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Evaluation of field performance of compact coffee variety under selected propagation methods and soil fertility amendment practices in the Northern Zone, Tanzania

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This study compares the field performance of three types of seedlings propagules (cuttings, grafting and seed) when combined with 75 g NPK (20:10:10) tree^{-1}, 37.5 g NPK + (10 and 20 Kg Farmyard manure) tree^{-1}. Two split plot experiments laid out in a Randomized Complete Block design (RCBD) with three replications were established at Lyamungu-Kilimanjaro region and Burka-Arusha region based on the existing climatic gradient. Such data as, soil organic carbon, soil texture, growth characteristics and coffee yield were collected in the period from 2019 to 2022. Cuttings-propagated plants outperformed seed and grafted-counterparts in all aspects ($p < 0.05$). This could be due to the greater physiological maturity of cutting propagated plants, causing earlier production capability. Cuttings propagated plants had the highest yield 2800 and 3600 Kg ha^{-1} green coffee at Burka and Lyamungu sites, respectively. The grafted propagated plants had the lowest green coffee yield of 800 and 1700 Kg ha^{-1} at Burka and Lyamungu sites, respectively. Therefore, it can be concluded that cuttings propagated plants under the age of 4 years with the same rooting age as seed and grafted plants perform better in the field than seeds and grafted plants.

Key words: *Arabica coffee*, cuttings propagules, farm yard manure, grafted propagules, seeds propagules, Tanzania.

INTRODUCTION

Coffee is one of Tanzania's primary agricultural export commodities accounting for about 5% of total export value, and generating export earnings averaging USD 100 million per annum over the last 30 years (TCB, 2017). The industry provides direct income to more than 400,000 farmer households thus supporting the livelihoods of an estimated 2.4 million individuals. Average yearly production over the past thirty years has stagnated at a level of about 50,000 tons, while yields have continuously decreased, thus contributing to low

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farm gate prices, and the development of rural poverty (TCB, 2020). As a way to overcome the problem of low productivity, improved coffee varieties that are high-yielding, resistant to disease with the best beverage quality have been developed by the Tanzania Coffee Research Institute (TaCRI) (Kilambo et al., 2015).

To expedite the adoption of the improved Arabica hybrids, TaCRI uses three seedling multiplication techniques namely; clonal propagation (use of cuttings), grafting and manual hybridization (TaCRI, 2011). TaCRI is producing compact hybrid seeds so that farmers can also use coffee seeds as a means of propagating hybrid coffee as they used to do with traditional varieties. Seeds have good viability if stored properly and are considered an economical way to obtain sufficient trees (Wrigley, 1988; TaCRI, 2011).

On the other hand, cutting-propagation is physiologically viable and ensures maximum crop homogeneity, besides other desirable traits, especially grain maturation, fruit yield and size, and plant vigor (Weigel and Jurgens, 2002). Moreover, the possibility of independent multiplication regardless of the time of the year is another fundamental factor in consolidating this technology (Junqueira et al., 2006). However, although there are gains obtained through the planting of cuttings, problems that arise from the genetic narrowing of the species and shallower radicular systems can be observed in the field. A few cuttings in the field have shown allometric growth, exhibiting uneven relationships between their aerial parts and radicular systems and in many cases resulting in the death of the plants. Bragança et al. (2010) observed sigmoidal growth for conilon coffee where there is no balance between the foliar area and the total biomass of the plant.

In the case of the grafting method, the scions of improved hybrid varieties are grafted on the rootstocks of traditional coffee varieties (TaCRI, 2011), thus exploiting the shoot characteristics of the new varieties and the root characteristics of the traditional varieties. Within the context of aiming to balance plant growth and ensure the permanence of the features obtained by vegetative propagation, grafting is a precise tool for adding a radicular system that has originated through sexual reproduction. According to Oliveira et al. (2004), grafting effectively enables a new balancing of the plant's biomass with quick results in arabica coffee beans contributing to increased productivity. The use of vegetative propagules of *Coffeea arabica* has been an important tool for the large-scale multiplication of improved coffee varieties in Tanzania, following major achievements made by TaCRI in the development of coffee varieties that are resistant to coffee berry disease (CBD) and coffee leaf rust (CLR) for Arabica and coffee wilt disease (CWD) for Robusta (Teri et al., 2011). However, the field performance of cuttings and grafted propagated compact coffee variety have not been studied in detail to guarantee their long-term adoption.

Soil fertility management is an important factor for successful crop production in all agricultural commodities. In the case of coffee, there are two sources of nutrients (inorganic and organic) that can be applied in the coffee field (Maro et al., 2014). The most common sources of organic manure used in crop production are livestock dung (farm yard manure), composted and green crop residues (Satyanarayana et al., 2002). Soil fertility amendment practices in Tanzania involve the application of 75-215 g of N:P:K (20:10:10), 60-175 g of CAN/ASN or 30 to 100 g of urea per tree depending on the production level of the coffee tree and season of the year (short rain/long rain). Phosphate fertilizer (TSP, DAP or SSP) in combination with 10 kg of farm yard manure (FYM) is used as planting fertilizer (TaCRI, 2011). Therefore, it is only at planting time that inorganic fertilizer is integrated with FYM. However, according to Jobe (2003) and Stockdale et al. (2002), the best remedy for soil fertility management is a combination of both inorganic and organic fertilizers, where the inorganic fertilizer provides nutrients and the organic fertilizer mainly increases soil organic matter and improves soil structure and buffering capacity of the soil.

