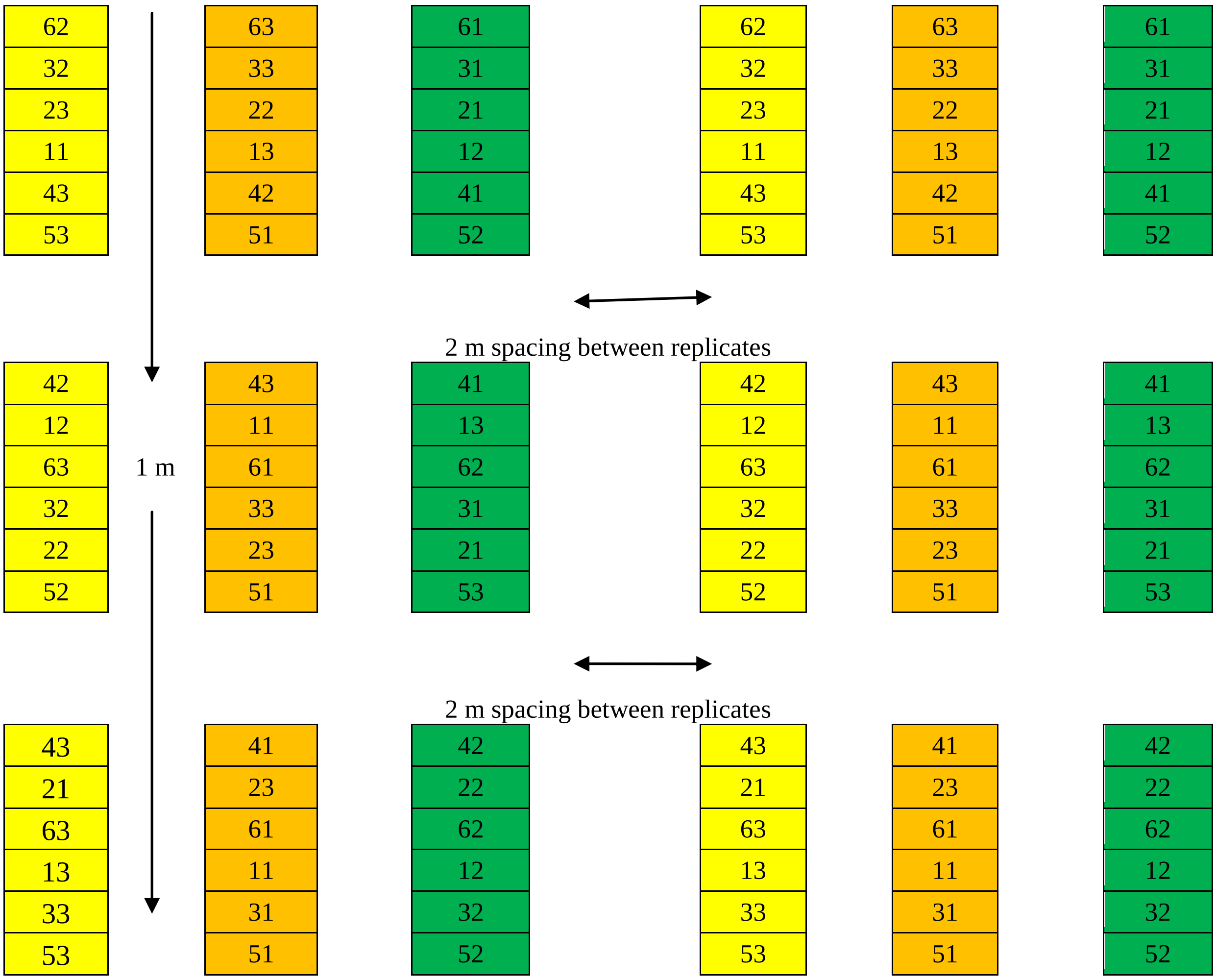


Figure 4: Experimental lay out at field level for conventional agriculture replications (left) and conservation agriculture plots (right). Numbers on the left within the plot represent treatments; 1 = anthill soil (5000 kg/ha); 2 = NPKS compound and urea $CO(NH_2)_2$ fertilizer full rate (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha); 3 = fertilizer half rate (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil top (5000 kg/ha); 4 = fertilizer half rate (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil base (5000 kg/ha); 5 = urea fertilizer (46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) + anthill soil top (5000 kg/ha) and 6 = cattle manure (10 000 kg/ha) + anthill soil top (5000 kg/ha), while those on the right depict maize seed varieties (1 = SC 403; 2 = PAN 413; 3 = ZMS 528)

3.4.5 Soil Sampling, Manure Collection and Analysis

Prior to establishing the trials, initial soil, anthill soil and manure samples were collected on research sites in order to determine the baseline status of the nutrients. Soil samples were taken from 0-20cm depth at each site using a soil auger in triplicate. A total of five sub-samples were randomly collected from each site and completely mixed to form a composite sample while manure samples were scooped from a heap using a spade. At the end of the study period, after harvest, soil samples were collected from near the roots of the crop on a plot by plot basis for determination of the effect of treatments on soil nutrients' dynamics.

The collected composite sample were subjected to air drying and passed through a 2 mm sieve in readiness for analysis. Nutrients of interest for analysis were pH, phosphorus, organic carbon, and nitrogen. The pH in water was measured using a pH meter (LASEC, ACCSEN) in a soil water ratio of 1-2.5 as prescribed by VanReeuwijk (1993). Bray-1 procedure was employed to extract available P. Organic carbon was determined, following sulfochromic oxidation titration method (Walkley & Black, 1934). Total N was determined by the Tecator standard Kjeldahl method. The exchangeable bases (Ca, Mg, Na and K) were extracted following similar procedure as stated above. The concentrations of Na, K, Ca and Mg were subsequently analysed by Atomic absorption flame spectrophotometer, Version UNICAM 919 (Van Reewijk, 2006) while available metallic micronutrients i.e Fe, Mn, Zn and Cu were extracted using diethylenetriamine pentaacetate (DTPA). Particle size analysis was done by the Bouyoucos hydrometer method.

3.5 Quantifying Phosphatase and Arylsulphatase Soil Enzymes Types and Nutrient Dynamics after Anthill Soil Application

3.5.1 Phosphatase and Arlylsulphatase Enzyme Estimation

Soil acid phosphatase and arylsulphatase enzymatic activities were determined following Sarathchandra and Perrott (1981) procedures. Phosphatase activity was determined by placing a quantity of field moist soil equivalent to 1 g oven-dry weight in a screw top tube (150 x 20 mm with a Teflon lined cap). A 1 mL p-nitrophenyl phosphate (115 mM) or p-nitrophenylsulphate (50 Mm) was later added. Following this was the addition of 3 mL of buffer (Modified Universal buffer) and sufficient water to make the total volume of the liquid up to 5 mL (exclusive of soil but including soil moisture). The tubes were then capped, swirled to mix and incubated in a water bath at 30 ^{o}C for 30 min (phosphatase) or 60 min (arylsulphatase). A 1 mL of 20% trichloroacetic acid (TCA) was added for phosphatase estimation (40% TCA for arylsulphatase) while mixing to stop the enzyme activity and then cooled in a 5°C water bath for 30 min.

A 10 mL diethyl ether was added (pre-cooled in the same water bath) to each tube, capped tightly and shaken for 60 min on a rotary shaker at room temperature. After cooling again at 5 ^{o}C for 30 min, a 5 mL aliquot from the ether layer was withdrawn from the tubes, while 5 mL of 0.5 NaOH was added in a 50 mL volumetric flask and mixed thoroughly. Ether was then evaporated by placing the Rask in a hot water bath (Mixing of the ether extract with NaOH solution before evaporation of the ether is essential as evaporation of the ether extract alone can result in low and variable recovery of p-nitrophenol). The flask was later cooled and diluted to the mark with distilled water.

The absorbance was estimated at 400 nm to calculate the p-nitrophenol concentration by reference to a calibration graph constructed using p-nitrophenoi standards. These standards were prepared in screw capped tubes by adding1 mL of a solution containing various concentrations of p-nitrophenol ranging from 0-4000 µg mL and 3 mL of the appropriate buffer to 1 g of the soil under study. The liquid volume was made up to 5 mL with water in screw-capped tubes, and treated as described for the enzyme assay. The activity of aryl-sulphatase and phosphatase enzymes was measured on account of understanding the role of sulphur in plants health and for agriculture soils in mobilizing S. Phosphatase was also considered in the present study because phosphorus is one of the limiting nutrients in soils of southern Zambia where this study was conducted.

3.5.2 Plant Tissue Analysis

Random sampling of first mature leaf from 20 plants in a plot was done after seedling stage but prior to or at tasselling (Thom, Brown & Plank, 2000). Plant samples were subjected to drying at constant weight, 60 ^{0}C in an oven for 48 hrs (Plate 4) and ground into powder for analysis of major nutrients of interest that included nitrogen, phosphorus and potassium.

3.6 Determining the Additive Effects of Anthill Soil Application on Moisture Retention and Water Productivity

In this study water productivity (WP) was computed as total Grain yields (kg) and agricultural water use (mm, m^3) over the cultivated area following Bouman *et al.* (2007) as illustrated in the following formula:

$$\text{Water Productivity (WP)} = \frac{\text{Crop produced (kg/ha)}}{\text{Water consumed (mm, } m^3)}$$

Agriculture water use was estimated as millimeter (mm) of rainfall received per research site which was later transformed to m^3 $ha^{-1}$where 1 mm is equivalent to 10 m^3 ha^{-1}.

During the crop growing period, soil moisture content was routinely determined per plot (Gitari *et al.,* 2019) for all the 216 established plots across the study sites in a 4-week interval using a digital soil moisture meter (4 in 1 soil survey instrument ϕ5 mm x 200 mm, Germany). The soil moisture content was taken by inserting the probe in between the maize crop plants, straight up and down, about half way between the plant stem. Several readings were taken per plot (5 in total) in order to confirm the findings. The data were then recorded as means in each plot treatment for every growing period. The moisture data were recorded as either dry+, dry, normal, wet or wet+. The moisture display area on the meter had 5 levels each increasing in wet.

3.7 Establishing Potential Net Economic Benefits of Maize Crop supplied with Anthill Soils and Other Organic and Inorganic NPK Sources

In order to determine the net economic benefits of using anthill soil against other organic and inorganic NPK sources, biophysical and social economic data were collected with a focus on grain yield, dry biomass and core weights and revenue per hectare from maize grown under different treatments from field trials. The net return per hectare was estimated for each maize yield observation (kg/ha) produced by each treatment, based on the maize market price series and the variable costs of each treatment. Variable costs, farm gate prices of maize and input costs were recorded during the period of the study. This was later applied to compute the net benefits of each treatment using Gross Margins Analysis.

Gross margins were measured to evaluate the financial benefits of different treatment options undertaken in this study. Costs of production involved in the analysis encompassed fertilizers, seed, labour for land preparation, planting, weeding and harvesting. Costs of inputs and producer price of maize were determined using the prevailing market prices. Economic returns and reduction in production risk are some of the factors that influence farmers' decisions to adopt new technologies.

3.8 Data Management and Analysis

3.8.1 Household Surveys

Collected qualitative data from household surveys were initially cleaned and there after analysis was undertaken using triangulation method and Computer Assisted Qualitative Data Analysis Software (CAQDAS), Nvivo version 10 while data from structured questionnaires were subjected to the Statistical Package for Social Sciences (SPSS). Origin Pro 9.0 software (www.originlab.com) and Microsoft Excel (version 2010) were used for graphical representations and special computations. Chi-Square (χ^2) test (McHugh 2013; Leech, Gormley & Seddon, 2008) was used to determine at 95% confidence interval any association between smallholder farmers' start year of using anthill soil to improve soil fertility and access to credit facilities and also use of mineral fertilizer. The multinomial logit model was further applied to analyze determinants of smallholder farmer's selection of anthill soil utilization in their agriculture crop production systems. The model adopted (Abdul, Bee, Xie & Huat, 2018) for anthill soil utilization determinants with possible conditional probabilities were specified as:

$$P(Y = 0|x) = \frac{1}{1 + e^{g_1(x)+\cdots+g_{c-1}(x)}}$$

$$P(Y = 1|x) = \frac{e^{g_1(x)}}{1 + e^{g_1(x)+\cdots+g_{c-1}(x)}}$$

$$P(Y = c-1|x) = \frac{e^{g_{c-1}(x)}}{1 + e^{g_1(x)+\cdots+g_{c-1}(x)}}$$

Where Y is an outcome and possible c value of (0, 1………, c-1); Y = 0 reference category and x = ($x_1 x_2 \ldots\ldots x_n$) = set of independent variables. Logit of category j against the baseline category was in the following form where j = 1, 2………………..c-1:

$$g_{j(x)} = \ln[P(Y = j|x] / P(Y = 0|x) = \beta_{j0} + \beta_{j1} x_1 + \ldots + \beta_{jp} x_p$$

β_{j0} is the intercept; $\beta_{j1} x_1, \beta_{jp} x_p$ are coefficients denoting independent variables determining use of anthill soil

3.8.2 Biophysical Data

Biophysical data had to undergo normality tests before analysis. All the data collected were then subjected to analysis with the aid of STATISTICA version 10 programme 2011 and GEN STAT, 15th edition (www.genstat.co.uk, VSN International), for the parameters of interest. Analysis of Variance (ANOVA) and Tukey's multiple comparison tests for significance differences among the treatment means was performed at 0.05 level of probability. Origin Pro 9.0 and Excel (2010 version) was applied for graphics and special computations. The study adopted the Snedecor and Cochran (1989) statistical model (Equation 1) and Wang and DeVogel (2019) factor effects statistical model (Equation 2) for data analysis concerning the pot experiment and soil data. The linear statistical model (Equation 3) for split-plot design (Alam *et al.*, 2018) was applied for the field experiments as specified below:

$Y_{ij} = \mu + T_i + \beta_j + E_{ij}$ for i = 1, 2...b; j = 1, 2...t (Equation 1)

where Y_{ij} = observation for each of the treatments; μ = overall mean; T_i = effects due to treatments; β_j = effects due to the block; E_{ij} = variation within treatments and blocks (i.e., error term)

$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{i.j} + \varepsilon_{ijk}$ for i = 1, 2...b; j = 1, 2...t; k = 1, . . . , nij (Equation 2)

where Y_{ijk} = observations; μ = grand mean; α_i = main effects of factor A; β_j = main effects of factor B; $(\alpha\beta)_{i.j}$ = interaction effects between factor A and B; ε_{ijk} = error term.

$Yijk = \mu + \tau i + \beta j + (\tau\beta)ij + \gamma k + (\tau\gamma)ik + (\beta\gamma)jk + (\tau\beta\gamma)ijk + \varepsilon ijk$ (Equation 3)

i = 1,2,…,rj = 1,2,…,ak = 1,2,…,b; where, τ_i , β_j and $(\tau\beta)_{ij}$ catalog the whole plot and γ_k, $(\tau\gamma)_{ik}$, $(\beta\gamma)_{jk}$ and $(\tau\beta\gamma)_{ijk}$ catalog the split-plot. Here τ_i, β_j and γ_k are block effect, factor *A* effect and factor *B* effect, correspondingly.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Investigation of the Constraints and Opportunities of Anthill Soil Utilization in Conservation Agriculture (CA) Systems

This section outlines results of descriptive statistics of the household characteristics who are involved in anthill soil utilization from the data collected during the survey in the study districts. Having insight of the socio and economic characteristics of smallholder farmers using anthill soils in their agricultural production is important as this may help to pinpoint factors that could explain the reasons behind their practice of the technology.

4.1.1 Household Demographic Characteristics

Females accounted for 14% of respondents and males 86%. The average age for respondents was 44 years with 70% married monogamy, 20% married polygamy, 5% widowed, 3% bachelors, 2% divorced, 1 % spinsters and 0.30% separated (Table 2). The demographic composition of a household has a huge influence on a farmer's choice of livelihood activities and contributes to income disparities. For instance, in an investigation on farming communities in the Democratic Republic of Congo, Bakkegaard Nielsen and Thorsen (2017) found that the marital status, family size and household age, influenced the income at household level resulting from the community's involvement in diversified livelihood strategies. From the foregoing we note that most of the respondents in the current study were married and this definitely contributed to making a choice for engaging in anthill soil utilization for crop production. Fang *et al.* (2014) also argued that the greater the human capital at household level, the more likely the farmers would choose agriculture as their main livelihood.

4.1.2 Social Assets

The majority (84%) were affiliated to social groups/organization. Results indicated that 71% of the respondents were associated with farmer cooperatives and this was key to accessing new information on farming practices including other livelihood strategies. Others reported a lot of conflicts (2%), having no money (2%), no benefits accrued (1%) and other reasons (6 %) as the contributing factors for not being affiliated to any social organization. Membership to social groups is important, especially for resource-constrained (poor, illiterate) smallholder farmers in technology adoption via the role of ensuring access to high standard inputs which encompass fertilizer and improved germplasm including credit schemes (Abebaw & Haile 2013).

4.1.3 Physical Assets

Mean numbers of agriculture physical assets owned by respondents in form of livestock were as follows; cattle (7), goats (9), poultry (19), pigs (1), sheep (1) and other livestock (4) while observed mean values for agriculture equipment accounted for cultivators (1), axes (3), ploughs (1) and other agriculture assets (2). For non-agriculture assets, the average number for beds was (3), television set (0), radio (1), bicycles (1) while for other non-agriculture assets the mean was 1.

In the current study, it was observed that livestock in form of poultry, goats and cattle are the major physical assets owned by the respondents coupled with some agriculture equipment such as ploughs, cultivators and oxcarts. The availability of these assets most likely contributed to the diversification of livelihood activities of the communities in the study districts. Hua (2017) stressed that ownership of physical assets is an incentive that drives communities to choose non-agricultural livelihoods and thus achieve transformed livelihoods.

4.1.4 Financial Assets

During the agriculture seasons of 2015/16 and 2016/17 respectively, most households indicated that their source of income in the period was accrued from sale of rain seed food crops ($ 382), sale of rain seed cash crops ($ 163) and petty trading ($ 143) respectively, for the farming season of 2015/16. This trend repeated itself in the following agriculture season of 2016/17 (Table 3). Pender, Place and Ehui (2006) stressed that different income strategies that smallholder farmers are engaged in, have a possible direct effect for the outcomes they are interested in and this also affect them indirectly when a decision is made regarding adoption of the technology and land management practices.

4.1.5 Natural Resource Assets - Land Resources

Based on the findings, this study observed that the respondents owned land for cultivation of various crops. However, 48 % reported having a challenge of security of land tenure while a further 41% acknowledged limited access to land as one of the land constraints faced on the farms. Most of the land in the study areas falls under the customary law, where the traditional leader has the authority and power of land distribution in the community. Regarding this, Pender *et al.* (2006) reflected that property rights and the type of land tenure possessed by the smallholder farmer, affect land management and productivity for various reasons. For instance, if there is insecurity of tenure, the household operating the plot may have less incentive to invest in land improvement. This may not be the case, however, if the smallholder can increase tenure security via investing in the land itself (Otsuka & Place 2001b). In this scenario, there may be more investment in the land with insecure tenure. Figure 5 depicts the land resource constraints as reported by farmers across the study districts.

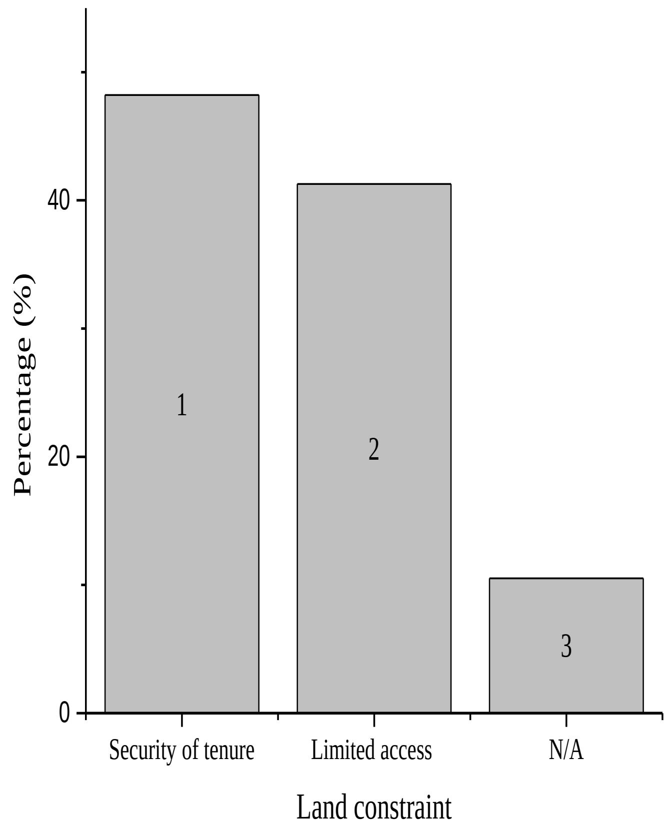


Figure 5: Land constraints faced on the farms across study sites

Table 2: Overall household demographic characteristics across the study sites

Variable	Mean (n=390)	Median (n=390)	Mode (n=390)	Std
HH size	9.00	8.00	8.00	3.20
HH Age	44.00	43.00	-	12.60
Number of male < 14 years old	2.40	2.00	1.00	2.03
Number of female < 14 years old	2.00	2.00	1.00	1.80
Number of male 15 - 49 years old	2.00	2.00	1.00	1.60
Number of female 15 - 49 years old	2.00	2.00	1.00	1.40
Number of male > 50 years old	0.30	0.00	0.00	0.50
Number of female > 50 years old	0.30	0.00	0.00	0.70
Number of biological girl children attending school	1.80	1.00	1.00	1.70
Number of orphaned girl children attending school	0.30	0.00	0.00	0.70
Number of biological girl children dropped out of school	0.30	0.00	0.00	0.90
Number of orphaned girl children dropped out of school	0.05	0.00	0.00	0.40
Number of biological boy children attending school	1.70	1.00	0.00	1.50
Number of orphaned boy children attending school	0.20	0.00	0.00	0.50
Number of biological boy children dropped out of school	0.30	0.00	0.00	0.70
Number of orphaned boy children dropped out of school	0.04	0.00	0.00	0.26

NB: n = number; HH = household; std= standard deviation

Table 3: Overall income sources (USD) across the study districts

Income Source (USD)	2015/16 Season				2016/17 Season			Std
	Mean (n=390)	Median (n=390)	Mode (n=390)	Std (n=390)	Mean (n=390)	Median (n=390)	Mode (n=390)	
Petty trading	143	0.00	0.00	382.3	125	0.00	0.00	275
Gardening activities	111	40	0.00	215	104	40	0.00	204
Local chicken rearing	69	20	0.00	175	64	15	0.00	258
Goat rearing	58	0.00	0.00	140	47	0.00	0.00	170
Cattle rearing	107	0.00	0.00	440	90	0.00	0.00	376.3
Remittances	13	0.00	0.00	79.3	12	0.00	0.00	53.1
Sale of rain seed food crops	382	0.00	0.00	1705	270	50	0.00	685
Rain seed cash crops	163	15	0.00	768	195	0.00	0.00	1060
Piece work	32	0.00	0.00	920	29	0.00	0.00	90
Charcoal sale	28	0.00	0.00	309	25	0.00	0.00	207
Other sources	44	0.00	0.00	400	47	0.00	0.00	320

NB: n = number; HH = household; std= standard deviation

4.1.6 Soil Characteristics of Sites

As noted by Waldman, Blekking, Attari and Evans (2017), the texture, structure, and physical characteristics of the soil in the study areas of Choma and Pemba districts are varied and on general scale have poor physical properties with low nutrients dominated by sand soils. This was no different from the findings in this study where in all sites across the districts, the major soil type as described by respondents was sandy (49%), clay (16%), loamy (15%) and a mixture of sandy loamy (12%), sandy clay (4%) and clay loamy (4%) respectively (Fig. 6). In terms of vegetation characteristics, most of the study area is composed of savanna dominated by *Hyperrenia* grass species. Given the major soil type in the study areas, it is justifiable that most smallholders turn to anthill soils as an alternative to industrial fertilizers for soil fertility enhancement required to boost their crop yields.

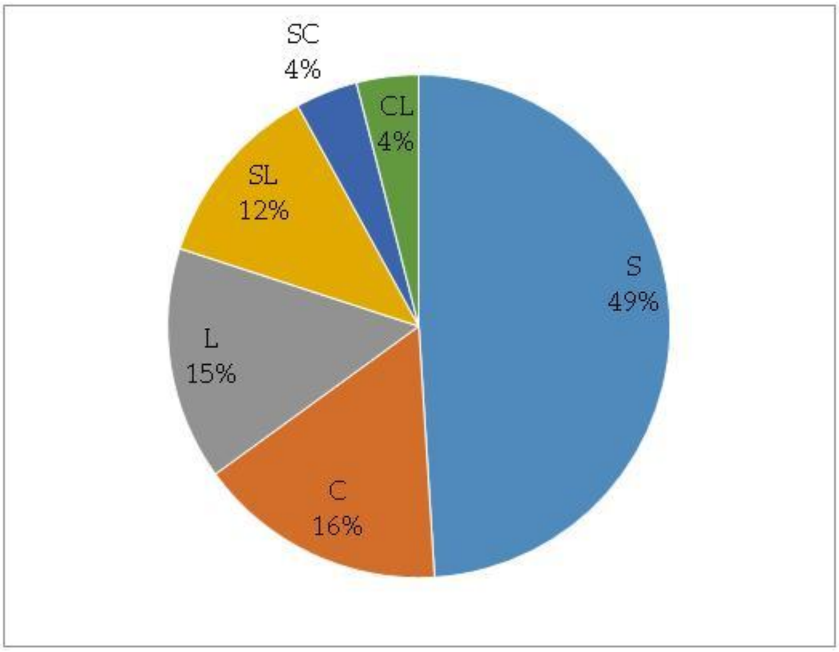


Figure 6: Soil texture of the study areas. (NB: S = sand; C = clay; L = loamy; SL = sand loamy, SC = sand clay, CL = clay loamy)

4.1.7 Application of Integrated Soil Fertility Management, Concepts and Principles by Farmers

Fairhurst (2012) defined integrated soil fertility management (ISFM) as a group of soil fertility management practices that involves use of industrial fertilizer, organic inputs and appropriate germplasm coupled with the knowledge on how to adapt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity. Fairhurst, further pointed out that all inputs need to be managed with best agricultural practices and economic principles. In this study, it was noted that most of the smallholder farmers practiced ISFM concepts and principles in their agriculture production, ranging from crop rotation, manuring, intercropping, organic and inorganic inputs application (anthill soil and mineral fertilizers). Overall, statistics indicated (Table 4) that crop rotation of cereals with groundnuts was highly practiced (59%), followed by cowpeas (53%), beans (21%), Bambara nuts (5%), soybeans (4%), pigeon peas (1%), velvet beans (1%) and others (14%). Despite smallholder farmers practicing crop rotation in the study districts, it was, however, noted that the area rotated between legume and cereal crops was not equivalent. This may have been due to some factors which among them were attributed to lack of enough legume seed by farmers and limited knowledge regarding the practice.

Table 4: Commonly rotated legumes with cereals across the study districts

Crop	Count	Percentage (%)
Groundnuts	228	59
Cowpeas	208	53
Beans	81	21
Other specify	54	14
Bambara nuts	18	5
Soybeans	17	4
Pigeon peas	3	1
Velvet beans	2	1

For other ISFM practices, it was observed in this study that a number of sampled households across the districts used inorganic fertilizers (96%), cattle manure (84%) and practiced intercropping (50%) as part of enhancing soil fertility. As for the fertility management practices employed, a majority of the respondents (Fig. 10) indicated that they generated the organic matter by using various anthill soil application methods involving heaping and spreading on flat field (89%), placement in ripped lines (14%), practicing crop rotation (12%), placement in potholes/basins (10%), mixing with cattle manure (8%), covering soil with crop residues (4%), intercropping (3%), spot application (2 %) and other methods (1%). This finding corroborates with the study by Acheampong, Owusu, Dissanayake, Hayford and Weebadde (2019) in Ghana who pointed out that farmers normally engage in some form of supplementary land management actions that help to rejuvenate the soil fertility. In agreement to this assertion, Ansong, Kimura, Addo, Oikawa and Fujii (2018) also reflected in Ghana that farmers opted to use organic based materials such as cattle manure, crop residues, land rotation among others in their agriculture production as a way of indigenous ISFM land management system.

