Influence of Duration of Agroforestry on Physico-Chemical Soil Quality Parameters in Machakos County, Kenya

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Abstract

The role of agroforestry in improving soil quality is well appreciated. However, there is debate as to how duration of agroforestry practice affects soil quality especially in the tropical region of Sub Saharan Africa where adoption of the practice is fairly recently. Therefore, objective this study was to investigate the influence of duration of agroforestry on physico-chemical soil quality parameters. The study was conducted using survey research design from a sample of 73 individual farmers, selected using stratified and random sampling. Soils were sampled from adopters and non adopters using soil auger. At least five sub-samples of soils were collected from each of the farmers and the soil mixed to get an integrated soil sample for analysis. The soil were packaged in two-kg khaki papers and taken to the laboratory for further physical attributes (sand, clay, silt and bulk density) and chemical analyses (pH, TN, TP, TOC, C/N and C/P). The exchangeable bases (K, Ca, Mg and Na) as well as micronutrients (Mn, Cu, Fe and Zn) were also analyzed. The results indicated that proportion of sand particles was significantly ($P < 0.05$) higher among non adopters compared to adopters while silt and bulk density was significantly ($P < 0.05$) higher among the adopters compared to the non adopters. Sand particle decreased with increasing duration of agroforestry adoption while proportion of silt and bulk density showed a significant increase in tandem to stand duration of agroforestry. The TN, TOC and C/P ratio was significantly ($P < 0.05$) higher among adopters and increased consistently with age of adoption, while C/N was higher among non adopters and decreased with increasing age of tree stand and duration of agroforestry. The trend in exchangeable bases and mineral contents in the soil were similar where higher concentrations occurred among adopters and displayed an increase with regard to length of adoption of agroforestry. The current study lends support to assertion that duration of agroforestry positively improves soil quality and therefore urges for mass adoption of the agroforestry practice to enhance increased agricultural productivity.

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1. Introduction

Agroforestry practices encompass an entire spectrum of land use systems in which woody perennials are deliberately combined with agricultural crops and/or animals in some spatial or temporal arrangement (Abbas *et al.*, 2017). The high productivity and sustainable land use makes adoption of agroforestry ubiquitous at the global scale (Dalemans *et al.*, 2018; McAdam & Curran, 2018; Fleming *et al.*, 2019). Agroforestry practices have demonstrated reducing or reversal of land degradation, sequestration of carbon from the atmosphere and securing rural livelihoods through provision of economic benefits mostly in rural areas (Catacutan *et al.*, 2017; Montagnini & Metzger, 2017; Waldron *et al.*, 2017; Saqib *et al.*, 2019). Agroforestry also provide ecosystem services and functions in addition to the products and services that motivate farmers to plant them (Kuyah *et al.*, 2017). These services are of particular importance in many low-income countries especially in Sub Saharan Africa, where large proportions of the populations work in an agricultural sector that does not attract much investment from either government or private sector (Meijer *et al.*, 2015; Benjamin & Sauer, 2018). As a result most of the new adopters of agroforestry reside in the tropical region of the world where conditions are favourable (Tscharntke *et al.*, 2011; Atangana *et al.*, 2013; 2014). Most of the adoption practices of agroforestry among smallholder farmers in Sub Saharan African occurred over the last five decades (Franzel *et al.*, 2001; Leakey *et al.*, 2005; Meijer *et al.*, 2015; Beyene *et al.*, 2019). Nevertheless, the exact duration of agroforestry adoption in the region remains largely unknown and therefore factors associated with adoption may vary widely.

While agroforestry can provide a number of environmental benefits, and play key roles in ecosystem services, there is also increasing focus of its effects on soil quality (Cardinael *et al.*, 2015; Weerasekara *et al.*, 2016; Udawatta *et al.*, 2017; Dollinger & Jose, 2018).

Proponents of agroforestry contend that soil conservation is one of its primary benefits (García de Jalón *et al.*, 2017; Sarminah *et al.*, 2018). In this case, the cover function involves reducing raindrop impact and wind action on soil particles by increasing soil cover through litter and pruning. The most widely held view is that trees in agroforestry systems can improve soil quality mainly by biological nitrogen (N) fixation and increasing the amounts of aboveground and belowground organic matter inputs (Isaac & Borden, 2019; Sarabia *et al.*, 2020). There are a number of benefits that are directly related to soil quality including preventing soil erosion through surface litter cover and under story vegetation (Akdemir *et al.*, 2016; Béliveau *et al.*, 2017), improving water infiltration (Sahin *et al.*, 2016), increasing soil moisture (Cardinael *et al.*, 2017; Feliciano *et al.*, 2018), maintaining soil fertility (Liu *et al.*, 2018), enhancing water dynamics (Ling *et al.*, 2017; Hasselquist *et al.*, 2018), conserving soil biodiversity (Torralba *et al.*, 2016), improving soil microbial biomass (Buyer *et al.*, 2017) and mitigation of climate change by carbon sequestration (Newaj *et al.*, 2016; Hasselquist *et al.*, 2018). To understand the dynamics of the impacts of agroforestry on soil requires an understanding of the soil quality parameters.

