POTENTIAL OF *CASUARINA EQUISETIFOLIA* AND *MELIA VOLKENSII* TREE SPECIES IN IMPROVING SOIL FERTILITY IN KWALE AND KILIFI COUNTIES, KENYA

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ABSTRACT

Low soil fertility is a major biophysical root-cause of declining per capita land productivity in Kenya. In most parts of the country, soils are deficient in nitrogen, phosphorus and in some cases potassium. Trees are important in soil fertility enhancement as they offer an excellent opportunity for farmers to meet nutrient demand in agricultural systems. The aim of the study was to determine the potential of *Casuarina equisetifolia* and *Melia volkensii* tree species on soil fertility improvement in Kwale and Kilifi Counties, Kenya. The experiment was established on-farm in a randomized complete block design (RCBD) with three treatments: Casuarina, Melia and control with eight replicates arranged in 20 x 20 m tree plots. Soil samples were obtained in 2013, 2014, 2015 and 2016 from depths of 0 to 20 cm, 20 to 40 cm and 40 to 60 cm and analyzed for soil pH, Electro Conductivity; soil Carbon (C), total nitrogen (N), available phosphorus (P) and Potassium (K), Data was subjected to Analysis of Variance using R version 4.0.2 for windows. Results indicated that total N and P were higher in *C. equisetifolia* and *M. volkensii* plots compared to the control treatment; and total Carbon was higher in M. volkensii treatment. There was a gradual decline soil C across the assessment period which could be attributed to higher decomposition rates at the study sites. There was also a positive relationship between soil pH and soil P (r^2=0.128, 0.345, 0.327 for 2014, 2015 and 2016 respectively). The results indicated that *C. equisetifolia* and *M. volkensii* slightly enhanced soil fertility through increased N and P, which can be attributed to nitrogen fixation by *C. equisetifolia* through Frankia bacteria and nutrient recycling by *M. volkensii*. The findings from this study can be by researchers and extension officers for advising farmers engaged in *C. equisetifolia* and *M. volkensii* farming and for promotion of agroforestry using these tree species.

Key words: Soil fertility, Woodlots, nutrients, *Casuarina equisetifolia*, *Melia volkensii*

INTRODUCTION

Low soil fertility is a major factor limiting farm productivity in Kenya. In most parts of the country, soils are often deficient in nitrogen (N), phosphorus (P) and in some cases potassium (K) (Gicheru, 2012). Nitrogen is known to be the most limiting nutrient in most farming systems, since it is required by plants in large quantities. Low soil fertility has in many cases been as a result of nutrient depletion over time due to continuous cultivation and inadequate replenishment of soil nutrients. Soil nutrient depletion is considered the most severe bio-physical root cause of declining per capita food production in Sub-Saharan Africa (Drechsel *et al*., 2001). Nutrient depletion in soils adversely affects soil quality and reduces crop yield, and consequently poses a potential threat to global food security and agricultural sustainability (Tan *et al*., 2005).

The main factors contributing to nutrient depletion are losses of N and P through soil erosion by wind, water, crop harvest and leaching. Nutrient losses specifically due to erosion in soils in Africa have been reported to range from 10 to 45 kg of NPK per hectare per year (Muriu *et al*., 2005, Julio and Carlos, 2006 and Gicheru, 2012). Declining soil fertility in Kenya has led to reduced land productivity, thus land users are being encouraged to adopt soil improvement technologies (Muriu *et al*., 2005). Nutrient gains in soils in Africa are mainly through mineral fertilizer application, organic matter mineralization, nutrient deposition by precipitation and Biological Nitrogen Fixation (BNF). Biological Nitrogen Fixation is essential as it offers an excellent opportunity for drawing upon the vast reserve of atmospheric nitrogen in an inexpensive and environmentally sound manner

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(Islam and Adjesiwor, 2017 and Bohlool *et al*., 1992). The introduction of nitrogen-fixing and highly mycotrophic plant species is a promising way to increase soil fertility. Among nitrogen fixing species, exotic trees such as *Casuarina equisetifolia* are widespread in tropical and sub-tropical zones. These species are known to play an important role in symbiotic relationships with mycorrhizal fungi and Frankia bacteria (to cite source??). These microorganisms increase plant growth and development and also improve nutrient availability particularly N and P for the plant host, which in return benefit from plant carbohydrates (Kandioura *et al*., 2013).

Over two million hectares of *C. equisetifolia* plantations throughout the tropics provide several socio-economic, environmental and ecological services. Their fast growth, adaptability to a range of edaphic and climatic conditions, multiple end uses and the symbiotic nitrogen fixing ability, make them a highly preferred group of trees for farmers (Diagne *et al*., 2013). The amount of N fixed by actinorhizal trees is comparable to that fixed by legumes and their rhizobium symbionts, and can significantly contribute to N-economy of ecosystems (Kandioura *et al*., 2013). In this regard, *C. equisetifolia* can play a crucial role in improving soil fertility, as it is able to grow in nitrogen deficient soils, where other plants may not thrive. The use of *C. equisetifolia* as a means of replenishing N in the soil has been explored in other parts of the world due to its nitrogen fixing capability (Santi *et al.,* 2013). However, the amount of nutrients made available for crop uptake and its potential to increase crop yields in an agroforestry system and in pure stands after harvesting the trees is not known.

One of Kenya's indigenous species, Melia (*Melia volkensii)*, is also believed to improve soil fertility and crop yields in agroforestry systems through nutrient recycling (Juma, 2003). Studies however show contrasting results on its ability to increase crop yields through soil fertility enhancement. Studies conducted in Machakos show that crop yields under Melia agroforestry system were significantly depressed (Rao *et al*., 1998); while reports by Mulatya *et al*. (2002), indicate that Melia increased maize yields and attributed this to effective NPK cycling by the species.

