EVALUATION OF THE VARIATION OF SELECTED CHEMICAL AND PHYSICAL SOIL PROPERTIES UNDER DIFFERENT AGES OF *FAIDHERBIA ALBIDA* CANOPIES

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DEDICATION

This report is dedicated to my lord Jesus Christ, brother Godfrey Muzyamba and my son Komana Muzyamba.

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ABSTRACT

The aim of this study was to investigate the variation of selected chemical and physical soil properties under different ages of *Faidherbia albida* (*F.albida*) tree canopy. Three (3) sites identified were Chongwe, Kasisi and Shimabala. From these sites, soils were randomly collected under and outside the canopies both for analysis and for a green house pot experiment. The collected soils were analysed for pH, soil organic carbon (SOC), available nitrogen (N), total nitrogen (%N), available phosphorus (P), potassium (K), bulk density, infiltration rate (*I*) and aggregate stability . To compare the dry matter yields of maize on soil collected from different ages as well as outside canopy, test crop maize was grown in the greenhouse pots for eight (8) weeks. After 8 weeks, the above ground portions were harvested, dried and weighed. The results of the study showed that there was a general improvement of the chemical and physical properties of soils with increasing age though some variations were also observed in some sites. Statistical analysis for Chongwe showed that there was a significantly higher pH value with increase in age (p=0.006). In addition, the SOC was significantly higher (p=0.04) under the canopy compared to outside the canopy though there were no significant differences between the different ages (p=0.139). There were also significantly higher amounts of P for soils collected under canopy than outside the canopy (p=0.046) while among the different ages, there was no significant difference (p=0.066).There was also no significant difference between dry matter for soils collected under and outside canopy (p=0.677) and between the different ages (p=0.387). For Shimabala, a significantly higher K under than outside the canopy (p=0.027) was observed but there was no significant difference among different ages (p=0.947). There was also no significant difference between %N under and outside canopy (p=0.199) and there were no significant differences between the different ages (p=0.816). Moreover, Higher stability of aggregates was observed under compared to outside canopy (p=0.009). For Kasisi, there was a significantly high bulk density outside than under canopy (p=<.001).There was also no significant difference between available N for soils collected under and outside canopy (p=0.074). Generally it was observed that the *albida* effect was realised as early as three (3) years and that the contribution of the *F.albida* generally increased with age.

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CHAPTER 1

1.0 INTRODUCTION

Soils in the arid and semi-arid regions are known for their low fertility and susceptibility to degradation mostly through wind erosion and nutrient-mining (Sanda *et al.*, 2013). Soil fertility depletion has been described as one of the major biophysical root cause of declining per capita food production (Bationo *et al.*, 2003). This fertility depletion has also been observed in many fields including most areas in Zambia especially among small scale farmers who are greatly affected because of their poor management practices and low inputs.

This coupled with problems associated with the fragile environment has made it necessary to find lasting solutions for a sustainable agricultural production. One of the ideas as a solution to these problems is the incorporation of *Faidherbia albida* (*F.albida*) trees with the annual crops by farmers in this region (Sanda *et al.*, 2013).

F.albida is an agroforestry tree capable of fixing nitrogen in the soil. *F.albida* has also a remarkable capacity for recycling nutrients from underground to the surface due to its very deep root system (Le Houerou, 1980 Kwesiga *et al.*, 1994; Akinnifesi *et al.*, 2008). This species has a unique phenology in that it sheds its leaves during the wet season and resumes leaf growth during the dry season. This makes it possible to grow crops under its canopy with minimum shading on the companion crop. The potential of mature *F.albida* trees for improvement of soil fertility and crop yields has been demonstrated in many parts of Africa (Saka *et al.*, 1994; Kang and Akinnifesi, 2000). But much of the work on the tree has focussed on mature trees without checking the effect of young trees on soil properties.

1.1 STATEMENT OF THE PROBLEM

Most small scale farmers in Zambia produce low yields due to many factors such as farmer practices, high cost of fertilizers and poor soils as a result of depletion of nutrients through leaching and soil erosion. *F. albida* has been seen to have the potential to improve soil fertility and maize yields within its vicinity. This has led to the promotion of planting *F.albida* trees by the Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU) (Shitumbanuma, 2012) and also by the government through Ministry of Agriculture and Livestock so as to cushion the nutrient balance.

Most of the research work has revealed that nutrient contents of N, P, K, Ca, Mg, Na, and organic matter content of soils under the *F. albida* canopy of mature trees are higher than away from the canopy (Umar *et al.*, 2012). In spite of the aforementioned contributions, it is clear that much of the research in Zambia has been concentrated on effect of mature *F.albida* trees on the soil properties. This then has left a knowledge gap on the contribution of younger ages of *F.albida* trees thus the need to determine the effect of different ages of *F.albida* trees on soil properties.

1.2 RATIONALE

Due to climate change and ever increasing costs of agriculture recurrent inputs, adoption of *F.albida* trees has been observed in many fields of small scale farmers. Successful results of increase in maize production under canopy of *F.albida* have been recorded followed by soybeans with the exception of cotton and groundnuts which did not produce good yields under *F.albida* canopies in most parts of Zambia (Shitumbanuma, 2012). With this information it is clear that *F.albida* indeed helps small scale farmers especially that they practice monoculture in most of their fields planting Zambia's staple crop, maize.

It is also known that the tree takes about 20 years for it to reach maturity and have an impact on the under storey crop (Kang and Akinnifesi, 2000). Furthermore, planting of the *F.albida* trees with closer spacing of 10 × 10 m, earlier impact can be achieved at 12–15 years (Akinnifesi *et al.*, 2010).

Thus, there is need to determine the age contributions to the soil properties so as to have a clear guidance on when the albida effect starts and when it is at peak.

1.3 GENERAL OBJECTIVE

To investigate the variation of selected soil properties under different ages of *F.albida* tree canopy.

1.3.1 Specific Objectives

- To determine the effect of age of *F.albida* on selected chemical properties of the soil.
- To determine the effect of age of *F.albida* on selected physical properties of the soil.
- To compare maize biomass yield grown on soils collected under and outside *F. albida* tree canopy of different ages.

1.4 HYPOTHESIS

- There are differences in soil chemical properties under the canopies of *F. albida* of varying ages.
- There are differences in soil physical properties under the canopies of *F. albida* of varying ages
- There is an increase in maize biomass under older than younger canopies of *F.albida* trees.

CHAPTER 2

2.0 REVIEW OF LITERATURE

2.1 Faidherbia albida

Faidherbia albida is a legume tree intrinsic to Africa and the Middle East. The tree has now been introduced in various parts of the world including India and Pakistan. It is a thorny tree which can grow up to 30 m tall and 2 m diameter (Wyk *et al.*, 1997). The tree has a bark which is grey in colour and it has a deep penetrating tap root which makes it highly resistant to droughts. It grows in areas of rainfall 250 – 600 mm per year (Hogan, 2010). The tree has a reverse phenology, for this reason, it does not interfere with the growth of the crops under the canopy during rain season.

2.2 Soil Reaction

Soil reaction (pH) is a major determinant of soil nutrient availability. Most soils that have a low pH, may result in toxic levels of Aluminium and Manganese in the soil solution. Despite growth of millet in soils with low pH, cultivation of other crops such as sorghum and maize is hindered. Soil physical properties also affect the characteristic of the soil and affect the chemical composition. Where there is higher clay content, there are usually more nutrients available and soil pH is well buffered and generally higher (Williams, 1992). Several research works have been done under mature *F.albida* canopy on soil reaction (pH). Soil pH was found to be lower in continuously fertilised maize fields than under the *F.albida* canopy grown in east Zambia (Chintu *et al.*, 2004). This is because addition of organic matter mitigates soil acidity (Haynes and Mokolobate, 2001). Another research carried out in the region of Kano State, Nigeria revealed that pH values for the samples outside the canopy significantly differed from the soils under the canopy of *F. albida*. Then all the samples under the canopy were close to neutral with samples outside canopy giving only slightly higher value.