It is further observed from Fig. 7 that the most practiced method of anthill soil application in the study sites was in the order; heaping and spreading on the flat field > placement in ripped lines > practicing crop rotation > placement in potholes/basins > mixing with cattle manure > covering soil with crop residue > intercropping > other methods. It appears application of the anthill soil on the flat field is prevalent, however, this may prove to be wasteful as the ideal approach would be placement of anthill soil in ripped lines or basins. This method may be more efficient and less laborious if embraced by smallholders. In addition, the system may also enhance nutrient concentration and hence availability to the crop.

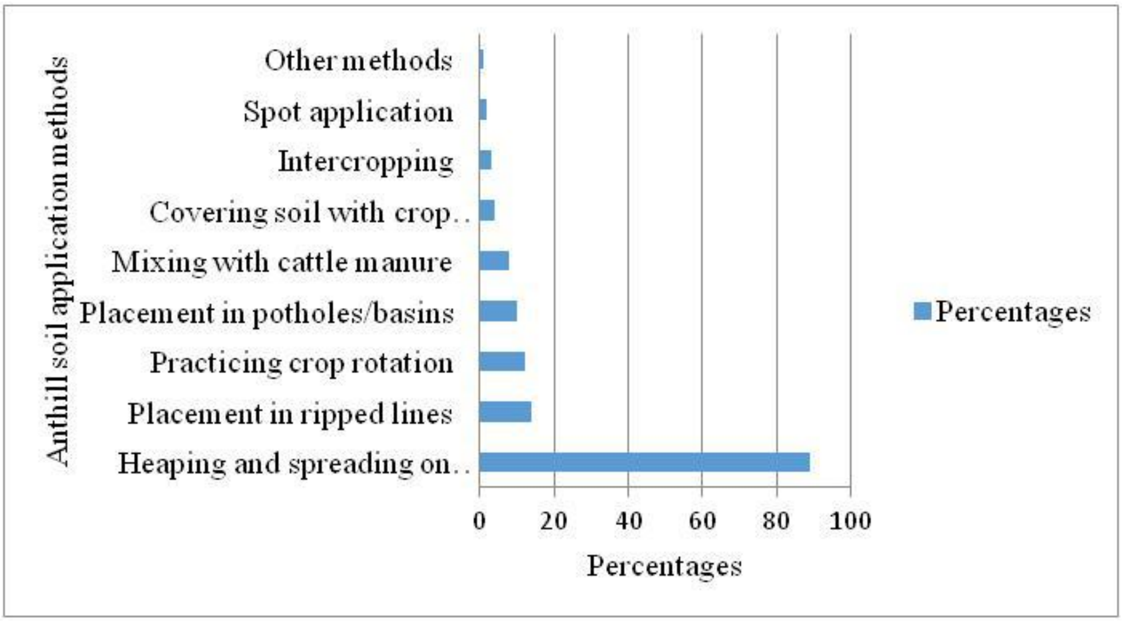


Figure 7: Comparison of anthill soil application methods

4.1.8 Status of Anthill Soil Utilization in Crop Production

Overall, it was observed in this study that most of the smallholder farmers started using anthill soil in crop production 3 years ago (32%) and those with 5 years and more than 10 years ago usage of the resource stood at 36% and 14% respectively (Fig. 8).

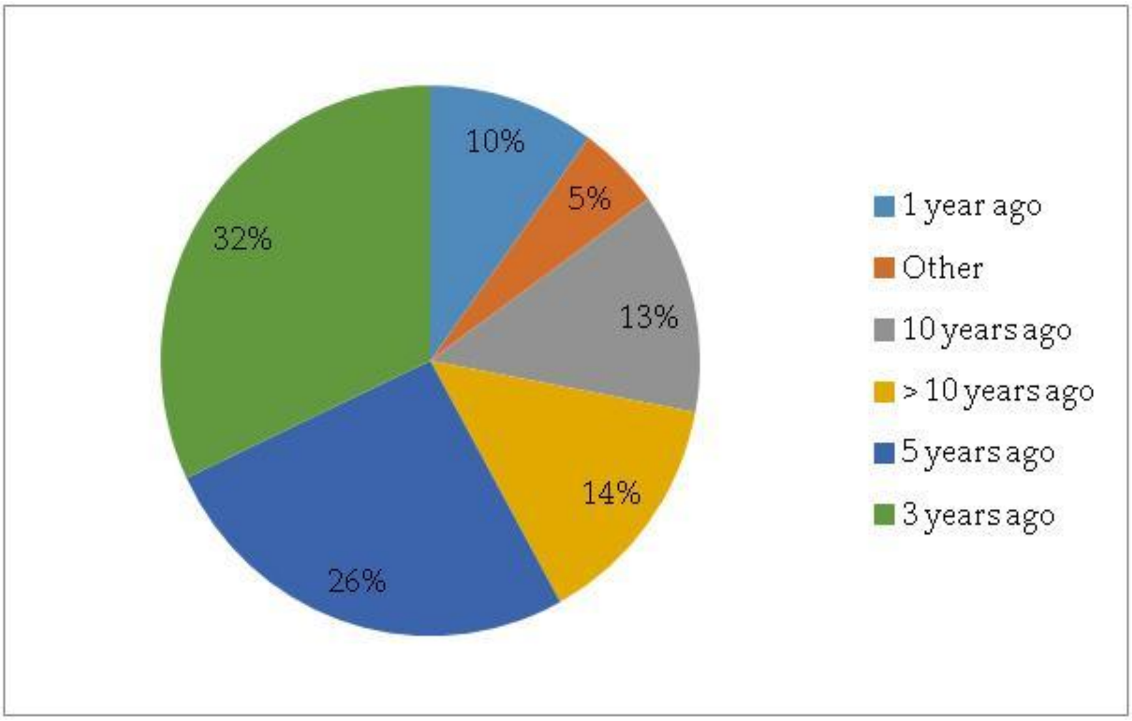


Figure 8: Showing year when households started using anthill soils in agriculture production

A number of factors prompted these farmers to use this resource in agriculture production. Among the social economic and biophysical factors was limited finance to purchase mineral fertilizer (90%) and soil factors (95%). All the maize varieties (99%) were reported being grown under anthill soil treatment while a paltry (1%) was not. The major improved maize varieties reported to be commonly grown under anthill soil as an alternative fertilizer included PAN 53 (55%), SC 513 (27%) and ZMS 606 (22%) respectively. All these varieties are early to medium maturity, suitable for region II where the study districts are located owing to the short rainfall duration, which normally ranges from 600-800 mm.

For local maize varieties, the smallholder farmers reported that they applied anthill soil mostly to Gankanta (42%), Go by red (24%) and Mapongwe a Chitonga (23%). All these maize varieties are traditional maize landraces grown amongst the Tonga people of southern Zambia and are a stop-gap measure to improved maize varieties if not accessed in time and also perceived to be resilient to drought conditions, which ensures food security at household level. Smallholder farmers further explained that the use of anthill soil in agriculture production lay in the belief that this resource can increase yield (84%), improve soil fertility (63%) and contributed to enhancing household food security (49%). The anthill soil in the study districts is also applied to legume crops.

Farmers perceived that with use of anthill soils and planting legume crops such as cowpeas, beans and groundnuts, accrued benefits were more than when they used commercial fertilizer only. Among the respondents, 30% expected improved soil fertility while 13% and 27% perceived yield increase and improved household food security respectively. In a similar study involving exploring farmers' indigenous knowledge of soil quality and fertility management in Ghana, Ansong *et al.* (2018) affirmed that the decision by farmers to use organic resources was as a result of the availability of the resource and general conditioning of the soil. Generally, farmers indicated that with the use of anthill soil in agriculture production, benefits were more compared to conventional soil fertility management practices, with 87% and 68% respectively reporting high yields and cheap access to the resource as the major gains observed.

A Chi-square test showed a significant association between smallholder farmers' start year of using anthill soil to improve soil fertility and access to credit schemes (Chi-Square (χ^2) =12.616, P-Value = 0.05) while there was no significant association on the use of mineral fertilizer (Chi-Square (χ^2) = 4.514, P-Value = 0.0607 respectively). There was also significant association (Chi-Square (χ^2) = 56.959, P-Value = 0.015) between the start year of utilizing the anthill soil (from 3 years and beyond) and benefits accrued. However, despite these reported benefits of anthill soils in agriculture production across the study districts, some farmers talked about the challenges faced that included requirement of more water by the resource (81%), inadequate labour (56%), handling and transportation (47%), determining the required anthill soil quantities by the crop (17%), with less requirement of water standing at 6% and other reasons (2%) (Fig. 9). Similar to farmers' observations, Khu Pakee, Nitichotiskang and Sanguansub (2014) indicated that the anthill soil requires more water because of its high suction characteristics compared with surrounding soil.

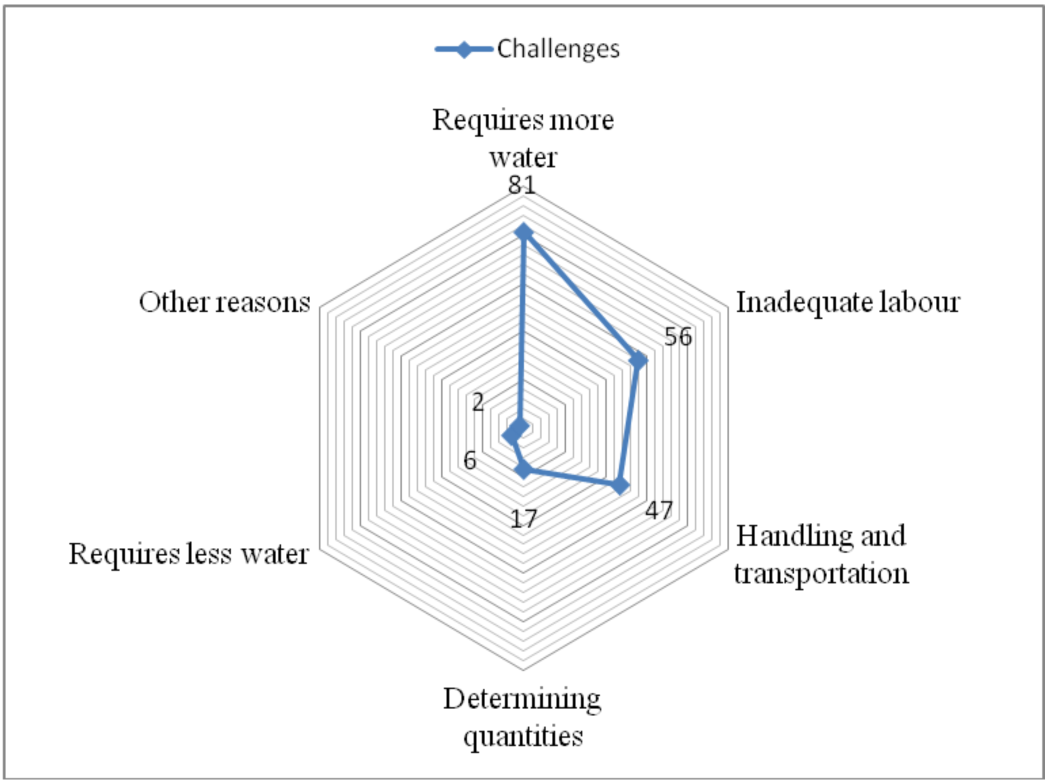


Figure 9: Comparison of the challenges in anthill soil utilization

In this study, it was also found that smallholder farmers used vegetation type i.e. species composition around anthill (85%), soil type (54%), other signals (4%), size and shape of anthill as part of indigenous knowledge or indicators for identifying the suitability of anthill for soil improvement in their agriculture production. It was further established that the anthill identification is usually done by men (59%) while a combination of both men and women was represented by 36%. Men at village level are normally considered as key decision makers on agriculture activities and hence have a big share in the anthill identification aspect.

4.1.9 Anthill Soil Fertility Management Calendar

Smallholder farmers across the study districts reported that identification of anthill soil for use in crop production commences mostly in June according to the 66% of the respondents while 25% and 11% of the sampled households mentioned the months of July and August respectively.

Further, farmers suggested that the underlying reason why most of them start anthill identification during the stated month of June is attributed to the condition of the anthill which is slightly soft at the time. With regard to this aspect, however, 49% of the sampled households revealed that they start anthill digging in June while 39 % and 21% begin the process in July and August respectively. In terms of transporting the resource to the field, it was found in the current study that the practice is mostly done in August (47%), followed by July (31%), September (25%), June (10%), October (8%), November (3%) with December having a paltry representation of 1%.

As for the participation in anthill soil application in the field, 81 % reported that both men and women were involved while men alone contributed (13%), women alone (2%) and hired labour (10%). Given this scenario, it was noted in this study that women play a crucial role in anthill soil application. The application or management methods also vary depending on the tillage system used by the farmers. In this study, it was found that heaping and spreading on the flat field was common practice (89%), followed by placement in ripped lines (14%), crop rotation (12%) and placement in plant potholes/basins (10%) among other methods.

4.1.10 Farmer's Choice of Using Anthill Soils in Agriculture Production

An estimation of the multinomial logistic model for the determinants of smallholder farmer's choice of anthill soil utilization in their agriculture crop production systems showed that labour and limited capital/finance were the main drivers in the choice of this soil fertility management strategy. As for the biophysical factors (soil factors, weeds, pests and diseases), there is no influence on the decision by smallholders to use anthill soil since no significant differences between the final and null model are observed. It is, however, expected that a female farmer is 19.905 and 20.291 times more likely to consider labour and limited capital/finance than the male counterpart in reference to other social economic factors before embarking on using anthill soil in agriculture production.

Of the two influencing variables (labour and limited capital/finance), only labour was found to be statistically significant at 5% level. The -2Log likelihood ratio has an estimated figure of 19.793. This helped in obtaining the Chi-Square value which normally informs on the goodness of fit for the model in comparison to the null model. The model containing the three variables (limited capital/finance, labour and others) was found to be significant at 5% confidence interval while the Cox and Snell R Square and Nagelkerke R Square were 0.022 and 0.044 respectively. Overall, it was noted that 90.8% of the respondents were predicted correctly (Table 5).

Table 5: Logistic Model Parameter Estimates – Social economic factors for anthill soil utilization

Social economic drivers for utilizing anthill soil[a]		B	Std. Error	Wald Test	df	Sig.	Exp (β)	95% Confidence Interval for Exp (β)	
								Lower Bound	Upper Bound
Labour	Intercept	-1.216	0.403	9.131	1	0.003			
	[Sex = female]	19.905	1.071	345.565	1	0.000	441088960	54087124	3597149460
	[Sex = male]	0[b]	.	.	0	.	.	.	.
Limited_capital	Intercept	2.405	0.201	143.188	1	0.000			
	[Sex = female]	20.291	0.000	.	1	.	649094122	649094122	649094122
	[Sex = male]	0[b]	.	.	0	.	.	.	.

a. The reference category is: others

b. This parameter is set to zero because it is redundant

Model Chi-square	8.844
Model Sig.	0.012
-2 Log likelihood	19.793
Cox and Snell R Square	0.022
Nagelkerke R Square	0.044
% correct predictions	90.8

4.1.11 Farmer Issues to Agriculture Production

Most farmers explained that anthill soil utilization has been beneficial to their agriculture production. Benefits disclosed lay in being cheap to access, improved crop yield, soil fertility improvement and food security while constraints reported focused on wilting of crops, germination challenges due to the hardness of the soil resulting in poor yield, labour intensiveness during collection of the resource, termite, pest and disease attacks. The discussants explained that these constraints itemized, were more pronounced during the drought periods and was never an issue in times of normal rain seasons.

The other major challenge which was also mentioned is poor soil condition and limited access to extension services (Fig 10). As a result of this, most smallholder farmers talked about how they tended to use the anthill soil as an alternative to boost the fertility of the poor sandy soils, prevalent in the study areas. In support of the use of anthill soils in crop production, Haitao, Xianguo and Xiaomin (2010) asserted that these soils are fertile due to the bioturbation activities that influence the soil chemical and physical characteristics. This is made possible through the ant building activities, where small residues are transported from deeper layer on to the surface and organic matter is interred under, thereby changing the bulk density, particle constituents including the water holding capacity. However, to cope with the constraints which are more prominent during the drought conditions, farmers made it clear that they engage in ploughing, ripping/basin making, application of cattle manure, replanting, harrowing, irrigating and also switch to alternative coping mechanisms that included trading and sale of livestock (Table 6).

Figure 10: Word cloud analysis showing a summary of major issues faced by smallholder farmers in the studied areas. Word size signifies the gravity of the challenge.

Table 6: Summary of farmer perceived challenges and opportunity in anthill soil utilization

Shared challenge	Hurdles to action	Courses of action taken/opportunity available
i) Droughts causing the soil to be hard, crop failure (germination difficulties, low yield)	Phenomenon outside farmer control	Re-cultivating (ripping, ploughing and harrowing)
		Replanting
		Irrigation
		Liming
		Mix anthill soil with manure
		Switch to alternative livelihoods (garden activities, piece works, petty trading and livestock sales)
		Plant drought-tolerant crops (e.g. cowpea)
		Seek technical advice
		Apply anthill soil half of the field
		Learn from previous experiences
ii) Extra labour	The soil is hard to cultivate, limited finance	Hire labour, Government and NGO credit facility
iii) Termites emerge due to drought conditions	Limited finance to buy chemical	Government and NGO credit facility
		Apply conventional insecticides
		Use local indigenous plants to kill termites after spraying
iv) Limited extension and research services	Government extension officers are constrained by transport challenges	Private sector extension services

4.1.12 Farmer Access to Anthill Soil Technology Information

A significant part of the respondents (87%) indicated that their most important source of information on general agriculture practices was government extension workers followed by neighbours (7%), radio/television (7%), own experience (6%), farmer's organization (3%) with school/Non-Governmental Organizations getting a paltry (2%). However, as for the major information gaps reported by farmers during focus group discussions related to anthill soil utilization lay in the aspects of limited extension or research services and lack of Non-Governmental Organizations, Faith-Based Organizations and Community Based Organization's presence, which play a key role in ensuring information, is disseminated to the rural communities on various agricultural practices. In this regard, the farmers called for the development of simple tools that could be used for anthill soil collection including more information on anthill soil application practices. Setting up of demonstrations on application methods in basins or ripped lines was reported to be key in disseminating the information on anthill soil technology utilization with emphasis on mechanization.

Tadesse (2016) asserted that experience across many countries has indicated that the adoption and spread of any technology call for adjustments in commitment and behavior of all key stakeholders without which adoption of the promoted technologies becomes a challenge. This was also affirmed by Wozniak (1984) who observed that exposure of farmers to training increased their ability to internalize and use the information relevant to the agriculture technology at farm level which essentially leads to immense use and ensure sustainability of the technologies. Matata, Ajayi and Agumya (2010) in agreement with this point stressed that extension contact is a very important aspect of changing attitude amongst farmers towards adopting any technology being promoted. Cafer and Rikoon (2018) stressed that the frequency of contact is considered a very important aspect of the smallholder farmer's ability to have access to any agriculture innovation earmarked for diffusion to them (Fig. 11).

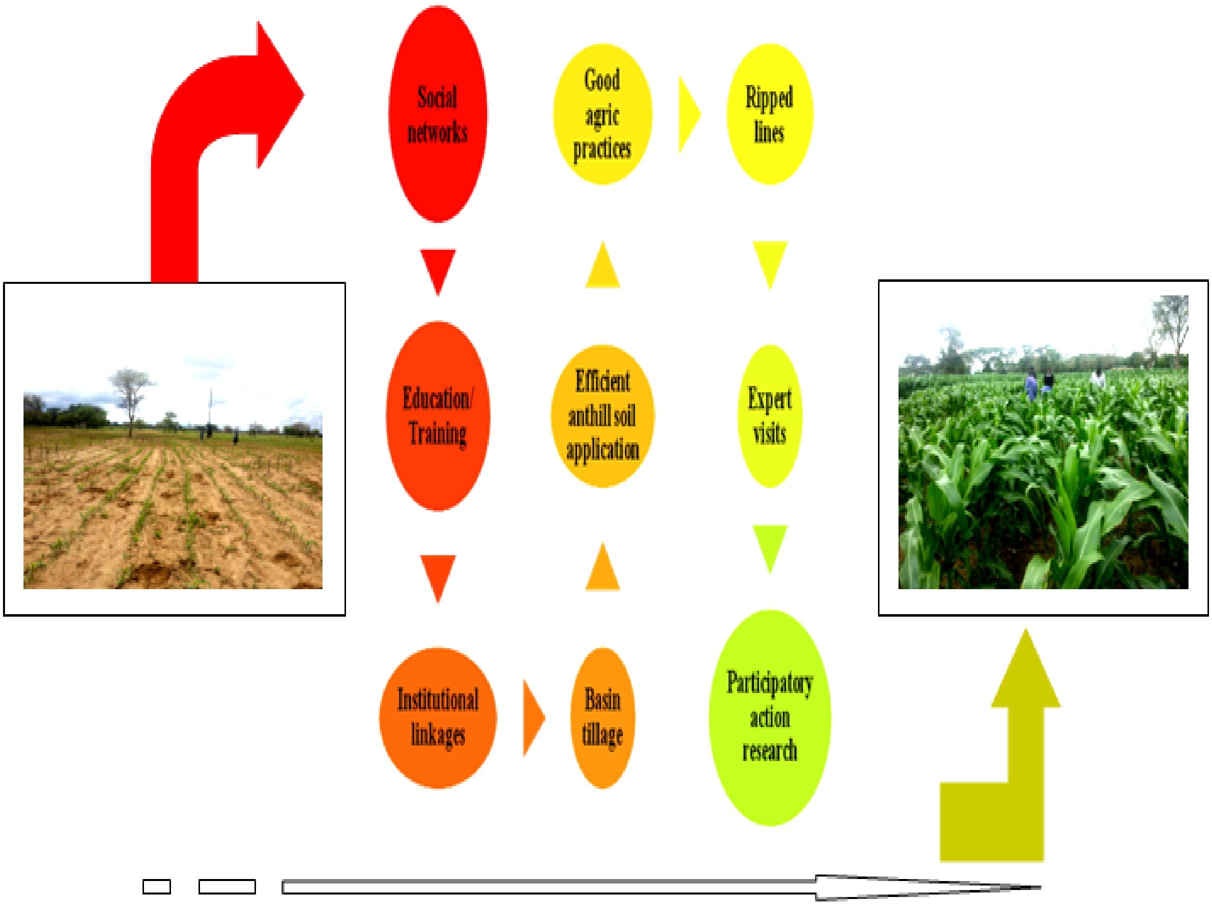


Figure 11: Smallholder farmers visioning of the pathway for which anthill soil utilization can contribute to the transformation of crop production and productivity in the study areas

4.2 Characterization of the Macro and Micro Nutrients of Anthill Soils

4.2.1 Soil pH

The soil pH in the top anthill soil averaged 6.53 while that of the base anthill soil had pH of 7.05 and soil from 10 m away from the anthill, pH values averaged 5.08. Generally, Pemba had higher pH values than Choma site (Table 7, Fig. 12). Our study showed that the soil pH values in the different soil collection points were alkaline to moderate levels and could support crop growth. However, a pH value of 4.3 could be detrimental to crop growth and would call for lime application to raise pH to acceptable levels for crop production. Chapoto, Chabala and Lungu (2016) reported that acceptable pH levels for most crops are 5.5–5.8 and at these scales there is no advantage from liming. In addition, Fairhurst (2012) reported that P availability is greatest from pH 5.5 to 7.0 while soil organisms required for N mineralization function best at soil pH 5.5–6.5 and all micronutrients, except Mo, are more available from pH 5.5 to 6.0. Mn and Fe toxicity is also drastically reduced in this range.

4.2.2 Total N

Total N in the top anthill soil averaged 0.08% while base anthill soil and that collected 10 m away from the anthill indicated an average of 0.07% and 0.06% respectively (Table 7). The proposed critical level for N was 0.20% (Fairhurst, 2012). Soil having critical levels below the suggested value is considered deficient in plant available N. Sarcinelli *et al.* (2009) reported that higher values of N in anthill may be attributed to fine organic material (twigs, grass etc) resulting from nest building activities of the ants.

In any case, if the smallholder farmers in Pemba and Choma study districts of southern Zambia with little capacity to purchase inorganic fertilizer continue using the anthill soil as an amendment, it would be beneficial for them to enhance N levels through application of top and or base anthill soil combined including other organic resources such as cattle manure and implementation of crop rotation with legume crops that may involve common beans, soybeans, groundnuts, cowpeas, pigeon peas etc. In such a situation, warranted corrective measures for enhanced N levels would include application of top or base anthill soil as there were no significant differences ($P > 0.05$) between them with regard to N content. However, for smallholder farmers who would afford inorganic fertilizers, combining with anthill soil could play a key role in boosting N availability. Studies conducted by Mtambanengwe and Mapfumo (2006) in Zimbabwe reported that combination of N mineral fertilizers and organic resources increased the organic matter loading in the soil which often resulted in farmers achieving high crop yields on coarse sandy soils. Ndakidemi and Semoka (2006) in a similar study, in Tanzania, recommended application of organic and/or inorganic fertilizers where N levels were below suggested critical levels.

Table 7: Comparison of soil chemical parameter values across studied sites

District	pH	N	P	K	Ca	Mg
Pemba	6.59±0.29a	0.09±0.01a	6.12±1.11a	1.53±0.31b	44.91±13.82a	5.64±1.36a
Choma	5.85±0.30b	0.05±0.00b	4.99±0.72a	74.47±31.53a	12.55±2.93b	1.01±0.17b
SCA						
T	6.53±0.34b	0.08±0.01a	8.04±0.94b	89.85±46.32a	52.58±19.33a	4.97±1.61b
B	7.05±0.19b	0.07±0.01a	6.34±1.24b	23.91±11.42ab	30.53±6.90ab	4.57±1.45b
A	5.08±0.31a	0.06±0.01a	2.30±0.42a	0.17±0.05b	3.09±0.85b	0.44±0.09a
Overall Treatment Effects – F statistics						
Site	0.03*	0.00*	0.31	0.01*	0.01*	0.00*
SCA	0.00*	0.26	0.00*	0.03*	0.01*	0.00*
Site * SCA	0.6	0.85	0.95	0.03*	0.03*	0.05

*NB: * Significant at P≤0.05; SCA = soil collection area, while A, B and T means soil collected 10 m away, base and top sections of anthill respectively. Means within the same column followed by the same letter (s) refer to no significance at (P≤0.05) based on Tukey's Honest Significance Test*

4.2.3 Available P

The available P, in the top anthill soil averaged 8.04 mg kg^{-1} across the two study districts. For the base anthill soil, P values averaged 6.34 mg kg^{-1}, while in the surrounding soil, 10 m away from the anthill, the average value was 2.30 mg kg^{-1}. Overall, Pemba District exhibited highest P content in the top and base anthill sections including 10 m away from the anthill structure compared to Choma (Table 7). This was however below the threshold levels for P pegged at 15 mg kg^{-1}.