The coastal region of Kenya, where both *C. equisetifolia* and *M. volkensii* are grown is often characterized by poor soils, which have contributed to low agricultural productivity leading to perennial food shortages (Mwangi *et al*., 2010). Farmers in this region often grow maize, which is highly vulnerable to harsh agro-ecological conditions, thus leading to massive losses. Farmers have in the recent past started practicing agroforestry using *C. equisetifolia* and *M. volkensii*. However, information on the potential of both *C. equisetifolia* and *M. volkensii* in improving soil fertility in Kenya is inadequate. This research aimed at evaluating the potential of *C. equisetifolia* and *M. volkensii* in improving soil fertility in Kwale and Kilifi Counties, Kenya.

MATERIALS AND METHODS

Study sites

The study was conducted in Kwale and Kilifi counties in Kenya (Figure 1). Kwale County has a total population of 649,931people and covers an area of 8,270.2 km^2 (KNBS, 2010). The population density is 79 per km^2 with 74.9 % of the population living below the poverty line. Kwale County has four major topographical features namely the coastal plain; the foot plateau, the coastal uplands and the Nyika plateau. It has a monsoon type of climate; hot and dry from January to April, while June to August is the coolest period of the year. Kwale County receives bimodal type of rainfall with short rains from October to December, and the long rains from April to June or July. The average temperature of the County is 24.2 ^{o}C and rainfall ranges between 400mm and 1,680 mm per annum. Key agricultural activities and industries pertain to fruit farming, where the main agricultural products are oranges, pawpaws, mangoes, and coconuts. Mixed farming is practiced throughout the county, and it is estimated that 22 % of the region's income is derived from cash crop farming (CRA, 2014).

Kilifi County covers an area of 12,245.90 km^2. The topography of the County is dominated by low-range sand-stone hills, and a terrain that generally slopes towards the sea. The county has 21 forests, cumulatively covering 246 km^2. The average annual rainfall ranges from 300mm in the hinterland parts of the County to 1,300 mm along the coastal belt. Based on the 2009 Kenya Population and Housing Census, the county had about 200,000 households and a population of 1,109,735, which accounted for 2.9 percent of the total Kenyan population (KNBS, 2010). The average precipitation of 900 mm and mean annual temperature of 27 °C hold great potential for agricultural development. Horticultural crops and vegetables such as chilies, brinjals, okra, onions and tomatoes can be cultivated along the Coastal plains. Staple food crops such as maize, rice, bananas, cow peas, green grams and beans also have potential (CRA, 2014).

Soil samples were collected from depths of 0 to 20 cm, 20 to 40 cm and 40 to 60 cm. The soil samples were stored in zip-lock bags to prevent contamination and further changes. Core samples were also obtained at the onset of the study for bulk density determination.

Figure 1: Map showing Kwale and Kilifi Counties in Coastal Kenya

Experimental design and Layout

The experiment was set in a Randomized Complete Block Design (RCBD) with eight replicates for each treatment, and 20 x 20 m^2 tree plots were established in 2013. The treatments were as follows: Control, which was under maize crop, Casuarina planted with crops, and Melia planted with crops.

Soil sampling

Baseline soil characterization was undertaken in 2013 with subsequent soil sampling conducted in 2014, 2015 and 2016 following compositing sampling design using a soil auger (Li, 2019). Four sampling points were randomly selected per plot using Y-sampling frame and samples for each depth thoroughly mixed to form a composite sample.

Soil analysis

The soil samples were air dried for 24 hour and pulverized to achieve homogeneity. The soil samples were then sieved with a 2 mm sieve to obtain a fine sample. Each soil sample was then divided into four equal parts from which diagonal parts were retained and the other two parts removed, referred to as quartering. This process was done several times until the successive quartering reduced the weight of the composite sample to 0.25 kg. The samples were then placed in zip-lock bags with clear identification. Soil samples were analyzed for the following components using standard analysis procedures: pH and Electro Conductivity values with glass electrode; total nitrogen was by kjeldahl method; available phosphorus by UV spectrophotometer method; and Potassium was determined using Atomic Absorption Spectrophotometer (Okalebo *et al*., 2002).

Data analysis

Data was analyzed through Analysis of Variance (ANOVA) using R Version 4.0.2 , 2020 for windows at 95 % confidence level. Means were separated using the Duncan's multiple comparisons test, (R Development CoreTeam, 2020).

RESULTS AND DISCUSSION

Baseline soil status

Table I shows the baseline soil status at the onset of the study in February 2013. For both sites, the baseline data shows that the soil in the study sites was deficient in Nitrogen (<0.09 %) and had moderate soil Carbon (<1.17 %). The soil pH ranged from slightly acidic to slightly alkaline (6.97 to 7.07) with low Electrical Conductivity (<0.03 mS/cm). The EC of soil is influenced by the concentration and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level. Generally, an EC <0.15 mS/cm will not affect plant growth (Apal, 2013). The available P concentration was low (<2.74 ppm) with moderate Potassium concentration (< 228.05 ppm). The soil had a mean bulk density of 1.34 g/cm^3, an indication that the soils were not compacted. Soil moisture content at the onset of the project was low (<5.4%).