2.3 Available Nitrogen

One of the major limitations to production of crops among farmers is the deficiency of nitrogen in the soil. This is because nitrogen in the soil is available in small amounts and only in two forms NO^-_3 and NH^+_4 of which the preferred form nitrate, is always leached down in the soil if not utilised by plants when available. Further, the soil colloids are predominantly negative and only adsorb positively charged cations such as K^+,Na^+,Ca^{2+} including NH^+_4 thus leading to repulsion of the negatively charged ions away from the colloidal surfaces. Therefore, despite the addition of fertilizers, the excess N is usually leached down the soil and the other is lost through runoff and volatilisation into the air.

Fertiliser trees can accumulate more than 60 kg N ha^{-1} per year through biological nitrogen fixation (BNF) (Ajayi *et al.*, 2011) which is far enough for a maize field requirement for one tonne maize grain yield per hectare of 40 kg N ha^{-1} per year (Sanchez and Palm, 1996) . To produce 4 tonnes maize grain per hectare 100kg N $ha^{-1}yr^{-1}$ is required (Sanchez and Palm, 1996). Thus a little supplement of synthetic fertilizer of 40 kg N per hectare would increase yields of smallholder farmers.

Soils under *F.albida* have much higher levels of nitrogen compared to those outside canopies of *F. albida* (Shitumbanuma, 2012). Also the amount of N in the soil is related to the amount of organic matter in the soil (Twaha, 2004). The organic matter accumulates from the litter fall off the tree. Increase in yield from crops grown below the tree has been attributed to increase in fertility due to nitrogen fixation, dung from livestock browsing and falling leaves and pods (Radwanski and Wickens, 1969).

2.4 Phosphorus and Exchangeable Base Cations.

The trees can recycle the soil's phosphorus (P), calcium (Ca), magnesium (Mg) and potassium (K), but these macronutrients must be sourced externally when they are highly depleted from the soil (Kwesiga *et al.*, 1994). In a research Potassium and Phosphorus levels which are among the plant nutrients showed higher values under the canopy than with increasing distance away from the canopy (Sanda *et al.*, 2013).

2.5 Soil Organic Carbon

The organic matter is important to the soil as it improves the soil physical properties as well as the chemical properties. Several research works have been done on organic carbon under the

F.albida canopy. The *F.albida* tree significantly increases organic carbon in topsoil under the canopy (Alexander, 1989).

A research carried out in Nigeria revealed that organic carbon was greater in the topsoil beneath the canopy as compared to soil outside the canopy (Kidd *et al*, 1992). Another research carried out in Burkina Faso also revealed that organic matter content, organic carbon, and organic nitrogen, available phosphorus, and exchangeable bases were higher in soils beneath *F. albida* (Depommier *et al.*, 1992).

2.6 Soil Physical Properties

One of the factors not considered by most farmers is the physical fertility of the soil. After harvest, the crop residues are burnt and little organic matter remains in the fields. As such most farmers' soils have poor soil structures characterised by high bulk density, low infiltration rate, low permeability, lower microbial activities in the soil and poor water-holding capacity.

There has been very little research works done concerning the physical properties of the soil under the *F.albida* tree. Fertilizer trees improve soil physical properties through the addition of litter fall, root biomass, root activity, biological activities and roots leaving macro pores in the soil following their decomposition. The trees also improve soil aggregation, thereby enhancing water filtration (Chirwa *et al.*, 2007), which reduces water runoff and soil erosion relative to production systems where maize was continuously cultivated without planting trees (Phiri *et al.*, 2003)

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Soil Sampling and Site Description

The soils were collected from three sites namely: Shimabala (Kafue), Chongwe and Kasisi Agricultural Training Centre. The land in Shimabala and Chongwe has been under conservation agriculture and the farmer mainly cultivates Maize, Groundnuts and Soybeans in rotation. The Shimabala field had *F.albida* trees of two age; 4 and 9 years old while the fields in Chongwe had tree's age of 3, 6, 7 and 10 years on one field and the other field only had one tree older than 25 years. The fields in Shimabala had beans and soya beans growing under 4 year's canopies and maize under the 9 years canopies. At Kasisi the area at time of sampling was characterised by natural grass and some shrubs. In Chongwe, both fields had maize growing both under and outside the tree canopies.

Soil samples were randomly collected under the tree canopies of *F.albida* in all the three sites. For each field, one composite sample was collected outside the canopies to act as a control. In addition, undisturbed samples were collected using core rings. Three core ring samples were collected under each canopy and an additional 3 undisturbed samples outside the canopy. Bulk samples were also collected under the canopies and also outside canopies for the greenhouse maize pot experiment.

3.2 SOIL PHYSICAL PROPERTIES

3.2.1 Infiltration Rate

Infiltration was determined using the micro-disc infiltrometer method as shown in Figure 1. For calculations the cumulative infiltration i was determined using the equation developed by Kostiakov (Uloma *et al.*, 2014):

$i = a.\ t^b$,

Where t= time of infiltration (s) a and b = empirical constants which are a function of soil characteristics. The infiltration rate I (expressed in $m.s^{-1}$) was determined as a derivative of the cumulative i.

$$I = \frac{di}{Dt} = a.\ b.\ t^{b-1}$$

The parameters a and b were solved by transforming the equation by Kostiakov into a linear equation (y= A + B . X) and performing a linear regression.

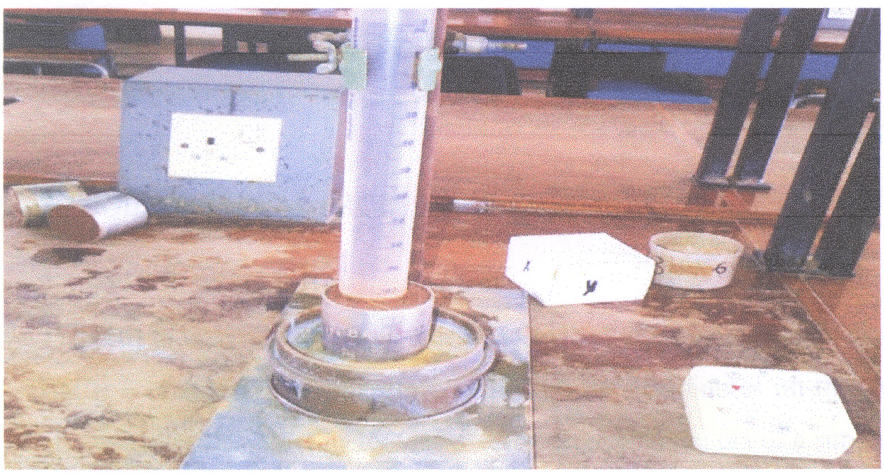


Figure 1: A laboratory Setup used to determine infiltration rate in undisturbed soil samples

3.2.2 Bulk Density and Moisture Content

Core rings were weighed and recorded before going to sample in the field. The core rings with moist soils were then weighed before oven drying at 105 ^{0} C for 24 hrs. There after, the oven dried samples were also weighed and the masses recorded.

3.2.3 Particle Size Distribution.

Particle size distribution was determined using the hydrometer method. Soil samples were firstly air dried, then sieved with a 2 mm sieve. Measurements were taken at 40 seconds for sand and silt then at 2 hours for clay.

3.2.4 Aggregate Stability (Wet and Dry Sieving)

Air dried aggregates of the same size were collected of which 200g was weighed. A set of Sieves 8, 4.75, 2, 1, 0.5 and 0.3 mm were prepared. For dry sieving, a collector at the bottom sieve and a cover at the top sieves were provided. The aggregates were put evenly and gently onto the 8 mm sieve and the machine was let to shake for 2 minutes. There after, soil aggregates on each sieve were collected and weighed.

