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Effect of Legume Cover Crops on Soil Moisture and Orange Root Distribution

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Authors' contributions

This work was carried out in collaboration between all authors. Author JMM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors HMS, LGM and LAW guided on field experimentation, data collection and interpretations and suggested necessary corrections on the revised manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Inadequate rain is a major hindrance to soil moisture and crop root growth in arid and semi-arid areas of Kenya. A field study was conducted in Ganda, Vitengeni and Matuga locations within the coastal lowland region of Kenya from May, 2012 to April, 2015 to evaluate the effects of three leguminous cover crops on soil moisture retention and orange tree feeder root distribution. Treatments included mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), dolichos (*Lablab purpureus*) cover crops and unplowed fallow of natural vegetation as a control. The experiment was laid out in randomized complete block design (RCBD) and each treatment was replicated four times. Data collected were: soil particle size distribution, soil moisture content and orange dry root density. The data collected was subjected to analysis of variance (ANOVA) using procedures of R statistical analysis version 3.3.2. Mean separation was done using the least significant difference (LSD) value at 5% level of significance. Results indicated that mucuna, dolichos and cowpea cover crops significantly (P=.05) increased soil moisture content. The mucuna treated plots recorded an

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increase in SMC by 39.0% and 33%, dolichos increased by 34.4% and 28.9% and cowpea by 33.6% and 27.3% at soil depth 0-20 and 20-40 cm, respectively, over their own controls. Mucuna and dolichos significantly (*P*=.05) increased orange feeder root distribution. Mucuna treated plots supported the highest increase in orange root distribution by 36.5% and 31.8%, dolichos increased by 30.2% and 34.1% while cowpea increased by 18.3% and 18.8% in soil depth 0-20 and 20-40 cm respectively compared to their own control. It can be concluded that the three legumes; mucuna, cowpea and dolichos cover crop improved soil moisture and root distribution in orange production. The overall ranking was as follows: mucuna > dolichos > cowpea. From the finding, the use of mucuna and dolichos cover cropping system is recommended as a soil management practice aimed at improving the orange productivity. Further evaluation on the long term (>3 years) effects of cover crops on soil moisture and orange root distribution under different agro ecological zones is suggested.

Keywords: Legume cover crops; root density; soil moisture; coastal Kenya; orange crop.

1. INTRODUCTION

Citrus root system plays an important in physical tree anchorage and support to the soil [1]. They also provide a mean of collection and transport of water and nutrients essential for tree growth and production [2]. These functions are, however, influenced by environmental conditions and rooting depth which varies with tree age, rootstock, and soil drainage characteristics [3]. The root distribution in the soil profile is important in determining the water and nutrient uptake by plants. However, these two factors are influenced by soil type and soil moisture content (SMC) [4]. Soil moisture is a major component of the root environment which affects growth and health of roots [5]. Plants in average have a higher roots biomass concentration in the upper soil layer and exhibit higher nutrient and water uptake than deep rooted plants [6]. Plants with deep roots tap water from lower soil layers and tend to tolerate periods of water stress than those with shallow roots [7]. Plants adapted to areas with limited rainfall such as arid areas develop shallow roots because precipitation is limited to the upper soil layer [8]. The planting density and time of inter-cropping mucuna and maize crop influenced the root length [9]. The orange root systems contain dense fibrous roots within the top soil (10-30 cm) which expands radically with time as the tree grows and decreases with soil depth [10]. The distribution of fibrous roots within the soil profile increases the chance of water and nutrient uptake [11]. Studies conducted in Florida on citrus root distribution have shown that citrus has a potential to have extensive roots under favorable soil conditions [12].