Additionally, Chemura et al. (2014) indicated that inorganic fertilizers are most effective at high water levels while organic manure performs better than inorganic fertilizers under low water levels possibly due to their ability to increase soil water retention. The combined application of inorganic and organic fertilizers, usually termed integrated nutrient management, is widely recognized as a way of increasing yield and or improving the productivity of the soil sustainably (Mahajan et al., 2008). The beneficial effect of integrated nutrient management in mitigating the deficiency of many secondary and micronutrients has been demonstrated by Singh (2000) and Mahajan et al. (2008). According to Tilahun-Tadesse et al. (2013), identifying the optimum dose of integrated nutrient application is, however, required for maintaining an adequate supply of nutrients for increased yield. This research study was, therefore, conducted to (1) compare the field performance of three types of seedlings propagules (cuttings, grafting and seed); (2) asses the combined effect of organic and when combined with 75 g NPK (20:10:10) tree^{-1}, 37.5 g NPK + (10 and 20 kg farmyard manure) tree^{-1} for improved productivity of the coffee in the Northern Highlands zone of Tanzania.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the Northern Highlands Zone of Tanzania along the slopes of Mt. Kilimanjaro (Hai district) and Mt. Meru (Arusha district), both characterized by a bimodal rainfall

(a) (b) (c)

Plate 1. Seedling multiplication methods used: Cuttings (a), grafting (b) and seeds (c).

pattern. Hai district represented areas with optimum conditions for growing coffee at the current time (rainfall above 1 200 mm per year and average temperature range of 20.07ºC for the past four decades). Annual rainfall in the Arusha region ranges from 800 to 1000 mm and an average temperature range of 20.38°C. In both areas, soils are deep, well-drained, brown to red sandy loam to sandy clay loam. The long rain occurs in March, April and May (MAM) and the short rainy season in October, November and December (OND). Rainfall variability is mainly caused by rapid warming of the Indian Ocean which causes an increase in convection and precipitation over the tropical Indian Ocean, contributing to the decrease in rainfall over the continental land surface, north-south movement of the Intertropical Convergence Zone (ITCZ) (Diem et al., 2014). El-Niño Southern Oscillation (ENSO), though relief features like Mount Kilimanjaro and Mt. Meru play a role in small-scale variations in rainfall.

Experimental design

Two split plot experiments laid out in a Randomized Complete Block design (RCBD) with three replications were established in the two areas with a climatic gradient. The first scenario comprised an area with optimum climatic conditions for growing coffee (Hai district) while the second scenario represents areas where optimum climatic conditions for growing coffee are supposed to have already changed (Arusha district). The type of seedling was treated as the main factor with three levels (cutting seedlings, grafted seedlings and seed seedlings). On the other hand, fertilizer management practices were treated as sub factor, again in three levels; 1 = normal application of fertilizer per tree (75 g of NPK 20:10:10), 2 = 20 Kg of farmyard manure (FYM) + half dose of normal inorganic fertilizer rate and 3 = 10 Kg of FYM + half dose of normal inorganic fertilizer rate).

Coffee seedling development

Three types of coffee seedlings were developed in a manner that they are of the same age. Therefore, the seeds for the seed seedlings were planted at the same time as the seeds for the rootstock. The cuttings for developing the cuttings seedlings were also developed at this time. This was to ensure that the roots for the three types of seedlings were of the same age. Following the procedure described in TaCRI (2011), grafted seedlings were developed from the rootstock of the old variety (KP 423) and the scion of the improved compact coffee variety. Cutting seedlings were developed from the cuttings of the compact coffee variety and seed seedlings were developed from compact coffee seeds (Plate 1).

Seedling planting and management

Seedlings were transplanted in the field in April 2020 at a depth of 60 × 60 cm holes using a spacing of 2 m × 1.5 m as recommended by TaCRI (2011). A border row of the same coffee varieties was planted around the experimental area to overcome border effects on the experimental units as recommended by Tesso et al. (2011). Replicates were separated by the 3 m border. The total number of experimental units per replication was 108 whereas the plot size was 1920 m^2. The number of experimental units per replication was reduced to 99 at the end of year one and 90 at the end of year 2 before the harvest. The number of experimental units was reduced because some plants were cut off for the determination of root: Shoot ratio. The experiment was conducted from July 2019 to July 2022. FYM was applied only once during the experiment while NPK fertilizer treatment was applied twice in the year (during the long rain and short rain). Agronomic practices such as weeding, insect and pest control were carried out uniformly in all plots as recommended by TaCRI (2011).