For the wet sieving, the same sets of sieves were used. The soil aggregates were evenly spread on the upper 8 mm sieve and then the set was gently lowered into the water. The machine was let to shake for 2 minutes then the samples from each sieve were collected with a stream of water. The samples were then oven dried at 105^{0} C for at least 48 hours to ensure that water evaporated and that soils were completely dry. There after, the oven dry samples were weighed and masses recorded.

3.3 SOIL CHEMICAL PROPERTIES

3.3.1 Soil Reaction (pH)

Ten (10) grams of soil was weighed and placed in a 50 cm^3 plastic bottles then 25 cm^3 of 0.01M $CaCl_2$ was added. The mixture was shaken for 30 minutes on the mechanical shaker and then allowed to settle. A pH meter was used to determine the pH of a supernatant solution, the reading was taken when the meter had stabilised.

3.3.2 Soil Organic Carbon

The Organic Carbon content was determined using the Walkley and Black Method.

3.3.3 Exchangeable Potassium

Ten (10) grams of air dry soil was weighed in 100 cm^3 plastic containers to which 50 cm^3 of ammonium acetate (NH_4OAc) buffered at pH 7 was added. The sample was shaken for 30 minutes on the mechanical shaker and then filtered. From the filtrate concentrations of potassium (K) were measured by Atomic Absorption Spectrophotometer.

3.3.4 Available Phosphorus

The Bray 1 method was used to extract phosphorus from the soil. The absorbance was determined using a Spectrophotometer at 882 nm wavelength.

3.3.5 Available Nitrogen (NO_3^- and NH_4^+)

Five (5) grams of soil was weighed into 100 cm³ plastic bottles to which 50cm³of 2.0M KCl was added and shaken on the mechanical shaker for 1 hour. The suspension was then filtered. For each sample the filtrate was distilled twice to determine NH_4^+ -N and NO_3^- -N separately. The distillates were titrated with 0.005N sulphuric acid to reddish-purple colour. The volume of H_2SO_4 used up during titration, were used to calculate the amount of available nitrogen in the soil reported in mg/kg soil.

3.3.6 Total Nitrogen

One (1) gram of soil, 3 grams of catalyst mixture and ten (10) cm^3 concentrated sulphuric acid were added into Kjeldahl flasks and digested. The digest were transferred from the flasks into hundred (100) cm^3 plastic containers. Ten (10) cm^3 of the digest and 10 cm^3 of ten(10) M NaOH were put into the distillation flask gently. The end of the distillation apparatus were connected to conical flask containing twenty (20) cm^3 of boric acid indicator solution and the distillate was collected for three minutes. Later the captured distillate was titrated with 0.01M HCl until the colour changed from green to pink, the volume of acid consumed was used to calculate percentage total nitrogen in the sample.

3.3.7 Green house pot experiment

A pot experiment using factorial split plot design was set in the green house from May to July 2014 for a period of eight (8) weeks. The factors for the design were; age of the tree and place of sampling that is under and outside the canopy. Then each factor was replicated three times. Pictures were taken each week to check the developments of the plants. At the time of harvest, the fresh above ground samples were weighed and these where oven dried at 70^0C for two days then weighed.

3.3.8 Data analysis

The data was analysed using split plot ANOVA for all the parameters using Genstat 16th edition.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 General Characteristics of Selected Chemical and Physical Soil Properties.

Tables 1, 2, 3 and 4 shows results for all soil characteristics used in the study. All the soils in Shimabala were found to be neutral because they were higher than pH 5.0. While that of Chongwe the soils where found to be neutral under 7 and 10 years canopies but that of under 3,6 years and outside canopies were found to be acidic soils. The phosphorus bray-1 extractable where all found to be less than the critical of 12 mg/kg soil. The potassium results were all greater than 112 mg/kg soil. The available nitrogen for all soils were greater than the 25mg/kg soil critical required for maize. The bulk densities ranged from 1.31 to 1.60 g/cm3 for all sites. Generally soils under canopy trees had lower bulk densities compared to the soils outside the canopy (Table 2).

Table 1: Particle size distribution for Shimabala, Kasisi and Chongwe.

Site	Particle size distribution			USDA textural
	%Sand	%Silt	%Clay	class
Shimabala	15.7	34.7	49.5	Clay
Kasisi	62.0	22.0	16.0	Sandy Loam
Chongwe 1	44.4	37.0	18.7	Loam
Chongwe 2	64.4	12.4	23.2	Sandy Clay Loam

Table 2: showing mean results for pH, bulk density, Soil organic carbon, Phosphorus, Potassium, Total nitrogen, available nitrogen and dry matter content for both under and outside the canopy (U.C and O.C) for different ages and for the different sites used in the study.

SITE	Age	Treatment	pH	Bulk Density	SOC	P	K	Total N	Available N	Maize biomass yield
			0.01M $CaCl_2$	(g/cm^3)	(%)	(mg/kg)	(meq/100g soil)	(%)	(mg/kg)	(g)
Shimabala	4	U.C	6.23	1.48	1.00	10.84	0.93	0.25	163.33	3.60
Shimabala	9	U.C	5.50	1.50	1.16	11.43	0.98	0.27	387.33	3.80
Shimabala	0	O.C	5.32	1.56	0.86	10.30	1.23	0.22	298.67	2.60
Kasisi	22	U.C	5.53	1.40	0.95	12.74	1.01	0.27	228.67	16.80
Kasisi	0	O.C	4.26	1.60	1.00	10.67	0.53	0.18	219.33	9.13
Chongwe	3	U.C	4.93	1.37	0.78	5.37	0.84	0.23	196.00	12.40
Chongwe	6	U.C	4.99	1.35	1.00	8.13	0.77	0.27	233.33	4.53
Chongwe	7	U.C	5.32	1.31	1.36	8.31	0.84	0.23	238.00	5.57
Chongwe	10	U.C	5.72	1.32	1.01	8.24	1.09	0.24	177.33	6.80
Chongwe	0	O.C	4.77	1.37	1.21	6.02	0.85	0.20	224.00	6.50
Chongwe	25	U.C	5.77	1.43	0.70	66.77	0.92	0.31	522.67	10.03
Chongwe	0	O.C	5.25	1.52	1.17	46.72	0.70	0.22	331.33	9.27

4.2.1 Soil reaction (pH)

The pH values of the selected sites as shown in Table 2, under canopy were higher than outside canopies. This correlated with the observation that pH values were higher under canopies of fully fertilised maize than outside the canopy in eastern Zambia (Chintu *et al.*, 2013). The pH values were generally higher with an increase in age at different sites as was observed in Chongwe (4.77 to 5.72) with outside canopy being lowest and under the canopy of 10 years being highest. For Shimabala pH values ranged from 5.32 to 6.23 with that of 4 years being the highest. From the ANOVA for Chongwe showed soils under canopy being significantly higher than outside canopy (p=0.005). Also among the ages there was a significantly higher pH with increase in age (p=0.006). For Shimabala, pH values for soils under canopy were significantly higher than that of outside canopy (p=0.028) though there was no significant difference among the ages (p=0.118). For Kasisi, soils under canopy had a significantly higher pH compared to that of outside canopy (p=0.003).

