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# Interactive Effects of Soil Moisture and pH on Early Growth of Bush Candle Tree (C*anarium schweinfurthii*)

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**SUMMARY**

An overexploitation of *Canarium schweinfurthii* (commonly known as the bush candle tree; family: Burseraceae) for fuel, medicine, food, and construction has resulted in a tremendous decline in its population in the Western Highlands Forest of Cameroon. The situation is exacerbated by a long latent period, which lowers the competitive ability of seedlings compared to rapidly germinating and fast-growing species. Investigating the responses of seedlings to environmental conditions in the ecosystem is crucial for developing strategies to enhance their growth. The aim of this study was to test the effect of moisture and pH on the early growth of *C. schweinfurthii*. Three-week-old plants were grown under three soil moisture regimes (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 % Field Water Capacity) and two soil pH levels (pH 7.0; pH 4.5 - 5.5). The treatments were laid out in a split plot design, with moisture as the whole plot and pH as the subplot. Measurements of growth were taken three months after the initiation of treatments. The data were subjected to split plot ANOVA and then Scheffe's test for mean separation. The high soil moisture regime significantly increased plant height, stem volume, number of leaves, and leaf area. The lower soil pH level suppressed height, stem volume, height-to-diameter ratio, number of leaves, and leaf area. There were significant effects of moisture × pH on height, stem volume, number of leaves, and leaf area, indicating that the effect of moisture depended on the pH treatment level. For instance, the increase in the number of leaves and leaf area due to the high soil moisture regime was limited only to seedlings in the higher pH treatment level. The findings of this study highlight the need to improve soil moisture and pH conditions in drier and acidic areas of the species' range in order to increase the growth potential of seedlings.

**Keyword:** *Canarium schweinfurthii*, Morphological growth, Overexploitation, Seedling

## INTRODUCTION

The establishment and survival of a forest plantation are highly dependent on factors such as planting material, edaphic factors, climatic conditions, and good silvicultural practices. Soil edaphic factors include the physical and biological properties of soil that result from biological and geological phenomena or from anthropogenic activities (Boyd and Rajakaruna, 2013). Soil chemical and physical properties affect the ecology and evolution of plants and their associated biota. Edaphic factors refer to soil properties such as soil type, soil structure, texture, pH, salinity, moisture, temperature, contents of organic carbon, nitrogen, and heavy metals. The most important of these factors include moisture, aeration, nutrient levels, pH, and soil temperature (Boyd and Rajakaruna, 2013; Furtak and Gałązka, 2019).

Soil acidity plays a significant role in biogeochemical processes within the natural environment. Consequently, soil pH is often described as the "primary soil variable" influencing numerous biological, chemical, and physical characteristics and processes that affect plant growth and yield (Neina, 2019). It is well established that soil pH impacts the availability and absorption of micronutrients, such as magnesium, which is crucial for the photosynthetic efficiency of plants (Dighton and Krumins, 2014).

Microbial processes, along with the solubility and accessibility of nutrients, are significantly influenced by pH levels. For instance, acidic soils typically offer greater availability of micronutrients for plants compared to neutral or alkaline soils, which often enhances plant growth (Lončarić et al., 2008). However, elevated levels of certain micronutrients and non-essential elements can become toxic to plants. In contrast, while the presence of various macronutrients increases in alkaline soils, the availability of phosphorus and specific micronutrients generally declines, potentially harming plant growth. Soil pH particularly affects various plant characteristics, including height, width, biomass, flower size and number, and pollen production (Jiang et al., 2017).