Data collection

Growth characteristics

All the growth characteristics and yield components data were collected at the end of 12 and 22 months after planting. The plant height was measured from the base of the stem to the plant apex using a graduated ruler (Assis et al., 2014; Tefera et al., 2016). The diameter of the main stem was measured at 5 cm above the ground using Vernier Calliper (Assis et al., 2014; Tefera et al., 2016). The length of bearing primary branches was measured from the point of attachment to the main stem to the apex using a graduated ruler as an average value of four longest bearing primaries per plant (the final length was multiplied by two to get the canopy width). The number of internodes was counted as an average value from the longest-bearing primaries per plant. Total number of primary branches was estimated by counting the total number of primary

Table 1. Soil organic carbon (%) at Lyamungu and Burka after treatment application.

Treatment	Lyamungu	Rating*	Burka	Rating*
75 g of N.P.K (20:10:10)	2.34	Medium	2.54	Medium
37.5 g of N.P.K (20:10:10)+10 Kg FYM	4.13	High	2.93	Medium
37.5 g of N.P.K (20:10:10)+ 20 Kg FYM	4.48	High	4.04	High

*Ratings by Sys et al. (1993).

branches per plant. The last three parameters followed Esther and Adomako (2010). Coffee trees to be used for root: shoot ratios determination was taken through the excavation method where all the roots were dug and removed from the soil. Substrates in the roots of the plants were gently washed off. The fresh weight of shoots and roots was recorded immediately after removing the free surface moisture with soft paper towels. Shoot and root samples were then oven-dried at 85°C for 48 h, and weighed for dry weight. The root/shoot ratio was calculated as the root dry weight/shoot dry weight (Li et al., 2018).

Yield and yield components

The number of berry clusters or the number of fruiting nodes was determined as an average number of berry clusters per plant from four heavily bearing primaries at the middle across all directions (Etienne and Bertrand, 2001). The yield was obtained by harvesting mature red cherries to get fresh weight for each tree per treatment using a gravimetric scale. The skin and pulp of the cherry were removed using the wet process method. The parchments were then dried to a moisture content of 11% (TaCRI, 2011). Parchment coffee means the green coffee bean contained in the parchment skin; to find the equivalent of parchment coffee to green coffee, the net weight of the parchment coffee was multiplied by 0.80 as recommended by ICO (2011).

Soil and soil moisture content data

Soil sampling for the determination of texture and organic carbon was done before and after trial establishment. Bulk soil samples for the determination of organic carbon and texture were collected with hand-auger from the depths of 0 to 30 cm at the Lyamungu and Burka sites. Soil samples for soil moisture content (SMC) determination were taken at a depth of 0 to 10 cm using a core sampler. A total of 27 soil samples were collected from each trial.

Data analysis

Soil analysis

Chemical and physical properties of the soil: The collected soil samples were analysed at Lyamungu Soil Laboratory. The bulk soil samples were air-dried, ground and sieved through a 2 mm sieve (Nunez et al., 2011) and analysed for organic carbon (by Walkley-Black wet digestion method). The texture was analysed by using the Bouyoucos Hydrometer method (NSS, 1990).

Soil moisture content: Immediately after receiving the soil sample in the lab, a known weight of the fresh sample was measured (W1), the sample was then evaporated in a ventilated oven at 105°C for eight hours to obtain constant weight (W2). Moisture content was calculated using the following formula:

$$\% \text{ Moisture content} = ((W1 - W2/ (W2)) *100 \quad (1)$$

Growth characteristics, yield and yield components

Data collected were subjected to analysis of variance (ANOVA) using STATISTICA Software version 6.311 using the following statistical model for the spilt plot design as described by Kuehl (2000) (Equation 2). Treatment means were separated using Tukey' HSD at 0.05 significance level.

$$Y_{ijk} = \mu + \alpha_i + P_k + d_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (2)$$

Where: μ = is the general error mean; α_i = the effect of the ith level of factor A; P_k = the effect of the kth block; d_{ik} = the whole-plot random error; β_j = effect of the jth level of factor B, $(\alpha\beta)_{ij}$ = the interaction effect between factors A and B; ε_{ijk}= is the sub-plot random error.

RESULTS

Soil organic carbon and soil moisture content (SMC)

Lyamungu (Hai district) and Burka (Arusha district) are characterized by loam and sandy loam soil respectively. The organic carbon (OC) content of the soil was affected differently by soil fertility management practices (Table 1). Before treatment application Lyamungu and Burka had 2.34 and 2.42% OC, respectively.

There was a significant difference ($P \leq 0.05$) in SMC taken on Jun 21st, 2021 due to soil fertility management practices and lack of significant difference ($P \geq 0.05$) in other sampling dates at Burka and Lyamungu sites. However, despite the lack of significance, 37.5 g NPK + 20 Kg of FYM resulted in higher SMC than other soil fertility management practices in all the sampling dates (Figure 1a and b).