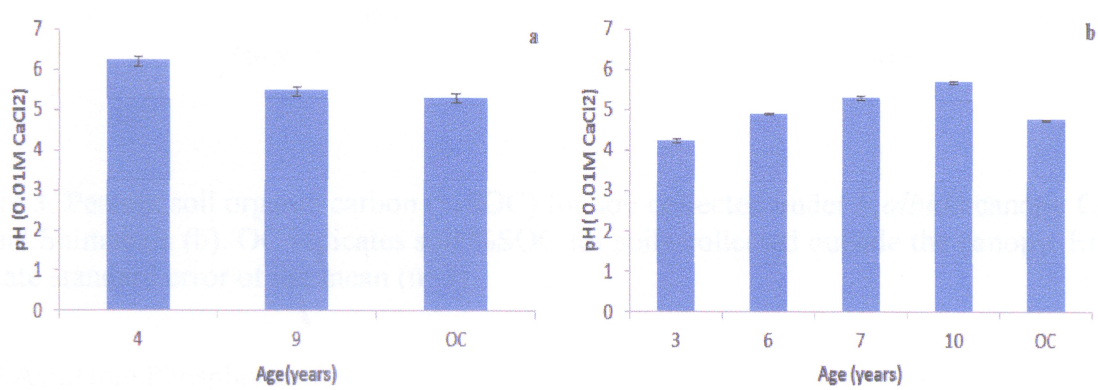


Figure 2: pH values for soils collected under the canopy from Shimabala (a) and Chongwe (b). OC indicates the pH value for soils collected outside the canopy. Error bars indicated standard error of mean (n=3).

4.2.2 Soil organic carbon

Soil organic carbon (SOC) for all sites was found to be higher under the canopies than outsides the canopies which proves true that *F.albida* increases organic carbon (Fredrik, 2005).The organic carbon content showed increase with age as can be seen from Figure 2. For instance in Chongwe SOC ranged from 0.78% to 1.36% with under 10 years being highest.The SOC was significantly higher (p=0.04) under the canopy compared to outside the canopy. Though there were no significant differences between the different ages (p=0.139). For Kasisi, there was a significant difference between SOC under and outside canopy (p=0.003). For Shimabala there was no significant difference for SOC under and outside canopy (p=0.425). There was no significant difference in SOC for soils collected under canopy of different ages (p=0.876).

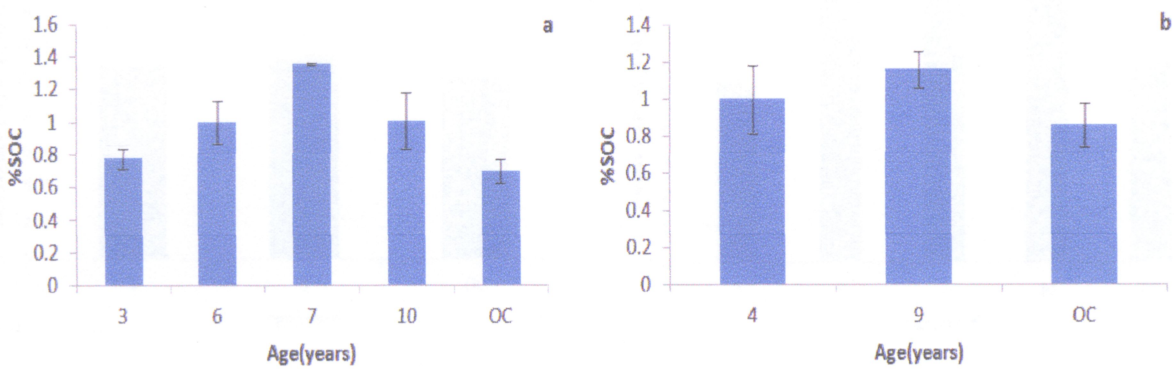


Figure 3: Percent soil organic carbon (%SOC) for soil collected under *F.albida* canopy Chongwe (a) and Shimabala (b). OC indicates soil %SOC for soils collected outside the canopy. Error bars indicate standard error of the mean (n=3).

4.2.3 Available Phosphorus

There was an increase in phosphorus (P) content with age as shown in Figure 3.The P contents were 10.84, 11.43 and 10.30 mg/kg soil for 4, 9 years and outside the canopy respectively for Shimabala. Thus there was an increase with age in phosphorus for the two ages in Shimabala. For Chongwe the results ranged from 5.37 to 8.24 mg/kg soil for 3 years lowest to 10 years highest P content. This also depicts an increase of phosphorus with age. For both sites the phosphorus amounts were higher under the canopies than outside canopies. This was also true for Kasisi and the other site in Chongwe.

The P content with age showed a good correlation of r^2 =0.57 for Shimabala. While that of Chongwe also showed good correlation of r^2= 0.63. These higher results in P under canopy confirms with several research that have been done on *F.albida.* A research by Sanda et al. (2013) showed that soil under albida canopy had significantly higher total P compared with another away from the canopy. The deficiencies of phosphorus as noticed in the lab analysis of less than 12mg/kg soil were manifested in maize growth with appearance of purple colours on maize leave edges (Figure 4).

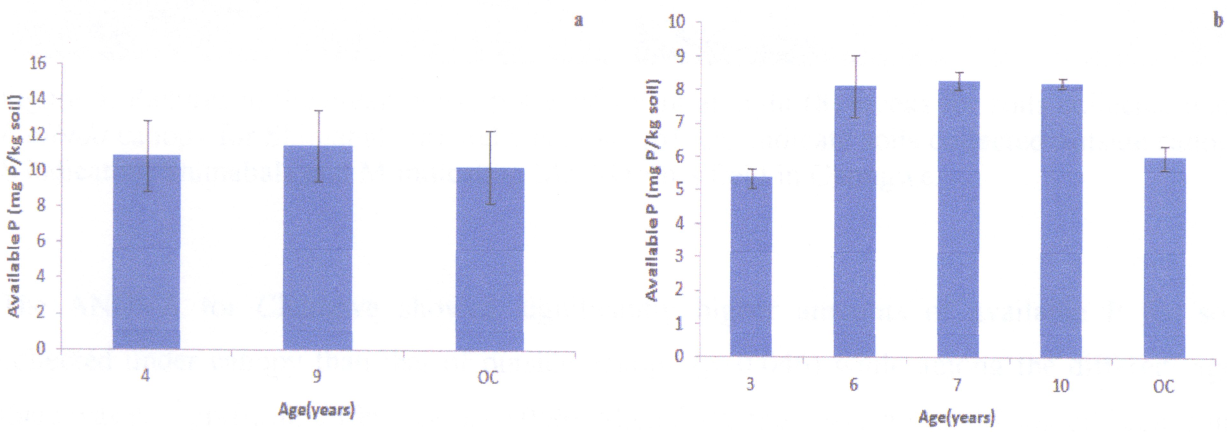


Figure 4: Phosphorus values collected under *F.albida* canopy for Shimabala (a) and Chongwe (b). OC indicating values for soil collected outside canopy. Error bars indicate standard error of the mean (n=3).