TABLE I- BASELINE SOIL STATUS IN KWALE AND KILIFI COUNTIES

Site	pH	E.C mS/cm	% C	% N	C:N	P (ppm)	K (ppm)	BD (g/cm^3)
Kwale	7.1	0.08	0.85	0.08	10.6	2.74	228.1	1.33
Kilifi	6.9	0.03	1.17	0.09	13.0	1.11	132.1	1.34

Effect of *C. equisetifolia* and *M. volkensii* on soil Phosphorus and Potassium

Figure 2 shows the concentration of P on plots under *C. equisetifolia* and *M. volkensii* at different sampling periods and depths. The concentration of P decreased with depth along the soil profile. This can be attributed to P immobility in the soil. The diffusion rate of P to the root zone is about $^1/_8$ of an inch per year (Penn State University, 2013). Menzies (2009) also reported that in soil profiles, phosphorus is usually concentrated in the soil surface as a result of phosphorus cycling through vegetation and its deposits on the soil surface. *Casuarina equisetifolia* and *M. volkensii* woodlots recorded the highest concentration of soil P (Figure 2) than the control treatment. This could be attributed to P cycling by the two tree species (Menzies, 2009). There was gradual increase of soil P from 2014 to 2016, and concentration of available P increased with increasing age of the woodlots. In *C. equisetifolia* woodlots, there was 9.4% increase in P from 2014 to 2016 while in *M. volkensii* woodlots, there was 144.8% increase in soil P during the same period in the soil surface (0-20 cm depth).The high soil P in *Casuarina equisetifolia* woodlots can also be attributed to *C. equisetifolia* symbiotic relationship with mycorrhiza fungi that enhances P availability in the soil as reported by Wielderholt and Johnson (2005) and Kandioura *et al*. (2013). Plots under *M. volkensii* recorded the highest P concentration (Figure 2). This can be attributed to nutrient cycling by *M. volkensii* (Wielderholt and Johnson, 2005 and Menzies, 2009).

Generally, P was low in all treatments (<11 ppm). This can be attributed to high soil pH and the inherent parent material which are low in P. The form and availability of soil phosphorus is noted to be highly pH dependent and P is most available at a pH of about 6.5 with moist and warm conditions (Menzies, 2009). At lower soil pH, more iron and aluminium are available to form insoluble phosphate compounds and therefore hindering its availability while at high soil pH phosphorus can react with excess calcium to form unavailable compounds in the soil (Penn State University, 2013). There was a gradual increase in soil phosphorus with increasing pH towards the optimal range of 6.5 as shown in Figure 3 below. The increase in soil P was optimum at pH range of 6 to 7 (Figure 2). Soil pH significantly influenced soil phosphorus in 2015 and 2016 ($p=0.0015$ and $p=0.003$ respectively) as shown in Figure 3.