Soil's capacity to sustain biological productivity can be estimated by the evaluation of physical, chemical and biological parameters (Bünemann *et al.*, 2018). Trees in agroforestry improve soil quality by fixing atmospheric N₂ which ultimately increase soil Nitrogen content (Nasielski *et al.*, 2015; Bayala *et al.*, 2018). Through root system accumulation and litter fall, agroforestry trees concentrates nutrients near the soil surface (Solanki & Arora, 2015; Bhatt *et al.*, 2017). Trees may also enhance above and below ground microclimate (Desta *et al.*, 2018; Kar *et al.*, 2019), while mesofauna and microfauna and microflora around plant roots may alter soil chemical, biological, and physical properties (Bhaduri *et al.*, 2017; Lenci *et al.*, 2018).

In Sub Saharan African, there is a large body of literature which describe the effects of agroforestry on soils and all have highlighted that agroforestry practices could effectively improve soil physical, chemical and biological properties and maintain long-term land productivity (Githae *et al.*, 2011; Lagerlöf *et al.*, 2014; Bayala *et al.*, 2018; Corbeels *et al.*, 2019). Although the beneficial effects of agroforestry on soil quality is overwhelming, it is still not clear the impact of stand age and duration of agroforestry on soil nutrient dynamics under the influence of agroforestry systems. Therefore, the objective of this study was to determine how duration of agroforestry adoption affects soil nutrient dynamics in the Sub Saharan soils, Machakos County in Kenya.

2. Methods

2.1 Study Area

The study was conducted in Machakos County (Figure 1) which covers an area of 5,953 km². It lies between latitudes 0°45'South and 1°31'South and longitudes 36°45'East and 37°45'East. Most of the land is semi-arid with population of 1,098,584 as per the 2009 Kenya National census (Kenya National Bureau of Statistics, 2010). Administratively the county is divided into 11 divisions: Kalama, Kangundo, Kathiani, Machakos Central, Masinga, Matungulu, Mavoko, Mwala, Ndithini, Yathui and Yatta. In terms of political structure, the county has eight constituencies including: Kangundo, Kathiani, Machakos Town, Masinga, Matungulu, Mavoko, Mwala and Yatta. There are overlaps between divisions and constituencies were they are in most cases referred to as sub counties. Among the division and constituencies, Kathiani, Mavoko and Machakos Town practice agroforestry. Four sites where agroforestry are practiced included: Mua (Mavoko, Machakos Town and Kathiani) and

Iveti Hills (Machakos Central and Kathiani), Kima-Kimwe and Kalama in Machakos Constituency.

Figure 1: Map of Machakos County showing the study area

The local climate is semi-arid with hilly terrain and an altitude of 1000 to 2100 metres above sea level. The area is composed of hilltops rising to 1594-2100 m above sea level. The annual average rainfall is 1000 mm (range, 500 mm to 1300 mm), and is bimodal; short rains occur in October to December and long rains in March to May. Temperatures range between 18.7°C and 29.7°C. The soils are well drained shallow dark red volcanic on hilltops and clay soils in the plains. Irrigation farming is practiced utilizing the permanent rivers and streams that flow from the hilltop catchment areas towards South Eastern to join Athi River. Crop such as maize, beans, pigeon peas, vegetables are dominant. Dairy and beef cattle, sheep, and goats are the major livestock kept.

2.2 Soil sampling, data and statistical analysis

Soils were sampled from adopters and non adopters using soil auger. At least five sub-samples of soil were collected from each of the farmers and the soil mixed to get an integrated soil sample for analysis. The soil were packaged in two-kg khaki papers and taken to the laboratory for further analyses.

Bulk density measurements were made in triplicate in each study plot using coring devices (42.2 mm diameter polyvinyl chloride PVC tubes) carefully driven into the soil to avoid compaction. Bulk density was calculated from oven-dried soil core weight and volume. Soil structure was determined by visual inspection.

Soil samples were collected from seventy three farmers for both adopter and non-adopter farms for physico-chemical characteristics and soil fertility test for N, P, K, Ca, Mg and micro-nutrients which was done at Kenyatta University Laboratory and Kenya Agricultural and Livestock Research Organization (KALRO) laboratory at Machakos and Nairobi Kabete laboratories. Secondary sources, on the other hand, involved retrieving information from desk research where journals, books and other relevant literature were obtained.

Difference in soil parameters between the adopters and non adopters was determined *t*-test. All analyses were declared significant at $P < 0.05$.

3. Results and Discussion

3.1 Physical attributes of the soils

The physical attributes of the soil sampled between farmers practicing agroforestry and those not practising were determined as shown in Table 1.