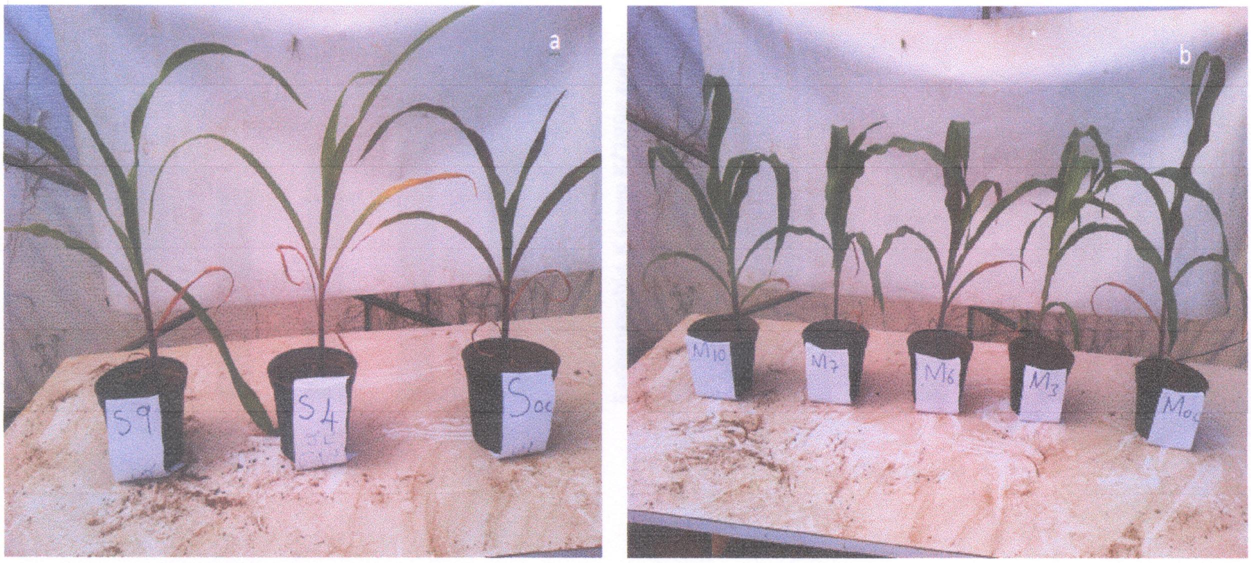


Figure 5: Pictures in the green house pot experiment at eight (8) weeks for soils collected under *F.albida* canopy for Shimabala (a) and Chongwe (b). OC indicate soils collected outside canopy, S indicating Shimabala and M indicating Mr. Martin's field in Chongwe.

The ANOVA for Chongwe showed significantly higher amounts of available P for soils collected under canopy than that of outside canopy (p=0.046) while among the different ages, there was no significant difference (p=0.066). Shimabala, there was no significant difference in P content between soils collected under and outside canopy (p=0.176). There was also no significant difference among the different ages (p=0.893). For Kasisi, there was significantly higher P for soils collected under than outside canopy (p=0.025).

4.2.4 Potassium

There was an increase in potassium with age. There was also a higher value of K outside canopy than under canopy for some ages (Figure 5). This could have been caused by fertilization and also other factors at sampling such as season of sampling because it was rain season and the field had different crops growing such as under 4 years there was soybeans and under 9 years there was maize. This then would have caused the variability. For Chongwe there was an increase with age starting from 6 to 10 years except for 3 years. The potassium results under the canopies were higher than outside canopy except for Shimabala. This then corresponds to the results of low potassium in maize fields due to high uptake of potassium by the maize in fertilized fields (Oluyede *et al.*, 2012).

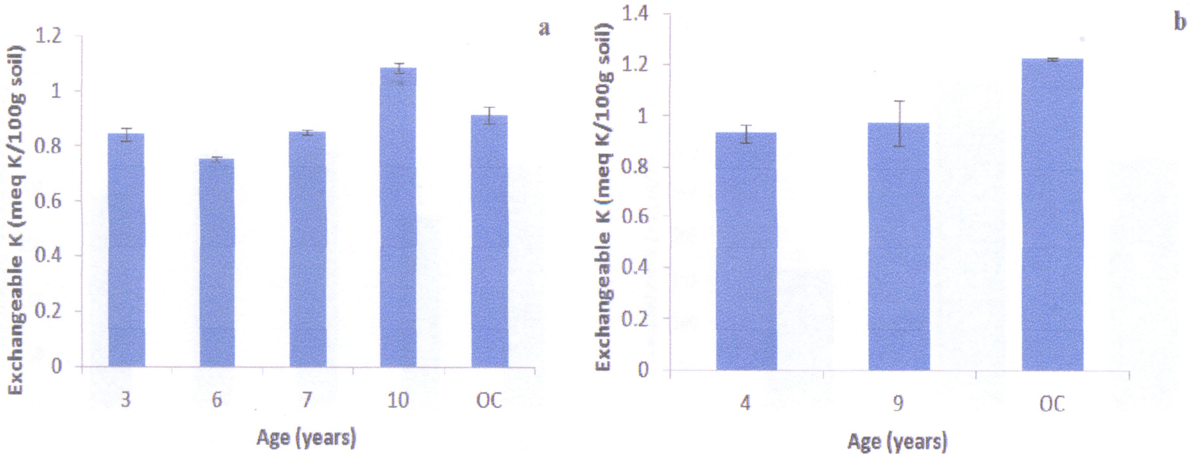


Figure 6: Potassium values for soils collected under *F.albida* canopy for Chongwe (a) and Shimabala (b). OC indicating potassium values for soil collected outside canopy. Error bars indicating standard error of the mean (n=3).

The ANOVA for Chongwe showed that there was no significant difference between K under and outside canopies (p=0.490) but there was a significantly higher K with increasing ages (p=<0.001). For Shimabala there was a significantly lower K under than outside the canopies (p=0.027) but there were no significant differences among there different ages (p=0.947). Kasisi, there was significantly higher K under than outside canopies (p=0.013).

4.2.5 Available Nitrogen

Available N generally increased with age (Figure 6). Though some variations were observed like in the case of Chongwe under 10 years. For Shimabala, there was an increase in available N with age. From the two sites, available nitrogen was higher under the canopies than outside the canopies. The *F.albida* fixes nitrogen usually when nitrogen in soils is at very low levels, (Fredrik, 2013) thus the increase in N under the canopies.

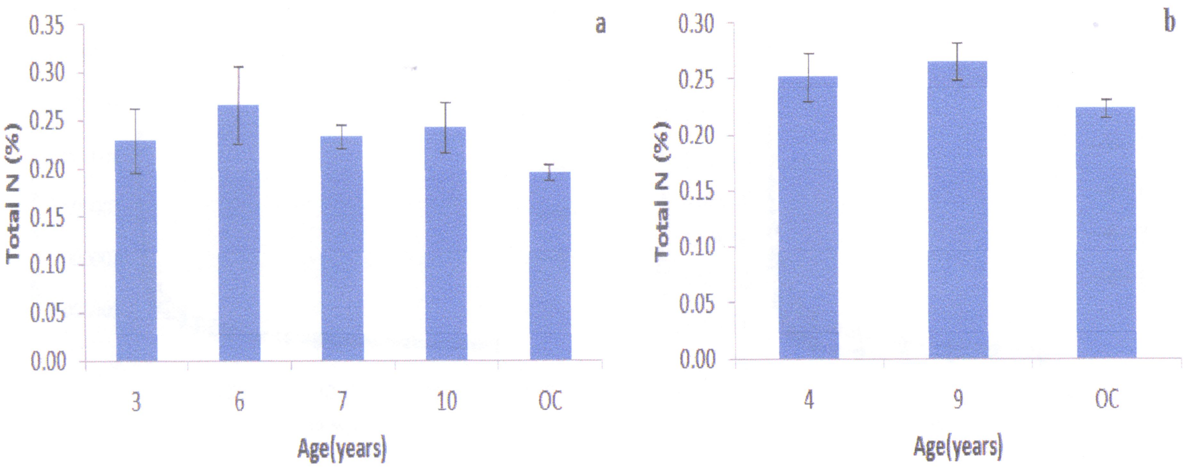


Figure 8 : Percent total nitrogen values for soils collected under *F.albida* canopy Chongwe (a) and Shimabala (b). OC indicating percent nitrogen values for soil collected outside canopy. Error bars indicating standard error of the mean (n=3).

Statistical analysis for Chongwe showed that there was no significant difference between %N under and outside canopies (p=0.147) and among the different ages (p=0.889). For Kasisi, there was no significant difference between %N under and outside canopies (p=0.102). For Shimabala, there was also no significant difference between %N under and outside canopies (p=0.199) and there were no significant differences between the different ages (p=0.816).

4.3.1 Infiltration rate

Figures 8 and 9 show infiltration rates for Shimabala and Chongwe. There was a general increase of infiltration rate (*I*) with age as observed in figure 10. In addition the infiltration rates for under canopy were all generally higher than outside canopy.