Soil moisture status affects crop root system growth, shape, structure, physiological function, water uptake characteristics as well as root shoot ratio [13]. Soil moisture status affects crop root system growth, shape, structure, physiological functions, water uptake characteristics as well as root shoot ratio [14] leading to establishment of a healthy root system and good positioning of lateral roots [15]. The contacts between outer cells of the root and the soil permits ready movement of water from the soil into the plant in response to differences in energy levels. Moisture within the rhizosphere also increases water flow and nutrient availability to roots [16]. However, according to [17] and [18], the amount of water and solute uptake by a plant is based on the root distribution within the soil profile hence the amount of root per given area can be used as an indicator of plant nutrient uptake quantity. The regions which experience erratic rains like the coastal region of Kenya and where supplemental irrigation is not done experience poor crop yields. Majority of the smallholder farmers are resource poor, they rarely use fertilizer or irrigate their orange tree crop and this has lead to poor yields [19,20]. There is, therefore, need for alternative soil and water management methods to improve water storage in the soil and orange trees nutrient uptake during low rainfall periods.

Legume cover crops have a long history of use in various cropping systems to prevent erosion on steep slopes and as an alternative method of weed control. The use of cover crops today is important for nutrient management, water relations, and weed management and as a traction surface for machinery and workers. There are several species of tropical legumes that have been student for their potential as cover crops and they have been reported to influence surface soil temperature and evaporation within the plant root zone leading to improved nutrient and water management [21]. The biomass accumulated from legumes form mulch on the soil surface increasing soil water recharging and storage capacity hence improved root growth and distribution of crops. Organic matter from LCC, also plays an important role on the soil physical, chemical and biological processes leading to reduced soil compaction, improves soil structure, nutrient and water holding capacity of soils [22,23]. Most of this work has however been tested and reported on annual crops. Information on the effects of LCC on perennial crops is, therefore, limiting. The study, therefore, sought to evaluate the effect of LCC on soil moisture content and orange root distribution in coastal Kenya.

2. MATERIALS AND METHODS

2.1 Study Sites

The experiment to determine soil moisture content and orange root distribution was set up at Matuga, Ganda and Vitengeni locations in coastal lowland region of Kenyafrom May, 2012 to April, 2015 (Fig. 1). Research sites were selected based on the most common grown orange variety in the region; orchard size; recommended tree spacing (6 m x 6 m); and the tree history. Orange trees of growth age (15—20 years) were selected because root distribution is known to increase with age of a tree among other factors [24]. The three study sites fall between latitude 1° and 4° South and longitudes 38° and 41° East. The three year average rainfall for Matuga was 840 mm, Ganda 993 mm and Vitengeni 709 mm. The average temperature of the three sites was 29℃ during the day and 25℃ during the night. Matuga and Ganda sites fall within Coastal Lowland three (CL3) while Vitengeni site is within Coastal Lowland four (CL4) of Kenya.

2.2 Experimental Layout, Design and Crop Husbandry

The treatment included three different LCC namely: dolichos (*Lablab purpureus),* mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), and a control plot, consisting of an unplowed fallow of natural vegetation. The experiment was

Fig. 1. Geographical location of the experimental sites in coastal Kenya
Source: Google map

laid down in a randomized complete block design (RCBD) and treatments were replicated four times. One orange tree represented a plot in the experimental layout. Each site had four blocks where the four treatments were randomly applied per block under the tree canopy making a total of 16 plots per site. An untreated orange tree was left within and between the blocks of the treated plots to act as a guard tree. The planting of cover crops was two seeds per hole at a spacing of 60 x 30 cm under the orange canopy within a radius of 3 m from the tree trunk.

There was no addition of fertilizer, manure or chemical pest control on the experimental units during the study period to avoid external variation other than that of the treatment. Since mucuna and dolichos are climbers, effort was made to ensure that any twining on the orange tree by the climbers was brought down. The cover crops were left to grow to their fullest potential but within the 3 m radius. The drying legume after its growth cycle and any vegetative growth on the control plots were slashed and spread evenly within the plot before planting the next cover crop.

2.3 Data Collection

Data collected included: soil particle size distribution (soil texture) soil moisture content and feeder root distribution.