Table 1: Physical attributes of the soil between farmers practicing and those not practising agroforestry

Age of adoption	Sand	Clay	Silt	Bulk density
0 (Non adopter)	62.15 ± 0.69	28.52 ± 0.23	9.13 ± 0.58	10.36 ± 0.22
1-5	60.75 ± 0.99	28.59 ± 0.26	10.42 ± 1.14	10.47 ± 0.17
6-10	60.41 ± 1.37	28.47 ± 0.24	11.08 ± 1.53	10.39 ± 0.11
11-20	58.99 ± 1.11	28.49 ± 0.20	11.45 ± 2.13	10.58 ± 0.13
>20	57.15 ± 0.67	28.53 ± 0.19	13.71 ± 2.28	10.76 ± 0.18
ANOVA				
F	50.598	0.494	13.577	13.634
df	4	4	4	4
P	0.0000	0.7403	0.0000	0.0000

Sandy particles proportion in the soil ranged from 56% to 63.2% among adopters and 61.2% to 63.2% for the non adopters of agroforestry. Based on the age and duration of agroforestry adoption, the proportion of sand on agroforestry adopters for 1-5 years was 60.75 ± 0.99%, 60.41 ± 1.37%, for those with 6-10 years adoption, 58.99 ± 1.11% among farmers with 11-20 years of agroforestry practice and 58.99 ± 1.11% for farmers with 20 years practice of agroforestry. Further statistical analysis indicated that there were significant differences in percentage of sand based on the duration of agroforestry practice ($P < 0.05$). Generally the proportion of sand particles was higher among non adopters compared to adopters of agroforestry and decreased in proportion with duration of agroforestry adoption and practise (Figure 2). The present studies indicate that agroforestry resulted in reduced proportion of sand in the soil which concurs with other studies (Pandey *et al.*, 2000; Puttaso *et al.*, 2011; Bhatt *et al.*, 2017; Cardinael *et al.*, 2017; Hewins *et al.*, 2017). The decrease in sand particles

could probably be due to the fact that the agroforestry tree species adopted contributed to the process of leaf litter and soil microbes helped in decomposition and may therefore result in reduction of sandy particles (Weerasekara *et al.*, 2016). Agroforestry also increase soil organic matter which increases the proportion of silt and other organic debris in the soil at the expense of sand particles (Weerasekara *et al.*, 2016).

Figure 2: Physical attributes of the soil sampled among farmers with different durations of agroforestry adoption

The percentage of clay in the soil ranged from 28.2-28.98% in soils practicing agroforestry while those that were not, the proportion of clay particle were 28.2-28.9%. Generally the percentage of clay where agroforestry is practiced for 1-5, 6-10, 11-20 and over 20 years did not change substantially between 28.59 to 28.9%. Subjected to further analysis, the results indicated that there was no differences in the clay particles between agroforestry adopters and non adopters ($P > 0.05$) regardless duration of agroforestry practice which concurs with other studies (Alfaia, 2004; Alam *et al.*, 2010; Akdemir *et al.*, 2016) probably due to the overall

nature of the soil being in semi arid landscape and may also be related to the inability of the tree litter to add much clay to the existing soils. Clay soil are result of microbial degradation of the soil and organic matter particles (Cardinael *et al.*, 2017) which was not possible under the condition of the soils in Machakos County.

The percentage of silt in the soil ranged from 8.6-15.9% in soils with agroforestry practices but in soil without any agroforestry practice, the proportion of silt was 7.7-9.7%. The percentage of silt among framers with 1-5 years agroforestry practice was $9.13 \pm 0.58\%$, those with 6-10 years practice it was $11.08 \pm 1.53\%$, then for farmers with 11-20 years of agroforestry practice it was $11.45 \pm 2.13\%$ while those with 20 years of agroforestry practice the percent was $13.71 \pm 2.28\%$. Further statistical analysis indicated that there was a significant difference in percentage of silt based on the duration of agroforestry practice ($P < 0.05$). These results indicate that the proportion of silt was significantly higher among the adopters compared to the non adopters and increased with increasing age and duration of agroforestry adoption. Increased proportion of silt in soil where agroforestry is practiced has been widely reported (Li *et al.*, 2015; Bhaduri *et al.*, 2017; Deng *et al.*, 2017; Dhaliwal *et al.*, 2019). Silt particles are formed due to decomposition of soil organic matter, allochthonous organic matter as well as soil microbial and biochemical processes (Hassink, 1997; Paul, 2016) which appears to originate from the agroforestry trees and thus agroforestry appears to improve the silt content of the soil, which was confirmed by the increasing silt with age and duration of agroforestry adoption.