Effects of type of seedling and soil fertility management practices on growth and yield components at Burka

Growth characteristics and yield components were

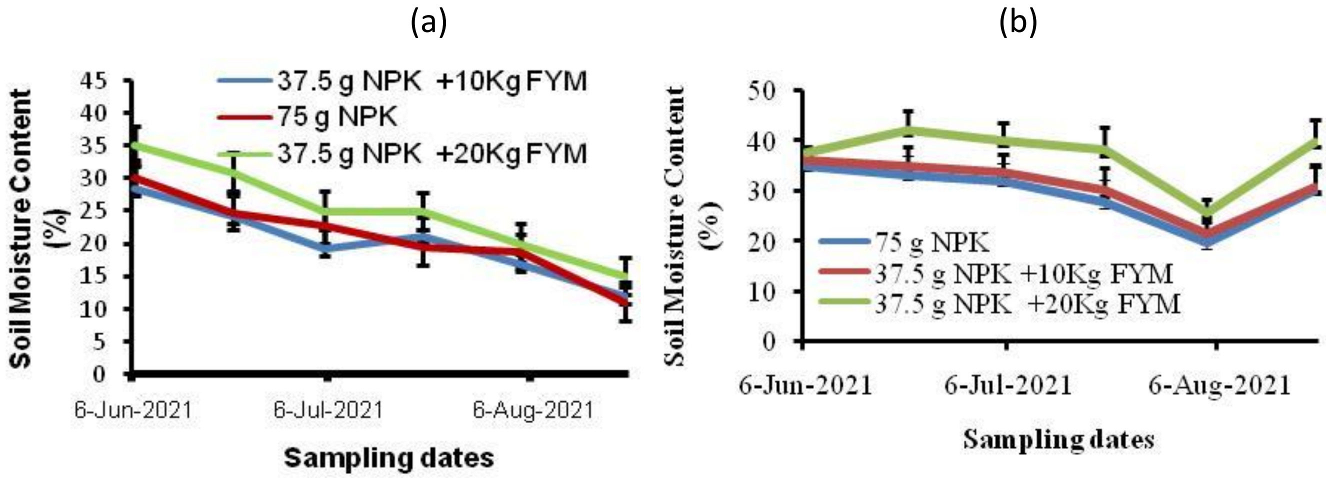

Figure 1. Soil moisture content due to different soil fertility management practices (a) Burka and (b) Lyamungu.

significantly (P ≤ 0.05) affected by the type of seedlings (Figures 2a, b, c and d), but insignificantly affected by the soil fertility management practices. Twelve months after planting, cutting-propagated plants produced plants that were significantly better (P≤ 0.05) than seeds and grafted propagated plants in terms of the number of primary branches, number of berry clusters, number of internodes, plant height, canopy width and stem girth. However, after 22 months of planting, plant height, stem girth and canopy width did not differ significantly between grafting and seeds propagated plants but the two differed significantly from the cuttings propagated plants.

Effects of type of seedling and soil fertility management practices on growth and yield components at Lyamungu

The type of seedlings (cutting, seed and grafting) produced growth characteristics and yield components that are significantly different (P ≤ 0.05) (Figures 3a, b, c and d). During the twelve months of growth, cuttings propagated plants produced significantly (P≤ 0.05) tallest coffee plants with a wider canopy and a greater number of primary branches than coffee plants propagated through seeds and grafting. However, grafted-propagated plants significantly differed (P≤ 0.05) from the other two types of seedlings (seeds and cuttings) in terms of stem girth during the first 12 months after planting, On the other hand, after 22 months of growth stem girth did not differ significantly (P≥ 0.05) among the three types of seedlings. Furthermore, insignificant (P≥0.05) difference between growth characteristics and yield components as a result of soil fertility management practices were observed.

Effects of type of seedling and soil fertility management practices on root: shoot ratio at Lyamungu and Burka

Moreover, the results indicate a significant difference in root:shoot ratio across the time in both sites (Figures 4a and b). Twelve months after planting coffee plants propagated by cuttings, seeds and grafting varied significantly (P≤ 0.05) in terms of root:shoot ratio at Burka and Lyamungu sites. The study also revealed a lack of significant difference (P≥ 0.05) in root:shoot ratio between seed and grafted propagated plants 22 months after planting, however, the two types of seedling differed significantly from cuttings propagated plants at the Lyamungu site. At the end of 22 months after planting most cuttings-propagated plants had root:shoot ratio ranging between 1:8 and 1:9.5 and seed propagated plants were 1:5 and 1:8 while grafted propagated plants ranked last in root:shoot ratio ranging between 1:4.5 and 1:6. Furthermore, 22 months after planting there was no significance difference of root:shoot ratio between seeds and grafting propagated plants at Lyamungu, however, the root:shoot ratio of the grafted propagated plants was significantly different from that of cuttings propagatedplants

Coffee yield

There was a significant difference (P≤ 0.05) between the coffee yield produced by cuttings-propagated plants and coffee yield produced by seed and grafted propagated plants at Lyamungu and Burka (Figure 5). Cuttings-propagated plants had the highest yield during the study period ranging between 1800 to 2800 Kg ha^{-1} green