2.3.1 Soil sampling and particle size distribution analysis

Soil sampling zone was within the 3 m radius from each orange tree trunk in each plot at two soil depth level 0-20 cm and 20-40 cm using a soil auger. Soil sampling was done before the start of the experiment and at the end of three year experimental period. At each sampling, a total of 96 soil samples from the three sites were taken to National Agricultural Research Laboratory in Nairobi for analysis. The SMC in a given soil is influenced by the type of soil based on soil particle sizes. Soil particle size distribution was determined using hydrometer method as described by [25].

2.3.2 Soil moisture content

The soil sampling zone was within the 2 m and 3 m radius from the orange trees trunk from each plot at two soil depth level 0-20 cm and 20-40 cm using a soil auger. Soil sampling was done at capillarity level 10 days after a given rainfall or after uniform irrigation to determine SMC.

The first soil sampling was done 4 weeks after emergency of the planted cover crops then three more soil sampling done within each six months for a period of three years. Each time, a total of 96 composite soil samples were taken from the three sites and immediately transported to the laboratory for analysis. The soil moisture content for each sample was determined using gravimetric method as described by [26] with minor modification. A 50 g working soil sample from the composite sample was weighed using an electronic weighing balance (Model PM 200, Mettler instrument limited, Switzerland) before placing it in a pre-weighed new kaki paper bag. Total weight of soil and paper bag was determined before oven drying at 105℃ for 24 hrs. Thereafter, the weight of oven dried soil was determined. The percentage soil moisture content in dry-weight basis (θ_{dw}) from each sample was calculated using the following formula:

$$\theta_{dw} = \frac{\text{weight of moist soil} - \text{weight of dry soil}}{\text{Weight of dry soil}} \times 100$$

Water in volumetric bases

$$\theta_v = \frac{\rho_b}{\rho_w} \times \theta_{dw}$$

Where (θ_v) Volume of moisture content, $\rho_b$is soil bulk density and ρ_w is the density of water usually taken as g cm^{-3} units.

2.3.3 Feeder root distribution

Soil sampling zone was within the area between 2 m and 3 m radius from the orange trees trunk where 80% of the orange feeder roots are found. Soil cores were sampled using a cylindrical soil auger with serrated cutting edge, with an internal diameter of 7 cm and core depth of 15 cm (Fig. 2). The composite samples from each soil depth contained both root and soil were placed in labeled sampling bags then taken to the laboratory for determination of root distribution.

All extract roots from the soil per given sample were put in a clean bucket half filled with clean water. To loosen the roots from the soil in each sample, hand stirring was done and the mixture carefully passed through a double sieve with 4 mm aperture (Fig. 3) in order to ensure all roots from the soil are capture.

Fig. 2. Part of root sampling soil auger with serrated cutting edge
Source: Photo by Jackson Mulinge

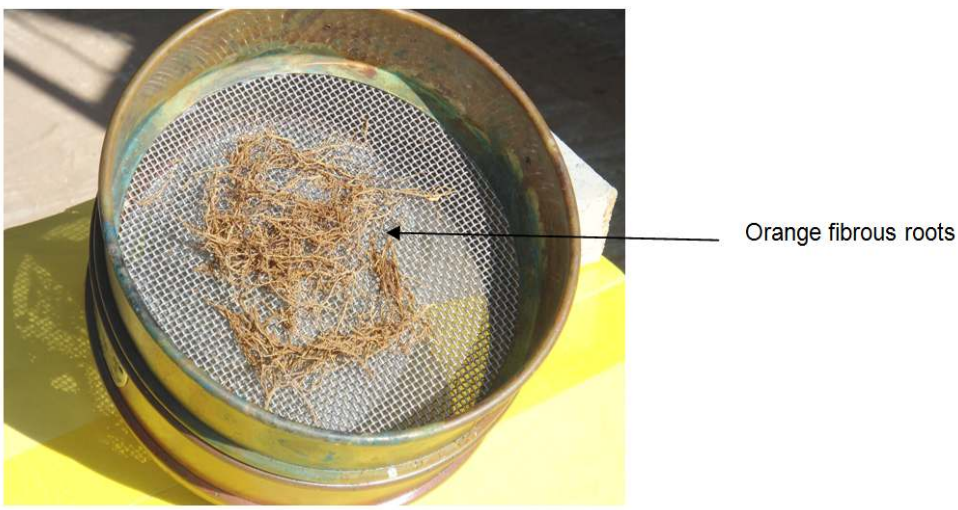

Fig. 3. A 4 mm aperture sieve for root-soil separation
Source: Photo by Jackson Mulinge