The bulk density in the soil ranged from 10.18-11.00 kg/m³ in soils where agroforestry was practiced but in soil without any agroforestry practice, the bulk density was 10.1.-10.8 kg/m³. The bulk density in soils for farmers with 1-5 years agroforestry practice was 10.47 ± 0.17

kg/m³, those with 6-10 years practice it was 10.39 ± 0.11 kg/m³, then among farmers with 11-20 years of agroforestry practice it was 10.58 ± 0.13 kg/m³ and those with 20 years of agroforestry practice the percent was 10.76 ± 0.18 kg/m³. Further statistical analysis indicates that there was a significant difference in bulk density based on the duration of agroforestry practice ($P < 0.05$). Bulk density in the soil was higher among the adopters as compared to the non adopters and increased with increasing duration of agroforestry adoption. These studies concurs with those of those of (Udawatta & Anderson, 2008; Udawatta *et al.*, 2009; Gama-Rodrigues *et al.*, 2010; Silva *et al.*, 2011; Chaudhari *et al.*, 2013) who showed a significant increase in soil bulk density associated with agroforestry practices. The increase in bulk density in the soil could be due to increased compaction of the soil (Hairiah *et al.*, 2006), addition of organic matters from decomposition leaves (Udawatta *et al.*, 2006) and wood debris in the soil. However, the current results differed from those by (Throop *et al.*, 2012) who showed no differences in the bulk density between agroforestry adopters and non adopters. The authors did not provide any explanation and thus it is not clear why the current results differ from those of these authors.

3.2 Chemical composition of the soils

The pH, and concentration of TN, TP, TOC, C/N and C/P ratios in the soils between farmers with different duration of agroforestry adoption in Machakos County are provided in Table 2.

Table 2: Chemical composition in the soils between farmers with different duration of agroforestry adoption in Machakos County

Age of adoption	pH	TN	TP	TOC	C/N	C/P
0	6.33 ± 0.34	0.04 ± 0.01	83.83 ± 21.95	1.09 ± 0.25	12.06± 3.57	0.01± 0.01
1-5	6.26 ± 0.29	0.14 ± 0.04	77.61 ± 24.21	1.50 ± 0.25	9.95± 2.40	0.02± 0.01
6-10	6.02 ± 0.31	0.14 ± 0.05	67.47 ± 29.04	1.61 ± 0.30	9.23± 1.60	0.02± 0.01
11-20	6.06 ± 0.27	0.19 ± 0.03	74.91 ± 19.21	1.97 ± 0.25	9.31± 1.74	0.03± 0.01
>20	6.28 ± 0.39	0.26 ± 0.05	82.00 ± 21.82	2.26 ± 0.32	8.08± 1.73	0.03± 0.01
ANOVA						
F	2.2145	30.673	1.6423	3.951	5.4453	7.1121
df	4	4	4	4	4	4
P	0.1342	0.0003	0.2373	0.0000	0.0237	0.0071

The pH of the soil ranged from 5.42-6.80 in agroforestry soils but was 5.53-6.82 in soil without agroforestry practice. The pH in soils where agroforestry was being practiced for 1-5 years was 6.26 ± 0.29 , those with 6-10 years practice it was 6.02 ± 0.31 , for 11-20 years of agroforestry practice it was 6.06 ± 0.27 and those with 20 years of agroforestry practice the percent was 6.28 ± 0.39 . Statistical analysis indicates that there was no a significant difference in pH based on the duration of agroforestry practice ($P > 0.05$). This indicates similarity in the soil pH between the adopters and non adopters, which concurs with several studies (Behera *et al.*, 2015; Singh, 2016; Rocha Junior *et al.*, 2018; Sousa Neto *et al.*, 2018; Yu, 2018). The lack of differences in pH may be attributed to the soil geology being over similar pH ranges and most trees planted rarely affect soil pH. The planting of trees did not use lime or fertilizers that may affect the soil pH and therefore may be the reason for the

observed similarity in the soil pH between agroforestry adopters and agroforestry non adopters.

The TN of the soil ranged from 0.07-0.30 ppm in agroforestry soils but was 0.02-0.07 in soil without any agroforestry practice. The TN in soils for farmers with 1-5 years agroforestry practice was 0.14 ± 0.04 ppm, those with 6-10 years practice it was 0.14 ± 0.05 ppm, among farmers with 11-20 years of agroforestry practice it was 0.19 ± 0.03 ppm and those with 20 years of agroforestry practice the percent was 0.26 ± 0.05 ppm. Further statistical analysis indicated that there was a significant difference in TN based on the duration of agroforestry practice ($P < 0.05$). The results show that the proportion of TN was significantly higher among the adopters compared to the non adopters and increased with increasing age and duration of agroforestry adoption (Figure 3). Increased proportion of TN in soil has been reported to occur in soils with long history of agroforestry (Lu *et al.*, 2015; Gurmessa *et al.*, 2016; Kim *et al.*, 2016; Weerasekara *et al.*, 2016; Atapattu *et al.*, 2017). Total Nitrogen in soil increased due to decomposition of leaves, use of nitrogenous fertilizers during planting of vegetables and autochthonous organic matter within the agroforestry practice complex. These results indicate that long term practice of agroforestry therefore increased nitrogen in the soil through nitrification and microbial breakdown of the leaves.