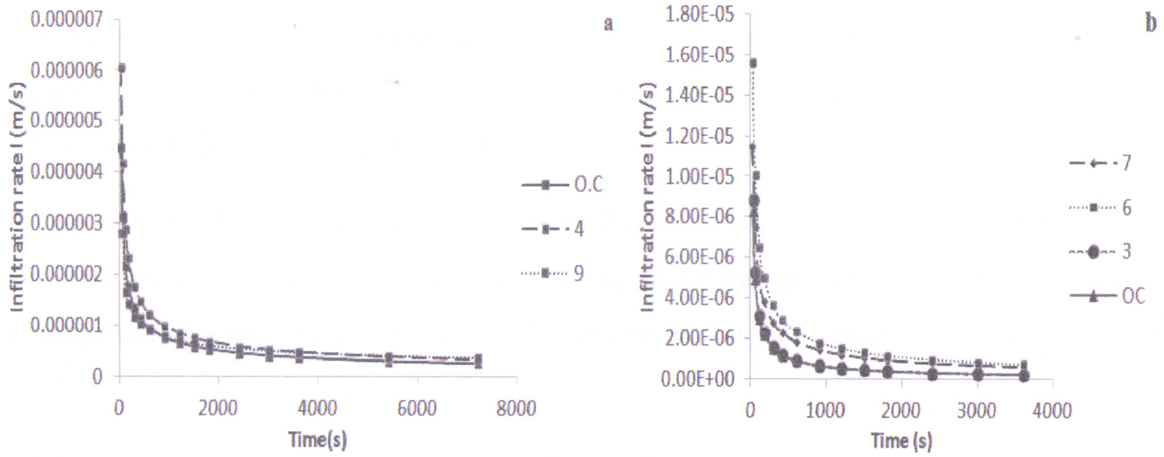


Figure 9 : Infiltration rate I (m/s) values for soils collected under *F.albida* canopy Shimabala (a) and Chongwe (b). OC indicating infiltration rate values for soils collected outside canopy.

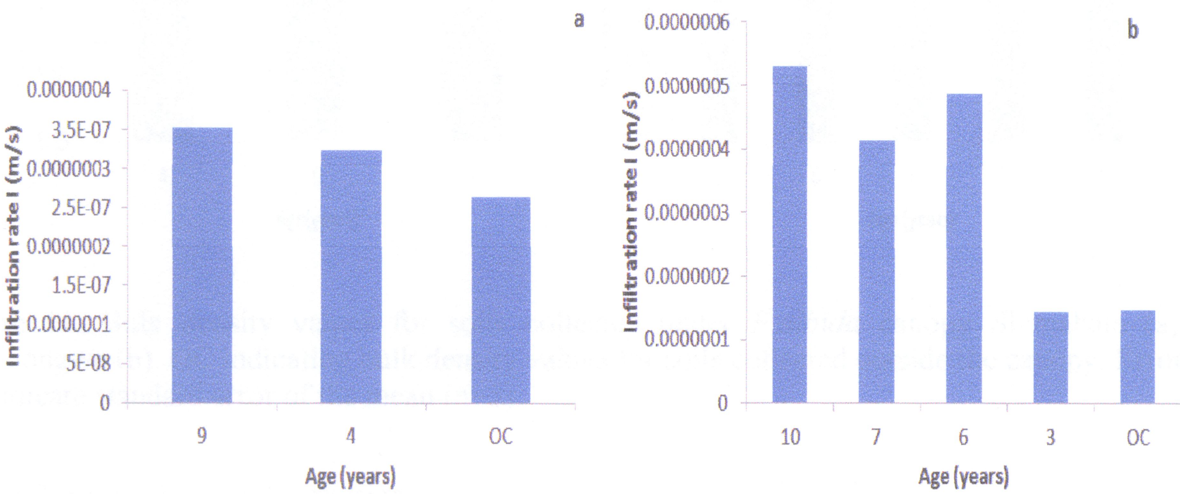


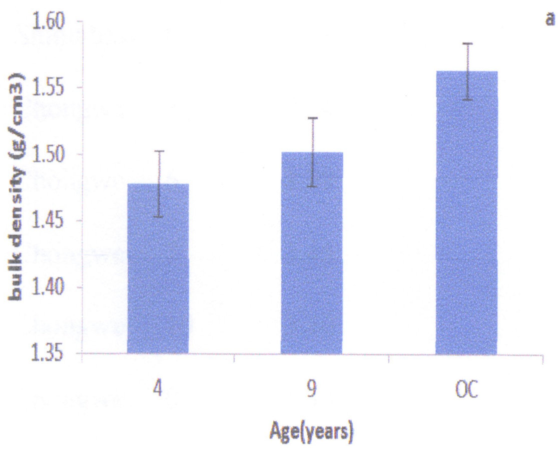
Figure 10 : Comparison of infiltration rate values for soils collected under *F.albida* canopy Shimabala (a) and Chongwe (b). OC indicating infiltration rate values for soils collected outside canopy.

4.3.2 Bulk Density

Bulk densities under the canopies of different ages from different sites as can be observed in Figure 10. For Shimabala it showed that outside canopies bulk density was higher. Compared with the two ages the bulk density under 9 years canopy showed that it was higher than that of 4 years canopy. For Chongwe the bulk density decreased with age (Figure 10).

All the sites bulk densities generally decreased with increasing age. Outside canopy bulk densities were higher than under canopy for all sites. The higher bulk densities observed correspond to low infiltration rates recorded under the 9 years canopy in Shimabala. Under the 9 years' canopy bulk density was higher thus lower infiltration rates.

The bulk density for the various sites showed that there was no significant difference between under and outside canopies ($p=0.225$) and among different ages ($p=0.321$) for Chongwe. There was a significantly high bulk density outside canopy than under canopies for Kasisi ($p=<0.001$).



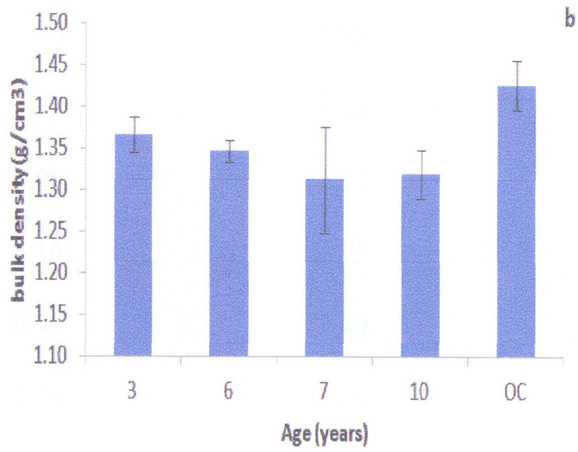


Figure 11: Bulk density values for soils collected under *F.albida* canopy Shimabala (a) and Chongwe (b). OC indicating bulk density values for soils collected outside the canopy. Error bars indicate standard error of the mean (n=3).

4.3.3 Aggregate size distribution.

Table 3 shows change in mean weight diameter (MWD) between dry and wet sieved soil aggregates. The smaller the difference, the more stable the aggregate (Gajic *et al.*, 2013). As observed there were variations in the results obtained. For Chongwe there was a decrease in the stability of the aggregates with increasing age. While for Shimabala, aggregates under 4 years where found to be more stable than those for under 9 years but both where more stable than outside the canopy.

Table 3: Aggregate size stability values for soils collected under *F.albida* canopy. Zero (0) indicating soils collected outside canopy. The smaller the change in mean weight diameters (ΔMWD) the more stable the soil aggregate.

Site	Age	∑ Midi Dry	∑ Midi Wet	ΔMWD (Dry-Wet)
Shimabala	4	3.47	2.22	1.25
Shimabala	9	3.55	2.18	1.37
Shimabala	0	3.78	1.28	2.50
Chongwe	3	2.54	1.43	1.11
Chongwe	6	3.29	1.08	2.21
Chongwe	7	3.45	1.10	2.35
Chongwe	10	3.10	0.70	2.40
Chongwe	0	1.94	1.70	0.24
Chongwe	25	1.80	0.99	0.81
Chongwe	0	1.81	1.16	0.65

Soils collected from Shimabala showed significantly higher stability of aggregates under canopy than that of outside canopy (p=0.009). Though there was no significant difference among the different ages (p=0.824). There was a highly significant difference for aggregates collected under canopy to that outside canopy (p=<0.001) for Chongwe. There was also a significant difference among different ages (p= 0.047).