Soil moisture refers to the amount of water present in the surface layer of soil, which can be measured by either volume or weight. While water plays a significant role in soil formation, structure, stability, and erosion, its most crucial impact is on plant growth. The temporal and spatial distribution of soil water content varies based on several factors, including soil characteristics, vegetation type and density, evaporation rates—which are influenced by temperature—and the distribution of rainfall and irrigation in cultivated areas (Niemczyk et al., 2007). These factors also determine the types of biomes present and identify suitable areas for plant cultivation. The health of plants depends on the availability of water and nutrients in the soil, and different species have varying water requirements for growth and development (Yan et al., 2015; Ambebe and Tanwie, 2020). Additionally, soil water content affects pH levels, the permeability of solvents and gases, and nutrient accessibility (Wolińska, 2022). According to Asongwe et al. (2020), the soil in the wetlands of Bamenda has a pH range of 4.3 to 7.8. These physiological and chemical properties of wetlands are continually changing due to anthropogenic influences.

While these environmental conditions independently affect plant growth and development, it is important to recognize that abiotic factors change concurrently in natural ecosystems and have often interacted to affect plants in unpredictable ways. The combined effect may not directly reflect the sum of the individual effects (Ambebe and Dang, 2010; Agbor and Ambebe, 2023). Furthermore, plant responses to ecosystem conditions may be constrained by species. The aim of this study was to investigate the interactive effects of soil moisture and pH on the early growth of *Canarium schweinfurthii*.

## MATERIAL AND METHODS

### EXPERIMENTAL SITE

The entire test was conducted at the Reforestation Task Force (RETAFO) that has its nursery at Mile 6 Nkwen in the Bamenda III Subdivision. The Mezam Division of the

Northwest Region of Cameroon includes the Bamenda council area, which is divided into three subdivisions, one of which is the Bamenda III Subdivision. This subdivision is located between latitudes 6°15'0" and 6°25'0" North and longitudes 10°02'0" and 10°15'0" East. It also serves as a transport link to the divisions of Boyo, Ngoketunja, Bui, and Donga Mantung. To the west, it borders the Tubah Sub Divisional Council; to the north, the Bamenda I Sub-Divisional Council; to the east, the Bamenda II Sub-Divisional Council; and to the south, the Bafut Sub-Divisional Council. The municipality encompasses two distinct villages, Nkwen and Ndzah, covering a total land area of 67.9 km² (Mbanga, 2018).

Bamenda III includes the sloping lowlands of Nkwen, the Nkwen Escarpment separating Ndzah from Nkwen, and the Ndzah Plateau in the southeast. Along with other flatlands, it is also the location of several streams and waterfalls that run through the escarpment. Flooded areas connected to Bamenda's marshes make up the lowlands. The Guinea-Savannah climate, which has two different seasons, is what gives the Bamenda III Council region its unique climate. The wet season lasts from mid-March to mid-November, and the dry season lasts from mid-November to mid-March. The average annual temperature is 19.3 °C, and the mean annual precipitation is between 2,000 and 3,000 mm. This region also frequently experiences high winds and a layer of low clouds.

## EXPERIMENTAL DESIGN

The experiment followed as split plot design. The main plot was the moisture treatment and the sub plots were the pH treatments. There were three moisture regimes (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 %) and two pH levels (pH 7.0; pH 4.5 - 5.5). The moisture treatments were controlled by measuring the water content of the growing medium daily with a VG200 Soil Moisture Meter and then adding water to maintain the respective target moisture level in each pot. The growth medium of the acidic pH treatment was achieved by adjusting the pH of normal tap water (neutral pH) with dilute HCL (30%) before using to water the seedlings. In the process, the pH of the water was determined with a Soil pH Meter (GroLine - HI98168).Three month’s old *C. schweinfurthii* seedlings were potted individually in polythene bags filled with soil from the nursery, and 10 randomly assigned to each treatment combination. The experiment was carried out in a shade house roofed with transparent plastic sheets. There were two replications of each treatment combination. The experiment ran from 30 June to 30 September 2023.