Orange feeder root distribution was determined using the dry root density method as described by [27] with minor modification. The roots from the sieves were placed in a smooth metallic bowel with clean water in order to clean them further. Root colour was used to distinguish orange tree roots (which are brownish) from other roots and other foreign bodies from the cleaned roots. The water from the cleaned roots was removed through decantation and the cleaned roots were placed on blotting paper to remove excess water. The entire extracted root per sample was then weighed to determine fresh weight using an electronic weighing balance. To ensure full oven drying of the bulky root sample enclosed in a kaki paper bag, oven dried temperatures to fully dry matter were set at 105℃ for 24 hrs and then reweighed.

Dry root densities (RD_d) in (kg m^{-3}) for each sample were determined by dividing the weight of the extracted and dried root mass M_d (kg) by the volume of the soil. The volume V (m^3) was calculated from the soil core radius of 0.07 m and length of 0.15 m.

$$RD_d = \frac{M_d}{V}$$

2.4 Data Analysis

All the data collected was subjected to analysis of variance (ANOVA) using procedures of R statistical analysis version 3.3.2 [28]. Mean separation was done using the least significant difference (LSD) value at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

The observed soils in Vitengeni were sandy clay loam (SCL) while Matuga had sandy loam (SL) and Ganda had sandy (S) (Table 1). The cover crops were, however, observed to have an insignificant (P=.05) effect on the soils texture over the experimental period.

3.2 Effect of Legume Cover Crops on Soil Moisture Content

Mucuna, dolichos and cowpea cover crops significantly (*P*=.05) increased soil moisture content (SMC). The results of the analysis of variance showed no significant (*P*=.05) interaction effect of mucuna, dolichos and cowpea cover crops on soil moisture content.

Mucuna treated plots recorded an increase in SMC by 39.0% and 33%, dolichos by 34.4% and 28.9% and cowpea by 33.6% and 27.3% at soil depth 0-20 cm and 20-40 cm respectively compared to their control (Table 2).

There was an increase in soil moisture over the three year (2012—2014) in both soil depth levels as a result of using different LCC (Fig. 4). The third year (2014) recorded the highest SMC while the first year (2012) recorded the least.

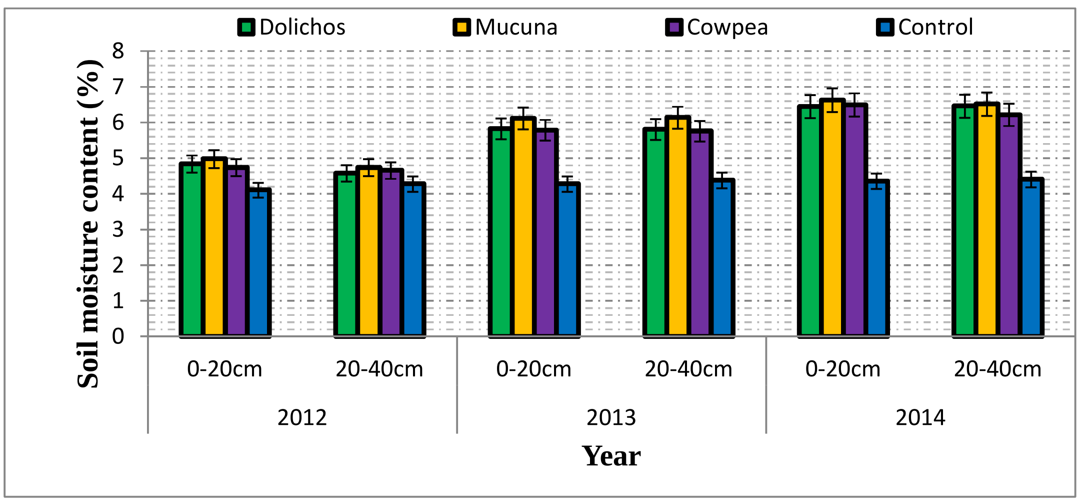

Fig. 4. A profile of soil moisture level at soil depth 0-20 cm and 20-40 cm in three years of using legume cover crops