4.3.4 Maize Biomass Yield

There was an increase in the biomass yield for soils collected under older ages and that the biomass yield was higher under canopy than outside the canopy. Variations in the maize biomass dry matter weight were observed on many soils. For instance for Chongwe under 3 years biomass yield was higher than the other ages but there was a general increase with age in the biomass.

Statistical analysis for the different sites indicated that there was no significant difference between dry matter for soils under and outside canopy (p=0.677) and between the different ages (p=0.387) for Chongwe. For Kasisi there was no significant difference between under and outside the canopies (p= 0.283). Shimabala, there was no significant difference between under and outside canopies (p=0.375) and among different ages (p=0.985).

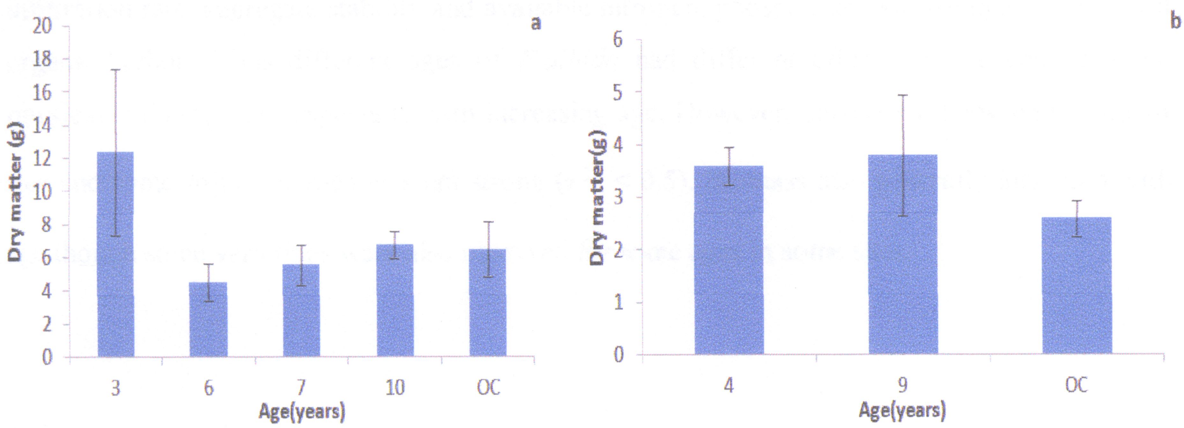


Figure 12: Dry matter (g) of maize for soils collected under *F.albida* canopy Chongwe (a) and Shimabala (b). OC indicating dry matter values for soils collected outside canopy. Error bars indicating standard error of the mean (n=3).

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A general improvement of soil properties due to *F.albida* was observed. By three (3) years some effects of the *F.albida* were realised for instance a reduction in bulk density, increase in infiltration rate, aggregate stability and available nitrogen, phosphorus, potassium as well as soil organic carbon. Thus different ages of *F.albida* had different effects on the chemical and physical soil properties especially with increasing age. However, correlation between the age of tree and some soil properties was not strong ($r^2 < 0.5$). Biomass also generally increased with age though some variations were also observed for some ages in some sites.

5.2 Recommendations

A Field experiment should be done to investigate the age effect on maize biomass under different ages of *F.albida* canopy. This is because under field conditions a more realistic conclusion would be made. A study with more sites should be conducted to improve the results.

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LIST OF APPENDICES

Appendix 1: ANOVA for soil organic carbon Chongwe

Variate: %SOC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.09444	0.04722	4.05	
Replicate. Treatment stratum					
Treatment	1	0.27338	0.27338	23.46	0.040
Residual	2	0.02331	0.01165	0.26	
Replicate.Treatment.Age stratum					
Age	4	0.51743	0.12936	2.88	0.139
Residual	5	0.22485	0.04497		
Total	14	1.13340			

Appendix 2: ANOVA for available nitrogen Chongwe

Variate: Available N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	2692.	1346.	0.12	
Replicate. Treatment stratum					
Treatment	1	395.	395.	0.04	0.868
Residual	2	22429.	11214.	3.81	
Replicate.Treatment.Age stratum					
Age	4	7758.	1940.	0.66	0.647
Residual	5	14733.	2947.		
Total	14	48007.			

Appendix 3: ANOVA for Dry Matter Chongwe

Variate: Dry_matter_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	65.45	32.73	4.68	
Replicate.Treatment stratum					
Treatment	1	1.63	1.63	0.23	0.677
Residual	2	13.99	7.00	0.33	
Replicate.Treatment.Age stratum					

Age 4 110.75 27.69 1.29 0.387

Residual 5 107.63 21.53

Total 14 299.46

Appendix 4: ANOVA for Available phosphorus Chongwe

Variate: P_mg_kg_soil

Source of variation d.f. s.s. m.s. v.r. F pr.

Replicate stratum 2 1.377 0.689 2.61

Replicate. Treatment stratum

Treatment 1 5.328 5.328 20.21 0.046

Residual 2 0.527 0.264 0.26

Replicate.Treatment.Age stratum

Age 4 18.364 4.591 4.46 0.066

Residual 5 5.151 1.030

Total 14 30.748

Appendix 5: ANOVA for Total Nitrogen Chongwe

Variate: Total N

Source of variation d.f. s.s. m.s. v.r. F pr.

Replicate stratum 2 0.006377 0.003188 1.66

Replicate. Treatment stratum

Treatment 1 0.010244 0.010244 5.32 0.147

Residual 2 0.003848 0.001924 0.82

Replicate.Treatment.Age stratum

Age 4 0.002483 0.000621 0.26 0.889

Residual 5 0.011727 0.002345

Total 14 0.034679

Appendix 6: ANOVA for Potassium Chongwe

Variate: meq_K_100g_soil

Source of variation d.f. s.s. m.s. v.r. F pr.

Replicate stratum 2 0.0007833 0.0003916 0.12

Replicate. Treatment stratum

Treatment	1	0.0023598	0.0023598	0.70	0.490
Residual	2	0.0067201	0.0033601	4.67	
Replicate.Treatment.Age stratum					
Age	4	0.1739647	0.0434912	60.47	<.001
Residual	5	0.0035959	0.0007192		
Total	14	0.1874239			

Appendix 7: ANOVA for pH Chongwe

Variate: pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.01232	0.00616	1.68	
Replicate. Treatment stratum					
Treatment	1	0.66339	0.66339	180.79	0.005
Residual	2	0.00734	0.00367	0.18	
Replicate.Treatment.Age stratum					
Age	4	1.19311	0.29828	14.67	0.006
Residual	5	0.10169	0.02034		
Total	14	1.97785			

Appendix 8:ANOVA for bulk density Chongwe

Variate: Bulk Density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Treatment	1	0.049817	0.049817	3.01	0.225
Residual	2	0.033145	0.016572		
Replicate. Treatment stratum					
Treatment	1	0.036046	0.036046		
Replicate.Treatment.Age stratum					
Age	4	0.041532	0.010383	1.39	0.321
Residual	8	0.059922	0.007490	1.15	
Replicate.Treatment.Age.*Units* stratum					
	3	0.019601	0.006534		
Total	19	0.240062			

Appendix 9: ANOVA for Aggregate size stability Chongwe

Variate: Aggregate_size_stability

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0018	0.0009	4.00	
Replicate. Treatment stratum					
Treatment	1	7.5916	7.5916	33989.86	<.001
Residual	2	0.0004	0.0002	0.00	
Replicate.Treatment.Age stratum					
Age	4	3.3027	0.8257	5.36	0.047
Residual	5	0.7702	0.1540		
Total	14	11.6668			