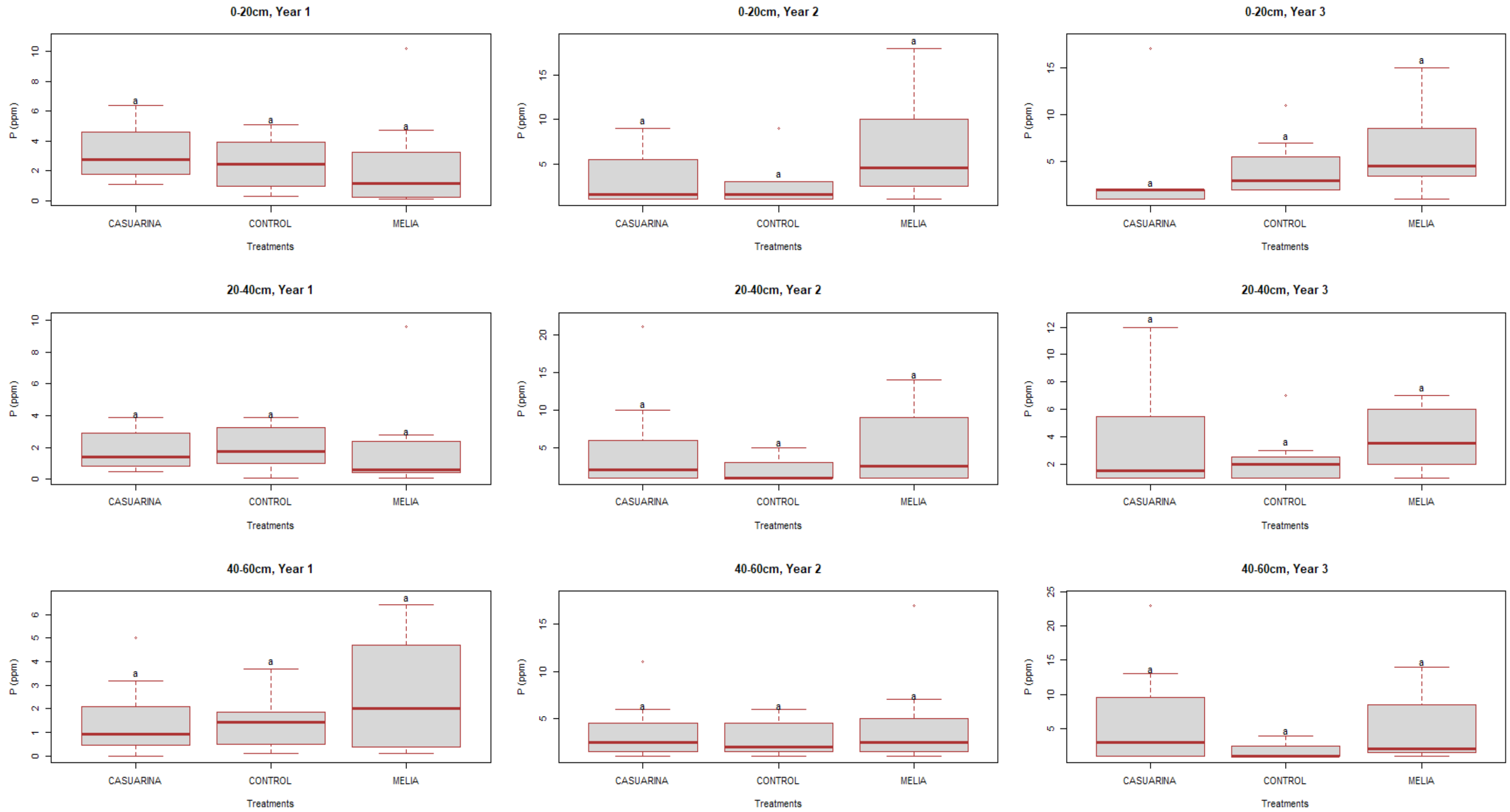

Figure 2: Soil Phosphorus under C. equisetifolia and M. volkensii at different sampling periods (2014-2016) and depths. NB: Treatment means denoted by the same letter are not significant at 95% confidence level according to Duncan's multiple comparison test.

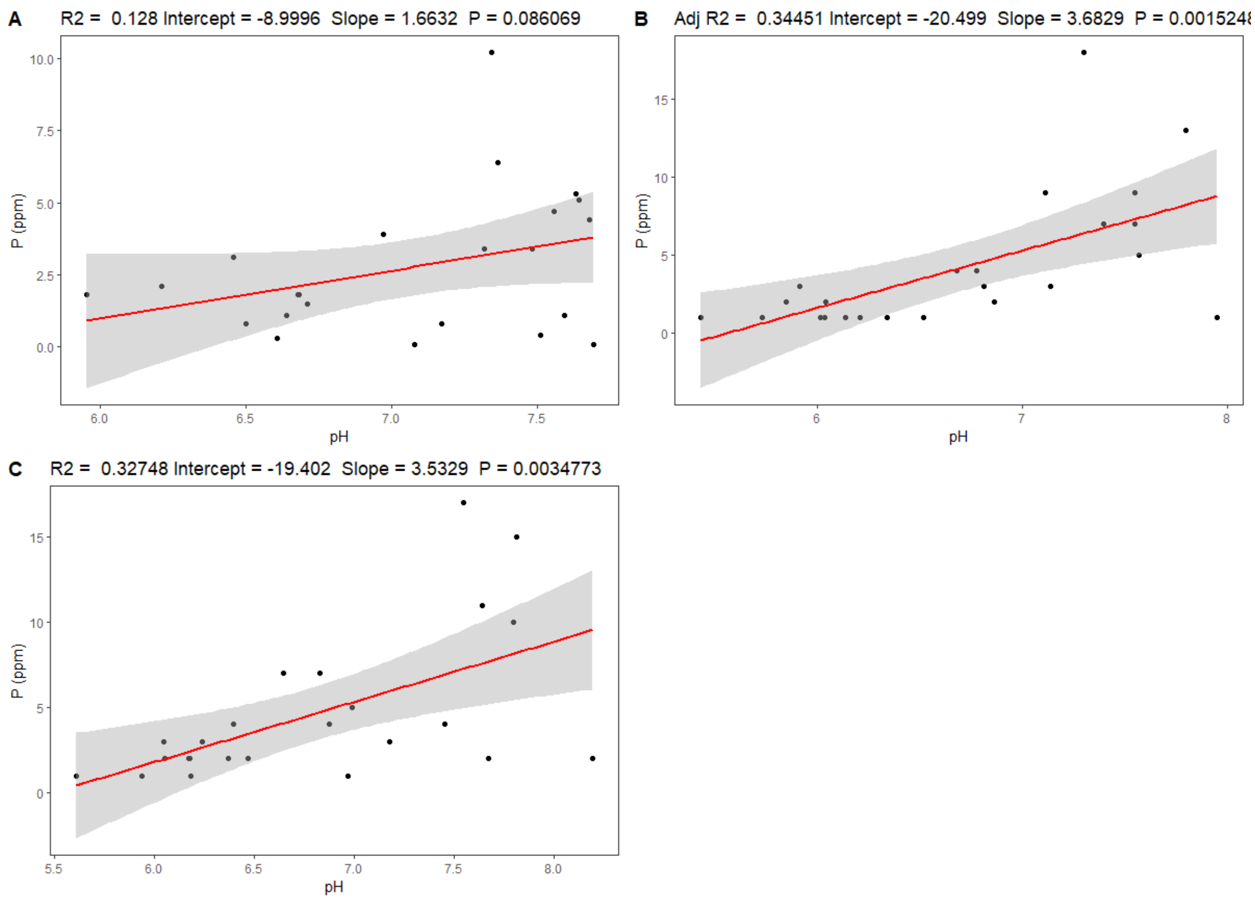

Figure 3: Relationship between soil pH and soil Phosphorus in 2014 (A), 2015 (B) and 2016 (C) at 0 to 20 cm sampling depth.

Phosphorus availability has been reported to increase in slightly acidic soils (NRCS, 2015). The limited solubility of P relates to its tendency to form a wide range of stable minerals in soil (McKenzie, 2003).This maximum solubility and plant availability of P at pH 6.5, declines as the pH increases into the alkaline range. This effect of reduced P availability in alkaline soil is driven by the reaction of P with calcium, with the lowest solubility of these calcium phosphate minerals at about pH 8 (Penn State University, 2013).