Table 1. Soil textural properties for the three study sites before and after the treatments

Soil PSD	**Sites**					
	Vitengeni		**Matuga**		**Ganda**	
	Initial soil texture	**Texture after treatment**	**Initial soil texture**	**Texture after treatment**	**Initial soil texture**	**Texture after treatment**
Sand %	65	64	84	84	91	90
Clay %	26	26	14	14	6	6
Silt %	9	10	2	2	3	4
Texture	SCL		LS		S	

PSD= Particle Size Distribution; SCL=sandy clay loam; LS= loamy sand; S=sand

Table 2. Effect of legume cover crop on soil moisture content (%) at two soil depth 0-20 cm and 20-40 cm

Treatment	Soil depth	
	0-20 cm	**20-40 cm**
Dolichos	5.71 a	5.62 a
Mucuna	5.91 a	5.80a
Cowpea	5.68 a	5.55 a
Control	4.25 b	4.36 b
LSD ($P \leq 0.05$)	0.23	0.26
CV%	21.86	23.02
Pr(>F)	0.0025	0.0357

Values are means of data from four treatments replicated four times.
Means within each column followed by same letter are not statistically P=.05 different

Table 3. Effect of legume cover crops on orange tree root density (kg m^{-3}) at two soil depth levels 0-20 and 20-40 cm

Treatment	Soil depth	
	0-20 cm	**20-40 cm**
Dolichos	0.164 a	0.114 a
Mucuna	0.172a	0.112 a
Cowpea	0.149 b	0.101 b
Control	0.126b	0.085 b
LSD ($P \leq 0.05$)	0.025	0.026
CV%	26.94	29.60
Pr(>F)	0.0185	0.0461

Values are means of data from four treatments replicated four times.
Means within each column followed by same letter are not statistically P=.05 different

3.2.1 Correlation between soil moisture and soil depths 0-20 cm and 20-40 cm

The mean moisture content determined through gravimetric method from soil depth 0-20 cm was plotted against that of 20-40 cm to obtain a regression curve (Fig. 5). There was a strong positive linear relationship between SMC from the two soil depths. The regression coefficient (R2) for the SMC was highly significant (0.969) for both soil depths. A 98.4% of the variation of SMC at soil depth 20-40 cm can be explained by soil moisture variation of 0-20 cm soil depth.

3.3 Effect of Legume Cover Crops on Orange Fibrous Root Distribution

The results of analysis of variance showed that there was significant (*P*=.05) interaction effects on orange dry root density in the soil between (i) cover crops and year (F=3.907; *P*=.0059) at soil depth 0-20 cm. Interaction of cover crops and year had significant (*P*=.05) effect (F= 3.477; *P*=.0026) on orange tree dry root density in the soil at soil depth 20-40 cm.

Effect of mucuna and dolichos cover crops were observed to significantly (*P*=.05) increase orange root distribution in both soil depth 0-20 cm and 20-40 cm (Table 3). The increase in orange root distribution as result of cowpea treatment was however not significantly (*P*=.05) different in both soil depths 0-20 cm and 20-40 cm compared to the control. Mucuna treated plots supported the highest increase in orange dry root density by 36.5% and 31.8%, dolichos increased by 30.2% and 34.1% while cowpea increased by 18.3% and 18.8% in both soil depth 0-20 and 20-40 cm respectively compared to their control.