Appendix 10: ANOVA %SOC Shimabala

Variate: %SOC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0194	0.0097	0.10	
Replicate. Treatment stratum					
Treatment	1	0.0968	0.0968	0.99	0.425
Residual	2	0.1963	0.0982	0.78	
Replicate.Treatment.Age stratum					
Age	2	0.0384	0.0192	0.15	0.876
Residual	1	0.1263	0.1263		
Total	8	0.4772			

Appendix 11: ANOVA Available Nitrogen Shimabala

Variate: Available_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	13633.	6816.	0.58	
Replicate. Treatment stratum					
Treatment	1	1089.	1089.	0.09	0.789
Residual	2	23411.	11706.	4.59	
Replicate.Treatment.Age stratum					
Age	2	75264.	37632.	14.77	0.181

Residual	1	2548.	2548.		
Total	8	115945			

Appendix 12: ANOVA for Dry Matter Shimabala

Variate: Dry_mass_

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	3.807	1.903	1.01	
Replicate. Treatment stratum					
Treatment	1	2.420	2.420	1.28	0.375
Residual	2	3.773	1.887	0.96	
Replicate.Treatment.Age stratum					
Age	2	0.060	0.030	0.02	0.985
Residual	1	1.960	1.960		
Total	8	12.020			

Appendix 13: ANOVA for Phosphorus Shimabala

Variate: P_mg_kg_soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	2.243	1.122	3.43	
Replicate.Treatment stratum					
Treatment	1	1.385	1.385	4.24	0.176
Residual	2	0.654	0.327	0.16	
Replicate.Treatment.Age stratum					
Age	2	0.516	0.258	0.13	0.893
Residual	1	2.041	2.041		
Total	8	6.839			

Appendix 14: ANOVA for Total Nitrogen Shimabala

Variate: Total_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0027440	0.0013720	2.00	
Replicate.Treatment stratum					
Treatment	1	0.0024500	0.0024500	3.57	0.199

Residual	2	0.0013720	0.0006860	1.17	
Replicate.Treatment.Age stratum					
Age	2	0.0002940	0.0001470	0.25	0.816
Residual	1	0.0005880	0.0005880		
Total	8	0.0074480			

Appendix 15: ANOVA for Potassium Shimabala

Variate: meq_K_100g_soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.02049	0.01024	2.44	
Replicate.Treatment stratum					
Treatment	1	0.15005	0.15005	35.79	0.027
Residual	2	0.00839	0.00419	0.17	
Replicate.Treatment.Age stratum					
Age	2	0.00279	0.00139	0.06	0.947
Residual	1	0.02441	0.02441		
Total	8	0.20613			

Appendix 16: ANOVA for pH Shimabal

Variate: pH0_01CaCl

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.19007	0.09503	5.55	
Replicate.Treatment stratum					
Treatment	1	0.58320	0.58320	34.07	0.028
Residual	2	0.03423	0.01712	1.50	
Replicate.Treatment.Age stratum					
Age	2	0.80667	0.40333	35.28	0.118
Residual	1	0.01143	0.01143		
Total	8	1.62560			

Appendix 17: ANOVA for Aggregate stability Shimabala

Variate: Aggregate_size_stability

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replicate stratum	2	0.10328	0.05164	2.00	
Replicate.Treatment stratum					
Treatment	1	2.79898	2.79898	108.40	0.009
Residual	2	0.05164	0.02582	0.57	
Replicate.Treatment.Age stratum					
Age	2	0.02124	0.01062	0.24	0.824
Residual	1	0.04503	0.04503		
Total	8	3.02017			

Appendix 18: ANOVA for Bulk Density Shimabala

Variate: Bulk_Density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Treatment	1	0.006517	0.006517	4.59	0.069
Residual	7	0.009933	0.001419	0.54	
Replicate.Treatment stratum					
Treatment	1	0.037507	0.037507	14.20	0.013
Residual	5	0.013204	0.002641	0.31	
Replicate.Treatment.Age stratum					
Age	2	0.002640	0.001320	0.15	0.860
Residual	7	0.060191	0.008599		
Total	23	0.129992			

Appendix 19: ANOVA for Soil Organic carbon Kasisi

Variate: %SOC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.01140	0.00570	0.63	
Replicate.Treatment stratum					
Treatment	1	0.01960	0.01960	2.15	0.280
Residual	2	0.01820	0.00910	0.41	
Replicate.Treatment.Age stratum					
Age	3	0.09380	0.03127	1.41	0.392
Residual	3	0.06640	0.02213		

Total 11 0.20940

Appendix 20: ANOVA for Available Nitrogen Kasisi

Variate: Available_N

Source of variation d.f. s.s. m.s. v.r. F pr.

Replicate stratum 2 2581. 1290. 0.92

Replicate. Treatment stratum

Treatment 1 17074. 17074. 12.11 0.074

Residual 2 2820. 1410. 0.49

Replicate.Treatment.Age stratum

Age 3 52833. 17611. 6.07 0.086

Residual 3 8711. 2904.

Total 11 84019.

Appendix 21: ANOVA for Dry Matter Kasisi

Variate: Dry_matter_g

Source of variation d.f. s.s. m.s. v.r. F pr.

Replicate stratum 2 93.1 46.5 14.97

Replicate.Treatment stratum

Treatment 1 6.6 6.6 2.12 0.283

Residual 2 6.2 3.1 0.02

Replicate.Treatment.Age stratum

Age 3 162.8 54.3 0.41 0.760

Residual 3 400.2 133.4

Total 11 668.9

Appendix 22: ANOVA for Phosphorus Kasisi

Variate: P_mg_kg_soil

Source of variation d.f. s.s. m.s. v.r. F pr.

Replicate stratum 2 2.4704 1.2352 5.50

Replicate.Treatment stratum

Treatment 1 8.7257 8.7257 38.84 0.025

Residual 2 0.4493 0.2247 0.48

Replicate.Treatment.Age stratum

Age 3 1.3327 0.4442 0.94 0.519

Residual 3 1.4161 0.4720

Total 11 14.3942

Appendix 23: ANOVA for Total Nitrogen Kasisi

Variate: Total_N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.002744	0.001372	1.62	
Replicate.Treatment stratum					
Treatment	1	0.007056	0.007056	8.31	0.102
Residual	2	0.001699	0.000849	0.70	
Replicate.Treatment.Age stratum					
Age	3	0.006795	0.002265	1.86	0.312
Residual	3	0.003659	0.001220		
Total	11	0.021952			

Appendix 24: ANOVA for Potassium Kasisi

Variate: meq_K_100g_soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.00820	0.00410	1.33	
Replicate.Treatment stratum					
Treatment	1	0.23419	0.23419	75.87	0.013
Residual	2	0.00617	0.00309	0.21	
Replicate.Treatment.Age stratum					
Age	3	0.13297	0.04432	3.06	0.192
Residual	3	0.04350	0.01450		
Total	11	0.42504			

Appendix 25: ANOVA for pH Kasisi

Variate: pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.27972	0.13986	7.20	

Replicate. Treatment stratum

Treatment	1	6.21671	6.21671	320.13	0.003
Residual	2	0.03884	0.01942	0.46	

Replicate.Treatment.Age stratum

Age	3	0.75296	0.25099	5.94	0.089
Residual	3	0.12684	0.04228		
Total	11	7.41507			

Appendix 26: ANOVA for Bulk Density Kasisi

Variate: BD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	26	0.35705	0.01373	0.82	
REP.TRMTN stratum					
TRMTN	1	1.76186	1.76186	104.78	<.001
Residual	26	0.43720	0.01682		
Total	53	2.55611			