Potassium concentration was moderately high across all the treatments (Figure 4). Potassium has been reported to be less limiting in most of the farming systems (McKenzie, 2003). Potassium concentration decreased gradually in plots under *C. equisetifolia* 126.5ppm in 2014 to 110.21ppm in 2016; this was 12.9% decrease across the assessment period. There was however a gradual increase in soil potassium in *M. volkensii* woodlots from258.1ppm in 2014 to 263.5ppm in 2016 which was an increase of 2.1%. The gradual increase in K in *M. volkensii* woodlots plots could be attributed to increase in litter fall under the canopies of *M. volkensii* (Belsky *et al*. 1989, Mulatya *et al*., 2002 and Menzies, 2009). Similar studies have shown that various soil fertility indices including soil K were elevated in soils under various tree species (Belsky *et al*. 1989 and Cardelús *et al*., 2009).

Effect of *C. equisetifolia* and *M. volkensii* on soil Nitrogen (N) and Carbon (C)

Total nitrogen increased gradually in the plots under *C. equisetifolia* and *M. volkensii* during the sampling period (Figure 5). Total N on surface soil under *C. equisetifolia* increased from 0.113% in 2014 to 0.155% in 2016, an increase of 37.2% while in *M. volkensii* plots, it increased from 0.119% in 2014 to 0.225% in 2016, an increase of 89.1%. In 2014, there was a declined in Total N along the soil profile from 0 cm to 60 cm (Figure 5). This could be attributed to the availability of soil organic matter in the topsoil, which is mineralized by soil microorganisms to release N (Belsky *et al*., 1989 and Menzies, 2009). In 2015 and 2016, there was a gradual increase in Total N along the soil profile. The elevated Total N along the soil profile can be attributed to the leaching of soil N to deeper soil layers during the rainy season (Lehmann and Schroth, 2003). Total N was higher in *C. equisetifolia* and *M. volkensii* plots compared to the control treatment. This could be attributed to the ability of *C. equisetifolia* to fix N through its symbiotic relationship with Frankia bacteria as reported in earlier studies by Nambiar and Brown (1997) and Ye *et al*. (2012) and ability of Melia to cycle nutrients from deep soil layers (Mulatya *et al*., 2002,). Studies have shown that *C. equisetifolia* can fix up to 95 kg N per year (Kandioura *et al*., 2013). The genetic make-up of plants, plant age, physical and chemical properties of soil greatly influence the population of Frankia bacteria to fix nitrogen (Pawlowski and Sirrenberg, 2003) thus influencing N fixation by Frankia.

The mean C/N ratio across the various treatments was <25 as shown in Figure 6 below thus suitable for net mineralization (Masakazu and Tomohirio, 1993). Soil C/N ratio is a sensitive indicator of soil quality, and is often considered as a sign of soil nitrogen mineralization capacity. High soil C/N ratio can slow down the decomposition rate of organic matter and organic nitrogen by limiting the soil microbial activity ability, whereas low soil C/N ratio could accelerate the process of microbial decomposition of organic matter and nitrogen, leading to nutrient release (Shunfeng, 2013). Top soil (0-20cm) under *C. equisetioflia* recorded the lowest C/N ratio compared to *M. volkensii* plots and the control. This could be attributed to increase in N concentration through N fixation by Frankia bacteria and higher decomposition rate of *C. equisetifolia* (Kandioura *et al*., 2013 and Hata *et al.,* 2012). The higher decomposition rate of *C. equisetifolia* could have resulted to higher carbon losses to the atmosphere during decomposition thus reducing soil Carbon in the plots.

There was a decrease in Total carbon for all treatments across the assessment period and sampling depths (Figure 7). For soil under *C. equisetifolia*, total C declined by 66.9% while in *M. volkensii* plots, it declined by 66.4%. The decline soil C can be attributed to carbon loss as a result of decomposition (Onti and Schutle, 2012). Generally, soil under *M. volkensii* recorded higher C content than the control and *C. equisetifolia* treatments. According to Horneck *et al*. (2011), the amount of organic matter, which is a determinant of soil C in surface mineral soils, can vary from less than 1 % in coarse-textured, sandy soils to more than 5 % in fertile soils. The amount of organic C in the soil was highest at the A horizon, compared to the lower soil horizons; a similar observation was made by Onti and Schutle (2012).