## DATA COLLECTION

At the end of the experiment, three seedlings were randomly chosen from each treatment and replication for measurements. Plant height ($H$) was measured using a ruler as the distance from the base of stem (at the soil surface) to the tip of the apical bud while stem diameter ($D$) was measured using a Vernier caliper. The number of leaves per plant was recorded after which the leaf located midway the longitudinal axis of the canopy was selected for leaf area determination. The area of the particular leaf was obtained by summation of the leaf area of its individual leaflets as measured with a graph paper. After determining the ratio of plant height to stem diameter ($\frac{H}{D}$), values of the two parameters were used to calculate stem volume (*SV*) as per the following equation of Aphalo and Rikala (2003).

$SV = D^2H$

## STATISTICAL ANALYSIS

Utilizing probabilities plots and histograms and all of the data were visually analyzed for homogeneity of variance and normality. Split plot ANOVA was then used to examine the effects of pH, soil moisture content, and their interactions on the early growth. Scheffe's test was employed for means separation when the impact of moisture or a combination of treatments was considerable for a particular parameter. Every analysis was carried out at $\alpha = 0.05$ using Data Desk 6.01.

## RESULTS

### HEIGHT

There was a significant effect of moisture and pH on height of *C. schwienfurthii*. In addition, the interactive effect of the factors was significant for this parameter (Table 1). Values of height were highest at pH 7.0 under the high moisture regime and lowest at pH 4.5 – 5.5 under the low moisture level. Responses of height to treatments were statistically comparable for all the other treatments (Figure 1).

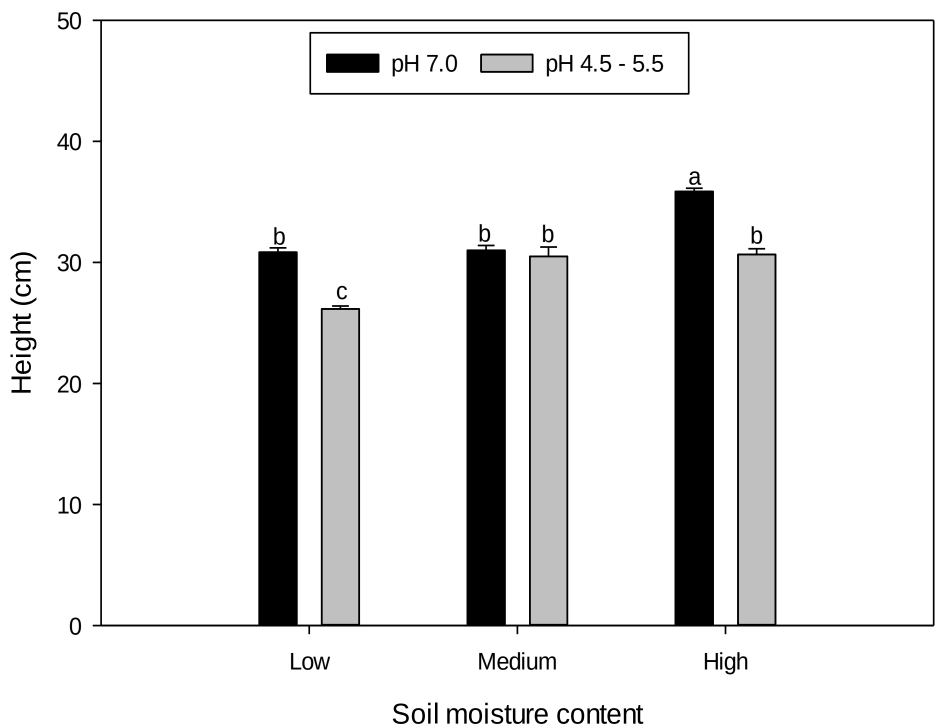


**Figure 1: Effects of soil moisture (low: 20 – 30 %; medium: 40 – 50 %; High: 60 – 70 % field capacity) and pH (pH 7.0; pH 4.5-5.5) on height of *Canarium schwienfurthii* seedlings. Bars represent Mean±SE. The letters above the bars indicate significant moisture × pH interactions. Means carrying different letters are different from each other.**

