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Effect of Different Watering Regimes on Agro-morphology of Selected Coffee Genotypes

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Authors' contributions

This work was carried out in collaboration between all authors. The research project was conducted by author MWK, a student at Kenya Methodist University. The contribution of the co-authors was as follows: Authors DM and BMG assisted greatly in the development of the concept note for this study and together with author JJC provided technical advice on design and layout of experiment. Author BMG analyzed and interpreted the data. Author MWK prepared the manuscript assisted by author BMG in consultation with authors DM and JJC. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The aim of this study was to determine the effect of different watering regimes on selected coffee genotypes and to evaluate drought tolerance among selected coffee genotypes. The study also aimed at determining the optimum watering interval for these genotypes under high temperature conditions.
Study Design: Completely Randomized Design (CRD) with 3 replications.
Place and Duration of Study: The experiment was conducted in a greenhouse at Coffee Research Station in Ruiru, Kenya between October and December 2012.
Methodology: A total of 11 coffee genotypes were used in this study. These comprised of *Coffea canephora* (Robusta), one wild accession and nine *Coffea arabica* genotypes. Six months old seedlings of the test genotypes pre-germinated and transplanted in black polythene bags were obtained from the Coffee Research Station experimental nursery. The seedlings were placed on raised benches in the green house and each potted seedling represented a plot. The seedlings were watered with 0.3 liters of water per pot at six watering regimes applied as follows: watering after every 2 days, 4 days, 7days, 14

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days, 21 days and no watering at all. Morphological data on leaf number, number of nodes and plant height were recorded at the start of the experiment and after every 7 days until termination of the experiment. Root to shoot biomass ratio was also computed as percentage at the end of experiment. The data were subjected to analysis of variance (ANOVA) at 5% level of significance. Least Significance Difference ($LSD_{5\%}$) was used to separate the means.
Results: Significant difference on change in leaf number, number of nodes, plant height and percent root: shoot biomass was observed among the genotypes. Growth was found to decrease as water stress increased.
Conclusion: It was concluded that there is a potential for selection for drought tolerance from a diverse population of coffee genotypes. The most promising genotypes were West Pokot accession and tall Arabica genotypes such as SL34.

Keywords: Coffee; drought; high temperature; Kenya.

1. INTRODUCTION

Coffee is the second most traded commodity in the international agricultural trade after oil [1] and it represents a significant source of income to farmers in Kenya. Arabica coffee accounts for more than 62% of the world coffee production [2] and 90% of the world coffee market [3]. Robusta coffee accounts for the rest. Coffee production is fundamental for over 50 developing countries, for which it is the main foreign currency earner [4]. Kenya produces Arabica coffee that is classified within the Colombian milds known for balanced acidity and body with pleasant distinctive aroma [5]. He attributed the reputable quality of Kenyan coffee to, among others, favorable climatic conditions and cultivation of varieties with proven genetic constitution. In Kenya, the main coffee growing areas ranges from low to high altitude (1200 m to over 1700 m above sea level) [6,7]. However, in the recent years coffee cultivation in Kenya has been shifting to environment unsuitable for its production since the land that has been traditionally used for coffee production is being taken by other more profitable enterprises.

Coffee is indigenous to African regions characterized by abundantly distributed rainfall and atmospheric humidity frequently approaching saturation [8,9]. For this reason, coffee probably evolved as ‘water spender’ species [10]. Coffee is therefore a highly environmentally-dependent crop and an increase of a few degrees of average temperature and/or short periods of drought in coffee-growing regions can substantially decrease yields of quality coffees [9]. It was also observed by Chaves et al. [11] that early plantations of coffee were under shade hence coffee evolved as an understory shrub showing all physiological and structural characteristics of a shade adapted plants. However, shaded coffee is increasingly being abandoned due to the high yielding potential of unshaded coffee thus increasing the demand for water usage. These changes driven by combination of elevated temperatures and increased occurrence of water deficit caused by altered rainfall patterns resulting from climate change scenarios are expected to enhance the vulnerability of coffee to drought.