Figure 3: Variation in pH, and concentration of TN, TP, TOC, C/N and C/P ratios in the soils among farmers with different durations of agroforestry adoption

The TP of the soil ranged from 8-125.4 ppm in agroforestry soils but was 50.03-122.7 ppm in soil without any agroforestry practice. The TP in soils for farmers with 1-5 years agroforestry practice was 77.61 ± 24.21 ppm, those with 6-10 years practice it was 67.47 ± 29.04 ppm, for farmers with 11-20 years of agroforestry practice it was 74.91 ± 19.21 ppm and those with 20 years of agroforestry practice the percent was 82.00 ± 21.82 ppm. Further statistical analysis indicates that there was no significant difference in TP based on the duration of agroforestry practice ($P > 0.05$). These results indicate a similarity of TP between the adopters compared to the non adopters and showed no significant change with age and duration of agroforestry adoption. Similarity in the TP in the soils between adopters and non adopters of agroforestry could be due to lack of any phosphate fertilizers during cropping system. Leaves of the trees also rarely contribute to any TP addition in the soils, beside the soil could be low in phosphorus content as reported for several tropical soils (Roy *et al.*, 2016; Maranguit *et al.*, 2017; Meyer *et al.*, 2018).

The TOC of the soil ranged from 0.98-2.60 ppm in agroforestry soils but was lower at 0.69-1.64 ppm in soil without any agroforestry practice. The TOC in soils for farmers with 1-5 years agroforestry practice was 1.50 ± 0.25 ppm, those with 6-10 years practice it was 1.61 ± 0.30 ppm, then among farmers with 11-20 years of agroforestry practice it was 1.97 ± 0.25 ppm and those with 20 years of agroforestry practice the percent was 2.26 ± 0.32 ppm. Further statistical analysis indicates that there was a significant difference of TOC based on the duration of agroforestry practice ($P < 0.05$). The concentration of TOC was also determined to increase significantly with age of agroforestry adoption. Higher concentration of TOC in soils where agroforestry is practiced has been reported in several studies (Benbi *et al.*, 2015; Bhaduri *et al.*, 2017; Bayala *et al.*, 2018; Lim *et al.*, 2018). Trees have extensive root systems which can grow deep into the mineral soil. The root-derived C inputs are critical

sources for the SOC pool in deeper soil horizons (Shi *et al.*, 2013). Specifically, root-derived carbon (C) is more likely to be stabilized in the soil by physico-chemical interactions with soil particles than shoot-derived C (Kukul & Bawa, 2014). Similarly, in croplands, total root derived C contributed between 1.5 times to more than 3 times more C to SOC than shoot-derived C (Johnson *et al.*, 2006). Thus, agroforestry systems store more C in deeper soil layers near trees than away from trees (Nair *et al.*, 2015).

The C/N ratio of the soil ranged from 4.66-14.32 ppm in agroforestry soils but was 6.39-17.16 ppm in soil without any agroforestry practice. The C/N in soils for farmers with 1-5 years agroforestry practice was 9.95 ± 2.40 ppm, those with 6-10 years practice it was 9.23 ± 1.60 ppm, then among farmers with 11-20 years of agroforestry practice it was 9.31 ± 1.74 ppm and those with 20 years of agroforestry practice the range was 8.08 ± 1.73 ppm. Further statistical analysis indicates that there was a significant difference in C/N based on the duration of agroforestry practice ($P < 0.05$). The concentration of C/N decreases significantly with age and duration of agroforestry adoption. The current results suggest that the net increase in carbon in the soil was less than the net increase in Nitrogen in the soil after long period of agroforestry practice. Higher concentration of Nitrogen relative to carbon in soils where agroforestry is practiced has been reported in several studies (Benbi *et al.*, 2015; Bhaduri *et al.*, 2017; Bayala *et al.*, 2018; Lim *et al.*, 2018). The accumulation of nitrogen in the soil may be added by leaf litter decomposition in addition to inorganic and organic fertilizers used during cultivation of food crops and therefore it is likely to increase at higher accumulation than nitrogen over a long period of time. The resulting enhanced tree and crop plant growth by subsequent increase in nitrogen (N) nutrition may result in an increase in SOC sequestration (Ziter & MacDougall, 2013). Similar, mixed plantings with N-fixing trees may cause higher biomass production and, thus, SOC sequestration and pools particularly in

deeper soil horizons as N may promote humification rather than decay. Also, changes in microbial decomposer community composition under N-fixing trees may result in greater retention of relatively stable SOC (Prescott, 2002). Aside from deep soil C inputs, another reason for the promotion of C sequestration in agroforestry systems is that tree roots have the potential to recover nutrients from below the crop rooting zone.