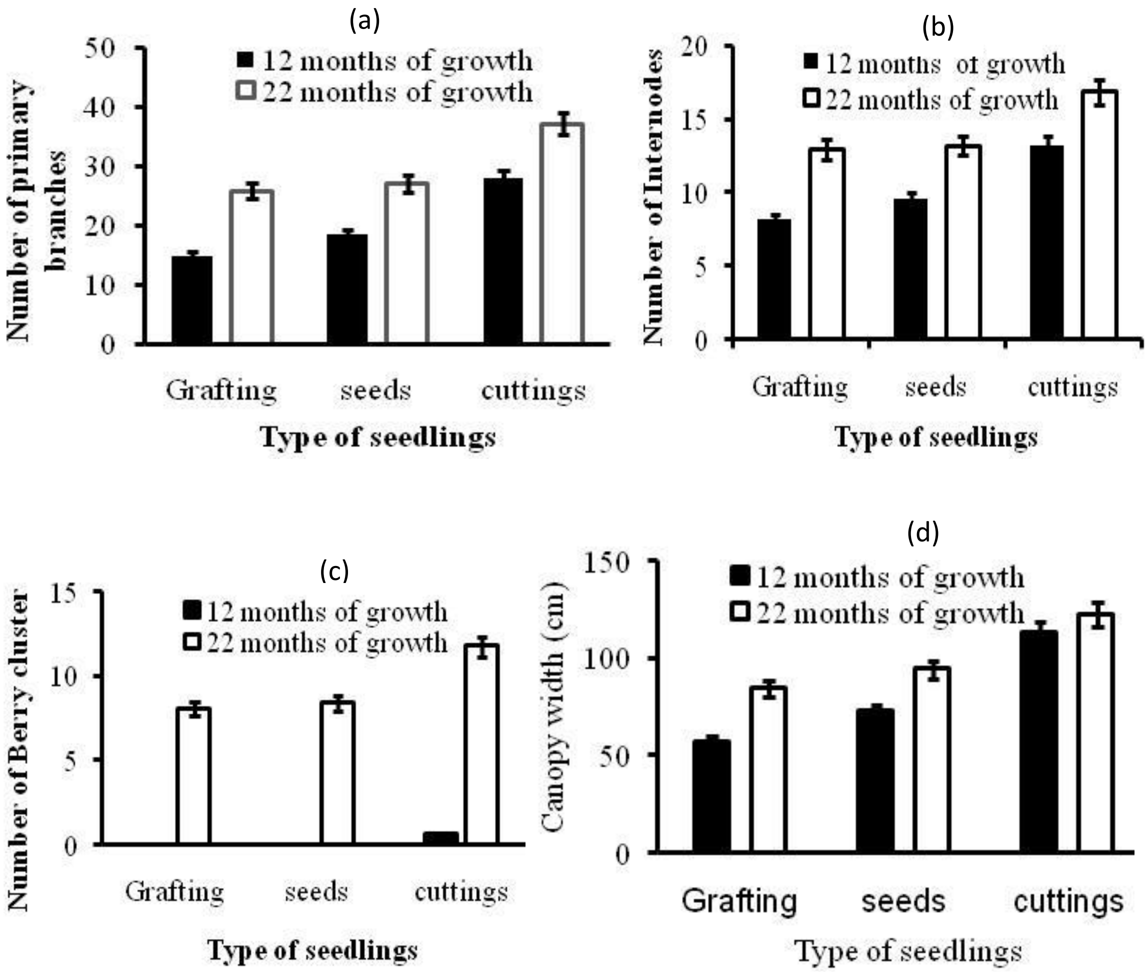

Figure 2. Effect of types of seedlings (cuttings, seeds and grafting) on the number of primary branches (a) number of internodes number of (b), number of berry clusters (c) and canopy width (d) at Burka site.

coffee at the Burka site and 3000 to 3600 Kg ha^{-1} green coffee at the Lyamungu site. The majority of seed-propagated plants had green coffee yields ranging from 1400 to 1600 and 1800 to 2800 Kg ha^{-1} at the Burka and Lyamungu sites, respectively. Furthermore, grafted-propagated plants had the lowest coffee yield which ranged from 600 to 800 kg ha^{-1} at the Burka site and 700 to 1700 Kg ha^{-1} at Lyamungu (Figure 5).

Furthermore, despite the lack of significant difference ($P \geq 0.05$) between soil fertility management practices and seedling types, the combination of cuttings-propagated plants and half dose of inorganic fertilizer plus 20 Kg of FYM produced the highest coffee yield at Lyamungu and Burka sites. Similarly, the combination of 37.5 g of NPK and grafted propagated plants resulted in a higher yield at Burka while at Lyamungu grafted propagated plants combined with 37.5 g NPK produced higher yields. A significant difference in green coffee (Kg ha^{-1}) was observed between the Lyamungu and Burka sites (Table 2).