The global warming caused by increase of greenhouse gas emissions (carbon dioxide and methane) in the atmosphere is causing wide changes in atmospheric events resulting to climate change [9]. These include, shifting of optimal growing zones, changes in rainfall (amount and distribution) changes in dynamics of crop diseases and pests, loss of agricultural land due to either rising sea levels and/or desertification [6,9]. The combined effects of this phenomenon have critical impacts on coffee production. The study carried out by DaMatta and Ramalho [12] showed that the plants requires a relatively high and constant supply of moisture that favors root development and absorption of nutrient. Both Arabica and Robusta coffee species grow well in regions where average rainfall is between 1500mm to 2300mm [9]. However, most of the growing areas fall short of this rainfall and therefore the plant experiences moisture stress which tends to contribute to low productivity. These limitations are expected to become increasingly important in several coffee growing regions due to the recognized changes in global climate and also because coffee cultivation has spread towards marginal lands, where water shortage and unfavourable temperatures constitute major constraints to coffee yield [12,6,9].

Researchers are being challenged to be better prepared by breeding varieties that will cope with the impacts of drought and high temperatures [13] and repackage and promote climate change mitigation strategies [14,6]. In some countries, research on developing drought tolerant coffee varieties for climate change adaptation has started. In Brazil plant breeders have registered considerable success in selecting some promising Robusta clones with relatively high bean yields and low year-to-year variation of bean production under rain-fed conditions [8,12]. In Kenya and Uganda, basic research is ongoing whereby coffee genotypes are being subjected to drought and heat stress by denying them sufficient water in a greenhouse to detect and select those that are tolerant. The genotypes will then be tried in hot and dry areas. Some Arabica coffee genotypes that are known to have some drought tolerance attributes include Tanganyika Drought resistant genotypes DR I and DR II (Trench, unpublished), and Indian cultivar Sln 9 [15]. The objective of this study was to determine the effect of different watering regimes on selected coffee genotypes and to select drought tolerant genotypes that can be exploited in future drought tolerance breeding programmes. The study also aimed at determining the optimum watering interval for these genotypes under high temperature conditions.

2. MATERIALS AND METHODS

2.1 Test Genotypes

A total of 11 coffee genotypes were used in this study. These comprised of *Coffea canephora* (Robusta), one wild accession collected from West Pokot in Western Kenya and designated WPA and 9 *Coffea arabica* genotypes. The Arabica genotypes included 7 Kenyan commercial cultivars (Batian 1, Batian 2, Batian 3, Ruiru 11, K7, SL28 and SL34) and 2 Indian commercial cultivars (Selection 5A and Selection 6). Three different entries of Ruiru 11 seedlings propagated through seeds, rooted cutting and tissue culture were used making a total of 13 entries.

2.2 Experimental Layout and Design

The experiment was laid out in a greenhouse at Coffee Research Station in Ruiru, Kenya between October and December 2012. The layout was a two factorial experiment (genotypes and watering regimes) in a Completely Randomized Design (CRD) with 3 replications. Six months old seedlings of the test genotypes pre-germinated and transplanted in black polythene bags were obtained from the Coffee Research Station experimental nursery. The potting bags were perforated and measuring 9” x 5” with a potting media comprising of soil, river sand and well decomposed farm yard manure at a ratio of

3:2:1. Triple Super Phosphate (TSP) fertilizer was added in the media at a rate of 125g/15 kg of potting mixture. The seedlings were placed on the raised benches in the green house and each potted seedling represented a plot. The seedlings were watered with 0.3 litres of water per pot at six watering regimes applied as follows:

1. Watering regime1 (WR1) – watering after every 2 days (Standard)
2. Watering regime 2 (WR2) – watering after every 4 days
3. Watering regime 3 (WR3) – watering after every 7 days
4. Watering regime 4 (WR4) – watering after every14 days
5. Watering regime 5 (WR5) – watering after every 21days
6. Watering regime 6 (WR6) – no watering at all (control)

Other abiotic factors (temperature, light, relative humidity and the potting media) were uniform.