A significant (*P*=.05) high mean root density was observed in the top 0-20 cm soil layer compared to lower soil profile 20-40 cm throughout the experimental period. The increase in root distribution could be attributed to the increase in water infiltration and soil moisture storage as result of the treatments.

4. DISCUSSION

The significant increase in mean SMC observed as a result of using LCC was attributed to their ability to form a ground cover, improved microclimate under the orange tree canopy and biomass accumulation hence increased soil holding capacity compared to their control. Mucuna cover crop increases the amount of biomass in the soil during their life time [29]. Biomass production in the soil varies with cover crop species [30] and this could have contributed to the observed variation in soil moisture storage. The continuous use of cover cropping systems added biomass in the soil with time, and this contributed to the reduction of soil bulk density in clay soils, improved soil structure and increased soil porosity [31,32]. The use of LCC, has been observed to increase soil organic matter, soil water holding capacity and the recharging of soil water from rainfall improved [33,34]. The varied increase in soil moisture from 2012—2014 in both soil depths 0-20 and 20-40 cm (Fig. 4) was because different LCC have different capacities in the increasing soil biomass, and hence the increase in SMC and water storage differed with treatment. The top soil profile 0-20 cm recorded a higher water storage compared to the lower soil profile 20-40 cm meaning that there was a reduction in surface soil water loss despite the soil texture site variation.

The results from the interaction outcome indicates that the source of variation were not only due to the cover crops but also variation effects from the different years contributed to the observed increase in root distribution at soil depth 0-20 and 20-40 cm. The sites received different amount of rainfall in different years, the root growth increases with time and this influenced the rate of root distribution in the soil. The growth of cover crops could have been influenced by rainfall received which varied with year and site.

The result in (Table 3) indicates that different LCC have different capacities in influencing the increase of orange tree root distribution in the soil. The use of LCC influences tree root growth and distribution which depends on water availability in the soil [35]. The amount and distribution of roots beneath the soil provide organic matter and enhances resistance to soil erosion [36]. The high root density in the upper soil profile was attributed to abundance in organic matter contributing to a mulching effect and lowered temperature. The increased

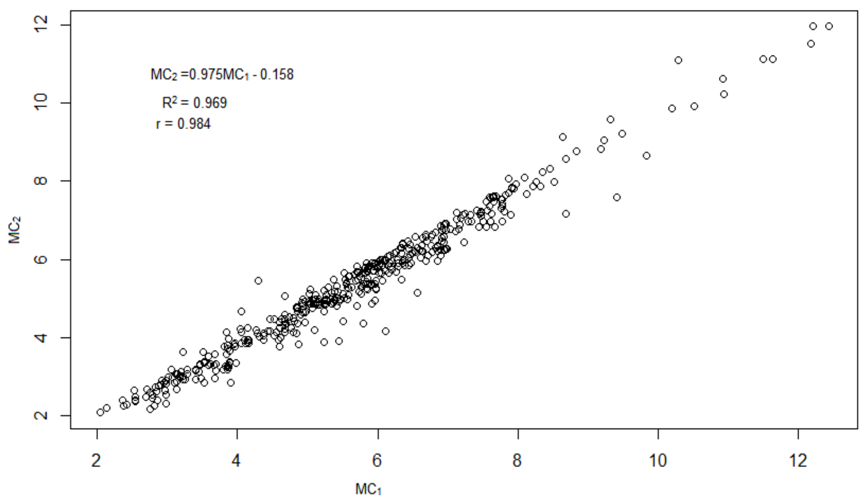

Fig. 5. A scatter plot on mean soil moisture from two soil depth levels MC_1 (0-20 cm) and MC_2 (20-40 cm)