The C/P ratio of the soil ranged from 0.01-0.04 ppm in agroforestry soils but was 0.01-0.03 ppm in soil without any agroforestry practice. The C/P ratio in soils for farmers with 1-5 years agroforestry practice was 0.01 ± 0.01 ppm, those with 6-10 years practice it was 0.02 ± 0.01 ppm, then among farmers with 11-20 years of agroforestry practice it was 0.02 ± 0.01 ppm and those with 20 years of agroforestry practice the percent was 0.03 ± 0.01 ppm. Further statistical analysis indicates that there was a significant difference in C/P ratio based on the duration of agroforestry practice ($P < 0.05$). The results show that the proportion of C/P was significantly higher among the adopters compared to the non adopters and increased with increasing age of adoption. Increased proportion of C/P in soil has been reported to occur in soils where agroforestry is practiced (Lu *et al.*, 2015; GurMESSA *et al.*, 2016; Kim *et al.*, 2016; Atapattu *et al.*, 2017; Bhatt *et al.*, 2017). These results suggest that carbon accumulation in the soil increased at a higher rate than phosphorus. The low rate of TP accumulation in the soils could be due to lack of any phosphate fertilizers during cropping system. Leaves of the trees also rarely contribute to any TP addition in the soils, beside the soil could be low in phosphorus content as reported for several tropical soils (Roy *et al.*, 2016; Maranguit *et al.*, 2017; Meyer *et al.*, 2018).

3.3 Exchangeable bases in the soil

The concentration of exchangeable bases in the soils between the adopters and non adopters in Machakos County is shown in Table 3.

Table 3: Concentration of exchangeable bases in the soils between the adopters and non adopters in Machakos County

Age of adoption	Potassium	Calcium	Magnesium	Sodium
0	0.96 ± 0.14	3.27 ± 1.05	5.91 ± 0.29	2.57 ± 0.82
1-5	1.16 ± 0.14	3.39 ± 1.17	5.82 ± 0.21	2.88 ± 0.93
6-10	0.89 ± 0.14	3.58 ± 1.32	6.37 ± 0.24	2.52 ± 0.57
11-20	1.16 ± 0.10	3.99 ± 1.00	5.93 ± 0.35	2.68 ± 0.74
>20	1.02 ± 0.13	4.02 ± 0.46	6.08 ± 0.51	3.51 ± 0.89
ANOVA				
F	8.674	13.455	13.423	7.951
df	4	4	4	4
P	0.00242	0.0001	0.0001	0.0007

The concentration of potassium in the soil ranged from 1.02-1.32 ppm in soil practising while in soils without such practices, potassium ranged from 0.83.-0.97 ppm. The potassium concentration in soils for farmers with 1-5 years agroforestry practice was 1.16 ± 0.14 ppm, those with 6-10 years practice it was 0.89 ± 0.14 ppm, then among farmers with 11-20 years of agroforestry practice it was 1.16 ± 0.10 ppm and those with 20 years of agroforestry practice the range was 1.02 ± 0.13 ppm. Further statistical analysis indicates that there was a significant difference in potassium based on the duration of agroforestry practice ($P < 0.05$).

The concentration of potassium in soils was higher among the adopters as compared to the non adopters and exhibited an increasing trend with increasing duration of agroforestry adoption (Figure 4). Higher potassium in soils practicing agroforestry has been reported in several other studies (Islam & Weil, 2000; Celik, 2005; Lang *et al.*, 2016; Atapattu *et al.*, 2017; Mulyono *et al.*, 2019). Higher available potassium in tree based systems may be due to nutrient rich litter of trees, which may have contributed to higher amount of potassium returned back to the soil in the form of litter (Clark *et al.*, 1998). The increased potassium in soils could also be due to decomposition of organic matter in soil which is higher in soils practising agroforestry.

Figure 4: Variation in concentration of exchangeable bases in the soils among farmers with different durations of agroforestry adoption.

The calcium in the soil ranged from 2.8-5.4 ppm in soils where agroforestry was practiced but in soil without any agroforestry practice it was 2.5 to 3.2 ppm. The calcium concentration

in the soils for farmers with 1-5 years agroforestry practice was 3.39 ± 1.17 ppm, those with 6-10 years practice it was 3.58 ± 1.32 ppm, then among farmers with 11-20 years of agroforestry practice it was 3.99 ± 1.00 ppm and those with 20 years of agroforestry practice the range was 4.02 ± 0.46 . Further statistical analysis indicates that there was a significant difference in Calcium based on the duration of agroforestry practice ($P < 0.05$). Concentration of calcium in the soil was higher among the adopters as compared to the non adopters and increased with increasing duration of agroforestry adoption. Increasing calcium in soils due to agroforestry has been reported in several studies (Behera & Shukla, 2015; Ngo-Mbogba *et al.*, 2015; Sharma *et al.*, 2016; Prakash *et al.*, 2018; Mulyono *et al.*, 2019). The increase in calcium in the soil could be due to addition of soil additives such as lime during tillage operation.