2.3 Data Collection

Determination of temperature and relative humidity (RH) was done using a Thermo-hygrograph which recorded maximum and minimum temperatures and RH. The instrument was placed next to the experiment as shown in plate 1.

Plate 1. Thermo-hygrograph used to record temperatures and RH

The experiment was conducted for 8 weeks after which it was terminated for destructive determination of root: shoot biomass. The data on morphological parameters were recorded as follows:

2.3.1 Number of nodes per seedling

The number of nodes per seedling was determined by physical count at the start of the experiment and after every 7 days until termination of the experiment. The change in number of nodes was calculated at the end of the experiment.

2.3.2 Leaf number per seedling

The number of fully unfolded leaves per seedling was determined by physical count at the start of the experiment and after every 7 days until termination of the experiment. The change in number of leaves was calculated at the end of the experiment.

2.3.3 Plant height

The plant height (cm) was measured vertically using a meter rule from the base to the tip of the seedling at the start of the experiment and after every 7 days until termination of the experiment. The change in plant height was calculated at the end of the experiment.

2.3.4 Root: Shoot biomass %

At the end of the experiment, the seedlings were destructively sampled for determination of root to shoot ratio. This was achieved by dissecting the polythene bag using a razor blade and carefully separating the seedlings from the soils with all the roots intact. Any soil attached on the roots was shaken off. Each seedling was then separated into shoot and root, oven dried at 70ºC for 48 hours and weighed using a sensitive balance. Root to shoot biomass ratio was computed as percentage using the following formula:

$$\text{Root:Shoot biomass \%} = \frac{\text{Root dry weight}}{\text{Shoot dry weight}} \times 100$$

2.4 Data Analysis

The data was subjected to analysis of variance (ANOVA) using XLSTAT version 2012 and effects declared significant at 5% level. Least Significance Difference (LSD_5%) was used to separate the means.

3. RESULTS

The average maximum and minimum temperature recorded during the experiment period averaged 33.07ºC and 12.71ºC respectively while the maximum and minimum RH averaged 73.24% and 28.54% respectively. Significant ($P<0.05$) difference in change in number of nodes was observed among the genotypes (Fig. 1a). West Pokot accession developed the highest number of nodes within the experiment period followed by SL34 while Ruiru 11 rooted cutting produced the least nodes. There was no difference in node growth between the three Batian cultivars (B1, B2 and B3) and K7. Other varieties that recorded similar node growth were Ruiru 11 from both seed and tissue culture, Robusta, SL28 and one of the Indian varieties, Selection 6. The genotypes also recorded significant ($P<0.05$) variation in change in number of leaves (Fig. 1b). K7, SL34, Batian 1 and West Pokot accession produced the highest number of leaves followed by Batian 2, Batian 3 and Selection 5A. There was no significant difference in leaf number between Ruiru 11 from seed, tissue cultured Ruiru 11, Robusta and SL28. Ruiru 11 rooted cutting recorded the lowest leaf growth.

Significant (P<0.05) difference in change in plant height was observed among the genotypes (Fig. 2a). There was no significant difference in change in plant height between Batian 2, Batian 3, SL28 and SL34. These four genotypes recorded the greatest change in plant height followed by Selection 6, West Pokot accession and Batian 1 in that order. Robusta and Ruiru 11 rooted cutting recorded the smallest change in plant height (Fig. 2a). Other varieties that recorded similar change in plant height were K7 and Ruiru 11 from both seed and tissue culture. The genotypes also recorded significant (P<0.05) variation in root to shoot biomass (Fig. 2b). The highest root/shoot biomass was observed in tissue cultured Ruiru 11 and Ruiru 11 from rooted cutting followed by Selection 6. The West Pokot accession recorded the lowest root/shoot biomass.