Availability of P is essential for controlling crop growth and development (Wyngaard, Cabrera & Jarosch, 2016). Overall, in this study, Pemba district exhibited highest P content in the top and base anthill sections including 10 m away from it compared with Choma. Additionally, this was significant ($P < 0.05$). With this scenario, it would be beneficial for resource constrained smallholder farmers to collect anthill from the top unlike the base for application in their agriculture fields as there is relatively higher P content. Hernandez, Fardeau and Lepage (2006) reported that feeding and the manner of construction influenced the P content of anthills. In the current study however, soils collected 10 m away from the anthill had the least concentration of P, attributed to the inherent parent material. Generally, P is one of the limiting nutrients in southern Zambia. A study by Yerokun (2008) also indicated that soils of different origins within the country showed similar lower trends in their amount of available phosphorous.

4.2.4 Exchangeable Mg and K

Exchangeable Mg averaged 3.33 cmol kg^{-1} (Table 7). The proposed critical value in most agriculture crops was 0.2 cmol kg^{-1} (Fairhurst, 2012). In the top anthill soil Mg averaged 4.97 cmol kg^{-1}, suggesting that Mg supply was adequate to support crop growth. For the base anthill soil, the Mg average level was 4.57 cmol kg^{-1} while values for soil collected 10 m away from the anthill, Mg values averaged 0.44 cmol kg^{-1}. All the studied sites had sufficient Mg levels, except few in Choma district, suggesting that to attain optimum crop yield, application of anthill soil, cattle manure and fertilizers would provide supplemental Mg.

Exchangeable K in the top anthill soil averaged 89.85 cmol kg^{-1} (Table 7) while for the base anthill soil, the average value was 23.91 cmol kg^{-1} whereas the soil collected 10 m away from the anthill, exhibited an average of 0.17 cmol kg^{-1}. For most crops grown in southern Africa, Fairhurst (2012) recommended 0.2 cmol kg^{-1} as a critical level of exchangeable K in soils. Most of the soils collected from top and base anthill had K levels above critical values compared to those collected 10 m away from anthill. One site in Choma district had K levels below critical value implying that to enhance the K nutrient in the deficient area there was need to apply mound soil, cattle manure and fertilizers as supplement for K.

4.2.5 Exchangeable Ca

Exchangeable Ca averaged 52.58 cmol kg^{-1} in the top anthill soil of the study sites. Base anthill soil exhibited an average level of 30.53 cmol kg^{-1} while the soil 10 m away from the anthill gave an average of 3.09 cmol kg^{-1} (Table 7). The proposed critical level of Ca for majority of crops was 0.5 cmol kg^{-1} (Fairhurst, 2012). All the sites had Ca levels above the suggested critical value, a situation that implied that the cation was the most prominent on the soil colloids. Additionally, Pemba district exhibited highest Ca content in the top anthill soils in comparison to Choma. Krinstiansen *et al.* (2001) observed that anthills are enriched with inorganic elements such as Ca, compared with nearby surface soils resulting from the anthill building ants collection of various woody debris and foraging activities.

4.2.6 Soil Organic Carbon (SOC)

Soil organic carbon (SOC) averaged 1.31% in the top anthill soil (Table 8). In the base anthill soil, the average was 0.97% whereas in the soil collected 10 m away from the anthill, the average was 0.83 %. The critical threshold of SOC is pegged at 0.4% (Raina *et al.*, 2007). Anything below this poses a critical loss in the soil health which may not support proper crop growth. In this respect, Sarcinelli *et al.* (2009) indicated that higher values of SOC observed in the top anthills are as a result of termite action of swallowing soil organic matter which is returned as faecal pellets. Soil organic carbon is a measure of the readily available oxidizable content of organic matter, which directly influences nitrogen supplying capacity of the soil.

Minasny and Mcbratney (2017) asserted that a 1% mass increase in soil organic carbon (or 10 g C kg^{-1} soil mineral), based on average, increased water content at saturation, field capacity, wilting point and available water capacity by: 2.950, 1.610, 0.170 and 1.160 mm H_2O100 mm $soil^{-1}$, respectively. The increase is reported to be in the order; sandy soils > loams > clays. Chapoto *et al.* (2016) were of the opinion that most of the agricultural lands across Zambia lacked the much required organic matter, which is cardinal to the fertility of any given soil. Absence of required organic matter has negative consequence on the physical, chemical and microbial health of the soil. Mtangadura, Mtambanengwe, Nezomba, Rurinda and Mapfumo (2017) reported that organic nutrient resources such as manure, anthill soil etc which are accessible by smallholder farmers in southern Africa have great potential to enhance soil organic matter despite having differences in their chemical quality and mineral N fertilization regimes.

4.2.7 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) averaged 32.19 cmol kg^{-1} in the top anthill soil in both studied sites (Table 8). Base anthill soil exhibited CEC average of 30.09 cmol kg^{-1} whereas soil collected 10 m away from anthill had an average of 4.21 cmol kg^{-1}. Most sites had CEC above critical value (6-10 cmol kg^{-1}) for except two sites away from the anthill in Pemba and Choma districts which were below 10.0 cmol kg^{-1}, the recommended minimum level. Such soils indicated that they have poor cation retention capacity for Ca^{2+}, K^{2+} and Mg^{2+}. To correct the situation, application of organic fertilizers would suffice as they contained high soil organic matter, which is an important source of cation exchange.

4.2.8 Electrical Conductivity (EC)

The measurement of EC averaged 439.99 µs cm^{-1} in the top anthill soil whereupon in the base anthill soil, the average was 904.48 µs cm^{-1}. For soil collected 10 m away from the anthill, the EC average was 54.20 µs cm^{-1}. Generally, the anthill soil had higher values of EC compared to the surrounding soil across the study districts (Table 8) but adequate to support crop growth.

The results showed that the anthill soil had higher values of EC compared to the adjacent soil across the studied districts but adequate to support crop growth. Knowledge of EC of the soil is important as it renders information about the concentration of soluble salts in the soils. Raina *et al.* (2007) reported that crops like maize, wheat, sorghum and rice among others are medium salt tolerant crops. It is therefore, a must to have an idea of the salts in a particular soil in order to know its suitability for different crops. Soils with less than 2000 µs cm^{-1} EC values are said to have low salinity (Heagle, Hayashi & van der Kamp, 2013).

4.2.9 Available Cu, Fe and Zn

Available Cu in the top anthill soil averaged 0.88 mg kg^{-1}. For base anthill soil, the average was 1.19 mg kg^{-1} while the soil collected 10 m away from the anthill exhibited an average of 0.13 mg kg^{-1}. All the soils from the anthills were above the proposed critical value of 0.2 mg kg^{-1}except for sites in soil collected 10 m away from the anthill (Table 9).

Table 8: Comparison of soil chemical parameter values across studied sites

District	SOC	CEC	EC	Zn	Cu	Fe
Pemba	1.01±0.05a	30.14±7.67a	841.65±262.36a	0.91±0.19a	0.81±0.16a	18.02±2.37b
Choma	1.07±0.06a	14.18±2.92b	90.81±18.46b	1.05±0.16a	0.66±0.13a	29.19±1.18a
SCA						
T	1.31±0.02a	32.19±8.92b	439.99±111.27ab	1.45±0.21b	0.88±0.20b	25.84±3.51b
B	0.97±0.04b	30.09±6.98b	904.48±391.56a	1.12±0.21b	1.19±0.08b	17.63±2.59a
A	0.83±0.04c	4.21±1.06a	54.20±11.96c	0.36±0.04a	0.13±0.05a	27.35±0.88b
Overall Treatment Effects – F Statistics						
Site	0.12	0.03*	0.00*	0.44	0.31	0.00*
SCA	0.00*	0.00*	0.01*	0.00*	0.00*	0.00*
Site * SCA	0.04*	0.25	0.01*	0.01*	0.93	0.03*

*NB: * Significant at P≤0.05; SCA = soil collection area, while A, B and T means soil collected 10 m away, base and top sections of anthill respectively. Means within the same column followed by the same letter (s) refer to no significance at (P≤0.05) based on Tukey's Honest Significance Test*

Chemical Fe fraction in the top anthill soil averaged 25.84 mg kg^{-1}. In the base anthill soil, the average was 17.63 mg kg^{-1} whereas the soil 10 m away from the anthill, Fe content averaged 27.35 mg kg^{-1}. Fageria and Baligar (2005) reported that termite anthill activities have a significant direct influence on the soil chemical properties which enhances their fertility. Lindsay and Cox (1985) proposed critical level for different crops ranging from 0.3 to 10 mg kg^{-1}. In all the studied soils, the Fe levels were above the critical level.

The amount of Zn extracted in the top anthill soil averaged 1.45 mg kg^{-1}. The Zn levels in base anthill averaged 1.12 mg kg^{-1}while for soil 10 m away from the anthill mound the average was 0.36 mg kg^{-1}. For Zn (DTPA), the proposed critical levels were 0.4–0.6 mg $kg^{-1}$and any values above 10–20 mg kg^{-1}were considered as having excess Zn levels (Silanpaaa, 1982). All the top and base anthill soils had adequate Zn levels while soils collected 10 m away from the anthill exhibited Zn deficiency.

A study conducted by Manzeke *et al.* (2012) in Zimbabwe indicated that inadequate Zn levels threatens crop production and food nutrition in most cereal-based cropping systems across Africa, a scenario that was also observed in the studied sites. Steffan, Burgess and Cerda

(2017) stressed that the state of a soil has implications on a particular soil's capability to provide services, such as growing nutritious foods.

Generally, the relationship between organic carbon and available mineral elements (N, P, K, Cu, Fe and Zn) in various soil collection points (n=36) in this study showed positive correlation between N, P, Cu and Fe and available organic carbon (r^2 = 0.567, P = 0.039; r^2 = 0.317, P = 0.003; r^2 = 0.074, P = 0.051 and r^2 = 0.180, P = 0.002) while other elements, K and Zn exhibited weak correlation (r^2 = 0.026, P = 0.006 and r^2 = 0.005, P = 0.820 respectively) (Figs.13 - 15). This scenario may be attributed to the termites. Fageria and Baligar (2005) reported that anthill termite activities have a significant direct influence on the soil chemical properties which enhances their fertility. This is through influencing the nutrient cycling regimes in the soil environment.

4.2.10 Soil Texture

Particle size distribution (PSD) revealed different composition of sand, clay and silt. The mean textural classes were in the order; clay on top anthill > clay on base anthill > clay 10m away from the anthill. Additionally, there were significant differences ($P < 0.05$) in terms of clay content from different anthill sections (Table 9). The mean clay content across the districts was 30.4%. The amounts of clay fractions found in various anthill sections were similar in magnitude to those observed by other scientists. For instance, Haitao *et al.* (2010), in their study of soil particle size distribution of anthills and effects on soil physical properties in wetlands of the Sanjiang plain, China, found that the silt and clay content of anthills were higher than for adjacent soil. In this regard, ants which are found in anthills are responsible for affecting the soil physical characteristics through their activities whereby the small particles are moved from the deeper layers to the surface, burying the organic matter deeper, resulting in changes in soil particle constituents.

Table 9: Comparison of soil physical parameter values across studied sites

District	Clay	Silt	Sand
Pemba	33.41±6.27a	7.66±1.33a	41.58±7.04a
Choma	27.30±6.26a	7.65±1.16a	45.85±7.56a
SCA			
T	56.62±7.06a	5.49±1.81b	27.30±6.15b
B	29.98±2.54b	11.36±1.25a	41.34±6.59ab
A	4.47±2.17c	6.13±0.69b	62.51±10.50a
Overall Treatment Effects – F Statistics			
Site	0.26	0.99	0.67
SCA	0.00*	0.01*	0.02*
Site * SCA	0.83	0.08	0.93

*NB: * Significant at P≤0.05; SCA = soil collection area, while A, B and T means soil collected 10 m away, base and top sections of anthill respectively. Means within the same column followed by the same letter (s) refer to no significance at (P≤0.05) based on Tukey's Honest Significance Test*

For silt composition in this study, the average values were; 5.49%, 11.36% and 6.13% respectively for the top, base and soil collected 10 m away from the anthill with significant differences ($P < 0.05$) being recorded across the collection areas. The average value between districts was 7.66%. Sand composition was more revealed in the soil collected 10 m away from the anthill (62.51%), followed by base anthill (41.34%) and top anthill (27.3%) respectively. The mean value across the districts was 43.7% and was insignificant ($P > 0.05$). However, significant differences ($P < 0.05$) were observed within the soil collection areas (Table 9).

These observed differences in textural classes were as a result of the original nature of the parent material in studied sites that was mainly composed of sandy. For instance, a study conducted by Chapoto *et al.* (2016) indicated that most of the soils in Agro Ecological Zone IIa, in which the studied areas are located, are of sandy texture. The higher sand percentage in the studied sites gave an indication that the soils were infertile and low in major crop nutrients. This confirms with a study conducted by Wyngaard *et al.* (2016) who revealed that most Zambian agricultural soils had inherent small amounts of phosphorus (P) in them. The low levels of phosphorus availability were linked to the low organic matter composition, nature of the soil, exacerbated by the micro environments where they were found.

4.2.11 Effects of Sites and Soil Collection Areas on Nutrient Availability in Anthill Soil

The tested factors (site and soil collection areas) had a significant effect ($P<0.05$) on pH, N, K, Ca and Mg across the studied sites while for soil collection areas, this was evident in pH, P, K, Ca and Mg. The interaction between sites x soil collection areas was significant only in K and Ca macro nutrients. All other interactions showed insignificance implying that nutrient composition was not dependant on the interaction between sites x soil collection areas.

In terms of CEC, EC and Fe significant effects ($P<0.05$) were also noted in the sites for the nutrient content while soil collection areas showed significance in SOC, CEC, EC, Zn, Cu and Fe. The interaction effect between sites x soil collection areas was observable in SOC, Zn and Fe. This indicated that the mineral concentration was not independent of the site and the segment of the anthill from which soil was collected.

Comparison of soil physical parameter values across studied sites showed significant effect ($P<0.05$) only in soil collection areas for clay, silt and sand. The interaction of site x soil collection areas showed no significant effect ($P>0.05$) attributable to almost similar site characteristics across the studied areas. Further analysis of the variance components indicated that across the two studied sites, effect of the soil collection area was the largest which confirmed that there is variation in nutrient composition of the anthill as you move from the top, base and adjacent areas of the structure (López-Hernández, Brossard, Fardeau & Lepage, 2005).

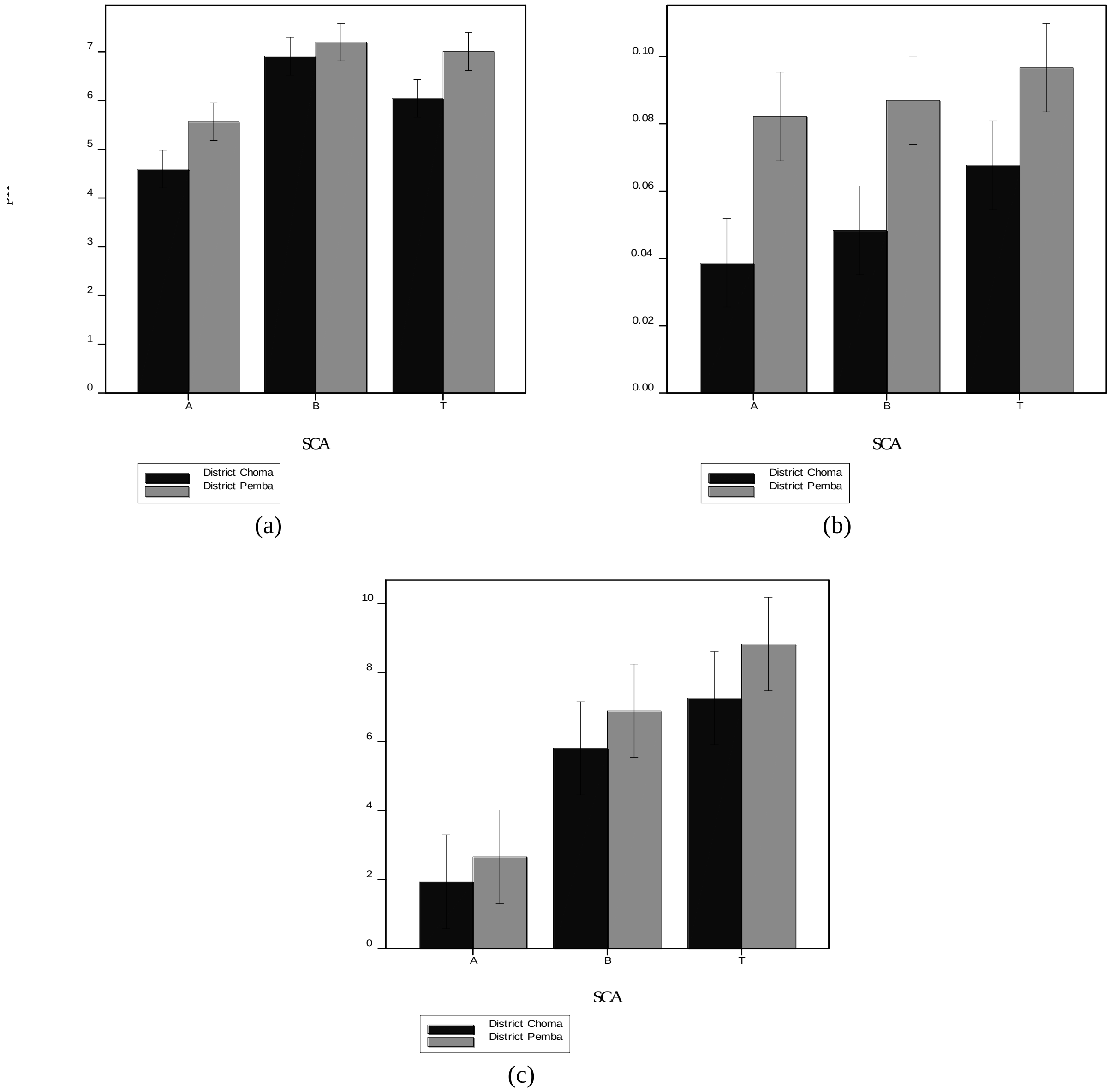
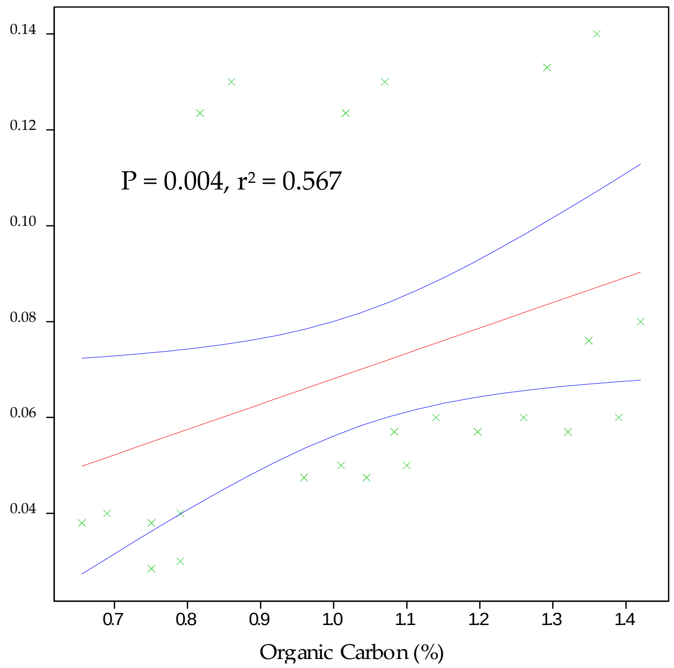


Figure 12: Mean variations in (a) pH, (b) N and (c) P across the soil sampling points i.e 10 m away from the mound, base and top areas. NB: SCA = soil collection area; A = soil collected 10 m away from mound; B = base anthill soil and T = top anthill soil



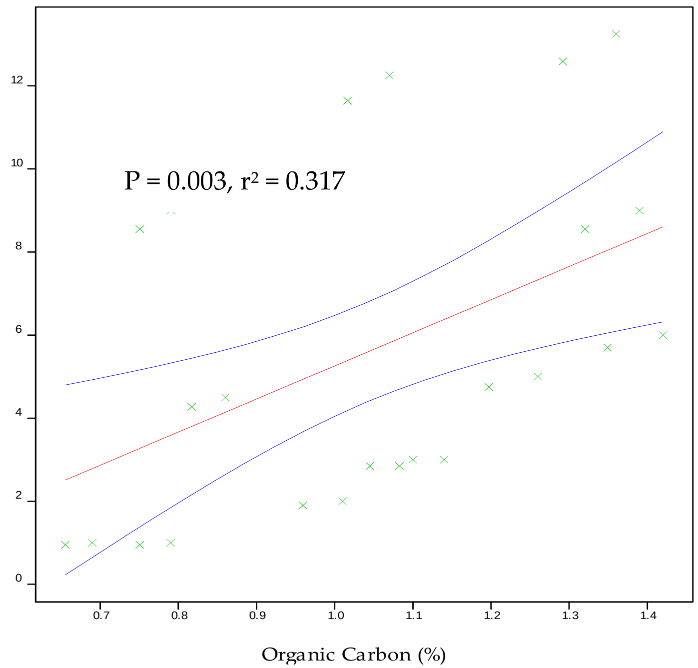
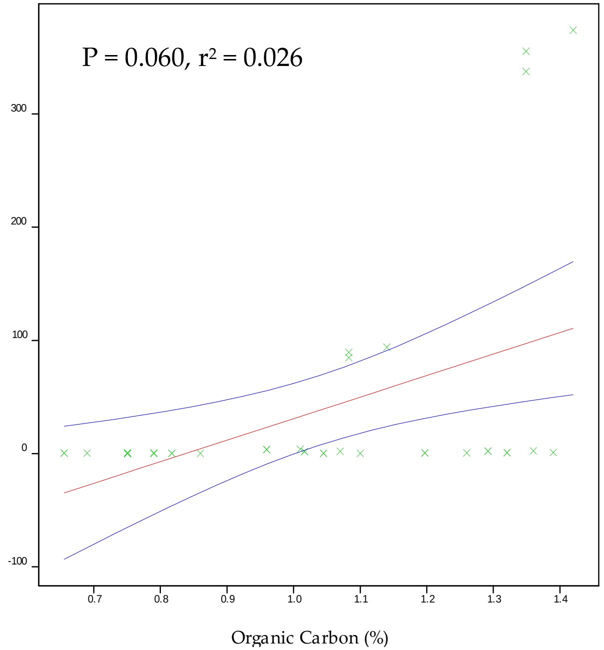


Figure 13: Relationships between organic carbon and available Nitrogen and Phosphorus at various soil collection (n=36). Green stars indicate nutrients on y-axis, blue lines represent 95% confidence intervals and red line is the linear for nutrients on y-axis



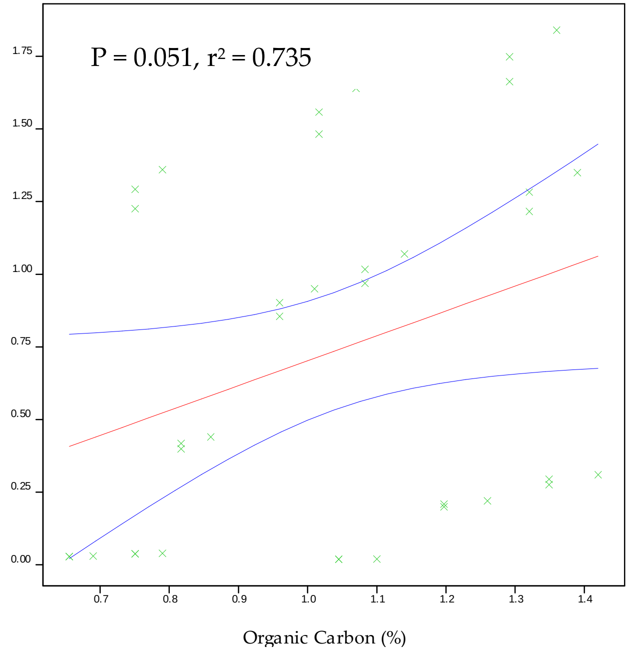
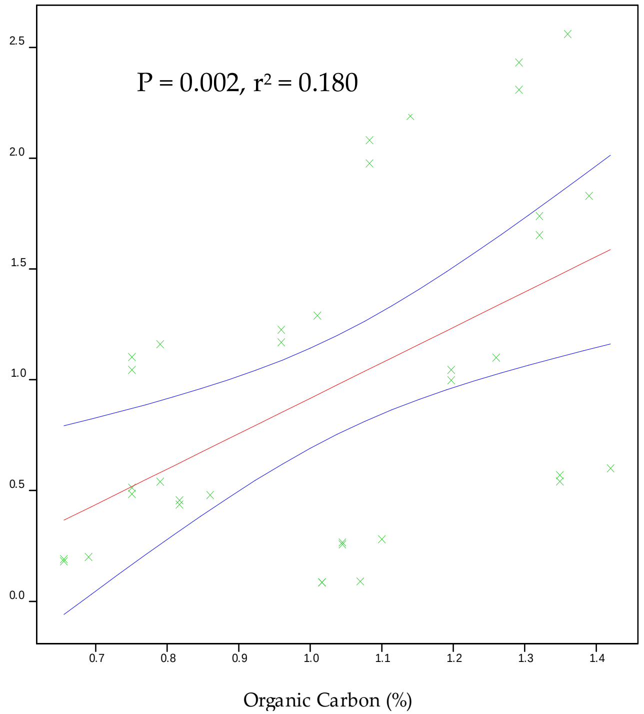


Figure 14: Relationships between organic carbon and available Potassium and Copper at various soil collection points (n=36). Green stars indicate nutrients on y-axis, blue lines represent 95% confidence intervals and red line is the linear fit for nutrients on y-axis



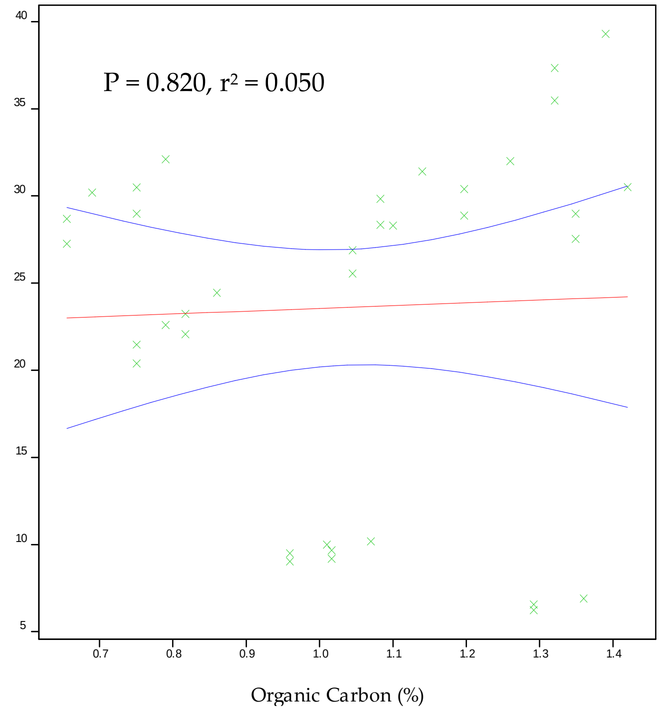


Figure 15: Relationships between organic carbon and available Iron and Zinc at various soil collection areas (n=36). Green stars indicate nutrients on y-axis, blue lines represent 95% confidence intervals and red line is the linear fit for nutrients on y-axis

4.3 Evaluation of the Effect of Anthill Soil Application on Growth and Yield Parameters of Maize

Results and discussion for the performance of the maize crop at both pot and field experiment are outlined in this section, including the baseline anthill soil, manure and control soil nutrient composition before they were applied as treatments.

4.3.1 Pot Experiments

Tables 10 and 11 present results of the baseline anthill soil, manure and control soil (collected 10 m away from anthill). Generally, results show that P, K, Ca, Mg and OC were below the critical values set for the benchmark soils in the research sites except for manure nutrients.