The magnesium in the soil was low in soils devoid of agroforestry practices (5.72.-5.99 ppm) but was higher in soils practising agroforestry (5.79-6.32 ppm). The Mg content in soils for farmers with 1-5 years agroforestry practice was 5.82 ± 0.21 ppm, those with 6-10 years practice it was 6.37 ± 0.24 ppm, for 11-20 years it was 5.93 ± 0.35 ppm and those with 20 years of agroforestry practice the range was 6.08 ± 0.51 . Further statistical analysis indicates that there was a significant difference in Mg based on the duration of agroforestry practice ($P < 0.05$). The concentration of Mg in the soil was higher among the adopters as compared to the non adopters and increased with increasing duration of agroforestry adoption. These studies concur with those of those of who showed a significant increase in Mg in soil is associated with agroforestry (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018; de Freitas *et al.*, 2018; Mulyono *et al.*, 2019). Magnesium is absorbed as the Mg^{2+} ion and is mobile in plants, moving from the older to the younger leaves (Tongkaemkaew *et al.*, 2018) and therefore likely to increased in areas adopting agroforestry trees. Magnesium can also be increased in

the soil due to liming which may not raise soil pH (Solanki, 2017). Therefore higher Mg content in the soils with a constant pH could have signalled that lime was the main sources of Mg in the soil.

The sodium in the soil without agroforestry practice was 2.54 -2.66 ppm while in soil practising agroforestry it was 2.56-3.63 ppm. Sodium content in soils for farmers with 1-5 years agroforestry practice was 2.88 ± 0.93 ppm, those with 6-10 years practice it was 2.52 ± 0.57 ppm, then among farmers with 11-20 years of agroforestry practice it was 2.68 ± 0.74 ppm and those with 20 years of agroforestry practice the percent was 3.51 ± 0.89 . Further statistical analysis indicates that there was a significant difference in Na based on the duration of agroforestry practice ($P < 0.05$). Sodium in the soil was higher among the adopters as compared to the non adopters and increased with increasing duration of agroforestry adoption. These studies concur with other studies which found a significant increase in sodium during agroforestry (Githae *et al.*, 2011; Lagerlöf *et al.*, 2014; Bayala *et al.*, 2018; Corbeels *et al.*, 2019). The possible application of organic residues during agriculture could be sources of sodium and the use of organic manure in the soils could have increased sodium in the soil.

The foregoing observations regarding higher exchangeable bases in the agroforestry soils, may suggest that these nutrients are being taken up mostly from the zone of higher tree root density and may be accumulating in tree biomass (Alfaia, 2004). Moreover, it seems these exchangeable bases may be considered limiting nutrient for plant growth in the region and therefore plants were able to extract them from the soil and accumulate them above ground or within the soils (Diehl *et al.*, 2008).

3.4 Micro-nutrients in the soils

The overall concentrations of micro-nutrients of the soils between the adopters and non adopters in Machakos County are shown in Table 4 while the trends in micro-nutrients with age and duration of agroforestry are provided in Figure 5.

Table 4: Concentrations of micro-nutrients of the soils between the adopters and non adopters in Machakos County

Age brackets	Manganese	Copper	Iron	Zinc
0	1.32 ± 0.03	8.62 ± 3.93	350.57 ± 85.22	32.20 ± 5.54
1-5	1.33 ± 0.03	8.80 ± 1.40	352.76 ± 98.93	33.64 ± 9.31
6-10	1.33 ± 0.04	8.01 ± 1.17	521.55 ± 105.22	51.93 ± 9.72
10-20	1.38 ± 0.04	12.32 ± 3.27	503.76 ± 90.44	37.09 ± 6.22
>20	1.36 ± 0.05	12.77 ± 2.07	514.73 ± 61.65	40.58 ± 11.62
ANOVA				
F	7.6145	6.675	6.9923	4.7721
df	4	4	4	4
P value	0.0004	0.0012	0.0002	0.0022

The Manganese (Mn) of the soil ranged from 1.32-1.39 ppm in soils practicing agroforestry, but was 1.30-1.32 ppm in soil without any agroforestry practice. The Mn in soils for farmers with 1-5 years agroforestry practice was 1.33 ± 0.03 ppm, those with 6-10 years practice it was 1.33 ± 0.04 ppm, then among farmers with 11-20 years of agroforestry practice it was 1.38 ± 0.04 ppm and those with 20 years of agroforestry practice the percent was 1.36 ± 0.05 ppm. Further statistical analysis indicates that there was a significant difference in

Manganese based on the duration of agroforestry practice ($P < 0.05$). The concentration of Mn increased with age and duration of adoption of agroforestry. These studies concur with those of those of who showed a significant increase in Mn in soil is associated with agroforestry (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018; de Freitas *et al.*, 2018; Mulyono *et al.*, 2019). The major pool of manganese in soils originates from crustal sources, with other sources including direct atmospheric deposition, wash-off from plant and other surfaces, leaching from plant tissues, and the shedding or excretion of material such as leaves, dead plant and animal material, and animal excrement (Parjono *et al.*, 2019). Therefore it is more likely that Mn sources during agroforestry was from wash off from plants an leachates from plant tissues as well as shedding of leaves, dead plants and livestock materials.

Figure 5: Variation in micro nutrients in the soils among farmers with different durations of agroforestry adoption.