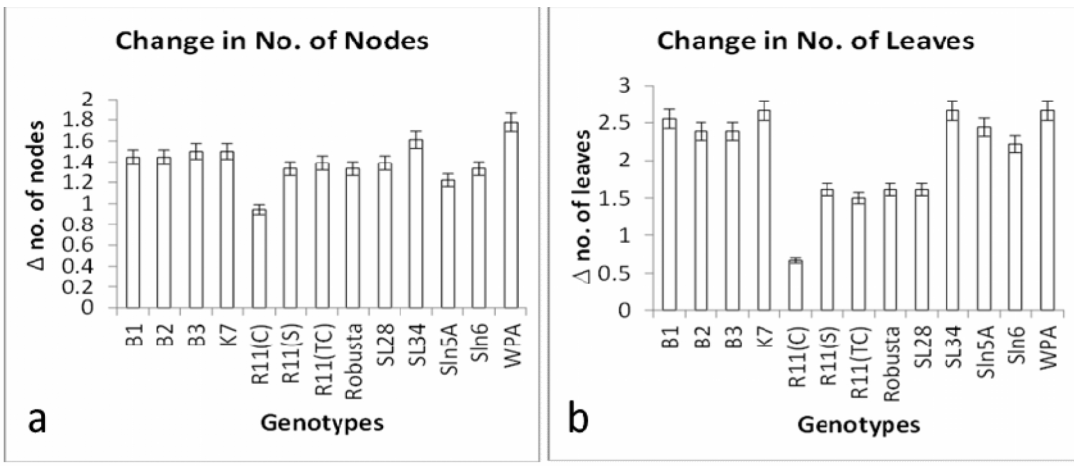

Fig. 1. Variation in node and leaf growth among the coffee genotypes

Key: B1 = Batian 1, B2 = Batian 2, B3 = Batian 3, R11(C) = Ruiru 11 rooted cutting, R11(S) = Ruiru 11 from seed, R11(TC) = Tissue cultured Ruiru 11, Sln5A = Selection 5A, Sln6 = Selection 6, WPA = West Pokot accession

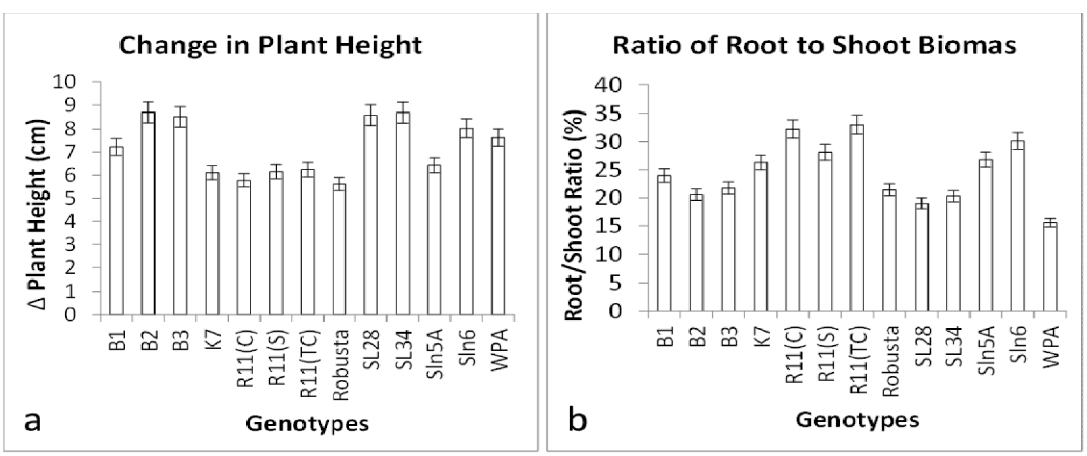

Fig. 2. Changes in plant height and root: shoot biomass variation among coffee genotypes

Key: See the key under figure 1.