Table 10: Baseline Soil Physical Chemical Characteristics

District	Soil collection area	pH(In H_20)	EC Us/cm	Cu (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	N (%)	OC (%)	P (mg/kg)
Pemba	Top Anthill	8.39	348	1.84	2.56	6.91	0.13	1.36	12.18
	Base Anthill	8.15	380	1.64	0.09	10.18	0.13	1.07	4.48
	10m from Anthill	6.45	32	0.44	0.48	24.45	0.14	0.86	3.73
	Top Anthill	6.3	1119	0.22	1.1	32	0.04	0.69	5
	Base Anthill	7.3	3303	0.95	1.29	10	0.05	1.26	2
	10m from Anthill	4.3	129	<0.03	0.2	30.2	0.06	1.01	1
Choma	Top Anthill	7.1	123	1.35	1.83	39.3	0.03	0.79	9
	Base Anthill	7	56	1.36	1.16	22.6	0.06	1.39	1
	10m from Anthill	4.6	36	<0.04	0.54	32.1	0.04	0.79	9
	Top Anthill	6.5	261	0.31	0.6	30.5	0.06	1.1	6
	Base Anthill	7.5	66	1.07	2.19	31.4	0.08	1.42	3
	10m from Anthill	4.3	31	<0.02	0.28	28.3	0.05	1.14	3
	Critical Levels	4.5	-	10	0.6	10	0.1	1.5	15

Table 10: *Cont*

District	Soil collection area	CEC (Cmol/kg)	Ca (Cmol/kg)	Mg (Cmol/kg)	Na (Cmol/kg)	K (Cmol/kg)	Clay	Silt	Sand	Texture
Pemba	Top Anthill	14	20.51	2.91	0.09	2.4	40.8	16.28	42.96	C
	Base Anthill	8.8	13.02	2.85	0.06	1.96	40.8	14.28	44.96	C
	10m from Anthill	1.4	1.32	0.63	0.01	0.16	17.8	7.28	74.96	SL
	Top Anthill	87.5	171.83	14.86	0.380	0.62	87.2	0.4	12.4	C
	Base Anthill	67.8	68.33	13.46	0.7	3.99	23.9	7.7	68.4	SCL
	10m from Anthill	10.7	8.36	0.89	0.14	0.53	0.3	2.4	97.3	S
Choma	Top Anthill	19.2	14.96	1.77	0.29	0.98	80.0	5.0	15.0	C
	Base Anthill	39.9	39.03	2.02	0.15	0.62	39.7	17.9	42.4	CL
	10m from Anthill	3.3	1.84	0.18	0.16	0.09	0.3	8.5	91.2	S
	Top Anthill	14.7	13.88	1.35	0.18	374	30.2	1.4	68.4	SCL
	Base Anthill	10.1	8.04	0.91	0.13	94	21.7	7.9	70.4	SCL
	10m from Anthill	2.3	1.47	0.14	0.08	0.21	0.4	7.6	92	S
	Critical Levels	10	5	2	-	0.2	>45	-	>50	

Table 11: Baseline Manure Analysis

Parameter	Value	Critical Levels (Fairhurst, 2012)
Available N (g/kg)	6.8	0.1
Available P (mg/kg)	831	15
K (cmol/kg)	17.6	0.2
Ca (cmol/kg)	5.3	5
Mg (cmol/kg)	2.2	2
Zn (mg/kg)	0.01	0.6
Cu (mg/kg)	1.2	0.2
Fe (mg/kg)	979.8	5.15

Table 12: Mean Height (cm) for Maize under Pot Experiment at Various Stages of Growth

Week/ Treatments	W1	W2	W3	W4	W5	W6
1. AHT	9.22	13.28	17.15	19.75	21.87	25.15
2. AHB	7.87	13.23	16.40	18.83	21.50	24.02
3. FRF	5.47	15.57	19.57	22.42	24.85	28.40
4. HRF+AHT	7.53	12.17	16.50	20.52	23.90	24.93
5. HRF+AHB	6.38	12.33	15.47	19.28	22.47	25.43
6. M+AHT	9.52	15.63	17.65	19.97	21.03	23.62
7. M+AHB	8.02	12.78	14.87	17.45	19.17	22.52
8. M	7.60	13.92	16.68	18.32	19.62	22.00
9. Urea+AHT	7.20	11.03	13.87	16.25	18.90	24.88
10. Urea+AHB	9.37	13.55	16.83	18.65	20.22	23.35
Grand Mean	7.82	13.35	16.50	19.14	21.35	24.43
C.V	17.10	16.60	12.80	8.7	7.30	8.6
SED	0.773	1.277	1.221	0.996	0.901	1.217
Fpr.	<.001	0.018	0.003	<.001	<.001	<.001

NB: AHT = anthill soil top; AHB = anthill soil base; FRF = full rate fertilizer; HRF = half rate fertilizer; M = manure; CV = Coefficient of Variation; SED = Standard Error of Difference; Fpr = F probability

Tables 12 – 16 outlines the effect of different anthill soil, fertilizer and manure treatments on the height, stem girth, dry matter, NPK concentrations, leaf length, leaf width and leaflet area. Findings demonstrate a significant difference amongst the treatments *($P<0.05$)*. In terms of height (Table 13), response was in the order; full rate fertilizer treatment (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S) > half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S) + anthill soil base > anthill soil top. However, the difference between the full rate and the other two treatments ranged from 2.97 to 3.25 cm, implying that the response of the anthill soil may have been attributed to its ability to release the nutrients slowly unlike the fertilizer which dissolves fast (Ndakidemi, 2014). Progressively, the anthill soil was expected to enhance uptake of the nutrients and thereby have a knock effect on the growth of the tested crop.

Table 13: Comparison of Mean Height (cm) for Maize under Pot Experiment at Various Stages of Growth

Week/ Treatments	W1	W2	W3	W4	W5	W6
1. AHT	9.217[b]	13.28[ab]	17.15[ab]	19.75[bc]	21.87[abc]	25.15[ab]
2. AHB	7.867[ab]	13.23[ab]	16.40[ab]	18.83[ab]	21.50[abc]	24.02[a]
3. FRF	5.467[a]	15.57[b]	19.57[b]	22.42[c]	24.85[d]	28.40[b]
4. HRF+AHT	7.533[ab]	12.17[ab]	16.50[ab]	20.52[bc]	23.90[cd]	24.93[ab]
5. HRF+AHB	6.383[a]	12.33[ab]	15.47[ab]	19.28[abc]	22.47[bcd]	25.43[ab]
6. M+AHT	9.517[b]	15.63[b]	17.65[ab]	19.97[bc]	21.03[abc]	23.62[a]
7. M+AHB	8.017[ab]	12.78[ab]	14.87[a]	17.45[ab]	19.17[a]	22.52[a]
8. M	7.600[ab]	13.92[ab]	16.68[ab]	18.32[ab]	19.62[ab]	22.00[a]
9. Urea+AHT	7.200[ab]	11.03[a]	13.87[a]	16.25[a]	18.90[a]	24.88[ab]
10. Urea+AHB	9.367[b]	13.55[ab]	16.83[ab]	18.65[ab]	20.22[ab]	23.35[a]

NB: *AHT = anthill soil top; AHB = anthill soil base; FRF = full rate fertilizer; HRF = half rate fertilizer; M = manure. Means followed by the same letter are not significantly different at the 0.05 level of probability using Tukey's honestly significant test.*

As for the stem girth, dry matter, leaf length, leaf width and leaflet area (Table 14), a similar pattern was observed in terms of responses to the treatments. There was a significant difference *($P < 0.05$)* between full rate fertilizer treatment and the rest of the treatments. For total dry matter there was also an indication of significant differences amongst the treatments *($P < 0.05$).* Full rate fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S (2154 mg) and soil + manure + anthill soil top (1895 mg) were the best performing treatments. For the leaf length, leaf width and leaflet area, significant differences were also observed with all the treatments. However, the full rate fertilizer

(NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S) and half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S) and anthill top recorded the highest responses. Just like in the previous explanation, the positive response of the crop to the fertilizer treatment was as a result of the high dissolution ability of the resource. In the second scenario, the anthill soil from the top contains more macro nutrients (Kaschuk *et al.,* 2006) and when combined with the industrial fertilizer, this enhanced the uptake as there was little washing away of the nutrients due to the presence of the organic matter in the anthill soil that anchored the fertilizer and thus was made available to the crop.

Table 14: Mean Stem Girth and Dry Matter of Maize at the end of Pot Experiment

Treatments	Girth (cm)	Total Dry Matter (mg)
1. AHT	0.50[a]	1140[a]
2. AHB	0.49[b]	1132[a]
3. FRF	0.67[a]	2154[d]
4. HRF+AHT	0.54[a]	1684[bcd]
5. HRF+AHB	0.54[a]	1463[abc]
6. M+AHT	0.44[a]	1895[cd]
7. M+AHB	0.47[a]	1416[abc]
8. M	0.46[a]	1340[ab]
9. Urea+AHT	0.46[a]	1083[a]
10.Urea+AHB	0.47[a]	1034[a]
Grand Mean	0.50	1429.30
C.V	31.20	17.9
SED	0.04	255.5
Fpr.	<.001	<0.001

NB: AHT = anthill soil top; AHB = anthill soil base; FRF = full rate fertilizer; HRF = half rate fertilizer; M = manure; C.V = Coefficient of variation; SED = Standard Error of Difference; Fpr = F probability. Means followed by the same letter are not significantly different at the 0.05 level of probability using Tukey's honestly significant test.

Table 15: Mean effects of anthill soil application, manure and NPK fertilizer on above ground biomass dry matter yield (mg), NPK concentration in shoots of Maize estimated at 42 days after planting (DAP)

Treatments	AGB Dry Matter (mg)	N Concentrations (mg/plant)	P Concentrations (mg/plant)	K Concentrations (mg/plant)
1. AHT	787.7^{ab}	102.4^{a}	102.4^{a}	174.1^{a}
2. AHB	806.9^{ab}	150.1^{ab}	150.1^{ab}	191.2^{ab}
3. FRF	1617^{d}	577.3^{e}	577.3^{e}	338^{e}
4. HRF+AHT	1091.9^{c}	355.9^{d}	355.9^{d}	239.1b^{cd}
5. HRF+AHB	1127.5^{c}	363^{d}	363^{d}	274^{d}
6. M+AHT	1012.8^{bc}	117.5^{a}	117.5^{a}	255.2^{cd}
7. M+AHB	947.6^{abc}	132.7^{a}	132.7^{a}	262.5^{d}
8. M	928.9^{abc}	130.1^{a}	130.1^{a}	226.7^{abcd}
9. Urea+AHT	744.8^{a}	211.5^{bc}	211.5^{bc}	203.3^{abc}
10. Urea+AHB	791.1^{ab}	227^{c}	227^{c}	193^{ab}

NB: AHT = anthill soil top; AHB = anthill soil base; FRF = full rate fertilizer; HRF = half rate fertilizer; M = manure; AGB = above ground biomass. Means in a column followed by the same letter are not significantly different at the 0.05 level of probability using Tukey's honestly significant test.

Table 16: Comparison of leaflet length, width and area for Maize under Pot Experiment at 6 weeks days after planting

Treatments	Leaflet Length (cm)	Leaflet Width (cm)	Leaflet Area [LxBx0.75] (cm^2)
1. AHT	42.72[ab]	1.97[a]	63.02[ab]
2. AHB	44.08[ab]	2.00[a]	66.12[ab]
3. FRF	54.64[c]	2.95[d]	120.89[d]
4. HRF+AHT	50.20[bc]	2.52[c]	94.77[c]
5. HRF+AHB	41.45[ab]	2.35[bc]	73.06[c]
6. M+AHT	42.32[ab]	2.17[ab]	68.78[ab]
7. M+AHB	41.67[ab]	2.22[abc]	69.29[ab]
8. M	38.73[a]	2.08[ab]	60.51[ab]
9. Urea+AHT	34.38[a]	1.90[a]	48.99[a]
10.Urea+AHB	41.37[ab]	1.93[a]	59.98[ab]

NB: AHT = anthill soil top; AHB = anthill soil base; FRF = full rate fertilizer; HRF = half rate fertilizer; M = manure. Means in a column followed by the same letter are not significantly different at the 0.05 level of probability using Tukey's honestly significant test.

4.3.2 Correlation Analysis between Number of Roots and Height (cm)

A correlation analysis was performed to determine the relationship between the number of roots from the planted maize in the pot experiment and height. Results showed that there was a positive correlation (Pearson r = 0.19, *P = 0.05*) while the adjusted R square indicated a value of 0.02 (Fig. 16). This implied that the number of roots developed underneath the crop had to some extent an influence on the height response observed in the pot experiment. The more the roots a plant has, the more likely the uptake of nutrients and other minerals required for growth and hence effects on growth parameters. Postic, Beauchene, Gouche and Doussan (2019) in their study in France reported a strong correlation between root colonization and yield obtained. Subira *et al.* (2016) affirmed that the type of root system exhibited by a crop influences the water and nutrient uptake functions.

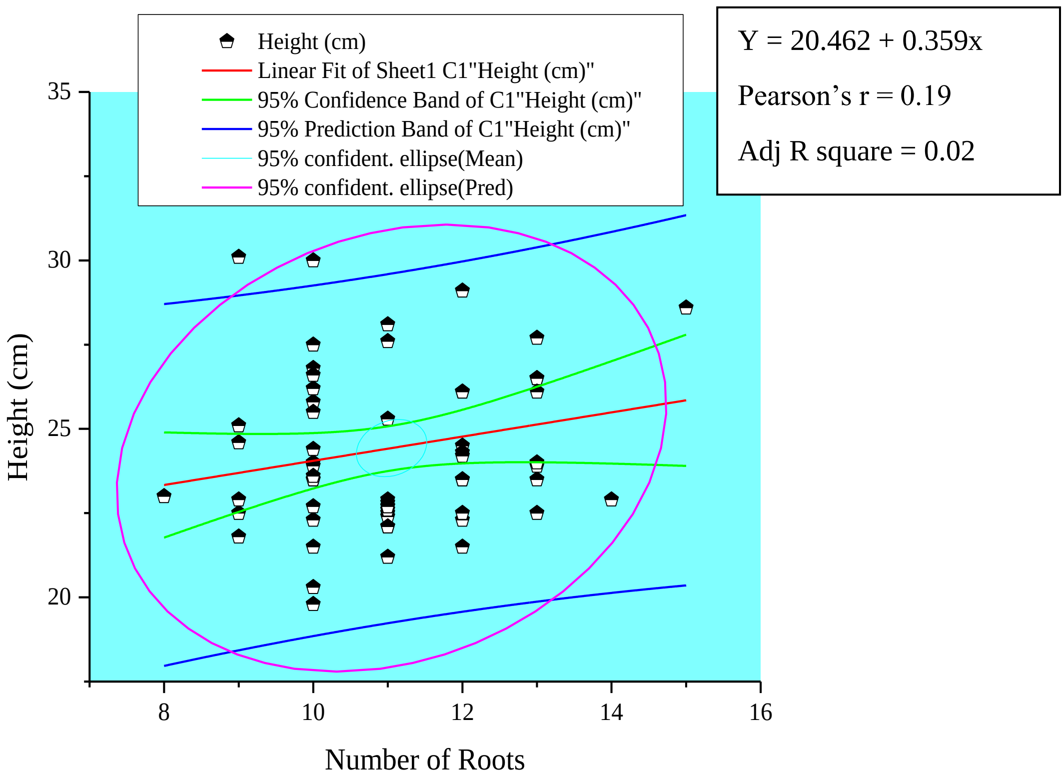


Figure 16: Correlation Analysis of Number of Roots and Height - cm (n=60)

The treatment effect on growth parameters during the pot experiment in this study where anthill soil alone and full rate fertilizer were applied - basal and urea combined (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) showed significant differences (*P<0.05*). The fertilizer treatment may have released the nutrients quickly to the planted maize due to the surface area and fast dissolution ability as compared with the organic resource (Ndakidemi, 2014), the anthill soil that releases nutrients at a slow pace. Similar observations were also noted regarding the stem girth and total dry matter parameters responses to the amendments. Given this scenario, the anthill soil may be more effective in sandy soils that are inherently poor in organic matter.

Further in the pot experiment, use of anthill soil and half rate recommended fertilizer did not differ significantly ($P>0.05$) whether use of top or base anthill soil combination. The top most anthill soil combined with fertilizer exhibited a higher height value compared with the base anthill soil. This implies that the top sections of the anthill soils may be richer in macro nutrients as compared with the basal soil. Sarcinelli *et al.* (2009) confirmed that there are higher values of C and N in anthill soils attributable to the activities of the termites that involves swallowing organic matter and this is subsequently returned as pellets of faecal matter, thereby enhancing soil aggregation. Other scholars such as Ackerman, Teixera, Riha, Lehmann and Fernandes (2007) have also indicated that the high C and N values in anthill soils is due in part to the concentration of organic matter in the anthills by termites. Lopez-Hernandez *et al.* (2006) also validated that the higher nutrient levels in the anthills is probably as a consequence of incorporated faeces in the nest of termites that feed on grasses and soil humus.

Further, there were similar observations regarding the treatment responses to stem girth, total dry matter and NPK concentrations parameters. NPK concentrations received greater responses in the full rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha), followed by half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill base or top treatment (5000 kg/ha). The high response rates in NPK showed that the soils in the studied sites were lacking these nutrients. The data presented corroborates with what Chapoto *et al.* (2016) found regarding the research sites having low major crop nutrients. Findings in this study also indicate that the leaflet length, width and area were appreciable in the same treatments. Given this scenario, the anthill soil may be effective in sandy soils that are inherently poor in organic matter.

4.3.3 Field Experiments - Rainfall Performance during the Cropping Seasons

The rainfall characteristics for both Choma and Pemba districts at the time of the study period are depicted in Figs. 17 - 20. Total rainfall received and number of rain days in the first and second seasons of test crop growth reflected 854.6 mm and 788.6 mm respectively while total numbers of rain days were 77 and 52, respectively. Most of the rainfall peaks for both districts occurred in the month of February, which is very critical as this is the time when the maize crop requires abundant water for grain filling purposes. In the second season the two study areas received less than normal rainfall due to the El Nino effects that were affecting the southern African region at the time of crop growth. This resulted in prolonged dry spells that affected crop development. The total seasonal rainfall for the two districts, Choma and Pemba trial sites were 273.3 mm and 402.3 mm respectively. This was far too below the normal rains expected in the districts pegged at 800 mm by the Meteorology Department in a season.

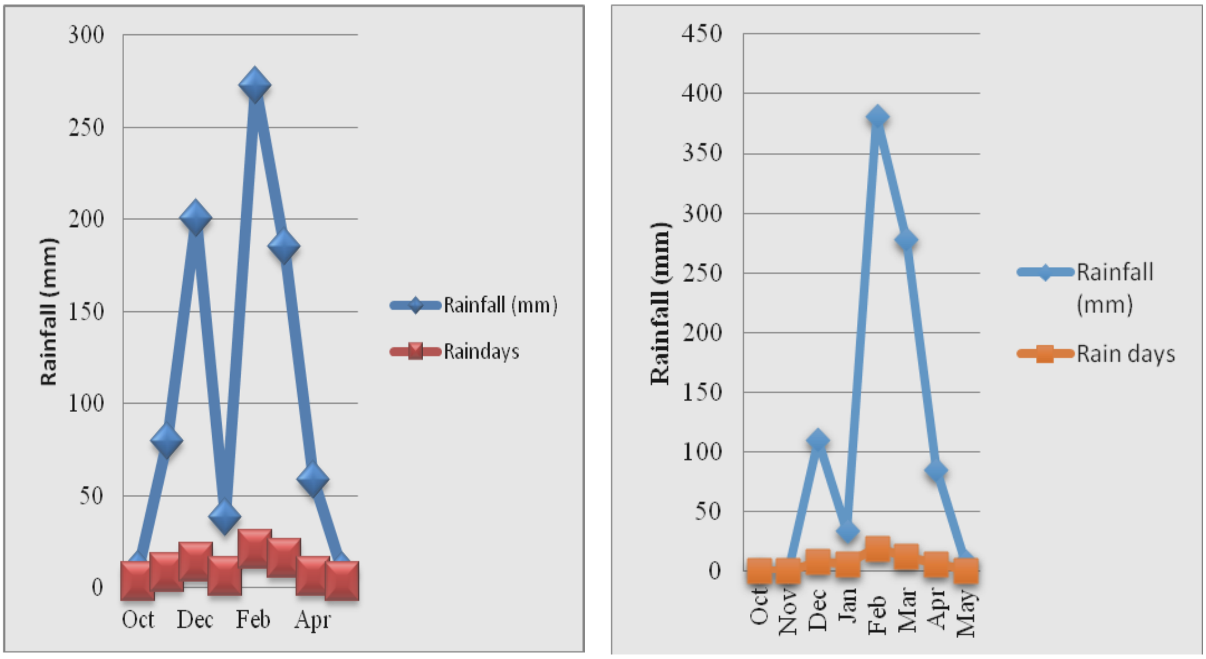


Figure 17: Choma left (a) and Pemba right (b) rainfall performance during 1st season of crop growth

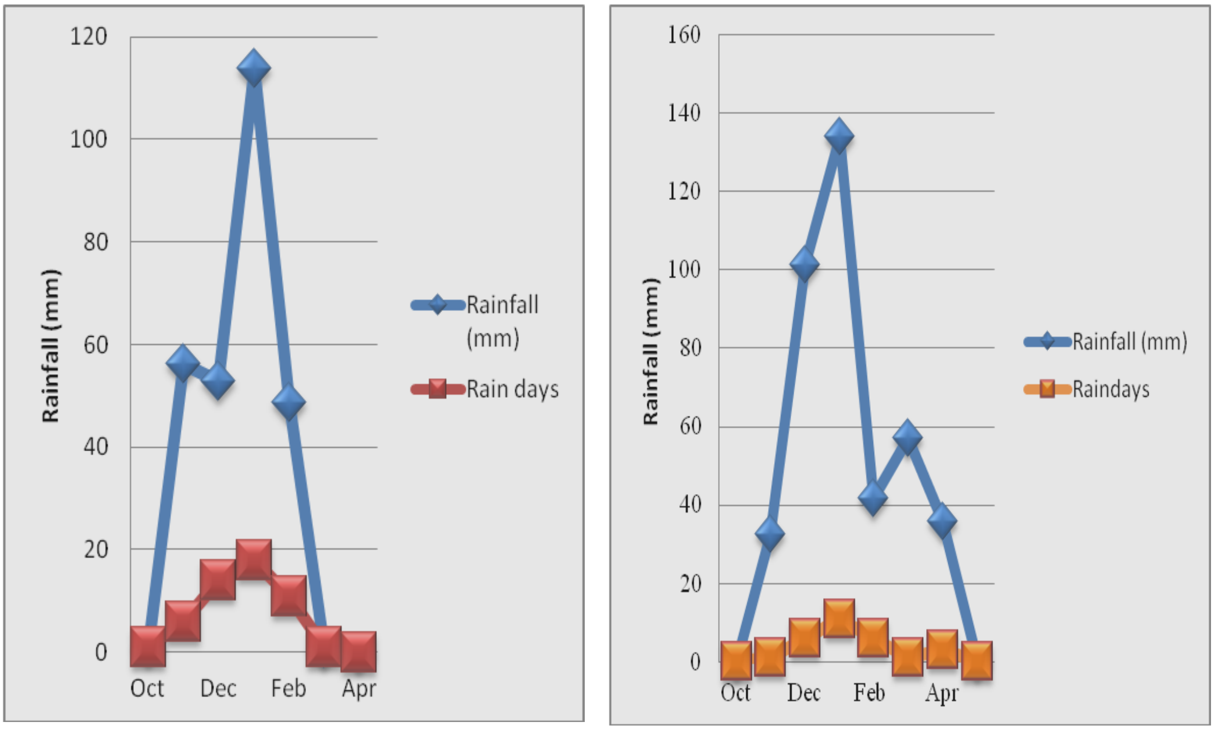
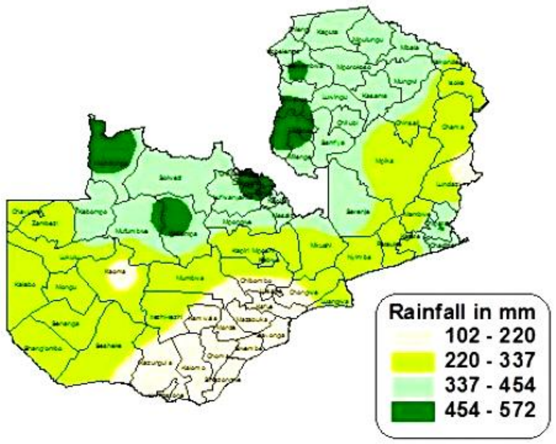
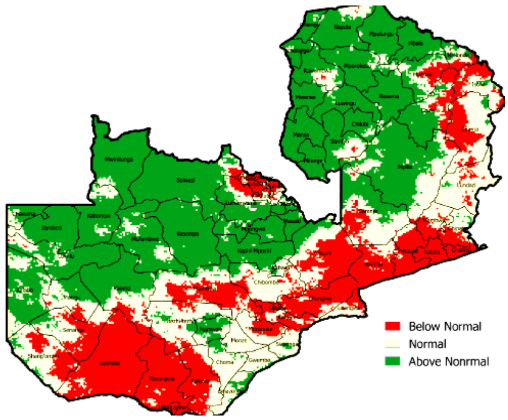


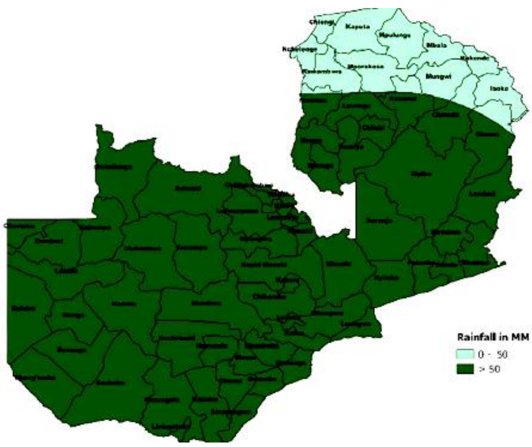
Figure 18: Choma left (a) and Pemba right (b) rainfall performance during 2nd season of crop growth



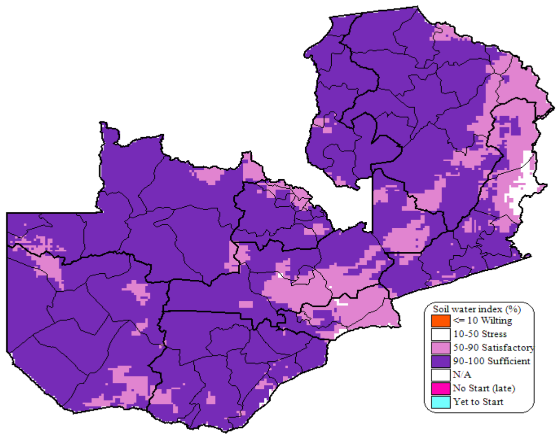
Cumulative rainfall in trial sites 1st July – 20th Dec in first season. Trial sites during the period received between 102 – 220 mm (white colour)



Rainfall departure Map in trial sites 1st July to 10th Jan first season. Trial sites received normal rainfall (yellow colour)

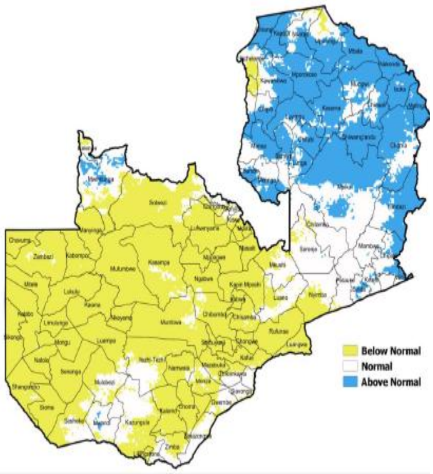


Rainfall forecast 21st – 28th February first season, trial sites received > 50 mm (green colour) during the period

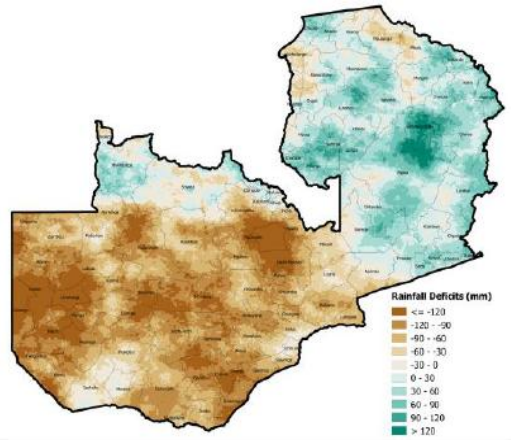


Soil water index for maize in trial sites was sufficient (90-100%) between 21st – 31st March first season (purple colour)

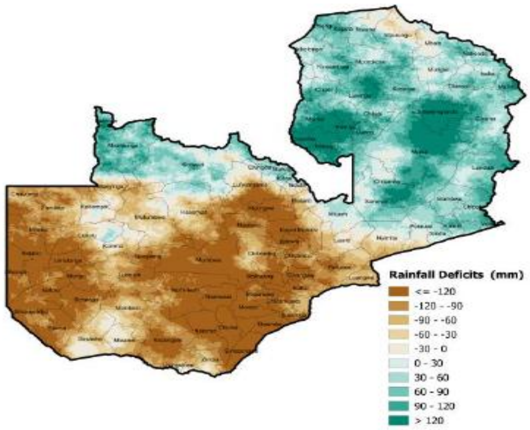
Figure 19: Satellite imagery of rainfall performance in first season of trial establishment (Courtesy of Meteorology Department)



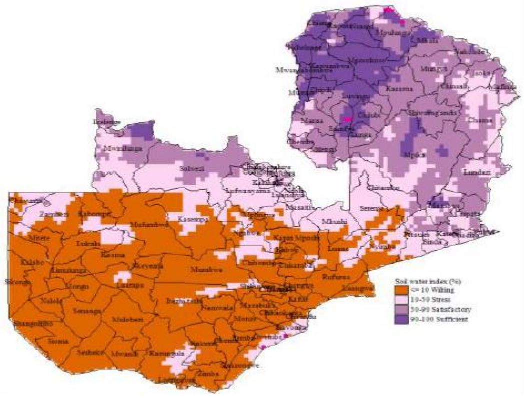
Rainfall performance 1st July – 31st December second season was below normal (less than 75% of normal rainfall) in trial sites (yellow colour)



Cumulative rainfall deficits in trial sites (-120 mm) 1st July – 31st January second season
(dark brown colour)



Cumulative rainfall deficits in trial sites (-120 mm) 1st July – 28th February second season (dark brown colour)



Soil water index for maize in trial sites was wilting (10%) between 21st – 31st March second season (light brown colour)

Figure 20: Satellite imagery of rainfall performance in second season of trial establishment (Courtesy of Meteorology Department)

4.3.4 Treatment Effects on Growth Parameters under Field Conditions

Tables 17 - 20 shows influence of the treatments on grain yield and yield components of the tested maize varieties in Pemba and Choma districts under two tillage systems i.e conventional and conservation agriculture. Generally, conservation tillage system treatments performed better than convention plots for the measured parameters that included, grain, stover and core yields (Figs. 21 - 22).