**Table 1: ANOVA p-values for the effect of soil moisture (Mst), pH, and their interaction on growth.**

| Source | Mst | pH | Mst×pH | Rp | Mst×Rp. | pH×Rp | Mst×pH×Rp |
|---|---|---|---|---|---|---|---|
| **H** | 0.0083 | 0.0459 | 0.0462 | 0.8535 | 0.7323 | 0.5806 | 0.5904 |
| **D** | ≤ 0.0001 | 0.5000 | 0.5000 | ≤ 0.0001 | ≤0.0001 | ≤ 0.0001 | ≤ 0.0001 |
| **SV** | 0.0003 | 0.0587 | 0.0292 | 0.6693 | 0.6986 | 0.3620 | 0.5222 |
| **H:D** | 0.0008 | 0.0349 | 0.0674 | 0.9621 | 0.7682 | 0.7395 | 0.6571 |
| **NL** | 0.6442 | 0.0704 | 0.0224 | 0.9286 | 0.133 | 0.9286 | 0.6578 |
| **LA** | 0.1804 | 0.0428 | 0.0034 | 0.2341 | 0.1389 | 0.1627 | 0.9443 |

H = height; D = stem diameter; SV = stem volume; NL = number of leaves: LA = leaf area; Rp = replication

**STEM DIAMETER**

Diameter was not significantly influenced by either pH or its interaction with moisture. In contrast, the main effect of moisture and all other treatment and replication related interactions were significant (Table 1).The medium moisture level significantly reduced stem diameter. On the other hand, the difference between the low and high moisture regimes for this parameter was statistically insignificant (Figure 2).

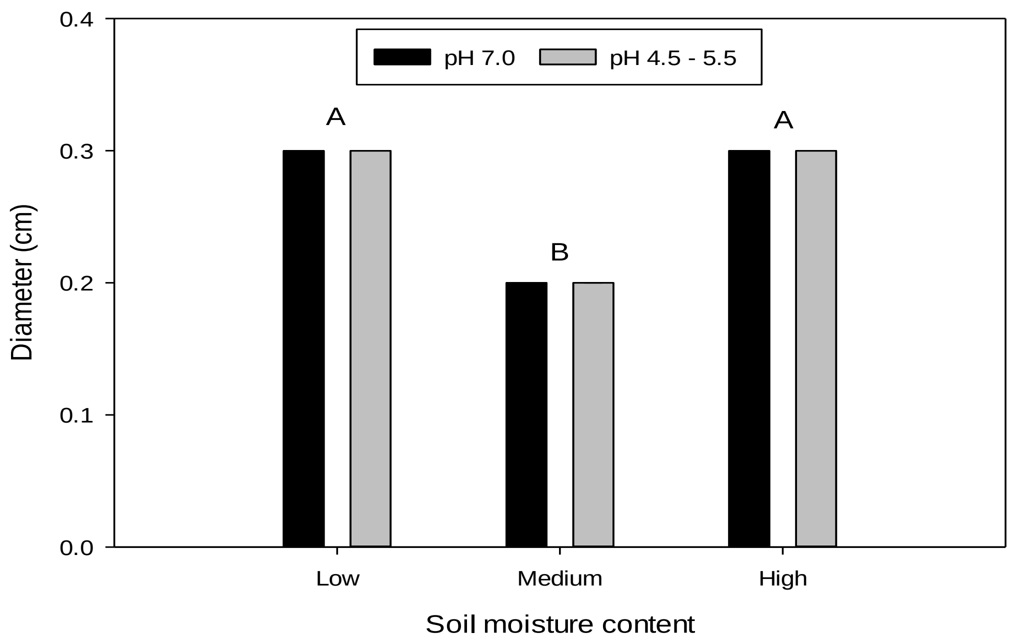


**Figure 2: Effects of soil moisture (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 % field capacity) and pH (pH 7.0; pH 4.5 - 5.5) on diameter of *Canarium schwienfurthii* seedlings. Bars represent Mean±SE. The letters above the bars indicate the effect of moisture. Means carrying different letters are different from each other.**

**STEM VOLUME**

Unlike pH, stem volume was significantly affected by moisture alone and its interaction with pH (Table 1). It was neither affected by replication nor its interaction with either of the treatments examined. The medium moisture regime suppressed stem volume to the same extent at each pH level. The parameter significantly increased from the low to the high moisture level for pH treatment levels. However, the pH 7.0 treatment resulted in higher values of stem volume than pH 4.5 - 5.5 at both the low and high moisture regimes (Figure 3).