DISCUSSION

The superiority of cutting propagated plants when compared with grafted plants can be due to the fact that these three types of seedlings were established at the same time in the sense that the roots from both types of seedling would be of similar age, therefore at the time when the KP-423 seeds to be used as the rootstock were sown, it was the time that cuttings seedlings were also established. KP-423 coffee seedlings were grafted with an improved compact coffee variety when they were five months and it took three months after grafting for the new growth to start. When the grafted seedlings were recovering from the injury of grafting their counterpart cuttings were growing in the nursery and increasing their biomass. Therefore, it is possible that at the time when

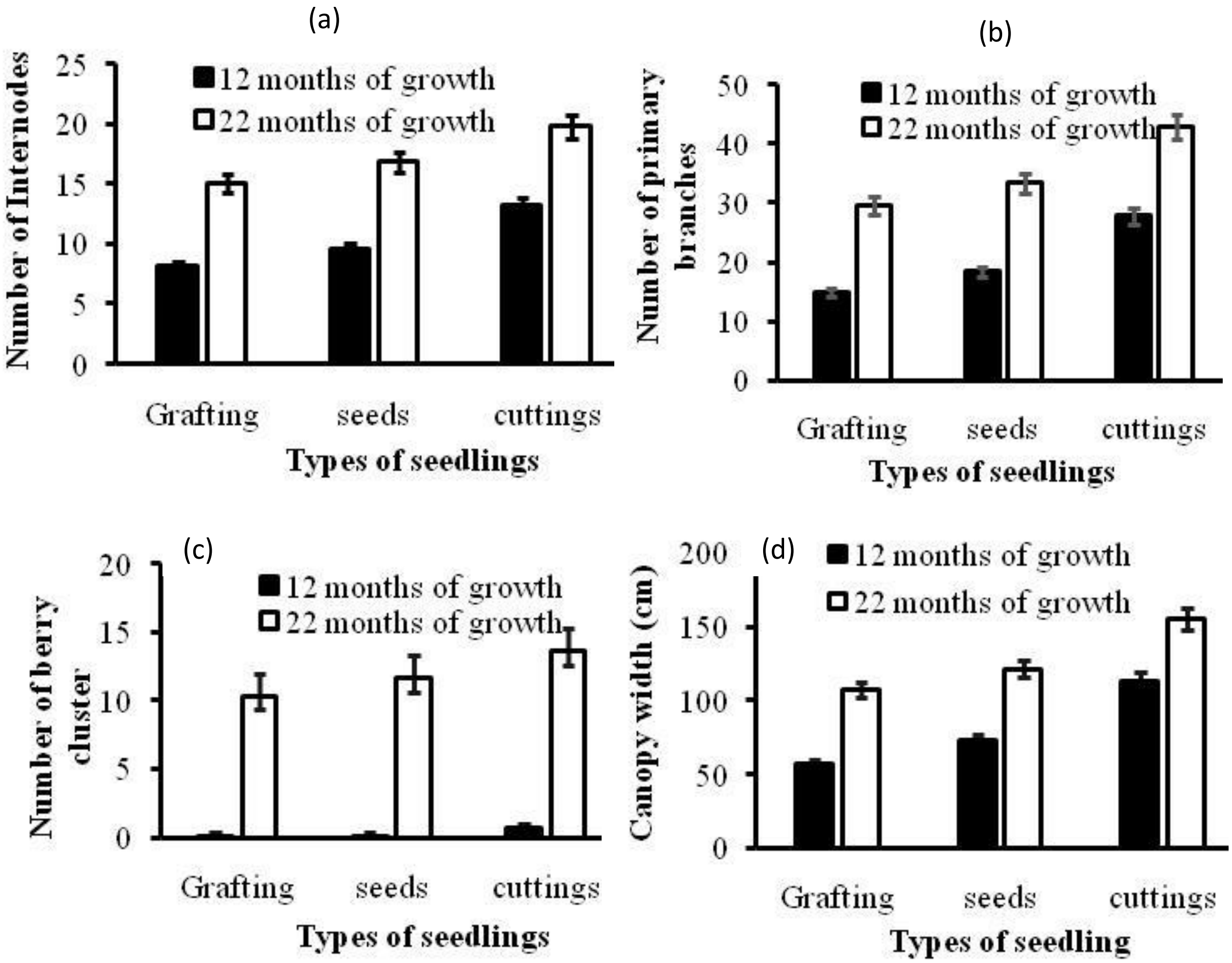

Figure 3. Effect of types of seedlings (cuttings, seeds and grafting) on the number of internodes (a), number of primary branches (b), number of berry clusters (c) and canopy width (d) at Lyamungu site.