With regard to treatment effect under field conditions, it was generally found that conservation tillage systems performed better than the conventional plots. The underlying reason for this departure or differences in yield parameters (grain, stover and core) observed could be attributed to the ability of the conservation plots to hold water as compared with the conventional methods. In conservation agriculture, basin tillage has the capacity to hold moisture due to limited drainage mechanisms and thereby provides the water needed for the translocation of the mineral nutrients to the crop. In conventional methods, the probability of the nutrients being washed away is much higher, which is a function of slope and soil factors. Idowu, Sultan, Darapuneni, Beck and Steiner (2019) indicated that conservation agriculture normally protects the soil from nutrient erosion through various means such as residues, enhanced moisture retention capacity and carbon sequestration including a reduction in the sun rays that impact on temperature of the soil. Nyamangara *et al.* (2013) confirmed that under planting basins which were employed in our work, effects of the treatments may be more evident in the early stages of CA due to water collection and soil amendments concentration or a combination.

Almost similar to these findings, Mupangwa, Twomlow and Walker (2013, 2012); Ngwira, Aune, Thierfelder and Mkwinda (2014, 2012a); Thierfelder *et al.* (2013a, b) and Thierfelder and Wall (2012) in their studies on CA practices in Malawi, Mozambique, Zambia and Zimbabwe respectively found that CA treatments performed better than the conventional tillage systems where 80% of the generated data indicated gains of CA above conventional tillage systems. CA tillage systems tried appeared to have dealt with the challenges in short to medium-term regarding maize productivity in the farming systems.

Additionally, during the growing period, most of the sites did not receive adequate rains to warrant efficient growth of the crop. In all the sites, the rains received were below normal except for Choma in first season. The study sites, Pemba and Choma received 788.6 mm and 854.6 mm in first season while the second season was even worse as intermittent rains were prevalent. There was prolonged dry spells that lasted more than 4 weeks and this had a huge impact on the growth of the crop. Earlier results from studies on CA in Southern Africa have indicated that soil water is fundamental for the responses of CA tillage systems (Mupangwa, Twomlow & Walker, 2008, 2011; Thierfelder *et al.,* 2013a; Thierfelder & Wall, 2009). The total rainfall received in Pemba was 402.3 mm while Choma recorded 272 mm. Both study areas fall in agro-ecological region II, where maximum rainfall is 800 mm and categorized as

Cwa by the Köppen - Geiger climate classification system (Nouri, Costa, Santamouris & Matzarakis, 2018). Cwa encounters ten times as much rain received in wettest month of summer period as driest month of winter.

Grain yields for Pemba and Choma in first cropping season across the study sites were significantly different (*P<0.05)* and all the treatments performed below the positive control, the full rate fertilizer application (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) treatment which was used as a benchmark. However, in the second cropping season of the study, the anthill soil base treatment performed better than the set inorganic fertilizer recommendations. This could have been attributed to enhanced release of the nutrients by the anthill soil coupled with rainfall received at the time. In addition, anthill soil is known to be less effective during the dry conditions as the resource becomes hard, thereby hampering the bioavailability of nutrients to the crop. Khu Pakee *et al.* (2014) also substantiated that the anthill soil requires more water attributed to the high suction properties compared with adjacent soil. This fundamentally affected the expected yield gains in this study.

Fertilizer level treatments exhibited significant effect in the first cropping season (*P<0.05*) for both CONV and CA treatments in Pemba study site (Table 17) while stover and core yield in CONV plots did not display significant effect (*P>0.05*) amongst the treatments. Additionally, varieties (SC 403, PAN 413 and ZMS 528) had no significant effect (*P>0.05*) in terms of grain yield for both CONV and CA plots while significant effect was observed in stover yield for both CONV and CA plots. Variety effect was also observed in core yield under CONV plots only. Furthermore, the interaction between fertilizer level and variety did show any significant effect on yield and yield components.

In the second cropping season, fertilizer level treatments exhibited significant differences (*P<0.05*) for grain yield in CONV plots only while CA plots for core yield exhibited the same trend in Pemba study site (Table 21). Stover and core yield in both CONV and CA plots did not differ significantly (*P>0.05*) amongst the treatments. The varieties (SC 403, PAN 413 and ZMS 528) did not also show significant effect (*P>0.05*) in terms of grain yield for CONV plots while significant effect was observed in CA plots. Variety effect on stover yield was observed in both CONV and CA plots while effect on core yield was evident only in CONV plots. Variety effect was also observed in core yield under CONV plots only.

Interaction between fertilizer level and variety did show any significant effect on yield and yield components.

Fertilizer level treatments showed statistical evidence of significant effect for grain yield, stover and core yields in the first cropping season ($P<0.05$) for both CONV and CA treatments in Choma study site (Table 18). Significant varieties (SC 403, PAN 413 and ZMS 528) effect ($P<0.05$) was observed in CONV plots in stover yields only. Interaction between fertilizer level and variety did not display any significant effect on yield and yield components.

The second cropping season for fertilizer level treatments for grain yield demonstrated significant effect ($P<0.05$) for both CONV and CA treatments in Choma study site (Table 18) while stover and core yield showed significant effect only in CA plots ($P<0.05$) amongst the treatments. Similarly, for the varieties (SC 403, PAN 413 and ZMS 528) significant effect ($P<0.05$) was evident only in CA plots. Furthermore, the interaction between fertilizer level and variety did show any significant effect on yield and yield components. Overall, results obtained in this study showed that the tillage system and the environmental conditions prevailing at the time of the experimental period including agronomic practices applied influenced the yield and yield components achieved.

Table 17: Maize crop response to anthill soil amendment under conventional (CONV) and conservation agriculture (CA) tillage systems; Pemba Site

Variable	Stover yield (kg/ha) First and second season		Grain yield (kg/ha) First and second season		Core yield (kg/ha) First and second season	
Tillage practice CA	231.44±10.4a	199.31±12.0a	1376.63±44.3a	716.39±43.1a	359.18±13.9a	112.07±6.0a
CON	230.86±9.2a	194.51±11.0a	1292.44±36.8b	759.40±51.4a	330.71±9.3b	91.63±5.6b
Fertilizer level 1 = AHT	180.86±15.3a	182.72±18.3a	1228.40±75.6a	602.47±59.3a	345.06±15.5a	86.83±10.3ab
2 = FRF	208.33±12.4ab	211.11±23.6a	1242.59±74.2a	818.72±70.7a	327.78±23.04a	119.34±11.6b
3 = FRF + AHT	267.97±18.7c	186.00±23.1a	1505.01±71.8b	786.21±77.3a	394.34±23.6b	111.11±10.9ab
4 = HRF + AHB	249.07±15.3bc	214.81±18.7a	1279.17±59.9a	854.73±111.1a	332.41±17.3a	115.22±10.3b
5 = Urea + AHT	230.56±14.9abc	178.60±17.1a	1262.50±58.6a	775.10±68.1a	326.85±17.9a	100.82±8.1ab
6 = M + AHT	235.19±16.6abc	208.23±19.0a	1444.44±59.7ab	590.12±83.9a	337.5±18.70a	77.78±7.5a
Maize varieties V_1	200.82±10.8a	150.62±11.3a	1251.58±54.6a	611.00±39.8b	359.18±13.9a	90.95±7.0a
V_2	246.84±11.02b	223.05±16.1b	1373.64±47.1a	862.96±73.6ab	330.71±9.3b	113.99±7.7a
V_3	240.05±12.4b	217.08±11.4b	1359.03±47.8a	739.71±48.5a	345.06±15.5a	100.62±6.8a

Table 17: *Cont*

Summary of all treatment effects (F-Statistics)	Stover yield (kg/ha) First and second season		Grain yield (kg/ha) First and second season		Core yield (kg/ha) First and second season	
Tillage	0.882	0762	0.038*	0.516	0.016*	0.014*
Fertilizer level	0.002*	0.624	0.007*	0.093	0.001*	0.024
Maize varieties	0.001*	0.000*	0.142	0.010*	0.000*	0.074
Tillage x fertilizer	0.132	0.749	0.776	0.894	0.084	0.453
Tillage x maize varieties	0.006*	0.139	0.539	0.375	0.431	0.333
Fertilizer level x maize varieties	0.487	0.838	0.021*	0.432	0.314	0.636
Tillage x fertilizer x maize varieties	0.412	0.553	0.368	0.915	0.171	0.982

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403*

Table 18: Maize crop response to anthill soil amendment under conventional (CONV) and conservation agriculture (CA) tillage systems; Choma Site

Variable	Stover yield (kg/ha) First and second season		Grain yield (kg/ha) First and second season		Core yield (kg/ha) First and second season	
Tillage practice						
CA	181.73±10.1a	107.82±10.4a	930.86±86.9a	602.54±38.8a	152.59±11.3a	88.07±8.4a
CON	188.98±10.1a	120.44±11.3a	771.78±68.6a	585.19±38.7a	134.96±8.2a	112.34±8.5a
Fertilizer level						
1 = AHT	143.43±14.4a	60.91±11.9a	578.65±44.9a	461.93±49.9a	115.15±5.2ab	77.78±11.9a
2 = FRF	184.44±12.3a	158.44±19.8b	506.52±78.4a	853.70±85.9b	97.04±5.7a	146.09±20.9b
3 = FRF + AHT	222.63±14.8b	129.22±19.9ab	1235.80±129.9b	611.32±63.6a	181.48±17.7d	99.18±11.9ab
4 = HRF + AHB	214.35±19.6b	126.75±17.7ab	1014.72±170.1ab	637.65±56.6ab	164.81±21.7cd	103.29±12.6ab
5 = Urea + AHT	149.89±16.6a	97.94±14.9ab	832.11±109.4ab	526.95±47.5a	151.63±16.7bcd	90.94±13.9ab
6 = M + AHT	179.89±10.6ab	111.52±20.9ab	676.83±92.4a	471.60±50.1a	120.11±6.6abc	83.95±11.8a
Maize varieties						
V_1	159.12±12.1b	77.36±10.2a	982.22±118.9a	469.96±39.5a	155.00±14.5a	81.69±9.6a
V_2	218.90±12.5a	124.89±12.9b	780.99±97.4a	668.72±49.3b	147.38±12.8a	111.11±9.8a
V_3	176.05±10.0b	140.12±14.5b	812.09±75.4a	642.90±46.7b	131.36±9.7a	107.82±11.5a

Table 18: *Cont*

Summary of all treatment effects (F-Statistics)	Stover yield (kg/ha) First and second season		Grain yield (kg/ha) First and second season		Core yield (kg/ha) First and second season	
Tillage	0.700	0.383	0.076	0.727	0.256	0.053
Fertilizer level	0.000*	0.007*	0.001*	0.000*	0.009*	0.032*
Maize varieties	0.000*	0.002*	0.229	0.003*	0.655	0.109
Tillage x fertilizer	0.961	0.871	0.836	0.426	0.851	0.564
Tillage x maize varieties	0.406	0.429	0.906	0.251	0.582	0.365
Fertilizer level x maize varieties	0.402	0.692	0.327	0.965	0.487	0.993
Tillage x fertilizer x maize varieties	0.993	0.701	0.732	0.900	0.892	0.998

** Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403*

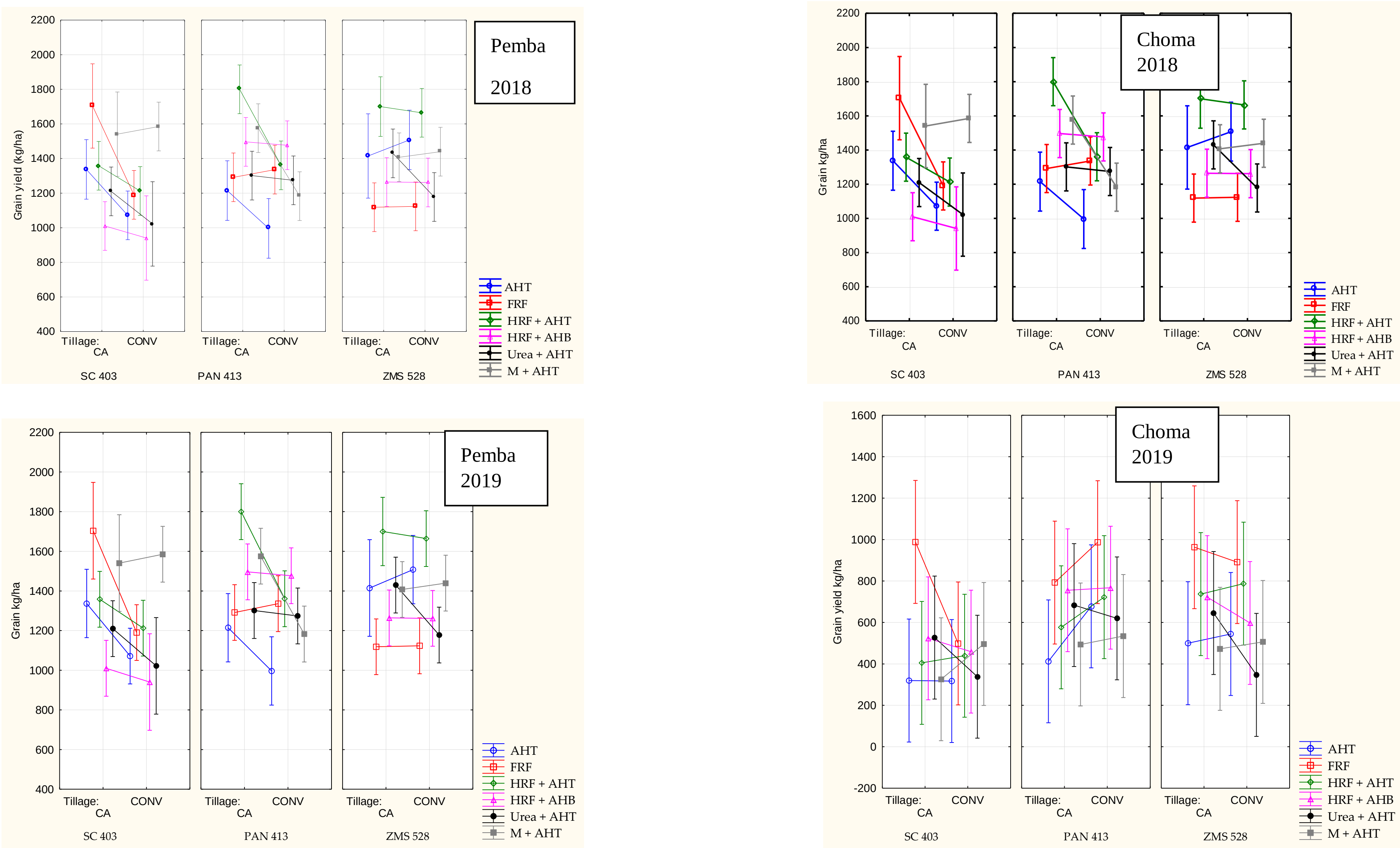


Figure 21: Main effects Plots for the interaction between tillage practice, fertilizer level and maize varieties across the study sites

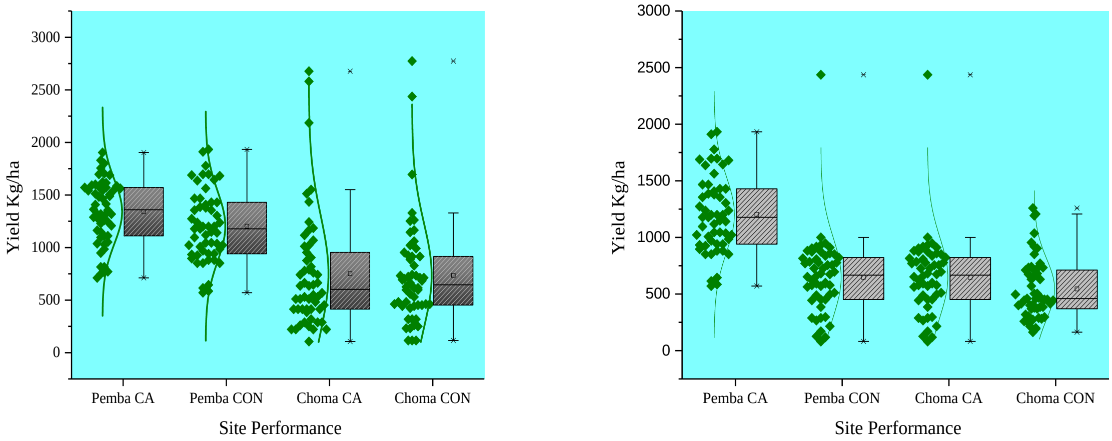


Figure 22: Box plots showing the mean variations of the tillage system performance in terms of grain yield across the study sites during 2018 (left) and 2019 seasons (right)

4.3.5 Nitrogen, Phosphorous and Potassium Amounts in Plant Tissue of Tested Maize Crop

Significant difference on N, P and K amounts in the maize tissue were noted (*P<0.05*) in both conservation agriculture and conventional tillage systems employed in this study (Tables 19 and 20). However, the variation was only evident in P and K while N did not show any statistical significance in N levels across the two study sites of Pemba and Choma districts. This suggested that there may have been almost similar nutrient availability at the micro sites. In agreement to this assertion, Mtambanengwe and Mapfumo (2006) reported that management of N is the most daunting task in African smallholder farming systems as there is insufficient use of fertilizers to meet N amounts required by the crop attributed to cost barrier. Furthermore, a combination of full rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) + anthill soil top (5000 kg/ha) resulted in significantly higher NPK levels in contrast to other treatments tested and was followed by urea fertilizer, (NPKS: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200kg/ha) + anthill soil top (5000 kg/ha); full rate fertilizer both basal and top dressing, (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha); half rate fertilizer, (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil base (5000 kg/ha); manure (10 000 kg/ha) + anthill soil top (5000 kg/ha) and anthill soil top (5000 kg/ha) treatments across the study sites.

The superior response of the treatment involving full rate fertilizer and anthill soil collected from the top of the anthill could have been as a result of the presence of elevated levels of N, P and K in the anthill soil which supplemented the already available N, P and K in the fertilizer used in the present study. Siame (2005) claimed that anthills possess higher levels of macro nutrients such as N, P and K as well as organic matter which contribute to crop growth. Moreover, the faster dissolution rate of the fertilizer may also have contributed to the increased concentration on the soil colloids (Ndakidemi, 2014) thereby making the nutrients available to the crop for uptake.

Anthill soil alone treatment exhibited lower response to N, P and K concentrations compared to other treatments in this study. This could have been as consequence of low release of nutrients characteristics of the resource. Mtambanengwe and Mapfumo (2006) in their studies on sandy soils with organic resources in Zimbabwe also found low N discharge from anthill soil attributable to high presence of clay in the resource. Hassink (1997) concluded that clay is known to reduce mineralization, leading to the stabilization of soil organic matter.

In terms of maize varieties used in the current study, maize variety ZMS 528 (V_3), a medium-early maturing variety demonstrated highest uptake of N, P and K in the tissues compared with other varieties (SC 403, V_1 and PAN 413, V_2) across the studied sites (Tables 21 and 22). Taken in use, results from this study suggest that smallholder farmers in Pemba and Choma have the prospects of benefiting from the combined usage of organic resources such as anthill soil and affordable inorganic mineral fertilizers in enhancing their soil fertility as a cheaper option in their agricultural production. In addition, cultivating of ZMS 528 would prove beneficial as the variety produces stable yields even in low organic matter inherent soils. Additionally, the hybrid maize variety takes less than 110 days to reach physiological maturity and is able to withstand rainfall variabilities and is resistant to most maize diseases.

Table 19: Effects of anthill soil application, cattle manure, mineral fertilizer and NPK concentration on maize test crop tissues at harvest under conventional (CONV) and conservation agriculture (CA) tillage systems; Pemba Site

Variable	**N (kg/ha)**	**P (kg/ha)**	**K (kg/ha)**
Tillage practice			
CA	1.38±0.15a	0.10±0.00b	1.28±0.02a
CON	1.39±0.08a	0.08±0.00a	1.17±0.05b
Fertilizer level			
1 = AHT	1.33±0.20b	0.09±0.01b	1.18±0.07b
2 = FRF	1.36±0.19b	0.09±0.01b	1.21±0.06b
3 = FRF + AHT	1.59±0.25a	0.11±0.01a	1.40±0.09a
4 = HRF + AHB	1.34±0.21b	0.09±0.01b	1.17±0.08b
5 = Urea + AHT	1.37±0.22b	0.09±0.01b	1.19±0.08b
6 = M + AHT	1.34±0.20b	0.09±0.01b	1.19±0.06b
Maize varieties			
V_1	1.15±0.11c	0.06±0.00c	1.03±0.04c
V_2	1.28±0.09b	0.08±0.00b	1.16±0.04b
V_3	1.73±0.20a	0.13±0.00a	1.48±0.04a
Summary of all treatment effects (F-Statistics)			
Tillage	0.737	0.000*	0.000*
Fertilizer level	0.000*	0.000*	0.000*
Maize varieties	0.000*	0.000*	0.000*
Tillage x fertilizer	0.116	0.084	0.012*
Tillage x maize varieties	0.000*	0.000*	0.000*
Fertilizer level x maize varieties	0.025*	0.038*	0.002*
Tillage x fertilizer x maize varieties	0.000*	0.003*	0.003*

** Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403*

Table 20: Effects of anthill soil application, cattle manure, mineral fertilizer and NPK concentration in maize test crop tissues at harvest under conventional (CONV) and conservation agriculture (CA) tillage systems; Choma Site

Variable	N (kg/ha)	P (kg/ha)	K (kg/ha)
Tillage practice			
CA	1.25±0.08a	0.09±0.00a	1.15±0.02a
CON	1.24±0.13a	0.07±0.01b	1.05±0.05b
Fertilizer level			
1 = AHT	1.19±0.18b	0.08±0.01b	1.06±0.06b
2 = FRF	1.22±0.18b	0.08±0.01b	1.09±0.06b
3 = FRF + AHT	1.44±0.22a	0.10±0.01a	1.26±0.08a
4 = HRF + AHB	1.21±0.19b	0.08±0.01b	1.05±0.07b
5 = Urea + AHT	1.23±0.20b	0.08±0.01b	1.07±0.07b
6 = M + AHT	1.20±0.18b	0.08±0.00b	1.07±0.05b
Maize varieties			
V_1	1.03±0.10c	0.06±0.01c	0.93±0.20c
V_2	1.15±0.09b	0.07±0.01b	1.05±0.24b
V_3	156±0.18a	0.12±0.01a	1.33±0.24a
Summary of all treatment effects (F-Statistics)			
Tillage	0.737	0.000*	0.000*
Fertilizer level	0.000*	0.000*	0.000*
Maize varieties	0.000*	0.000*	0.000*
Tillage x fertilizer	0.117	0.084	0.013*
Tillage x maize varieties	0.000*	0.000*	0.000*
Fertilizer level x maize varieties	0.024*	0.038*	0.003*
Tillage x fertilizer x maize varieties	0.000*	0.003*	0.003*

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403*

4.4 Quantifying Phosphatase and Arylsulphatase Soil Enzyme Activity and Nutrient Dynamics after Anthill Soil Application

4.4.1 Phosphatase and Arylsulphatase Soil Enzymes Activities

In this study all enzyme activities involving phosphatase and arylsulphatase exhibited significant differences ($P<0.05$) in Choma except in Pemba study site where phosphatase showed no differences between the CONV and CA tillage systems (Fig. 23). These findings are similar to earlier studies by Acosta-Martinez and Tabatabai (2001) who found lower values of phosphatase in conventional tillage in comparison with no till (CA) systems but with no significant differences. This may be related to having uniform P bioavailability in both tillage systems. Bergtorm *et al.* (1998) also reported higher phosphatase and arylsulphatase enzyme activity under no till (CA) system compared with conventional systems. Mankolo, Reddy, Senwo, Nyakatawa and Sajjala (2012) indicated that under CONV tillage system the probability of organic and nutrient loss is much higher and thus leads to decreased microbial activity. The aforementioned enzymes are therefore very important due to their driving role of mineralizing P and S in the soil environment.

Generally, the phosphatase activity across the study districts was lower compared with arylsulphatase. As for the treatment performance regarding the enzyme activities in the present study, results showed statistical evidence of significant differences across the treatments. Phosphatase activity was more pronounced in the sole anthill soil top treatment (AHT at 5000 kg/ha) in both study sites (Table 23), suggesting that organic matter presence may have enhanced the enzyme activity in the anthill. Full rate fertilizer treatments (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) in both study sites showed lowest stimuli of phosphatase enzyme activity. The biological parameter activity may have been hampered by the mineral fertilizer as a result of chemical reactions.