There was a significant (P<0.05) effect of watering regimes on change in number of nodes (Fig. 3a), change in number of leaves (Fig. 3b), change in plant height (Fig. 4a) and root/shoot biomass accumulation (Fig. 4b). Water regime 1 (watering after every 2 days) recorded the highest node and leaf growth while water regime 6 (no watering at all) recorded the lowest growth. Water regimes 2 and 3 did not differ significantly in change in number of nodes (Fig. 3a) although their effects on leaf growth were significantly different (Fig. 3b). There was a significant (P<0.05) effect of watering regimes on change in plant height (Fig. 4a) and root/shoot biomass (Fig. 4b). The greatest change in plant height was observed in water regime 1 which was not significantly different from that of water regime 2. The effect of water regimes 4 and 5 (watering after 14 and 21 days respectively) on plant height was not significantly different. The smallest change in plant height was observed in water regime 6 (Fig. 4a). Unlike plant height, the highest root/shoot biomass was observed in water regimes 3 and 4 (watering after 7 and 14 days respectively) while water regimes 1, 2 and 5 did not differ significantly in root/shoot biomass accumulation. The lowest root/shoot biomass was observed in water regime 6 (Fig. 4b).

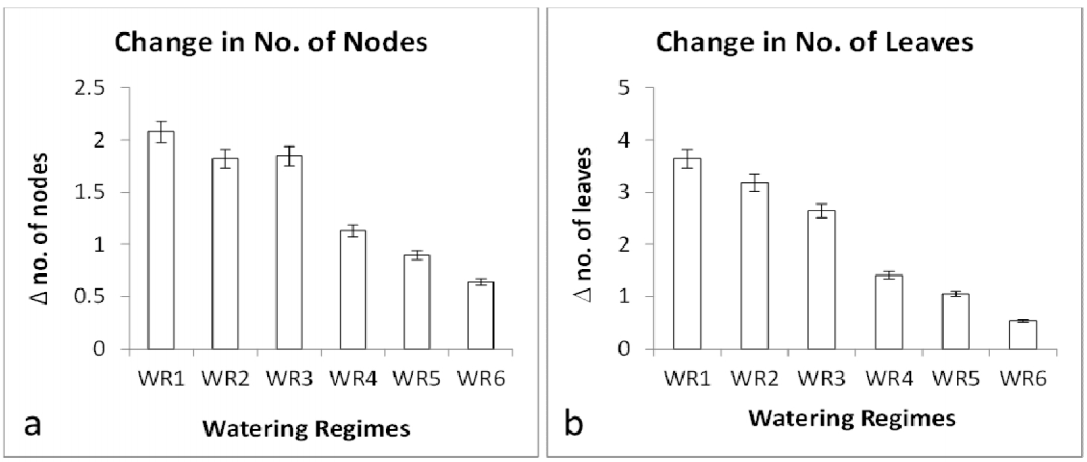

Fig. 3. Effect of watering regimes on node and leaf growth of coffee genotypes

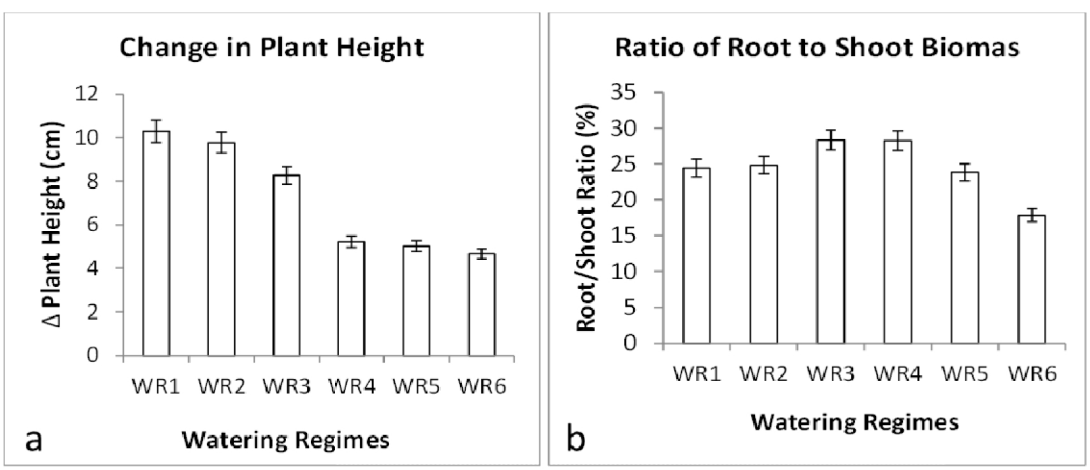

Fig. 4. Effect of watering regimes on plant height and root to shoot biomass of coffee genotypes