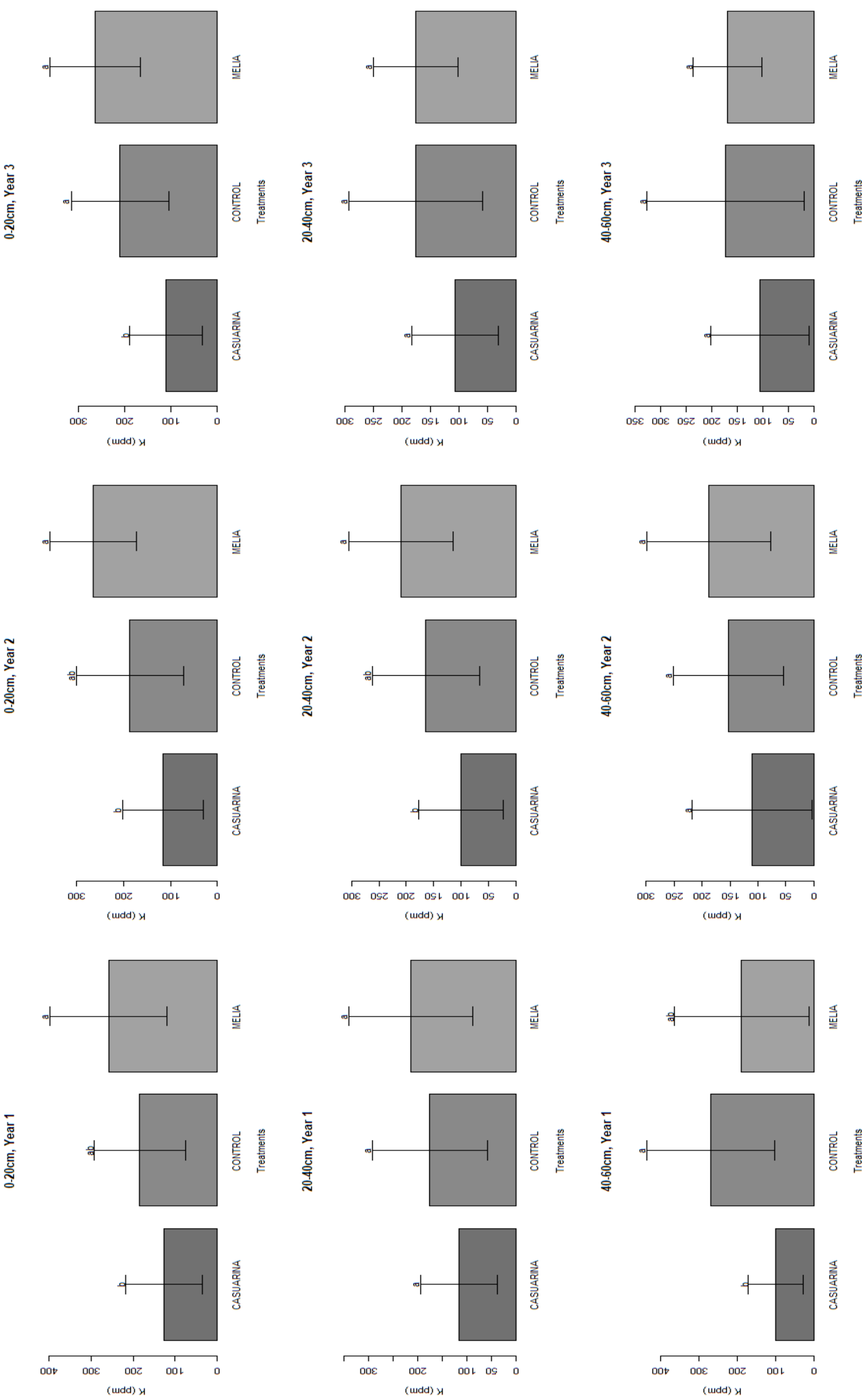

Figure 4: Soil Potassium under M. volkensii and *C. equisetifolia* at different sampling periods (2014-2016) and depths. NB: Treatment means denoted by the same letter are not significant at 95% confidence level according to Duncan's multiple comparison test.