The concentration of copper in the soil ranged from 8.56-10.70 ppm in soils without agroforestry but was 8.82-12.98 ppm in soil whose owners practice agroforestry. The Cu in soils for farmers with 1-5 years agroforestry practice was 8.80 ± 1.40 ppm, those with 6-10 years practice Cu was 8.01 ± 1.17 ppm, and 11-20 years of agroforestry practice it was 12.32 ± 3.27 ppm and those with 20 years of agroforestry practice the percent was 12.77 ± 2.07 ppm. Further statistical analysis shows that there was a significant difference in copper relative to the duration of agroforestry practice ($P < 0.05$). The concentration of copper increased with age and duration of adoption of agroforestry. These studies concur with those of those of who showed a significant increase in copper in soils is associated with agroforestry (Lambert & Ozioma, 2012; Uthappa *et al.*, 2015; Sistla *et al.*, 2016; Dhaliwal *et al.*, 2019; Prasad *et al.*, 2019). Copper present as an impurity in silicate minerals or carbonates (Gautam *et al.*, 2017). In some soils, organic matter and soil pH influence copper availability where copper availability increases as organic matter in soil increases since organic matter binds copper from the free state and liberate the copper when it decomposes (Mounissamy *et al.*, 2017). Therefore the high organic matter content can be the main source of copper in agroforestry soils.

In the soils, practice of agroforestry elevated iron from 355 to 527 ppm compared to 350 to 278 ppm in soils devoid of agroforestry. The iron concentration in soils for farmers with 1-5 years agroforestry practice was 352.76 ± 98.93 ppm, those with 6-10 years practice it was 521.55 ± 105.22 ppm, then among farmers with 11-20 years of agroforestry practice it was 503.76 ± 90.44 ppm and those with 20 years of agroforestry practice the concentration was 514.73 ± 61.65 ppm. There was a significant difference in iron based on the duration of agroforestry practice ($P < 0.05$). Further statistical analysis indicates that there was a significant difference in iron based on the duration of agroforestry practice ($P < 0.05$).

Increased iron concentration with age and duration of agroforestry has been reported in other studies as well (Lorenz & Lal, 2014; Schwab *et al.*, 2015; Abreu *et al.*, 2016; Wang *et al.*, 2017; Salgado *et al.*, 2019). Most of the iron in soil are found in silicate minerals or iron oxides and hydroxides, forms that are not readily available for plant use (Pandey *et al.*, 2000; De Souza *et al.*, 2012). Most of the iron are derived from organic matter and degradation of the organic matter pool renders iron readily available in the soils (Yadav *et al.*, 2011). Practices that increase levels of soil organic matter, such as adding manure to soil during agroforestry therefore seems to result in increased iron content in the soils. Iron can also have been increased by spraying of the plants grown during agroforestry with supplemental iron containing fertilizers.

The zinc in the soil ranged from 31.4 to 33.2 ppm in soils with no form of agroforestry soils but was 33.4 42.6 ppm in soil practicing agroforestry. The zinc in soils for farmers with 1-5 years agroforestry practice was 33.64 ± 9.31 ppm, those with 6-10 years practice it was 51.93 ± 9.72 ppm, then among farmers with 11-20 years of agroforestry practice it was 37.09 ± 6.22 ppm and those with 20 years of agroforestry practice the concentration was 40.58 ± 11.62 ppm. Further statistical analysis indicates that there was a significant difference in zinc based on the duration of agroforestry practice ($P < 0.05$). Further statistical analysis indicates that there was a significant difference in zinc based on the duration of agroforestry practice ($P < 0.05$). The concentration of zinc increased with age and duration of agroforestry adoption. These studies concur with those of those of who showed a significant increase in zinc in soil is associated with agroforestry (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018; de Freitas *et al.*, 2018; Mulyono *et al.*, 2019; Parveen *et al.*, 2019). Zinc can be increased in the soil by application of fertilizers containing zinc, of which the most common are zinc chelates, zinc Sulfate and zinc oxide which common in most fertilizers formulation (Meena *et al.*,

2019). It has also been reported that high levels of phosphorus found in several phosphate fertilizers (e.g. DAP) may increase the concentration of zinc in the soil by interfering with its metabolism in plants and help in the precipitation of zinc in soil (Bhaduri *et al.*, 2017; Lenci *et al.*, 2018; Sarabia *et al.*, 2020).

Conclusion

Analysis of the physical attributes of the soils indicate that proportion of sand particles was higher among non adopters compared to adopters of agroforestry while the proportion of silt and bulk density in the soil was higher among the adopters. In terms of chemical properties, the study established that TN, TOC, Ca, Mg, Mn, Cu, Fe, Zn and C/N ratio were higher in soils where agroforestry was being practiced but soil pH, total phosphorus, potassium, and sodium showed similarity between soils practicing agroforestry and those without the practice. Overall physical and chemical attributes in the soil appeared to improve with increasing duration of agroforestry adoption. The study recommends adoption of agroforestry and longer period of practices to improve and enhance physico-chemical soil quality parameters for higher agricultural productivity in the tropical regions of Sub Saharan Africa.

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