Regression analysis showed that there was a significant negative association between different watering regimes and change in number of nodes and leaves (Fig. 5a) as well as change in plant height (Fig. 5b). Therefore, the average plant growth decreased as water stress increased. However, root/shoot biomass was higher in moderately watered (WR3 and WR4) seedlings than in frequently watered (WR1 and WR2) and water stressed (WR5 and WR6) seedlings (Fig. 4b).

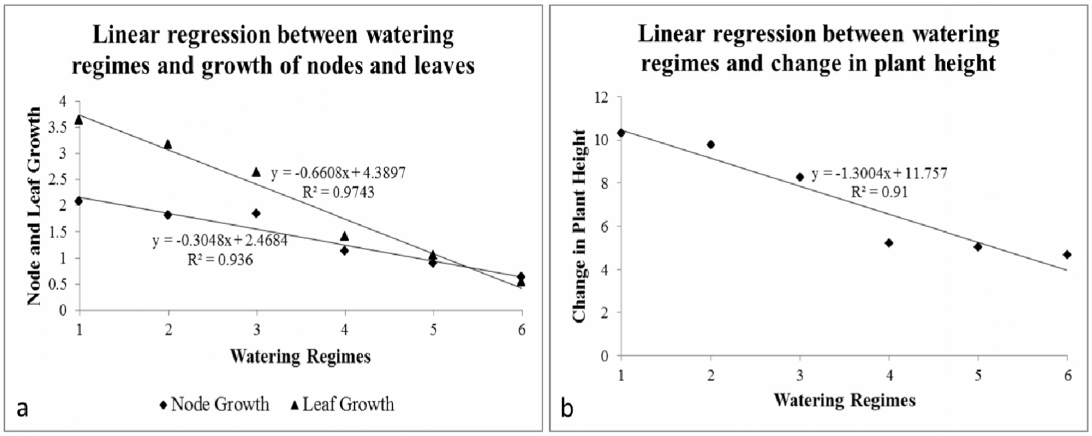

Fig. 5. Linear regression between watering regimes and growth of nodes, leaves and change plant height

4. DISCUSSION

Coffee growth is reportedly affected by both high and low temperatures [16,17]. The optimum mean annual temperature range for Arabica coffee is 18-21ºC while for Robusta coffee is 22 to 30ºC [12,9]. Continuous exposure to temperatures above this range could result in not only depressed growth but also in abnormalities such as yellowing of leaves and growth of tumors at the base of the stem [12]. On the other hand, exposure to low temperatures lowers stomatal conductance, photochemical efficiency of the photo system (PS) II, thylakoid electron transport rate, enzyme activity and carbon metabolism, as well as the photosynthetic pigment complex systems and membrane lipids [18,19].The high temperature conditions achieved in this study provided good selection conditions for both Arabica and Robusta coffee considering that experts are foreseeing a temperature rise of up to 5.8°C in the tropical area by the end of the 21st century [20]. High levels of relative humidity such as those recorded in this experiment are normally observed under greenhouse conditions. Although relative humidity is known to influence many physiological processes of coffee tree, it is not generally thought to play an important role as thermal and moisture conditions in defining potential yield or ecological limitations for this crop [20].