Arylsulphatase on the other hand showed variable results across the study sites with treatments in the studied tillage systems. In Pemba site for instance, highest arylsulphatase enzyme activity was detected in the treatment involving urea fertilizer (200 kg/ha) + anthill top soil (5000 kg/ha) while the lowest enzyme stimuli were found in the full rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) + anthill top soil (5000 kg/ha). The highest arylsulphatase activity value detected may have been due to the already present sulphur in the urea mineral fertilizer.

Similarly, in Choma site, the treatment with half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil base (5000 kg/ha) recorded highest arylsulphatase enzyme activity which may also have been influenced by nitrogen and sulphur in the fertilizer. These findings in this study, corroborates with those of Mankolo *et al.* (2012) who reported that the arylsulphatase enzyme activity is enhanced by N fertilization and is an indicator of microbial activities. Overall, arylsulphatase enzyme activity was more elevated in Pemba than Choma studied site. However, as for the tillage systems, findings in this study showed a higher presence of arylsulphatase in CA than CONV tillage systems. A myriad of factors may have contributed to this scenario among them the management aspects of the soil including the inherent soil parent material. Balota, Colozzi-Filho, Andrade and Dick (2004) concluded that CA systems have an influence on mineralization of nutrients including microbial biomass thus provides a favourable environment for the micro-organisms in the soil.

Based on the findings in this study, it may be helpful to adopt CA systems by smallholder farmers in the study areas and this should be considered as one of their priorities not only for mitigating climate change variability but also for sustaining the bioavailability of nutrients and microbial activities in the soil system for enhanced agriculture productivity. Elbl *et al.* (2019) claimed that enzymatic activities are normally used by scientists to assess the influence of different soil management approaches and agriculture techniques including organic conditioners on soil health and quality.

4.4.2 Nutrient Dynamics after Anthill Soil Application - Soil pH, Residual P, Ca, Mg, Zn, Cu and Fe at Harvest

Tables 21 and 22 provides evidence for the effect of anthill soil, manure and NPK fertilizer rates and/or their combination on selected macro and micro nutrients such as pH, P, Ca Mg, Zn, Cu and Fe in the current study. Results show that there was a significant variation ($P<0.05$) in the concentrations of these nutrients at the end of the cropping season. The treatments made available in this study showed that there was a significant ($P<0.05$) change in soil pH, P, Zn, Fe and Cu concentrations in both CONV and CA tillage systems in Pemba site at the time of harvest (Table 25). Similar increases in soil pH have also been reported by Savin (2000) and Kpomblekou and Tabatabai (2003) with use of organic amendments in crop production. Calcium and Magnesium did not exhibit any significant differences ($P>0.05$) in the tested tillage systems. This could be attributed to uniform bioavailability of the nutrients at the micro sites. Across the treatments on the other hand, there were significant differences (*$P<0.05$*) in Mg concentrations and were below the recommended threshold level of 2 cmol/kg. Additionally, more P was evident in the half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil top (5000 kg/ha) treatment. All treatments nevertheless, had elevated residual P greater than the optimum of 15 mg P/kg set for maize production. Presence of anthill soil may have contributed to the increase in enhanced P availability. During formation of anthills, termites responsible for the activity exude material rich in phosphates catalyzed by phosphatase enzymes. Kwabiah, Palm, Stoskopf and Voroney (2003) also confirmed that the mineralization of P would occur in the short - range depending on the enrichment of organic inputs. Residual micro nutrients, Zn, Fe and Cu showed statistical evidence of significant differences (*$P<0.05$*) only in tillage systems and not within the treatments though the values varied.

As for Choma study site, the treatments illustrated no significant variation in soil pH, P, Zn, Fe and Cu concentrations in both CONV and CA tillage systems (Table 23). However, significant differences (*$P<0.05$*) were observed within the treatments for pH and P. Half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil base (5000 kg/ha) treatment recorded highest reduction in pH in comparison to the control soil while residual P increased. Decreased levels of pH may have been attributed to the decomposition process of the organic materials (Ndakidemi, 2014) in the soil that released organic acids. Calcium and Magnesium did not, display any evidence of significant differences (*$P>0.05$*) in the tested tillage systems.

Nonetheless, there were significant differences within the treatment combinations that raised the residual levels compared with the control soil. This may point to higher content of Ca and Mg in anthill soils (Sarcinelli, 2009; Robert, 2007; Siame, 2005). Residual micro nutrients were only evident in Fe that displayed no significant differences between the two tillage systems. However, the levels increased in contrast to the control. The highest value was observed in manure (10 000 kg/ha) + anthill top (5000 kg/ha) treatment. As for Cu and Zn, the study did not find any variance after application of treatments in Choma site. The measured Cu and Zn values were below 0.01 mg/kg measurable concentration levels. This suggested that there are less ISFM techniques being used by smallholder farmers in the study area for enhancing soil fertility. Manzeke *et al.* (2019) concluded that micro nutrient deficiencies are largely high in sub-Saharan Africa (SSA) due to extremely poor soil and less soil fertility management choices at smallholder farmer level. In support of this assertion, Soropa, Nyamangara and Nyakatawa (2018) also confirmed that deficiencies in nutrients in SSA are common in smallholder farming systems due to poverty and cultivation of heavy feeder crop genotypes that deplete the already short supply nutrients.

Table 21: Effects of anthill soil application, NPK fertilizer or cattle manure and their combination supply on pH, residual P, Ca, Mg, Zn, Fe and Cu in the soil collected near the root zone of the maize test crop at harvest, Pemba Site

Variable	pH (H_2O)	P (mg/g)	Ca (cmol/kg)	Mg (cmol/kg)	Zn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
Tillage practice							
CA	6.99±0.06	17.81±1.21	5.83±0.71	0.64±0.06	0.23±0.09	118.65±7.92	0.17±0.04
CON	7.2±0.05	22.44±1.28	5.70±0.66	0.68±0.08	3.87±1.70	230.26±12.97	6.72±1.40
Fertilizer level							
1 = AHT	6.93±0.10	18.22±1.86	4.79±0.71	0.59±0.07	0.01±0.00	146.17±23.67	2.06±1.12
2 = FRF	7.06±0.08	19.83±1.77	5.37±1.17	0.66±0.12	0.37±0.35	205.74±19.68	3.54±1.49
3 = FRF + AHT	7.11±0.09	22.89±2.92	8.08±1.70	0.93±0.18	3.55±2.12	159.76±27.67	5.36±2.62
4 = HRF + AHB	7.28±0.04	19.89±1.78	5.92±0.89	0.56±0.07	0.15±0.14	192.44±23.19	2.74±1.19
5 = Urea + AHT	7.01±0.13	18.83±2.03	3.39±0.75	0.39±0.02	0.25±0.18	180.38±19.27	1.09±0.51
6 = M + AHT	7.20±0.09	21.11±2.79	7.04±1.39	0.81±0.14	7.97±4.55	162.23±22.14	5.88±3.01
Maize varieties							
V_1	7.12±0.07	19.02±1.57	4.99±0.71	0.60±0.07	1.91±1.24	175.25±16.52	3.34±1.38
V_2	7.11±0.05	22.69±1.64	6.28±0.80	0.68±0.08	2.47±1.98	167.98±14.37	3.28±1.33
V_3	7.07±0.08	18.67±1.45	6.03±0.99	0.70±0.10	1.77±1.18	180.13±17.61	3.73±1.29
Summary of all treatment effects (F-Statistics)							
Tillage	0.01*	0.01*	0.90	0.69	0.04*	0.00*	0.00*
Fertilizer level	0.13	0.74	0.14	0.06	0.07	0.33	0.47
Maize varieties	0.87	0.15	0.55	0.73	0.94	0.84	0.97
Tillage x fertilizer	0.32	0.17	0.45	0.74	0.08	0.37	0.43
Tillage x maize varieties	0.84	0.57	0.46	0.90	0.97	0.51	0.97
Fertilizer level x maize varieties	0.79	0.69	0.99	0.99	0.98	0.99	0.99
Tillage x fertilizer x maize varieties	0.95	0.99	0.92	0.89	0.99	0.99	0.99

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*

Table 22: Effects of anthill soil application, NPK fertilizer or cattle manure and their combinations supply on pH, residual P, Ca, Mg and Fe in the soil collected near the root zone of the maize test crop at harvest, Choma Site

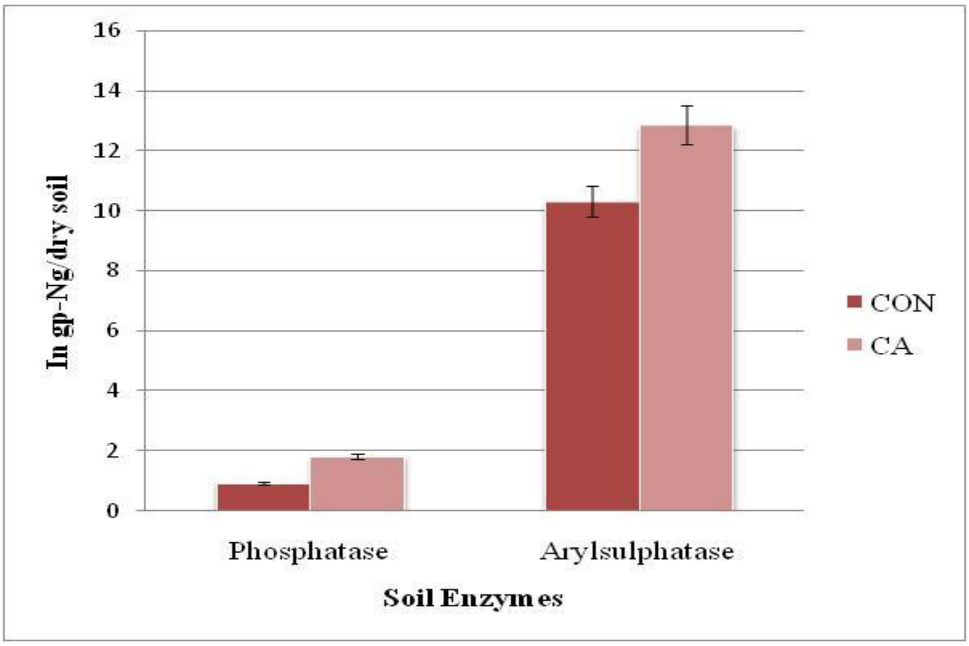
Variable	**pH (H_2O)**	**P (mg/g)**	**Ca (cmol/kg)**	**Mg (cmol/kg)**	**Fe (mg/kg)**
Tillage practice					
CA	5.10±0.04	16.61±0.74	0.92±0.03	0.22±0.01	56.28±3.10
CON	5.13±0.04	16.72±0.96	0.89±0.03	0.22±0.01	54.85±3.06
Fertilizer level					
1 = AHT	5.14±0.04	12.78±0.73	0.94±0.04	0.23±0.01	55.07±5.43
2 = FRF	5.11±0.08	17.89±1.70	0.84±0.04	0.21±0.01	59.99±5.07
3 = FRF + AHT	5.08±0.08	17.11±1.27	0.87±0.06	0.19±0.01	57.72±5.09
4 = HRF + AHB	4.96±0.06	20.11±2.05	0.92±0.04	0.21±0.01	57.01±5.16
5 = Urea + AHT	5.07±0.05	14.72±0.96	0.87±0.05	0.24±0.02	49.42±5.50
6 = M + AHT	5.34±0.26	17.06±1.29	1.01±0.08	0.25±0.01	60.18±5.92
Maize varieties					
V_1	5.13±0.05	17.56±1.12	0.93±0.04	0.22±0.01	57.27±3.82
V_2	5.15±0.31	15.19±0.91	0.86±0.03	0.21±0.01	56.46±3.43
V_3	5.07±0.22	17.08±1.08	0.93±0.04	0.23±0.01	52.97±4.06
Summary of all treatment effects (F-Statistics)					
Tillage	0.58	0.85	0.43	1.00	0.78
Fertilizer level	0.00*	0.01*	0.30	0.08	0.83
Maize varieties	0.37	0.24	0.32	0.31	0.76
Tillage x fertilizer	0.65	0.86	0.76	0.99	0.99
Tillage x maize varieties	0.61	0.82	0.43	0.16	0.70
Fertilizer level x maize varieties	0.83	0.99	0.88	0.93	0.98
Tillage x fertilizer x maize varieties	0.18	0.16	0.44	0.71	0.99

** Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5 000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5 000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS.*

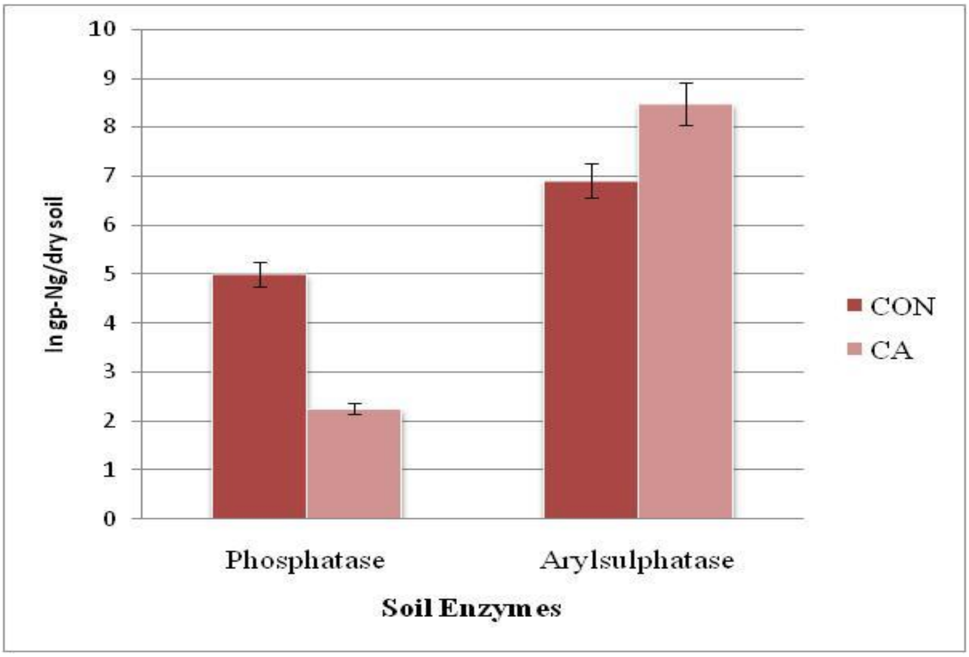
Table 23: Estimated Phosphatase and Arylsulphatase Enzymatic Activities (µg *p*-nitro phenol g^{-1} dry soil hr^{-1}) in conventional (CONV) and conservation agriculture (CA) tillage systems under various treatments across the studied sites

Variable	Choma Site		Pemba Site	
	Phosphatase	Arylsulphatase	Phosphatase	Arylsulphatase
Tillage practice				
CON	5.00±0.46a	6.91±0.44b	0.95±0.70a	10.30±0.61b
CA	2.26±0.63b	8.48±0.32a	1.83±0.36a	12.84±1.62a
Fertilizer Levels				
1 - AHT	6.40±0.65a	5.69±0.55d	3.66±1.16a	11.30±1.23c
2 = FRF	2.20±1.25c	6.89±0.41c	0.14±0.91b	11.37±0.88c
3 = FRF + AHT	3.73±0.83b	8.01±0.66e	0.61±0.83ab	8.08±0.48b
4 = HRF + AHB	3.09±0.78bc	9.28±0.87a	2.31±1.08ab	10.92±1.26c
5 = Urea + AHT	3.41±1.46bc	8.46±0.61b	0.48±0.67ab	16.16±4.56a
6 = M + AHT	2.96±0.60bc	7.86±0.69e	1.12±0.89ab	11.60±1.28c
Maize varieties				
V1	4.30±0.65a	7.37±0.20b	2.55±0.63a	9.43±0.67c
V2	3.25±0.75b	7.19±0.50b	1.29±0.74ab	14.99±2.36a
V3	3.35±0.74b	8.53±0.63a	0.32±0.63b	10.29±0.62b
Summary of all treatment effects (F-Statistics)				
Tillage	0.00*	0.00*	0.05*	0.00*
Fertilizer level	0.00*	0.00*	0.00*	0.00*
Maize varieties	0.00*	0.00*	0.07	0.00*
Tillage x fertilizer	0.00*	0.00*	0.01*	0.00*
Tillage x maize varieties	0.00*	0.00*	0.40	0.00*
Fertilizer level x maize varieties	0.00*	0.00*	0.02*	0.00*
Tillage x fertilizer x maize varieties	0.00*	0.00*	0.08	0.00*

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*



(a)



(b)

Figure 23: Graphical summary of soil enzyme activities of Phosphatase and Arylsulphatase in: (a) Pemba and (b) Choma study areas

4.5 Additive Effects of Anthill Soil Application on Moisture Retention and Water Productivity

4.5.1 Soil Moisture Retention

Tables 24 – 26 indicate the moisture retention variations during the two cropping seasons of the experimental period for the critical months of January to March for each cropping season in the research sites. In this study, it is generally observed that CA plots had retained more water compared with the CONV plots. Verhulst *et al.* (2011) also confirmed observing higher moisture content in CA and CONV tillage systems where organic application treatments were involved in a maize experiment under semi-arid environment of Turkey than in the untreated plots. Furthermore, treatment 2 (full rate of fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) and treatment 6 (manure at 10 000 kg/ha+ anthill top soil at 5000 kg/ha) in January of the first cropping season performed better than other treatments in terms of water retention in Pemba site while in the subsequent month of February, the treatments involving treatment 1 (anthill top soil at 5000 kg/ha); treatment 4 (half rate fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha + anthill soil base at 5000 kg/ha) and treatment 6 (manure at 10 000 kg/ha+ anthill soil top at 5000 kg/ha) were the best performers in terms of water retention. This was also the case for the month of March for treatment 6 (manure at 10 000 kg/ha+ anthill top soil at 5000 kg/ha). This scenario might have been attributed to the manure and fertilizer treatments that contributed to improving the physical properties of the soil. This was also observed across all the three varieties used in this study.

Mujdeci, Simsek and Veli (2017) affirmed that availability of water content in soils is dependent on the type of soil and environmental characteristics. Additionally, soil structure plays a key role for varying water retention and movement in a particular type of soil. Organic matter content and tillage practices also control the soil structure. In support of this assertion, Gao *et al.* (2017) indicated that different soil tillage methods play a significant role in influencing moisture related soil physical characteristics that include pore size distribution, location, total porosity, infiltration and bulk density. In a similar study in Zimbabwe, Nyamangara *et al.* (2001) concluded that organic soil amendments/fertilizers enhance water available to the plant partly due to improved infiltration including water retention. Sojka and Orts (2005) also observed that organic amendments such as anthill soils have the ability to increase infiltration, water retention, support aggregation and substrate for soil biological action thereby enhancing soil aeration. Additionally, commercially available fertilizers affect soil physical and chemical processes which improve the soil capacity to retain water. Findings in this study also show that plots where variety V_2, PAN 413 was planted almost showed consistent in terms of the water retention capacity, which was complemented by fertilizer treatments used in this study.

As for Choma site (Table 25), during the period of January of the first cropping season, the treatments involving organic resources; treatment 1 (anthill top soil at 5000 kg/ha) and treatment 6 (manure at 10 000 kg/ha + anthill soil top at 5000 kg/ha) exhibited better water retention values compared with other treatments. In February, however, the water retention was more pronounced in treatment 2 (full rate fertilizer NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) and treatment 6 (manure at 10 000 kg/ha + anthill soil top at 5000 kg/ha). During the same period, varieties, V_1 (SC 403) retained more water compared with the rest. In March, treatment 3 (full rate fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha + anthill soil top at 5000 kg/ha) and treatment 6 (manure at 10 000 kg/ha + anthill soil top at 5000 kg/ha) showed more water retention compared with other treatments. In this period variety, V_2 had more water in the plots compared with other treatments.

With regard to the month of January in the second cropping season, conventional tillage system in Pemba site demonstrated more water retention than the CA tillage system while in Choma study site there were no significant differences between the systems (Table 26). A myriad of factors led to this situation one of which was low rainfall received and extended dry spells during the period and also the management practices carried out by the experimental host farmers as they were involved in trial management for the first time. In agreement to this observation, Thierfelder, Mutasa and Rusinamhodzi (2014) also claimed that lack of management skills by host trial farmers often affected crops in CA practices compared with the conventional methods.

Furthermore, treatments that showed higher water retention capacity for Pemba site during January period were observed in treatment 4 (half rate fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha + anthill soil base at 5000 kg/ha) and treatment 6 (manure at 10 000kg/ha + anthill soil top at 5000 kg/ha) with no significant differences in water retention recorded for the plots in all varieties (SC 403, PAN 413 and ZMS 528) tested in this study.

In Choma site, there was a different scenario, exhibited in terms of water retention performance amongst the treatments. All the treatments except treatment 1 (anthill soil top at 5000 kg/ha) exhibited almost same levels. This situation may be attributable to the short duration of rainfall received during the period. There were regular dry spells during the period that continued until the months of February and March. As such no further data were collected for soil moisture in this period. Choma site received a total of 273.3 mm of rainfall during the season against 800 mm expected for the district. This was the lowest precipitation received in 46 years according to Meteorological records. The erratic rainfall experienced in the growing season undeniably influenced the water moisture regimes in the soil environment of the treatment plots and yield obtained on test crop in this study.

Table 24: Water Retention (m^3) during Critical Months of the Test Crop Growth in Conservation and Conventional Plots

Pemba Site

Variable	**First Cropping Season**		
	January	February	March
Tillage practice			
CON	1.36±0.05b	1.62±0.03a	4.29±0.12a
CA	1.95±0.09a	1.62±0.03a	1.94±0.08b
Fertilizer Levels			
1 - AHT	1.63±0.13ab	1.67±0.06a	3.23±0.03a
2 = FRF	2.06±0.20a	1.58±0.05a	3.04±0.32a
3 = FRF + AHT	1.53±0.09b	1.62±0.06a	3.23±0.37a
4 = HRF + AHB	1.34±0.10b	1.64±0.05a	3.06±0.34a
5 = Urea + AHT	1.34±0.09b	1.60±0.06a	2.81±0.32a
6 = M + AHT	2.03±0.15a	1.60±0.03a	3.31±0.37a
Maize varieties			
V1	1.62±0.11a	1.66±0.04a	3.12±0.24a
V2	1.69±0.10a	1.60±0.04a	3.20±0.24a
V3	1.66±0.11a	1.60±0.04a	3.02±0.23a
Summary of all treatment effects (F-Statistics)			
Tillage	0.00*	1.00	0.00*
Fertilizer level	0.00*	0.90	0.44
Maize varieties	0.80	0.55	0.61
Tillage x fertilizer	0.00*	1.00	0.13
Tillage x maize varieties	0.44	1.00	0.38
Fertilizer level x maize varieties	0.52	0.18	0.62
Tillage x fertilizer x maize varieties	0.85	1.00	0.61

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403*

Table 25: Water Retention (m^3) during Critical Months of the Test Crop Growth in Conservation and Conventional Plots

Choma Site

Variable	**First Cropping Season**		
	January	February	March
Tillage practice			
CON	0.99±0.00b	1.43±0.05a	4.29±0.12a
CA	1.14±0.04a	1.07±0.03a	3.98±0.13a
Fertilizer Levels			
1 - AHT	1.07±0.04a	1.18±0.06a	4.22±0.21a
2 = FRF	1.06±0.04a	1.30±0.09a	3.92±0.27a
3 = FRF + AHT	1.04±0.04a	1.26±0.11a	4.36±0.19a
4 = HRF + AHB	1.03±0.02a	1.27±0.08a	4.02±0.24a
5 = Urea + AHT	1.03±0.02a	1.12±0.07a	3.88±0.21a
6 = M + AHT	1.20±0.11a	1.41±0.09a	4.40±0.20a
Maize varieties			
V1	1.08±0.04a	1.33±0.08a	4.16±0.16a
V2	1.08±0.04a	1.22±0.05a	4.21±0.13a
V3	1.06±0.03a	1.22±0.05a	4.03±0.18a
Summary of all treatment effects (F-Statistics)			
Tillage	0.00*	0.00*	0.11
Fertilizer level	0.23	0.10	0.46
Maize varieties	0.87	0.23	0.71
Tillage x fertilizer	0.23	0.09	0.60
Tillage x maize varieties	0.85	0.51	0.60
Fertilizer level x maize varieties	0.86	0.79	0.55
Tillage x fertilizer x maize varieties	0.87	0.35	0.87

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403*

Table 26: Water Retention (m^3) during Critical Months of the Test Crop Growth in Conservation and Conventional Plots

Pemba and Choma Sites

Variable	**Second Cropping Season**	
	Pemba	Choma
Tillage practice		
CON	4.94±0.03a	4.99±0.01a
CA	4.46±0.17b	4.99±0.00a
Fertilizer Levels		
1 - AHT	4.89±0.09ab	4.96±0.03a
2 = FRF	4.93±0.04ab	5.00±0.00a
3 = FRF + AHT	4.29±0.36ab	5.00±0.00a
4 = HRF + AHB	5.00±0.00b	5.00±0.00a
5 = Urea + AHT	4.08±0.34a	5.00±0.00a
6 = M + AHT	5.00±0.00b	5.00±0.00a
Maize varieties		
V1	4.71±0.15a	4.98±0.01a
V2	4.64±0.16a	5.00±0.00a
V3	4.74±0.15a	5.00±0.00a
Summary of all treatment effects (F-Statistics)		
Tillage	0.01*	0.58
Fertilizer level	0.01*	0.15
Maize varieties	0.89	0.19
Tillage x fertilizer	0.02	0.91
Tillage x maize varieties	0.93	0.73
Fertilizer level x maize varieties	0.99	0.09
Tillage x fertilizer x maize varieties	0.99	0.98

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*

4.5.2 Water Productivity

Water productivity (WP) was measured by computing the total grain yields and agricultural water use (mm, m^3) over the cultivated area following Bouman, Humphreys, Yuong and Barker (2007) formula. Table 27 presents WP values obtained for different tillage systems and treatments used in this study. Findings show that there were significant differences (*P<0.05*) recorded in the WP values across the fertilizer level treatments. Generally, CA tillage systems had better WP values than the CONV systems attributed to several reasons. The significant variation in WP was due in part to the differences in rainfall patterns. Highest WP value (0.19 kg/m^3) recorded in Pemba site during the first cropping season was in the treatment involving half rate fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil top (5000 kg/ha) followed by manure (10 000 kg/ha) + anthill soil top (5000 kg/ha) treatment that exhibited a WP value of (0.18 kg/m^3). This variation in these values may be attributable to the poor rainfall distribution experienced during the growing period that significantly influenced moisture conditions and crop growth. This finding confirms Qureshi (2019) assertions that sub Saharan Africa and some parts of Asia have very low WP mainly influenced by rainfall amounts received amongst other variables. In agreement to this finding, Brauman, Siebert and Foley (2013) also documented WP values of maize in some parts of sub-Saharan Africa to be below 0.3 kgm^3 with highest values recorded in USA and China standing at 1.7 kgm^3.

Similar to Pemba, Choma site during the first cropping season showed similar trend in terms of the treatment performance. The highest WP (0.14 kg/m^3) was observed in the half rate fertilizer, (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil top (5000 kg/ha), followed closely by the half rate fertilizer, (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil base (5000 kg/ha) and top dressing, (urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) + anthill soil top (5000 kg/ha) treatments, both recording WP of 0.11 and 0.10 kg/m^3 respectively. The sole anthill soil treatment exhibited a paltry 0.05 kg/m3. The volatile and erratic rainfall received during the period may have contributed to this lower value. In times of poor rainfall, the anthill soil gets dry easily with little moisture available to the crop. In support of this assertion, Khu Pakee *et al.* (2014) also indicated that anthill soil has a high suction characteristic and in times of poor rainfall, the water retention capacity is lowered.