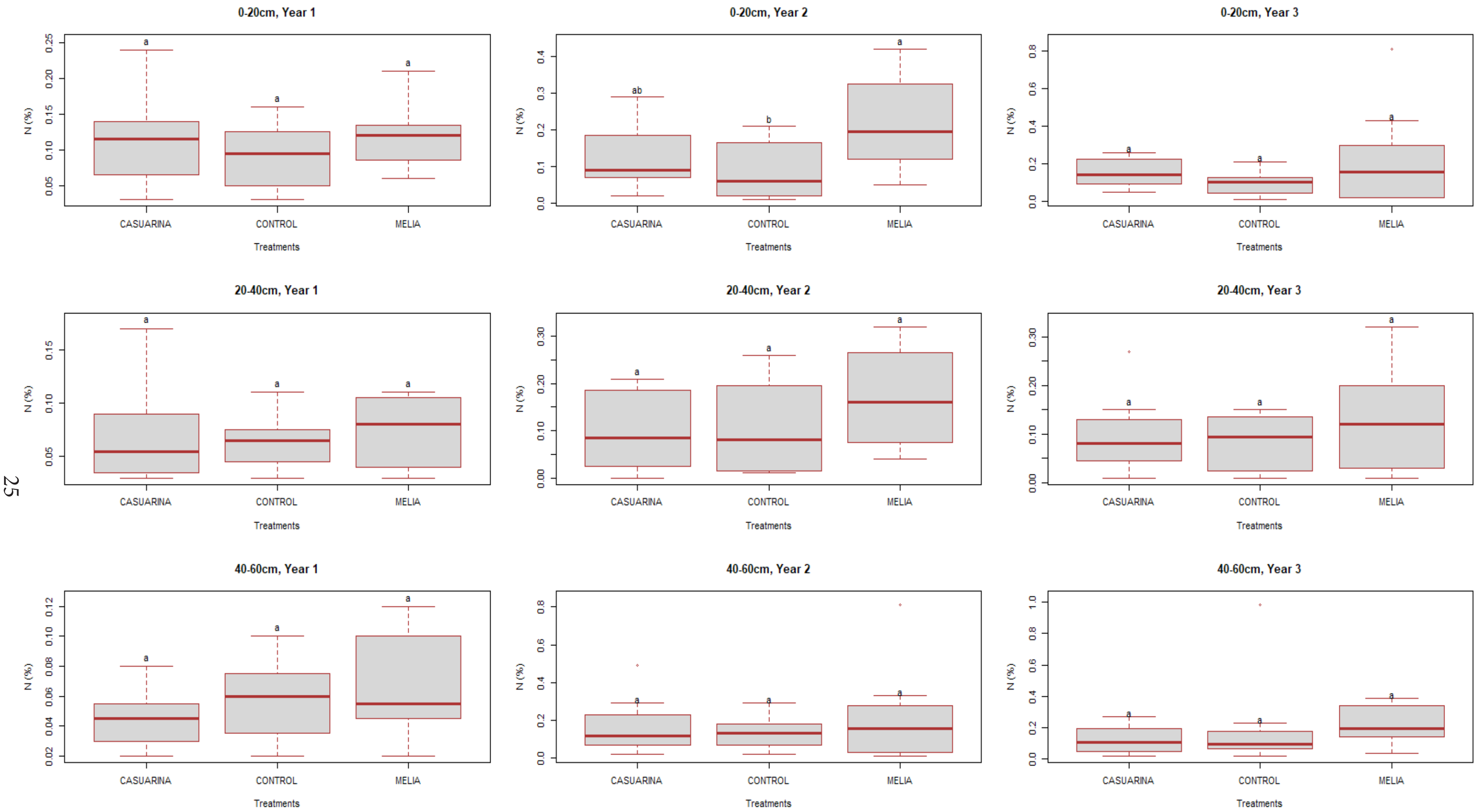

Figure 5: Soil nitrogen under *C. equisetifolia* and M. volkensii at different sampling periods (2014-2016) and depths. NB: Treatment means denoted by the same letter are not significant at 95% confidence level according to Duncan's multiple comparison test.

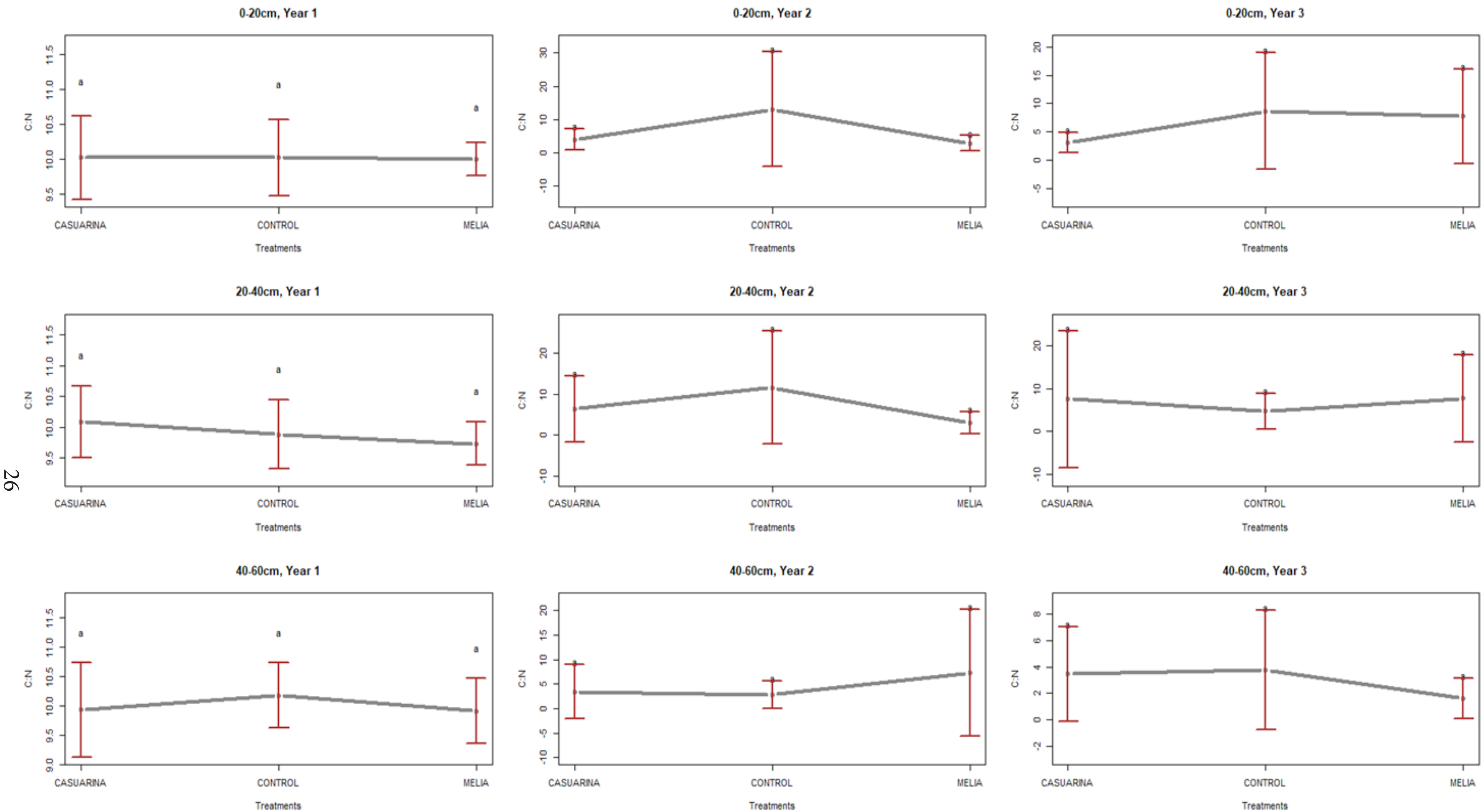

Figure 6: Soil nitrogen under *C. equisetifolia* and M. volkensii at different sampling periods (2014-2016) and depths. NB: Treatment means denoted by the same letter are not significant at 95% confidence level according to Duncan’s multiple comparison test.