the seedlings were established in the field, cuttings-propagated seedlings had enough reserve which was directed to produce biomass for the aerial parts, allowing cutting-propagated plants to excel in all growth characteristics against the same grafted material. This finding is in agreement with that of Partelli et al. (2014). However, our findings are in contrast with that of Andrade Junior et al. (2013) where in their study they found conilon grafted plants to be superior to cuttings propagated plants. In the study of Andrade Junior et al. (2013), cuttings seedlings were established 90 days after the establishment of the rootstock. Therefore, at themoment of grafting on day 90, there was already a rootstock radicular system that had exhibited satisfactory growth. Thus, it is possible that the entire reserve of the graft was directed to produce biomass for the aerial parts, ensuring their expressive growth against the same clone materials. Gemmel et al. (1991), indicated that differences resulting from these types of seedlings tend to decrease over time as the trees mature. Therefore, caution should be exercised when the studies are conducted in young trees.In their study, Carvalho et al. (2008) found that plants propagated through vegetative methods had better plant characteristics than seed-propagated ones. Such, studies have also shown that plants with higher height tend to have a higher number of plagiotropic branches (Carvalho et al., 2008). The findings of this study also show that cuttings-propagated plants entered the reproductive stage earlier than seed and grafted-propagated plants. Partelli et al. (2014), pointed out that plants derived from cuttings have earlier production capability. Thus, these plants were able to develop a higher number of productive (plagiotropic) branches sooner than seed and grafting-propagated plants. The plagiotropic branches of a coffee plant present several nodes where the flower buds will be formed and then fruits (Vezy et al., 2020). Therefore, the plagiotropic branches have a direct relationship with the difference in

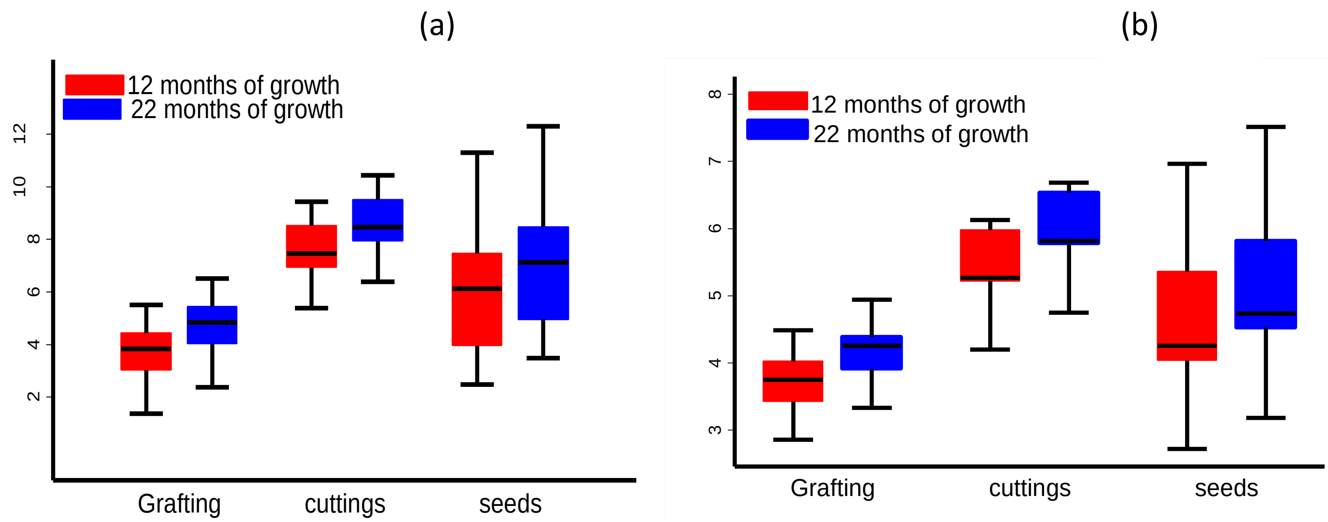

Figure 4. Effect of cutting, seeds and grafted propagated coffee plants on root: Shoot ratio at Burka (a) and Lyamungu (b) sites.

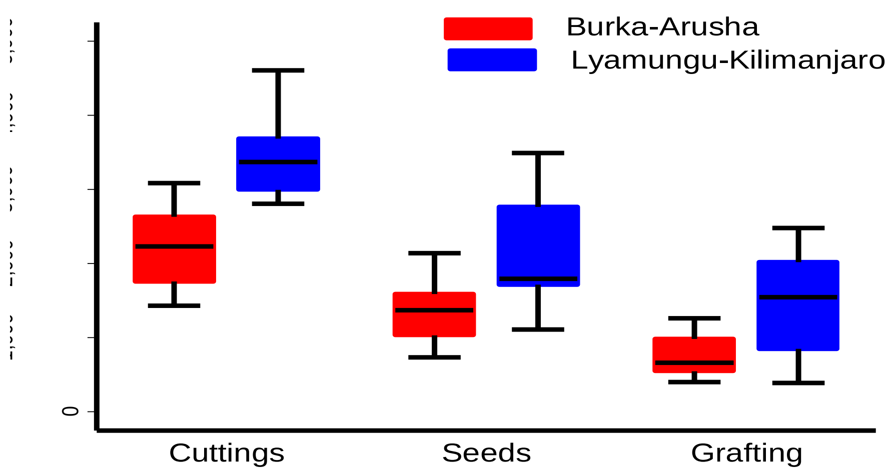

Figure 5. Effect of types of seedlings on coffee yield.