In the second cropping season, Pemba site did not show significant differences in terms of fertilizer level treatments (*P>0.05*) with regard to WP. However, for Choma site in the second cropping season, the treatment effect showed overall significant differences (*P<0.05*) in the fertilizer level under both CA and CONV plots. Highest WP value (0.31 kg/m3) was recorded in the fertilizer full rate treatment (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha) followed by the half rate fertilizer, (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) + anthill soil base (5000 kg/ha) treatment that recorded WP value of 0.23 kg/m^3. The sole anthill soil top (5000 kg/ha) treatment demonstrated 0.17 kg/m^3 WP value.

Lopez-Lopez, Jiménez-Chong, Hernández-Aragón and Ibarra (2018) indicated that WP varies at different scales because of factors such as weather variability, crop selection and water management in plots and inputs, including labour and fertilizers. Options to improve the WP in agriculture at the level of the plot are available according to different scholars. Options suggested may involve conducting research on plant physiology and agronomy methodologies with a focus on ensuring transpiration is more efficient and productive, by means of minimizing non-beneficial evaporation and by employing more precise and efficient fertilizer amounts (Shao *et al.*,2014; Kadiyala *et al.*, 2015; Linquist *et al.*, 2015). In this study, the host farmer's management of the trials may have had an effect on WP values obtained as most of them were exposed to CA practices for the first time under the researcher – farmer collaborative work.

Generally, WP is employed to carry out comparisons between productivity of water and other contributing variables that allow limitations in the efficient use of soil moisture or rainfall during crop production. Molden *et al.* (2010) concluded that WP should always be considered whenever farming practices are being implemented as this contributes to producing more food and consequently more income generation with minimal amount of agricultural water. It is therefore critical to pay attention to WP issues as doing so, will furthermore contribute to improved livelihoods for the rural communities including the ecosystem services at large. Embracing agronomic techniques that modify tillage systems, soil fertility and planting dates may have incremental effects on yield obtained with water units used as well as output per unit area of land utilized.

This study also explored the correlation analysis between tillage, fertilizer level treatment, variety and water productivity (Table 28, Fig. 24). Findings revealed that there was a positive correlation between these variables and water productivity in Pemba site, in the first cropping season. As for Choma site, no significant ($P<0.05$) correlations were recorded during the same period. In the second cropping season, however, there was a negative correlation recorded between tillage and water productivity in Pemba while in Choma site in the same time, recorded a positive correlation only between variety and water productivity. A number of factors might have contributed to this scenario. Some host farmers were involved for the first time in trial management and possibly lacked some skills to carry out timely agronomic practices such as weeding. In agreement to this Zhang, Li, Yang, Wang and Chen (2011), confirmed that the manner in which the field is managed has a significant effect on soil moisture status. Additionally, there was variability in rainfall distribution during the cropping season which was not favourable to maintain soil moisture conditions. Continuous erratic rainfall was a usual occurrence for most parts of the season which rendered loss of water from the soil through evapo-transpiration processes due to high temperature conditions.

Table 27: Water Productivity (kg/m^3) for Conservation and Conventional Plots across Research Sites

Variable	First cropping season		Second cropping season	
	Pemba	Choma	Pemba	Choma
Tillage practice				
CON	0.15±0.01b	0.09±0.01a	0.21±0.01a	0.20±0.01b
CA	0.17±0.01a	0.09±0.01a	0.16±0.01b	0.24±0.01a
Fertilizer Levels				
1 - AHT	0.14±0.01c	0.05±0.01cd	0.15±0.01a	0.17±0.02b
2 = FRF	0.15±0.01bc	0.05±0.01d	0.20±0.02a	0.31±0.03a
3 = FRF + AHT	0.19±0.01a	0.14±0.02a	0.20±0.02a	0.22±0.02ab
4 = HRF + AHB	0.16±0.01bc	0.11±0.02ab	0.21±0.03a	0.23±0.02ab
5 = Urea + AHT	0.16±0.01bc	0.10±0.02abc	0.19±0.02a	0.19±0.02b
6 = M + AHT	0.18±0.01ab	0.07±0.01bcd	0.15±0.02a	0.17±0.02b
Maize varieties				
V1	0.15±0.01a	0.09±0.01a	0.15±0.01b	0.17±0.01a
V2	0.17±0.01b	0.08±0.01a	0.21±0.02a	0.24±0.02b
V3	0.17±0.01b	0.09±0.01a	0.18±0.01ab	0.24±0.02b
Summary of all treatment effects (F-Statistics)				
Tillage	0.01*	0.84	0.00*	0.05*
Fertilizer level	0.00*	0.00*	0.05*	0.00*
Maize varieties	0.01*	0.52	0.00*	0.00*
Tillage x fertilizer	0.45	0.28	0.27	0.75
Tillage x maize varieties	0.75	0.35	0.43	0.50
Fertilizer level x maize varieties	0.35	0.28	0.29	0.96
Tillage x fertilizer x maize varieties	0.68	0.57	0.72	0.73

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*

Table 28: Correlation Analysis between Tillage practice, Fertilizer level, Variety and Water Productivity (kg/m³)

Variable	Pemba	Choma	Pemba	Choma
	First cropping season		Second cropping season	
Tillage	0.212*	0.016	-0.261*	0.174
Fertilizer	0.215*	0.171	-0.018	-0.157
Variety	0.213*	-0.055	0.151	0.250*

* Correlations are significant @ *p<0.05*

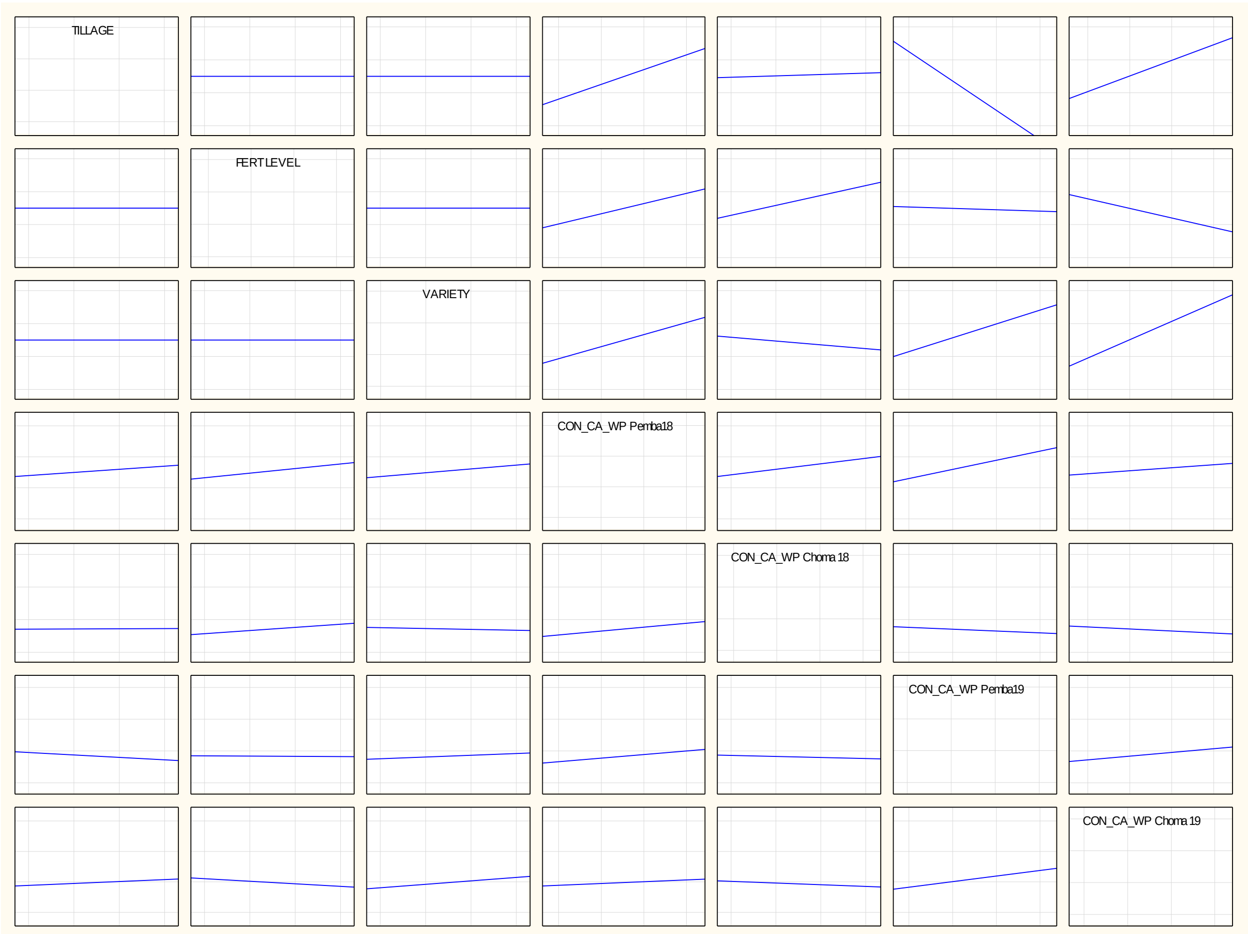


Figure 24: Summary Matrix Graph showing Water Productivity Dynamics in Tillage, Fertilizer Levels and Variety in Studied Sites

4.6 Establishing Potential Net Economic Benefits of Maize Crop Supplied with Anthill Soils and Other Organic and Inorganic NPK Sources.

4.6.1 Economic Analysis

To make good recommendations for farmers, it is always advisable to evaluate alternative technologies from the farmers' point of view. Therefore, this study looked at the benefits and costs of organic /inorganic combination technology in maize production which could be of interest to smallholder farmers. The analysis in this research looked at the risks involved in adopting anthill soil fertilizer inputs technology use in crop production for maize (costs and benefits).

The maize grain yield was used in the agronomic analysis to help understand and visualize the relationship between maize yield response and the environment (treatments). However, two other measures or evaluation criteria with more meaning to farmers are net income per hectare and grain yield per unit of cash cost. This last decisive factor is crucial and indicates how much grain can be produced for a unit of cash invested in the fertilizer, labour, seed and other inputs purchased in the production of maize.

This study therefore envisioned that to make good proposals for technologies being evaluated for rural communities by any research undertaking, there is always need to consider alternative technologies from what farmer's form as a mental picture. This study therefore considered such issues as:

(i) Farmers are worried about the benefits and costs of certain technological options;
(ii) Farmers normally adopt innovations in a logical manner and;
(iii) Farmers think about the risks involved in adopting new agriculture techniques.

Based on the foregoing, a financial analysis in this study was conducted to determine the risks and benefits involved in adopting anthill soil alone or a combination with commercially available mineral fertilizer and manure technologies being assessed. International Maize and Wheat Improvement Centre (1988) stressed that agronomic data upon which recommendations are based from field experiments must be relevant to the smallholder farmers' own environmental conditions and the evaluation of the data must be in line with the farmers' aspirations and socio-economic situation prevailing. Trapnell, Ridley, Christy and White (2006) also claimed that financial analyses are vital for making informed decisions concerning the benefits of alternative technological investments at farm level. In agreement to this assertion, Pannell *et al.* (2006) added that the adoption of a technology also depends on how straight forwardly it can be tested and gained knowledge of prior to adoption.

In this study, the technique of marginal analysis was therefore adopted as it was viewed to help evaluate the differences from one technology to the alternative by comparing the variances in costs and benefits linked with each and every treatment. Fundamentally, this was meant to identify the best fit technology based on the farming systems variables of the study sites. Tables 29 - 33 demonstrates the Gross margins analysis for each period/year the experiment was being implemented between 2017 and 2019 farming seasons. The computation was applied to all the seed input i.e the three maize varieties (SC 403, PAN 413 and ZMS 528) used in the present study which had different costs.

4.6.2 Gross Margins Analysis for the Field Experiments

Gross margin is described as the gross return from crops grown less the costs (variable costs) under production process (Li, Singh, Brennan & Helyar, 2010). These costs may involve those of land preparation/tillage, fertilizer, seed, planting, crop management, fuel, insurance, harvesting including marketing.

In the present study, the major input was fertilizer. The cost of fertilizer at the time of planting in December of cropping season was US$ 32/50 kg and this translated to US$ 0.640/kg. Price of maize in the first cropping season was US$ 0.140/kg. The official maize price during the marketing period for the first cropping season was US$ 0.140/kg or US$ 7/50 kg. Input/output ratio in this experiment was computed as US$ 0.640/0.140 = 4.570. This implied that for each kg of fertilizer invested in the production function/process, a smallholder farmer was expected to gain US$ 0.460.

In the second cropping season, fertilizer cost in December during the time of sowing was pegged at US$ 26/50 kg and this was equivalent to US$ 0.520/kg. The maize price during marketing period for the second cropping season was pegged at US$ 0.170/kg or US$ 8.5/50 kg. Input/output ratio was worked out to be US$ 0.520/0.170 = 3.050, meaning that for each kg of fertilizer spent in the production of maize commodity, a smallholder farmer in the study areas anticipated to reap US$ 0.310. It may be observed from this computation that in the first cropping season more benefits were expected to be accrued due in part to the costs of inputs. The estimate of the field price of the inputs was done by going to the agro dealers where most farmers in the study areas bought their inputs and checked the retail price for appropriate size package. For determining the benefits of different treatments used in this study, gross margins were calculated. The net income for each treatment was computed using the following formula:

Net Benefits = Y x Z – TVC (CIMMYT, 1988) where:

Y is the grain yield of maize crop (kg/ha), Z is the market price for maize (US$ /ha) and TVC symbolizes the total variable costs for inputs used in the experiment (fertilizer, seed and labour US$ /ha). Costs of fertilizer, seed and labour (planting, weeding and harvesting) used in the computations are itemized in Table 29. The selling price of maize crop in the first and second marketing seasons was set at $ 0.140/kg and $ US0.170/kg respectively.

Further analysis in the present study showed that generally benefits (monetary) though negative were accrued more under conservation agriculture than the conventional tillage systems in the first cropping season in Pemba study site (Table 30). The treatment combinations however, exhibited significant differences ($P<0.05$) in net benefits. Specific treatments that showed better benefits were; treatment 1 (anthill soil top at 5000 kg/ha) and treatment 6 (manure at 10 000 kg/ha + anthill soil top at 5000 kg/ha) respectively. The two treatments resulted in financial returns of $ 45.980, $ 35.980, $ 39.980 and $ 72.620, $ 62.620 and $ 66.620 respectively. In the second cropping season, Pemba study area, showed the same trend with treatment performance in terms of accrued benefits (Table 31). The net income recorded was however reduced in the second cropping season attributable to lower grain yields achieved influenced by low rainfall events.

As for Choma study site, all net benefits were negative and significant ($P<0.05$) across the treatments with the pattern of treatment performance reflected similar to that of Pemba site (Tables 32 and 33). Choma recorded negative values for gross margins as a result of low yields and elevated variable costs. Climatic conditions experienced in the growing season played a big role. The poor rainfall received especially in the second season during the growing period essentially affected crop development, resulting in low aggregate yield and consequently the profitability observed.

Availability of water and optimal temperature conditions influence the degree to which the crops grow including the management aspects up to maturity level. Given this scenario, it was observed that financial returns were slightly more lucrative in the first cropping season of this study than the second season in both studied sites.

Based on the findings in this study, it can be alleged that benefits were more visible in the treatment that involved manure (10 000 kg/ha) + anthill soil top (5000 kg/ha). This clearly shows the economic significance of ISFM in maize production. This study has also demonstrated that maize growing can be beneficial with the supplied anthill soil top alone or combination with manure. Findings call for re-birthed interest in organic agriculture research in the studied sites and identification of other locally available organic sources that can be useful for enhancing soil fertility. Most likely continuous practicing of systematic crop rotations and associations of legumes and cereals could be central in building up the nutrient loads in studied smallholder farms.

In support of this model; Nezomba, Mtambanengwe, Chikowo and Mapfumo (2013) concluded that sequencing of legumes and cereals would contribute to build up of P through annual additions of P and gradually enhancing microbial activities in the soil environment. Li and Brennan (2010) on the other hand cautioned that choice of crops by smallholder farmers may not only be premised on benefits expected to be accrued but also on the contribution to overall farming system. For example, growing of legume crops that fix N in the soil may help to reduce the input variable costs. Whereas the gross margins of such crops may be negative or low, they may contribute to reducing input costs for the next non-legume crops grown. This consequently improves soil health, thereby enhancing yield of rotated crops.

4.6.3 Net Benefits for Maize Varieties

Generally net benefits from maize varieties used in this study were more evident in V_2 (PAN 413 variety) which was almost consistent across the studied sites. In Choma site, however, V_1 (SC 403 variety) exhibited better benefits in the first cropping season as compared to the second cropping season. A lot of factors may have contributed to this scenario, which may have been attributable to genetic makeup of the variety encompassing the physiological maturity period and also the environmental conditions in terms of rainfall and management of the plots. From the foregoing it would be beneficial for smallholder farmers in the studies areas to consider early maturing varieties such as PAN 413 to be cultivated considering the short duration rainfall experienced and benefits that can be accrued in terms of financial and also food security wise. In support of this opinion, Giller *et al.* (2011) confirmed that short run benefits are critical in making decisions by smallholder farmers considering that they are normally food insecure with high vulnerability index.

Table 29: Input costs used for computing gross margins for first and second cropping season

Input	Amount per ha	Unit price (US$)/ha	Total (US$)
Fertilizer (Basal and Top dressing)	400 kg	0.665	266
Maize seed SC 403	20 kg	1.900	38
Maize seed PAN 413	20 kg	2.400	48
ZMS 528	20 kg	2.200	44

Labour costs for on-farm activities for first cropping season

Input	Cost (US$/ha)
Planting	22
Cost of herbicide	9
Weeding twice per ha	44
Harvesting	22
Planting	22

Gross margins for second cropping season

Input	Amount per ha	Unit price (US$)/ha	Total (US$)
Fertilizer (Basal and Top dressing)	400 kg	0.525	210
Maize seed SC 403	20 kg	1.600	32
Maize seed PAN 413	20 kg	2.000	40
ZMS 528	20 kg	1.850	37

Labour costs for on-farm activities for second cropping season

Planting	22
Cost of herbicide	12
Weeding twice per ha	44
Harvesting	22

Table 30: Gross margins analysis – First Cropping Season Pemba Site

Variable	Gross Benefits ($)	Net Benefit I ($)	Net Benefit II ($)	Net Benefit III ($)
Tillage practice				
CON	180.30±4.99a	-96.91±17.47a	-84.27±15.74a	-98.00±17.12a
CA	193.22±6.25a	-97.32±17.21a	-94.02±16.31a	-88.76±16.91a
Fertilizer Levels				
1 – AHT	171.98±10.58b	45.98±10.58b	35.98±10.58c	39.98±10.57a
2 = FRF	173.96±10.38b	-218.04±10.38c	-228.04±10.38b	-224.04±10.38d
3 = FRF + AHT	213.86±9.99a	-178.14±9.98c	-188.14±9.98a	-184.14±9.98d
4 = HRF + AHB	177.09±8.13b	-183.62±14.66c	-91.91±8.12d	-87.91±8.12b
5 = Urea + AHT	177.21±7.71b	-81.79±7.72a	-91.79±7.72d	-134.73±21.83bc
6 = M + AHT	198.62±8.64ab	72.62±8.64b	62.62±8.64c	66.62±8.64a
Maize varieties				
V1	173.39±7.04a	-103. 34±24.03a	-95.61±21.5a	-100.47±22.91a
V2	192.31±6.60a	-94.07±19.03a	-84.51±18.02a	-88.34±19.00a
V3	192.61±6.89a	-94.61±21.20a	-88.49±19.92a	-92.55±21.17a
Summary of all treatment effects (F-Statistics)				
Tillage	0.04*	0.30	0.04*	0.16
Fertilizer level	0.01*	0.00*	0.00*	0.00*
Maize varieties	0.14	0.23	0.14	0.38
Tillage x fertilizer	0.78	0.25	0.78	0.96
Tillage x maize varieties	0.53	0.80	0.54	0.78
Fertilizer level x maize varieties	0.02*	0.20	0.02*	0.54
Tillage x fertilizer x maize varieties	0.37	0.51	0.37	0.93

** Significant at P ≤ 0.05 level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha);* V_1 *= Maize variety SC 403;* V_2 *= Maize variety PAN 413;* V_3 *= Maize variety ZMS 403.*

Table 31: Gross margins analysis – Second Cropping Season Pemba Site

Variable	Gross Benefits ($)	Net Benefit I ($)	Net Benefit II ($)	Net Benefit III ($)
Tillage practice				
CON	138.15±8.98a	-74.02±13.22a	-80.66±13.22a	-79.02±13.22a
CA	140. 91±5.76a	-71.41±14.06a	-79.41±14.06a	-76.41±14.06a
Fertilizer Levels				
1 – AHT	126.29±8.11a	28.29±8.11a	20.29±8.11a	23.29±8.11a
2 = FRF	145.67±10.73a	-162.33±10.73c	-170.33±10.73c	-167.33±10.72c
3 = FRF + AHT	143.87±12.55a	-164.13±12.55c	-172.13±12.55c	-169.13±12.55c
4 = HRF + AHB	151.19±19.03a	-51.82±19.04b	-59.82±19.03b	-56.82±19.04b
5 = Urea + AHT	135.00±11.78a	-68.00±11.78b	-76.00±11.78b	-73.00±11.78b
6 = M + AHT	128.64±12.34a	30.64±12.34a	22.64±12.33a	25.64±12.34a
Maize varieties				
V1	117.76±4.95b	-92.24±14.79b	-100.24±14.79b	-97.24±14.79b
V2	164.46±12.67a	-49.04±18.57a	-57.04±18.57a	-54.04±18.57a
V3	136.39±7.17ab	-76.45±16.13ab	-84.45±16.13ab	-81.45±16.13ab
Summary of all treatment effects (F-Statistics)				
Tillage	0.87	0.87	0.87	0.87
Fertilizer level	0.72	0.00*	0.00*	0.00*
Maize varieties	0.00*	0.00*	0.00*	0.00*
Tillage x fertilizer	0.83	0.83	0.83	0.83
Tillage x maize varieties	0.41	0.42	0.42	0.41
Fertilizer level x maize varieties	0.68	0.68	0.68	0.68
Tillage x fertilizer x maize varieties	0.86	0.86	0.85	0.85

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*

Table 32: Gross margins analysis – First Cropping Season Choma Site

Variable	Gross Benefits ($)	Net Benefit I ($)	Net Benefit II ($)	Net Benefit III ($)
Tillage practice				
CON	128.75±12.01a	-138.93±17.34a	-146.03±17.16a	-142.03±17.16a
CA	104.07±8.95a	-160.71±15.70a	-170.71±15.67a	-166.71±15.67a
Fertilizer Levels				
1 – AHT	81.011±6.29b	-44.99±6.29c	-54.98±6.29c	-50.99±6.29c
2 = FRF	68.76±9.18b	-323.24±9.18b	-333.24±9.18b	-329.24±9.18b
3 = FRF + AHT	173.01±18.19a	-218.98±18.19a	-228.99±18.19a	-224.99±18.19a
4 = HRF + AHB	136.09±21.51ab	-122.91±21.50d	-132.91±21.50d	128.91±21.50d
5 = Urea + AHT	116.84±14.45ab	-149.55±15.62d	-152.16±14.44d	-148.16±14.44a
6 = M + AHT	88.44±13.60b	-37.55±13.60c	-47.56±13.60c	-43.56±13.60c
Maize varieties				
V1	136.98±16.05a	-136.27±24.29a	-141.52±23.90a	-137.52±23.90a
V2	106.63±12.89	-165.24±20.82a	-175.24±20.82a	-171.24±20.82a
V3	108.14±10.30a	-146.83±16.28a	-156.83±16.28	-152.83±16.28a
Summary of all treatment effects (F-Statistics)				
Tillage	0.06	0.09	0.06	0.06
Fertilizer level	0.00*	0.00*	0.00*	0.00*
Maize varieties	0.21	0.31	0.21	0.21
Tillage x fertilizer	0.78	0.78	0.78	0.78
Tillage x maize varieties	0.92	0.85	0.92	0.92
Fertilizer level x maize varieties	0.29	0.20	0.29	0.29
Tillage x fertilizer x maize varieties	0.71	0.69	0.71	0.71

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*

Table 33: Gross margins analysis – Second Cropping Season Choma Site

Variable	Gross Benefits ($)	Net Benefit I ($)	Net Benefit II ($)	Net Benefit III ($)
Tillage practice				
CON	102.43±6.60a	-100.57±10.48a	-108.57±10.48a	-105.57±10.48a
CA	99.48±6.58a	-103.52±11.63a	-111.52±11.63a	-108.52±11.63a
Fertilizer Levels				
1 – AHT	78.53±8.50b	-19.47±8.50a	-27.47±8.50a	-24.47±8.50a
2 = FRF	145.13±14.60a	-162.87±14.60c	-170.87±14.60b	-167.87±14.60c
3 = FRF + AHT	103.92±10.81ab	-204.08±10.81c	-212.08±10.81c	-209.08±10.81c
4 = HRF + AHB	108.40±9.62ab	-94.60±9.62b	-102.60±9.62b	-99.60±9.62b
5 = Urea + AHT	89.58±8.07b	-113.42±8.07b	-121.42±8.07b	-118.42±8.07b
6 = M + AHT	80.17±8.51b	-17.83±8.52a	-25.83±8.52a	-22.83±8.52a
Maize varieties				
V1	79.89±6.71a	-123.11±13.45a	-131.11±13.45a	-128.11±13.45a
V2	113.68±8.38b	-89.32±14.09b	-97.32±14.09b	-94.32±14.09b
V3	109.29±7.93	-93.71±12.56b	-101.71±12.56b	-98.71±12.56b
Summary of all treatment effects (F-Statistics)				
Tillage	0.73	0.73	0.73	0.72
Fertilizer level	0.00*	0.00*	0.00*	0.00*
Maize varieties	0.00*	0.00*	0.00*	0.00*
Tillage x fertilizer	0.43	0.43	0.43	0.42
Tillage x maize varieties	0.25	0.25	0.25	0.25
Fertilizer level x maize varieties	0.97	0.97	0.96	0.96
Tillage x fertilizer x maize varieties	0.90	0.90	0.90	0.90

* *Significant at $P \leq 0.05$ level; ns= not significant. Means in the same column followed by the same letter denote no significance at 0.05 probability level based on Tukey's Honest Significance Test. AHT = Anthill soil top (5000 kg/ha); FRF = Full rate fertilizer (200 kg/ha); HRF + AHT = Half rate fertilizer (100 kg/ha) + anthill soil top (5000 kg/ha); HRF + AHB = Half rate fertilizer (100 kg/ha) + anthill soil base (5000 kg/ha); Urea + AHT = Top dressing fertilizer (200 kg/ha) + anthill soil top (5000 kg/ha); M + AHT = Manure (10 000 kg/ha) + anthill soil top (5000 kg/ha); V_1 = Maize variety SC 403; V_2 = Maize variety PAN 413; V_3 = Maize variety ZMS 403.*

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The specific objectives of this research were as follows: (a) to carry out an investigation of the constraints and opportunities of anthill soil utilization in conservation agriculture (CA) systems; (b) to analyze the macro and micro nutrients of anthill soils; (c) to evaluate the effect of anthill soil application on growth and yield parameters of maize; (d) to quantify phosphatase and alrysulphatase soil enzymes and nutrient dynamics after anthill soil application; (e) to determine the additive effects of anthill soil application on moisture retention and water productivity and (f) to establish potential net economic benefits of maize crop supplied with anthill soils and other organic and inorganic NPK sources.

The thesis was partitioned in five segments and each was part of the different chapters and the associated sections. Chapter 1 provided a general background to the study and the problem to be solved by the study. Chapter 2 reviewed state of knowledge regarding anthill soil utilization in crop production. Materials and methods was the subject of Chapter 3 that gave a comprehensive overview of the materials and study approaches employed to conduct this research. Chapter 4 outlined the results and discussion of the study and finally, Chapter 5 is a conclusion and provides a summary of the findings including recommendations.