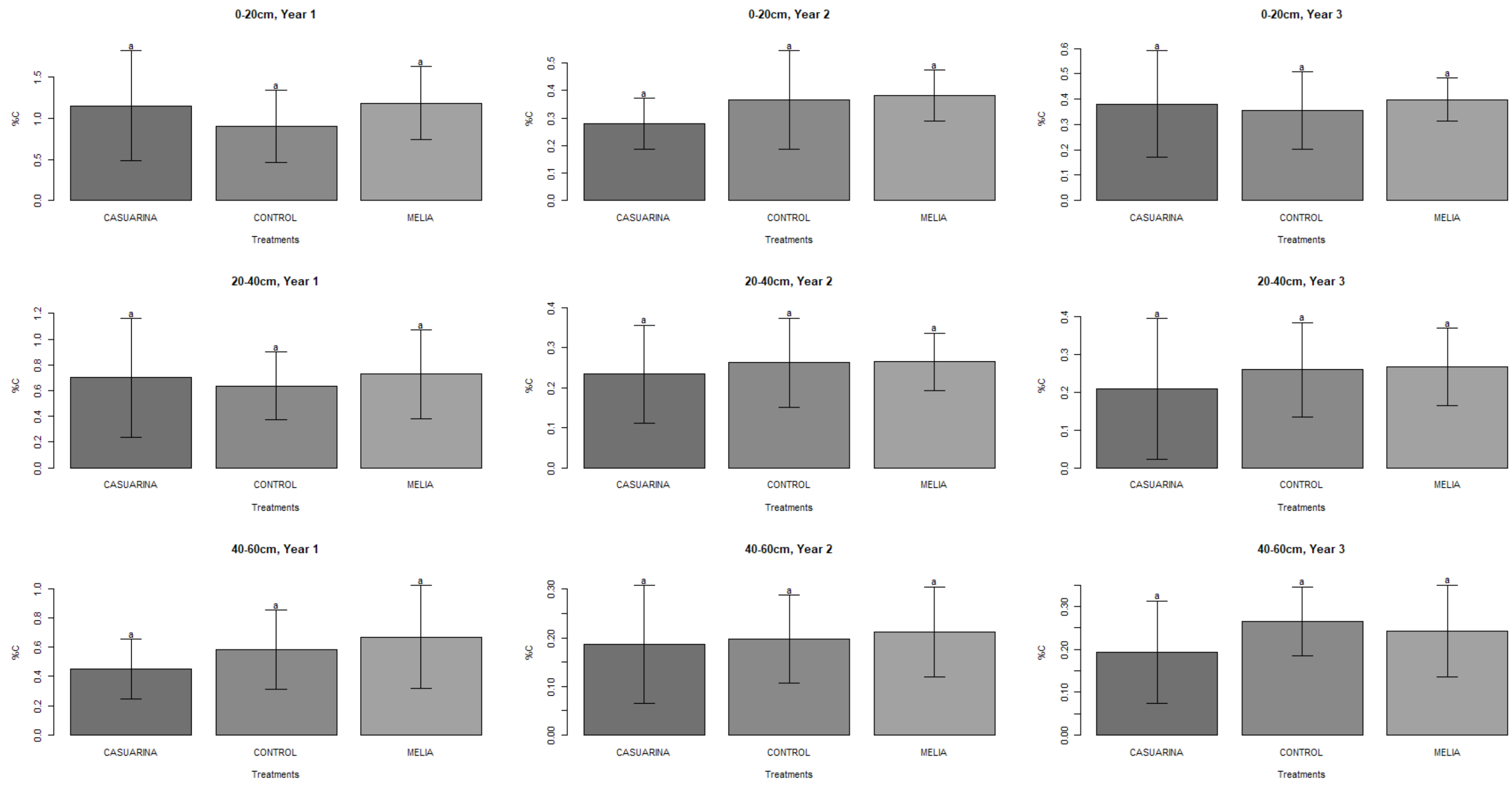

Figure 7: Soil Carbon under C. equisetifolia and M. volkensii at different sampling periods (2014-2016) and depths. NB: Treatment means denoted by the same letter are not significant at 95% confidence level according to Duncan's multiple comparison test.

The amount of Soil Organic Carbon (SOC) depends on soil texture, climate, vegetation, as well as historical and current land management. Soil texture affects SOC because of the stabilizing properties that clay has on organic matter. Soils with high clay content therefore tend to have higher SOC than soils with low clay content under similar land use and climatic conditions; this could explain the low Carbon content in the study sites which were dominated by sandy soils. Climate affects the amount SOC, as it is a major determinant of the rate of decomposition and therefore the turnover time of C in soils (Milne, 2012). The ability of soils to accumulate C is generally influenced by texture, where clay soils typically accumulate more C than sandy soils, and some management practices that influence soil C sequestration, particularly the use of trees in agricultural systems (Paudyal, 2003).

Effect of *Casuarina equisetifolia* and *Melia volkensii* on soil pH

Figure 7 below shows the effect of *C. equisetifolia* and *M. volkensii* on soil pH at different sampling depths and periods. There was no significant difference in soil pH among various treatments as shown below across the sampling periods. This contrary to findings by Habumugisha *et al.* (2019) who reported significant effects of trees on soil pH the mechanism under which trees affect soil pH is subject to further studies.

CONCLUSION AND RECOMMENDATIONS

The results indicate that *C. equisetifolia* and *M. volkensii* slightly improved soil fertility through increase of Phosphorus and Nitrogen. There was increase in soil P from 2014 to 2016 by 9.4% and 144.8% in *C. equisetifolia* and *M. volkensii* treatments respectively; soil N also increased by 37.2% and 89.1% in *C. equisetifolia* and *M. volkensii* respectively during the same assessment period. To fully understand the dynamics of soil nutrients under *C. equisetifolia* and *M. volkensii*, there is need to undertake the soil assessment for a long period of time and conduct litter decomposition experiments ascertain litter decomposition rates of the two tree species.

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