There was a significant effect of reduced irrigation frequency on seedlings growth as determined by reduced change in plant height and reduced leaf and node growth. This could reflect the variations among the coffee genotypes in growth rate which in turn depend upon stem nature (stiff or flexible) and size of water conducting tissue [21]. The observed effect of reduced irrigation frequency on growth was in agreement with the finding of Worku and Astatkie [3] that every growth characteristics in coffee seedlings is affected by drought stress. Therefore with decline in water availability the growth of coffee plants is reduced.

Reduction in the growth of coffee under field and/or greenhouse conditions due to drought stress or inadequate irrigation has also been reported by various authors [17,2,22]. Reduced growth signifies that fewer nodes are present for flower formation and subsequent fruit production [23]. There was less growth in Robusta and different types of the dwarf cultivar Ruiru 11 than in the tall genotypes. These genotypes could therefore be less suitable for areas that do not receive frequent rainfall. Among the tall genotypes, the Indian cultivars (Selection 5a and Selection 6) recorded the lowest growth under reduced irrigation. This was attributed to different production systems in India where coffee is mostly grown in southern India under monsoon rainfall and heavy shade conditions.

In this study, the genotypes recorded significant variation in root to shoot biomass. Similar findings were reported by Pinheiro et al. [8], Worku and Astatkie [3] and Kufa [21]. The highest root/shoot biomass was observed in different types of the compact Ruiru 11 cultivar. This genotype appeared to be the most affected by reduced irrigation since it also recorded the smallest growth. Unlike Ruiru 11, higher growth but smaller biomass was observed in the taller genotypes, WPA, SL34, SL28, K7, B1, B2 and B3. The tall stature of these genotypes suggests that their root system may be more extensive than for compact genotypes. Worku and Astatkie [3] found that relatively more biomass was allocated to roots than to stems for intermediate and compact varieties, and to stems than to leaves and roots of open varieties. Ludlov [24] reported that drought stressed coffee plants tend to have greater biomass allocation to the root than to the shoot, smaller leaf area and heavier leaves than well watered plants. Pinheiro et al. [8] also observed a deeper root system and larger root dry mass in drought tolerant than in drought sensitive Robusta clones. According to Quarrie et al. [25] and Damatta [26], drought adapted plants are often characterized by deep and vigorous roots. Root characteristics therefore play a crucial role in maintaining the water supply to the plant. Robusta accession used in this study appeared to be drought sensitive since it recorded both smaller growth and smaller root/shoot biomass.

Significant difference between watering regimes for root/shoot biomass was also observed. Higher root/shoot biomass was recorded in moderately watered seedlings (watering after 7 and 14 days respectively) than in water stressed and frequently irrigated seedlings. This partly concurred with the findings of Kufa [21] who reported higher root dry mass in drought-stressed than in well-irrigated seedlings. This response could suggest a drought-stress tolerance strategy investing more of the daily biomass production in the root system at the expense of the shoot system. Linear regression analysis between watering regimes and seedlings growth showed that for every increase in moisture stress there was a significant reduction in growth of the seedlings. According to Kufa [21], this response suggests a major mode of adjustment to reduced soil water demand by the coffee seedlings, at least in the early stages of soil moisture deficit irrigation, consisting of maintenance of nearly constant status on area basis through a reduction in growth rate. Meinzer et al. [27] also noted that close to accurate estimates of water requirements for coffee are crucial because too little water can substantially reduce growth without wilting.

5. CONCLUSION

The study provided information on the morphological response of different coffee genotypes to varying irrigation levels under high temperature condition. It was concluded that there is a potential for selection for drought tolerance from a diverse population of coffee genotypes. The most promising genotypes were West Pokot accession, and tall Arabica genotypes such as SL34. Robusta and Ruiru 11 were found to be less suited to drought and high temperatures. However, these results may not be conclusive enough since the experiment was conducted in a greenhouse set up. It would be necessary to assess the genotypes in a field set up especially in low rainfall areas.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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