yield obtained in the three types of seedlings. The findings of this study indicate also an increase in root:shoot ratio across time, a characteristic of vegetation in early successional phases as the plants were still young and the upper part of the plants was more developed than the roots. There is no fixed "(tops to roots) ratio" in coffee trees, but generally, the ratio of tops to roots may be figured to be 8:1 for a matured coffee trees of 7 years old (Guiscafré-Arrillaga and Gómez, 1938). In this study cuttings propagated plants at 12 months attained the root:shoot ratio of 1:9.5. This may lead to imbalanced growth biomass between the roots and the shoots. Other studies have also indicated that a few cuttings in the field may exhibit allometric growth, exhibiting uneven relationships between their aerial parts and radicular systems and in many cases resulting in the death of the plants. Bragança et al. (2010) also observed sigmoidal growth for conilon coffee where there is no balance between the foliar area and the total biomass of the plant. Furthermore, the combination of FYM and half dose of inorganic fertilizer produced growth and yield characteristics that are comparable with the recommended inorganic fertilizer rates. The comparative performance of integrated fertilizer to inorganic fertilizers has also been reported by Nyalemegbe et al. (2010) and Chemura et al. (2014) who concluded that combining poultry manure with inorganic fertilizers resulted in similar yields in rice as those obtained from using inorganic fertilizers alone. Moreover, Maro and Mbwambo (2020) in their study to explore the behavior and usability of the

Table 2. Comparison of green coffee (Kg ha^{-1}) at Burka and Lyamungu.

Treatment		Green coffee yield Kg ha^{-1}	
Type of seedling	**Fertilizer options**	**Lyamungu**	**Burka**
Cuttings	75 g of N.P.K (20:10:10)	3502.56	2194.72
Seed	75 g of N.P.K (20:10:10)	2090.16	1468.96
Grafting	75 g of N.P.K (20:10:10)	1333.0	771.22
Cuttings	35.7 g of N.P.K (20:10:10) + 10 Kg FYM	3214.21	2095.62
Seed	35.7 g of N.P.K (20:10:10) + 10 Kg FYM	1944.22	1050.42
Grafting	35.7 g of N.P.K (20:10:10) + 10 Kg FYM	1513.28	690.44
Cuttings	35.7 g of N.P.K (20:10:10) + 20 Kg FYM	3603.06	2296.75
Seed	35.7 g of N.P.K (20:10:10) + 20 Kg FYM	2224.98	1528.45
Grafting	35.7 g of N.P.K (20:10:10) + 20 Kg FYM	1437.8	804.47
Mean		2318.147	1433.45
Standsrd error		294.96	209.39
t-test			2.32 (0.035)

new model SAFERNAC over the coffee growing areas in Tanzania found that the difference in yield between NPK 160:80:80 alone and a combination of NPK 80:40:40 (half dose) plus 5 tons' manure was not significant. Moreover, according to Mbwambo et al*.* (2021), there is limited knowledge of the extent to which the current agronomic practices can bring about the resiliency of coffee cropping systems. Therefore, long-term experiments are important to generate a data set that will allow the quantification of stability for different agronomic management practices. Yield stability cannot directly be measured in a single field experiment in a single year, it must be assessed based on measurements of yield over years and locations (Reckling et al., 2021). Using field experiments to predict outcome such as that of “what if” scenarios are costly and time-consuming, especially for perennial crops like coffee. Crop growth models may be used to simulate the relationship between plants and the environment to predict the expected yield for applications such as crop management and agronomic decision-making, as well as to study the potential impacts of climate change on crop productivity. (Kasampalis et al., 2018).

CONCLUSION AND RECOMMENDATIONS

Integrated nutrient sources can provide sufficient nutrients to the three types of seedlings (cuttings, grafting and seed) for healthy coffee growth just as the recommended rates of inorganic fertilizer. Thus, the use of integrated fertility management could be the most attractive option given that apart from providing nutrients to the coffee plants the package also helps in improving water retention properties of the soil. Cuttings-propagated plants under the age of 4 years with the same rooting age perform better in the field than seeds and grafted propagated plants by producing plants with better characteristics in terms of plant height, plant vigour, canopy width, number of berry clusters, number of internodes and number of primary branches. The yield of cutting-propagated plants under the age of 4 years if established at the same time with seeds and grafted propagated plants is significantly higher than that of seed and grafted-propagated coffee plants. The presence of tap-root (seeds and grafts) or lack thereof (cuttings) has little effect if any on the growth and yield of Arabica coffee under the age of 4 years. However, cuttings-propagated plants have indicated imbalanced growth between the above-ground parts and the root biomass.

The study recommend a longer experimental period to be conducted to satisfactorily monitor the response of the types of seedlings propagated through seed, grafting and cuttings above the age of four years assuming that at a later age, the coffee tree will have reached its maximum production and so more nutrients and water will be required. Generally, long-term experiments are important to generate data sets that will allow the quantification of stability for different agronomic practices. Yield stability, for example, has to be measured over years and locations and not just in a single year. Using field experiments to predict such outcomes from long experiments is costly and time-consuming, especially for perennial crops like coffee. Crop growth models may be used to simulate the relationship between plants and the environment as well as study the potential impacts of climate change on crop productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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