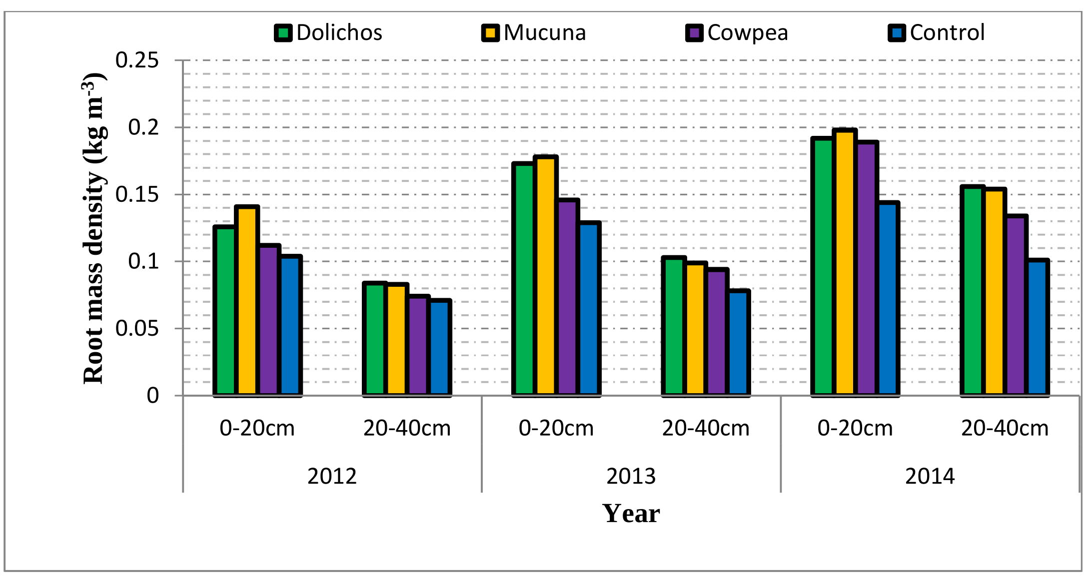

Fig. 6. A profile of mean orange root density at soil depth 0—20 cm and 20—40 cm in three years of using legume cover crops

bio-matter and water storage reduces the resistance to root penetration [37]. The root growth and distribution were enhanced due to increase of moisture in the soil. The upper soil profile allows free air movement and root growth compared to lower depths, where oxygen and root growth is restricted due to soil compaction [38,39]. Dry root density from the soil core increases with the diameter of the root [40]. Root distribution and growth capability often depends on the soil type, the type of roots and their ability to penetrate the soil profile [41]. The root distribution increased with time but decreased with increase in soil depth.

There was an increase in the three year study period (2012—2014) and root distribution within the two soil depth 0-20 and 20-40 cm (Fig. 6). The continuous use of LCC could have contributed to the increase in root distribution over time. Though root growth normally increases with time, there was an influence on the observed distribution as a result of using cover crop compared to their control. The increase in water storage in the soil as a result of cover cropping system enhanced root growth and hence the observed relative increase in root density in the two soil profiles. The soil type had an influence on the increase in root distribution [42].

5. CONCLUSIONS AND RECOMMENDATIONS

The results of this study showed that the use of legume cover cropping system increased soil moisture retention and orange tree root distribution in the soil. The mucuna cover crop treated plots recorded the highest soil moisture content in both soil depth 0-20 and 20-40 cm. Similary, mucuna treated plots recorded the highest orange fibrous root distribution in soil depth 0-20 cm. Dolichos recorded the highest orange tree fibrous root distribution in lower soil profile 20-40 cm. The control plots recorded the lowest moisture content and root distribution in both soil depth 0-20 and 20-40 cm. Legume cover cropping system is a viable farming system that can aid in improving soil moisture in orange orchards and enhance orange root distribution in the soil profile. It can be concluded that the three legumes; mucuna, cowpea and dolichos cover crop improved soil moisture and root distribution in orange production. From the outcome of this study, mucuna and dolichos LCC are recommended for use as cover crops in orange tree orchards as they are useful in improving soil moisture retention and orange tree root distribution.

The adoption of these findings and recommendation by the farmers and their socio-economic impact also need to be established. Since orange trees are a perennial crop, further studies are, therefore, recommended to evaluate the long term (>3 years) effects of the cover crops on soil moisture and orange tree root distribution under different agro-ecological zones.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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