The first specific objective was to carry out an investigation of the constraints and opportunities of anthill soil utilization in conservation agriculture (CA) systems in Choma and Pemba districts of southern Zambia. Results demonstrated that most smallholder farmers started using the anthill soils at minimum 3 years ago. The main reason which forced the farmers to be captivated in the practice is largely in part due to social economic and biophysical factors which among them included limited finance to procure mineral fertilizer and poor soil condition. Overall, it was observed in this study that most of the smallholder farmers reported having key benefits accrued with the use of soils as fertilizer from specific anthills and this lay in the belief that the resource can increase yield, improve soil fertility and contribute to enhanced household food security.

Additionally, farmers indicated that with use of anthill soil in agriculture production, benefits were more compared with conventional soil fertility management practices, as the resource was easy to access. However, despite these reported benefits of anthill soils in agriculture production across the study districts, some farmers explained that they faced challenges that included the requirement of more water by the resource, inadequate labour at the household level, handling and transportation and determining the required anthill soil quantities per unit of area such as a hectare.

The second specific objective was to analyze the macro and micro nutrients of anthill soils. Findings showed that soil from the top and base sections of the anthill structures in southern Zambia, contain potential macro and micro nutrients (P, K, Ca, Mg, Cu, Fe and Zn) which can substantially support crop growth. This can play a key role in integrated nutrient management systems, where manure, crop rotation, intercropping or application of commercially available fertilizer may be used to boost P levels of soils lacking the nutrient. Top sections of the anthills exhibited more fertility than the base and the adjacent soils.

The third specific objective was to evaluate the effect of anthill soil application on growth and yield parameters of maize under pot and field conditions. The study exhibited higher performance of anthill soil alone or in combination with cattle manure or half rate commercially available fertilizer requirements in both pot and field conditions. This proved to be the best option to undertake, in order to attain meaningful yield of probably more than 1200 kg/ha if maize crop is well managed for field environment.

The fourth specific objective was to quantify phosphatase and arylsulphatase soil enzymes and nutrient dynamics after anthill soil application. By and large, the phosphatase activity across the study districts was inferior to arylsulphatase. Phosphatase activity was more prominent in the sole anthill soil top treatment (AHT at 5000 kg/ha) in both study sites than other treatments. Overall, arylsulphatase enzyme activity was more pronounced in Pemba than Choma studied site. However, as for the tillage systems, findings in this study showed a higher presence of arylsulphatase in CA than CONV tillage systems.

The fifth specific objective was to determine the additive effects of anthill soil application on moisture retention and water productivity. With regard to this aspect, the current study found consistency trends in terms of water retention capacity in both CONV and CA plots in Pemba study site. This was evident in treatment 1 (anthill soil top at 5000 kg/ha); treatment 2 (full rate fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 200 kg/ha); treatment 4 (half rate fertilizer, NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea: 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha + anthill soil base at 500 kg/ha) and treatment 6 (manure at 10 000 kg/ha + anthill soil top at 5000 kg/ha) with all varieties (SC 403, PAN 413 and ZMS 528). In Choma site, there was a different scenario, exhibited in terms of water retention performance amongst the treatments. All the treatments except treatment 1 (anthill soil top at 5000 kg/ha) exhibited almost same levels.

Finally, the sixth specific objective was to establish potential net economic benefits of maize crop supplied with anthill soils and other organic and inorganic NPK sources. Financial analysis results arising from applying the technique of gross margins analysis in this study revealed that more benefits (monetary) were observable in the first cropping season of the experiment compared with the subsequent season. Treatments that involved anthill soil top alone (5000 kg/ha) and a combination with manure (10 000 kg/ha) + anthill soil top (5000 kg/ha) exhibited greater benefits than the rest of the treatments tested in the study. This implied that variable costs played a pivotal role in benefits accrued.

5.2 Recommendations

Based on the laid down objectives and results of this study, the following recommendations are suggested that may necessitate future research work:

(i) During the study it was observed that collection of anthill soils is more labour intensive and use of rudimental tools (e.g hoes) to dig the soils is a common feature amongst the resource constrained smallholder farmers. In view of this narrative, future studies should focus on the entire anthill soil collection process with development of simple tools that could be used to collect the anthill soil to ease the burden confronted by the users. In addition, costs related to labour for anthill soil digging and transportation need to be studied in depth.

(ii) Most smallholder farmers apply the anthill soil anywhere in the field thereby creating wastage. It is therefore crucial that capacity building programmes are instituted in the study areas and elsewhere to ensure that anthill soil is only applied where it is required especially in basins or ripped lines formations under conservation agricultural tillage systems. By so doing, this will ensure the crop planted receives the much needed P to boost growth as there will be reduced nutrient losses expected. For effective application of the anthill soil, two handfuls (approximately 500 g) may be feasible especially where basin planting structures have been dug by the farmer under conservation agricultural systems.

(iii) The current study demonstrated that anthill soil top alone (5000 kg/ha) or in combination with cattle manure (10 000 kg/ha) or half rate of commercially available fertilizer (NPKS: 10% N, 20% P_2O_5, 10% K_2O, 6% S and urea 46% N, 0% P_2O_5, 0% K_2O, 0% S at 100 kg/ha) treatments are the best options to embark on for implementing in the smallholder farms of the studied sites and other areas with similar environment.

(iv) This study focused only on two soil enzyme types (arylsulphatase and phosphatase). In order to get the full understanding, it would be beneficial to know and characterize the other soil enzymes prevalent in the anthills.

(v) Further studies are needed to identify the types of termites responsible for building anthills' structures in Choma and Pemba districts of southern Zambia. In this regard such studies should focus on this aspect in order to understand the various species and the sub families associated with the anthills in the studied areas.

(vi) Future research should also focus on developing software that may help in estimating the age of the anthill which can make it easy to know the maturity of the anthill for use in crop production.

(vii) More research is also warranted on the quantity of anthill soil for increased crop yields that may contribute to the sustainable development goals numbers 1 (No poverty); 2 (Zero hunger) and 3 (Good health and well-being) promulgated by the United Nations aimed at transforming the world.

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APPENDICES

Appendix 1: Questionnaire for Key Informants

Nelson Mandela African Institution of Science and Technology (NM-AIST)

Qualitative Questionnaire for Key Informants

Quantifying Socio-Economic & Biophysical Aspects of Anthill Soil Utilization in South Zambia

A: BACKGROUND INFORMATION

Date:…………………………Name of the Interviewer:………………………………………

A1. Name of Key Informant:…………………………………………………………………..

A2. Name of District:……………………………………………………… ………………

A3. Profession:.…………………………………………………………………………….

A4. Position held:…………………………………………………………………………..

B: CROP PRODUCTION IN THE DISTRICT

B1. What is the current population of smallholder farmers in the district? (a) 0-1000 (b) 1000-3000 (c) >3000

B2. What is the size of the average fields of farmers in the district? (a) 0-1ha (b) 2-5ha (c)>5ha

B3. What are the major crops grown in the district? (Response may be multiple)

1) Maize, 2) Cowpeas, 3) Beans, 4) Soybeans, 5) Groundnuts, 6) Sorghum, 7) Cotton, 8) Sunflower, 9) Mbabara nuts, 10) Pigeon peas 11) Other (specify)

B4. How much land is allocated to maize production on average by farmers? (a) 0-1ha (b) 2-5ha (c)>5ha

B5. Do farmers have access to fertilizer? (a) Yes (b) No

B6. Who are the major suppliers? (a) Govt - FISP (b) Private companies (c) Other (specify)

B7. Do you think fertilizer is affordable to most of the farmers? (a) Yes (b) No

B8. Are most of the farmers under e-voucher system? (a) Yes (b) No

B9. On average what is the percentage range of farmers on e-voucher system? ………….

B10. If answer to B8 is yes, how many farmers are under e-voucher system in this district?

B11. What has been the production and productivity trends of maize per farmer in this district for the last 3 years?

Year	2014/15	2015/16	2016/17
Maize production (Kg)			
Maize productivity (Kg/ha)			

B12: Why do you think the production and productivity of maize has increased?

………

B13: Why do you think the production and productivity of maize has decreased?

………

C: ANTIHILL SOIL UTILIZATION IN AGRICULTURE

C1. Any knowledge on farmers utilization of anthill soil in agriculture fields? (a) Yes (b) No

C2. When do you think this practice started? (a) 20 years ago (b) 30 years ago (c) >40 years ago (d) Other (specify)

C3. What do you think prompted farmers to start utilizing anthill soil as fertilizer? (a) High cost of fertilizer (b) Poor soil (c) Farmer's perceptions (d) Other (specify)

C4. What type of crops are grown on anthill soils (a) Maize (b) Sorghum (c) Cowpeas (d) Groundnuts (d) Beans (e) Soybeans (f) Other (specify)

C5. Do you think anthill soil improves crop yield (a) Yes (b) No (c) n/a

C6. If yes, why do you think so…………………………………………………………………

C7. What have you observed as challenges which farmers face in utilizing anthill soil in agriculture production? (a) Labour (b) handling (c) Other (specify)

C8. What benefits have you observed for farmers in utilizing anthill soil in agriculture production? (a) Soil improvement (b) Improved yields (c) Other (specify)

C9. What is your recommendation on anthill soil utilization in agriculture production?

……………………………………………………………………………………………………..

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…………………………………………………………………………………………………

Appendix 2: Questionnaire for Focus Group Discussions

Nelson Mandela African Institution of Science and Technology (NM-AIST)

Qualitative Questionnaire for Farmers

Quantifying Socio-Economic & Biophysical Aspects of Anthill Soil Utilization in South Zambia

A. HOUSEHOLD INFORMATION

A1. Date:……………………………………Interviewer Name:……………………………………………………

A2. District Name:……………………………………………………………………………

A3. Agricultural Camp Name:…………………………………………………………......................

A4. Province Name:…………………………………………………………………………….

B AGRONOMIC/MANAGEMENT PRACTICES

B1. What is the size of your arable fields on average……………(ha)

B2. What type of crops do you mainly grow?

Legumes (List)	**Cereals (List)**

B3. How much land is allocated to maize growing? (a) 0-1ha (b) 2-5ha (c)>5ha

B4. What is the size of your arable fields on average?………………(ha)

B5. Do you fertilize your maize? (a) Yes (b) No (c) n/a

B6. Is fertilizer costly for you to purchase? (a) Yes (b) No

B7. If yes what fertilizer do you use? (a) Cattle manure (b) Anthill soil (c) Other (d) n/a

B8. When did you start utilizing anthill soils in agriculture production? (a) 20 years ago (b) 10 years ago (c) 5 years ago (d) < 3 years ago

B9. How did you know about utilizing the anthill soil in agriculture production? (a) Parents (b) Fellow farmer (c) Ministry of Agriculture (d) NGOs (e) Other

B10. Do you think this could be a good alternative as fertilizer for the financially constrained farmers?

B11. Name the crops you have observed where the anthill soils enhance crop productivity?

B12. In which month of the year do you start digging up the anthill soils for application in the fields?

B13. What is the source of labour (a) Family labour (b) Hired (c) Other

B14. If family labour, who is involved in anthill soil digging and collection? (a) Husband (b) Wife (c) Husband, wife and children (d) Other

B15. How do you transport the anthill soil? (a) Use of oxcart (b) Carry on head using sacks (c) Other

B16. If you use oxcarts, how many do you apply in a hectare (100mx100m)?

B17.What is your experience on weeds infestation where you apply the anthill soils in agriculture fields? (a) Weeds grow fast (b) Weeds growth is suppressed (c) Other

B18. Any use of herbicides/pesticides (a) Yes (b) No (c) Other (d) n/a

B19. What are the challenges/benefits of using anthill soils in agriculture production?

C FARMER KNOWLEDGE ON CONSERVATION AGRICULTURE

C1. Do you have any knowledge on conservation agriculture (a) Yes (b) No (c) n/a

C2. What type of tillage system are using in your field? (a) ripping (b) potholing (c) conventional (d) Other (e) n/a

C3. Have you ever attended any training on conservation agriculture (CA)? (a) Yes (b) No (c) n/a

C4. If yes, when did you first attend the training? (a) A year ago (b) 3 years ago (c) 5 years ago (d) Other

C5. What aspects of CA were you trained on? (a) Soil cover (b) Ripping (c) Basin making (d) crop rotation (e) Other

C6. Who trained you on CA practices? (a) Government extension officer (b) NGOs (c) Fellow farmer (d) Other

C7. Any other information you may wish to share on anthill soils and their utilization in crop production?…………………………………………………………………………………
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THE END!

REMEMBER TO THANK THE FARMERS

Appendix 3: Household Questionnaire

Nelson Mandela African Institution of Science and Technology (NM-AIST)

Quantifying Socio-Economic & Biophysical Aspects of Anthill Soil Utilization in South Zambia

INSTRUCTIONS TO INTERVIEWERS

1. Introduce yourself to the participant
2. Explain the purpose of the interview
3. Reassure the participant that all response will be held in confidence
4. Ensure that all questions are answered and indicate response by ticking the appropriate letter or filling in space(s) provided
5. Thank the participant at the end of each interview

Study conducted with support from the Centre for Research, Evidence, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security (CREATES - FNS)

April 2019

SECTION A: HOUSEHOLD IDENTIFICATION DETAILS

A1. Enumerator Name: **A1a**.Supervisor signature:	**A2**. Date of interview: ______ / _____ / 2017 A2.1 Day A2.2 Month A2.3 Year		**A3**. District: 1=Choma, 2=Pemba	**A4: Country**
A5. Constituency:	**A6**. Ward:		**A7a**. Region:	**A7b**. CSA:
A8a. Village Name:	**A8b**. Village ID number:	**A9**. Household number:	**A9a**. Phone #:	
A10. Geographical Location of the home: Latitude (°, ‘, “): S____ , ______ , ______ Longitude (°, ‘, “): E______ , ______ , ______ A10a. ° A10b. ‘ A10c. “ A10d. ° A10e. ‘ A10f. “			**A11**. Elevation: ________ **m.a.s.l.**	

A12: Name of site/Agricultural camp………………………

A13: Name of household head……………………………..

A14: Age of household head……………………….. years

A15: Sex of household head: 1. Male 2. Female

A16: Marital status of household head:

i) Married - Monogamy ii) Married - Polygamy iii) Widow (er) iv) Divorcee v) Separated

vi) Bachelor vii) Spinster

A17: **Household composition:**

Age group	**Number**
Male (0-14yrs)	
Female(0-14yrs)	
Male (15-49yrs)	
Female (15-49yrs)	
Male (50 and above)	
Female (50 and above)	

A18: **Education**

Age group	**Number**
Number of biological girl children attending school	
Number of orphaned girl children attending school	
Number of biological girl children dropped out of school	
Number of orphaned girl children dropped out of school	
Number of biological boy children attending school	
Number of orphaned boy children attending school	
Number of biological boy children dropped out of school	
Number of orphaned boy children dropped out of school	

SECTION B: HOUSEHOLD CAPITAL ASSETS

B1: SOCIAL CAPITAL ASSETS

B1a. Is your household affiliated to any social Organization/group?	1= Yes 2= No
B1b. If YES to B1a, which type of group?	1=farmer association /cooperatives 2=church supported farmers group 3= women/men club 4=other, (specify)……………………………………………………………….
B1c: What activities is the group involved in?	Specify ………………………………………………………………
B1d: If NO to B1a, what are the reasons for not being affiliated with any organization/group?	1= I do not see benefits 2= I waste time with meetings 3= there are a lot of conflicts 4= I do not have money for membership fees 5= other (specify) …………………………………………………..
B1e: Have you ever been a leader of any group?	1= yes 2= no
B1f: If yes to B1e, what position have you held?	1= chairperson 2= secretary 3= treasurer 4= committee member 4= other (specify) ………………………………………………..
B1g: What are the benefits of belonging to a group?	
B1h: What are the disadvantages of belonging to a group?	

B1i: Based on your experience, have you observed any differences in the level of participation in farmers groups between men and women	1=yes, 2=no
B1j: If YES to B1i, explain why the difference?	
B1k: what do you recommend to improve women participation in groups	

B2: HOUSEHOLD HUMAN CAPITAL ASSETS

B2a: Education level of household head	1=Primary 2= Secondary 3=Tertiary 4=Never been to school 5=Other (specify)
B2b: Educational level of household spouse	1=Primary 2= Secondary 3=Tertiary 4=Never been to school 5=Other (specify)
B2c: Other than farming, what is your other main skill?	1= Crafts 2=Carpentry 3=Bricklaying 4=Petty Trading 5= Others (specify)
B2d: Is any household member chronically ill?	1= Yes 2= No

B2e: If, YES to B2d, what is the status of household member who is chronically ill	1 = Husband 2 = Wife 3 = Child dependant 4 = Adult dependant
B2f: What has been the effect of the household member's chronic illness in terms of household livelihood?	

B3: HOUSEHOLD PHYSICAL ASSETS

TYPE OF ASSET	QUANTITY	CONDITION 1=New, 2=Good, 3=Fair, 4=Old
Livestock		
B3a.Cattle		
B3b.Goats		
B3c.Poultry		
B3d.Pigs		
B3e. Sheep		
B3f. Donkeys		
B3g. Other………………………………….		
Agricultural Implements		
B3a1.Ridging plough		
B3b1. Cultivator		
B3c1. Ripper		
B3d1. Axes		
B3e1.Ox carts		
B3f1.Harrows		
B3g1.Treadle pumps		
B3h1.Yenga Oilpress		

B3i1.Ploughs		
B3j1. Other………………………………………		
Non-Agricultural Assets		
B3a2.Beds		
B3b2.Television		
B3c2.Radios		
B3d2.Bicycles		
B3e2. Other………………………………………………..		
B3f2. What type of dwelling do you live in?	1=Mud hut with grass thatched roof 2=Mud hut with asbestos/iron roof 3=Brick house with grass thatched roof 4=Brick house with asbestos/iron roof 5=Block house with grass thatched roof 6=Block house with asbestos/iron roof 7=Pole and dagga with grass thatched roof 8=Other (specify)	

SECTION C: HOUSEHOLD INCOME SOURCES

From which of the following livelihood strategies did the household source income in 2015/16 and 2016/17? (i.e for the last two agricultural seasons)

Income Sources	**Estimate Annual income (ZMW/USD)**	
	2015/16	**2016/17**
C1: Petty trading(others)specify		
C2: Gardening activities/offseason farming		
C3: Local chicken rearing		
C4: Goat rearing		
C5: Cattle rearing		
C6: Remittances		

C7: Sale of rain seed food crops(specify)		
C8: Sale of rain seed cash crops(specify)		
C9: Piece work		
C10: Sale of charcoal		
C11: Other (specify)		
C12: Other (specify)		
C13: Other (specify)		
C14: Total annual income		

C15: Do you have access to any credit facility?	1=Yes 2=No
C16: If yes what is your source?	1=Government 2=NGO 3=Private lending institution 4=Fellow farmer 5=Others (specify)
C17: Does household have a savings account?	1=Yes 2=No

SECTION D: SITE CHARACTERIZATION

D1: Number of years of residence on site ……………………………………………………………………………..

D2: Soil type……

D3: Vegetation type ……
.

D4: Types of crops household has been growing
……

D5: Soil fertility management practices farmer has been using for crop management
……………………..……………………………………………………………………………….

……

……

……

D6: Tillage practices: 1=Conventional (ox-drawn plough), 2=hand-hoe, 3=ripping, 4=pot-holing/basins

SECTION E: APPLICATION OF INTEGRATED SOIL FERTILITY MANAGEMENT CONCEPTS AND PRINCIPLES

E1: What principal legume crops do you grow in rotation with cereals? Response could be multiple.	Crop 1: Cowpeas
	Crop 2: Beans
	Crop 3: Groundnuts
	Crop 4: Soybeans
	Crop 5: Pigeon peas
	Crop 6: Mbabara nuts
	Crop 7: Velvet Beans
	Crop 8: Other (specify)
E2: Is the area under legume crops in the preceding season equivalent to the size of the cereal crop	1=Yes, 2=No

field in the following season in the rotation	
E3: Does household use inorganic fertilizer to fertilize crops?	1=Yes, 2=No
E4: Does household use livestock manure to fertilize crops?	1=Yes, 2=No
E5: Does household practice intercropping?	1=Yes, 2=No
E6. If yes list crops intercropped	1) Maize + Cowpeas, 2) Maize + Groundnuts, 3) Maize + Sunflower, 4) Maize + Pumpkins, 5) Maize + Beans, 6) Maize + Sunflower, 7) Maize + Soybeans, 8) Maize + Cassava, 9) Other (specify)
E7: Name commonly used improved maize varieties under anthill soil treatment?	1) MRI 514, 2) MRI 614, 3) MRI 624, 4) ZMS 402, 5) ZMS 602, 6) ZMS 606, 7) ZMS 616, 8) PAN 413, 9) PAN 53, 10) PAN 6777, 11) SC 403, 12) SC 513, 13) SC 602, 14) Other (specify)
E8: Name commonly used local maize varieties under anthill soil treatment?	1) Gankanta, 2) Go by Red, 3) Red cob, 4) Hickory King, 5) 8-Line, 6) Chibahwe, 7) Panda, 8) Silintuba 9) Kazungula, 10) Siampungani, 11) Mapongwe – a – Chitonga, 12) Other (specify)

SECTION F: ANTHILL SOIL UTILIZATION IN CROP PRODUCTION

F1: When (year) did household start using ant hill soil to improve soil fertility?	(1) 1 year ago (2) 3 years ago (3) 5 years ago (4) 10 years ago (5) > 10 years ago (6) Other (specify)
F2: What push factors drove your household to start utilizing anthill soil?	
(a) Social - Economical factors	(1) Limited capital (finance) (2) labour (3) Other (specify)
(b) Bio-physical factors	(1) Soil factors (2) Weeds (3) Pests and diseases (4) Other (specify)
F3: What type of crops do you grow under ant hill soil treatment?	Reason for growing these crops under anthill soil treatment. Response could be multiple. 1) Yield increase, 2) Improve soil fertility, 3) Improve HH food security, 4) Other (specify)
Crop 1: Maize	
Crop 2: Cowpeas	
Crop 3: Beans	

Crop 4: Groundnuts	
Crop 5: Soybeans	
Crop 6: Sunflower	
Crop 7: Sorghum	
Crop 8: Finger millet	
Crop 9: Rice	
Crop 10: Cassava	
Crop 11: Other	
F4: What benefits have you observed of anthill soil utilization compared to conventional soil fertility management practices?	1= High yields, 2= It's cheaper to access anti hill soil, 3=other (specify) ………………………………………
F5: What challenges have you observed in anthill soil utilization compared to conventional soil fertility management practices?	1) Inadequate labour, 2) Requires more water, 3) Requires less water, 4) Determining anthill soil quantities required by crop, 5) Handling and transportation, 6) Other (specify)
F6: What indigenous knowledge/indicators do you use to identify the suitability of anthill for soil improvement?	1=Vegetation type (i.e species composition) around the anti hill, 2= Soil type, 3=Size and shape of the anti hill, 4=Other (specify)
F7: What are the ant hill soil management practices do you employ (Application/management methods)?	1) Spot application, 2) Heaping and spreading on flat field, 3) Placement in ripped lines, 3) Placement in plant potholes/basins, 4) Crop rotation, 5) Intercropping, 6) Cover with crop residue, 7) Mix with cattle manure, 8) Other (specify)

Anthill Soil Fertility Management Calendar

Activities/Months	June	July	August	September	October	November	December
F8: Anthill Identification							
F9: Digging							

F10: Transportation							
F11: Application							

Labour Disaggregation by Activity by Gender

Activities	**Principle labour sources**			
	Principally men	**Principally women**	**Both men and women**	**Hired labour**
F12: Anthill identification				
F13: Digging				
F14: Transportation				
F15: Application				

F16: Do you use anthill soil in combination with other soil fertility management practices? 1=yes, 2=no

F17: If YES, which ones?
………………………………………………………………………………………

F18: If YES, why?
………………………………………………………………………………………

F19: If NO, why?
………………………………………………………………………………………

F20: H14: What crop production constraints do you experience in relation to anti-hill soil utilization in a drought season? ……….

……………………………………………………………………………………………

F21: If yes, what measures do you take to cope with the situation?

……………………………………………………………………………………………………

F22: H14: What crop production constraints do you experience in relation to anti-hill soil utilization in a season when there is too much rain?

………………………………………………………………………………………………………

F23: If yes, what measures do you take to cope with the situation?

………………………………………………………………………………………………………

F24: When an anthill is dug up, how long does it take to rejuvenate again if at all it does? …………years

F25: After how many years do you reapply anthill soil to the same field? ……………….. years

F26: How much quantities of anthill soil do you think would be appropriate for applying in a hectare (100mx100m, use football stadium size for farmer to understand hectare) to achieve optimum yield (This is based on farmer perception)…………… (kg or number of oxcarts)

F27: Do you recommend anthill soil utilization by other farmers? Explain ………………………………

SECTION G: FARMER CONSTRAINTS TO AGRICULTURE PRODUCTION

Please list the most important constraints that you face on your farm (both socio – economic and biophysical challenges)?

No.	**Bio-physical Constraints**	**Tick**
G1a.	Decreasing soil fertility	
G1b.	Soil erosion	
G1c.	Soil type	

G1d.	Weeds	
G1e.	Insect pest and diseases	
Technical/Technological Constraints		
G1f.	Limited farm products	
G1g.	Lack of soil fertility leguminous green manures and food legumes	
G1h.	Lack of soil fertility tree seedlings	
G1i.	Lack of knowledge of agroforestry tree species	
	Land Constraints	
G1j.	Limited access to land	
G1k.	Security of land tenure	
	Other Constraints	
G1l.	Inadequate labor	
G1m.	Poor infrastructure development	
G1n.	Limited capital	
	Institutional Constraints	
G1o.	Limited access to research and extension services	
	Poor institutional linkages in Conservation Agriculture outreach/Promotion	
G1p.	Low and variability of crop prices	
G1q.	**Agro-climatic Constraints**	
	Poor rainfall patterns	
	Extreme temperatures	

SECTION H: HOUSEHOLD ACCESS TO AGRICULTURE TECHNOLOGY INFORMATION

H1. What are your sources of information on the following?

	Sources of Information (*)	
	Most important source	**Other sources**
H1a. General farming practices		
H1b. Erosion control		
H1c. Soil fertility management		
H1d. Water conservation techniques		
H1e. New crop cultivation techniques		
H1f. New seed		
H1g. Disease & Pest control		
H1h. Animal husbandry		
H1i. Market and market prices		
H1j. Farm tree planting and management		

*(*) **Access to information**:*

0 = None (Added)

1 =own experience

2 = other household members

3 = neighbours/other farmers

4 = school/NGO

5 = government extension workers

6 = private company extension workers

7 = Input dealers

8 = radio/television

9 = farmers' organization

10 = newspaper/magazine/other print media

11 = none

12 = others (specify)

H2. Are you adequately involved in making decisions on any agriculture technology implementation at your farm?

1 = Yes 2 = No

H3. How are you organized in the implementation of such technologies?

1 = Groups 2 = Individually

H4. Who have been the main promoters of Agricultural technologies you have used over the past period? What were the roles of key players in the promotion?

Key Players in Agriculture Technology Promotion	**Role Played**

H5. What kind of support are you enjoying for the implementation of different agriculture technologies by the Promoters?

[ ] Free access to all training materials 1 = Yes [ ] 2 = No [ ]

[ ] Partial support for training material 1= Yes [ ] 2 = No [ ]

[ ] No support for training materials 1= Yes [ ] 2 = No [ ]

[ ] Access to subsidized inputs 1= Yes [ ] 2 = No [ ]

[ ] Access to credit facilities 1= Yes [ ] 2 = No [ ]

[ ] Others (please explain)

H6. Any other comment from farmer concerning agriculture technologies being promoted

……

………

……
…

END OF INTERVIEW

REMEMBER TO THANK THE RESPONDENT