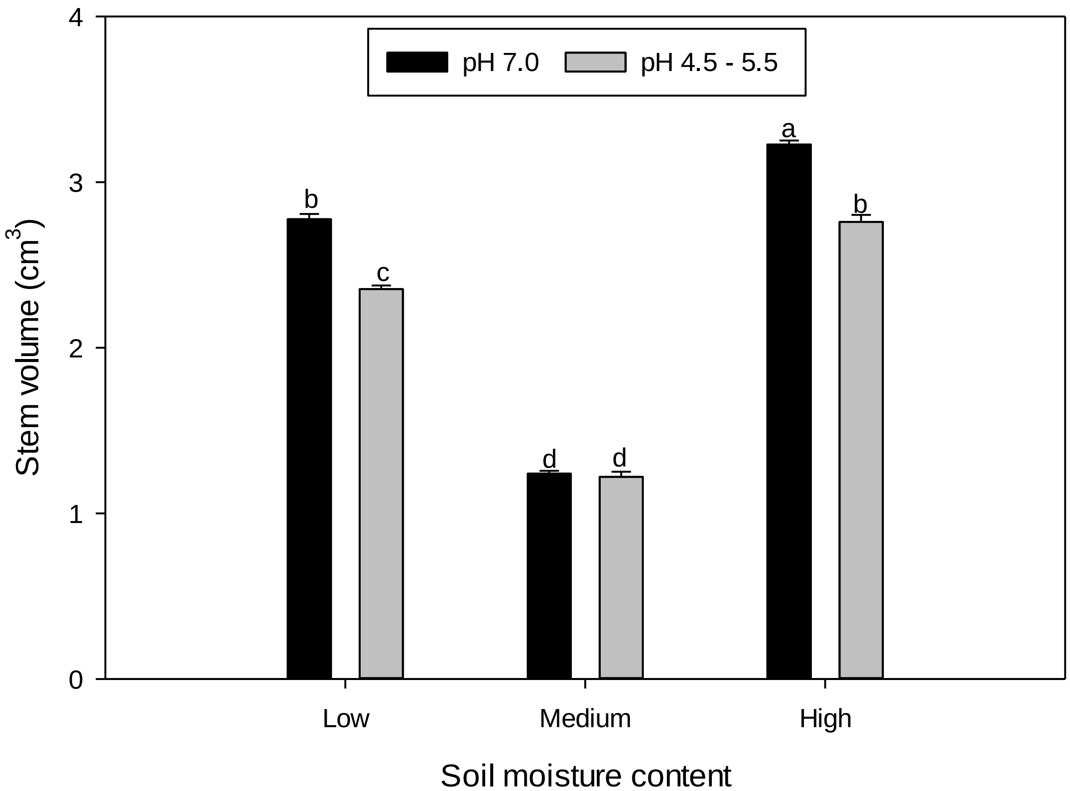


**Figure 3: Effects of soil moisture (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 % field capacity) and pH (pH 7.0; pH 4.5-5.5) on stem volume of *Canarium schwienfurthii* seedlings. Bars represent Mean±SE. The letters above the bars indicate significant moisture × pH interactions. Means carrying different letters are different from each other.**

**HEIGHT : DIAMETER**

There were significant main effects of height and diameter on the ratio of height to diameter but no a complete absence of a significant effect of interactions of the treatments (Table 1). No two moisture treatments showed similarity in the response of this variable, with values highest in the medium and lowest in the low moisture levels. As for pH, height:diameter was markedly increased by pH 7.0 (Figure 4).

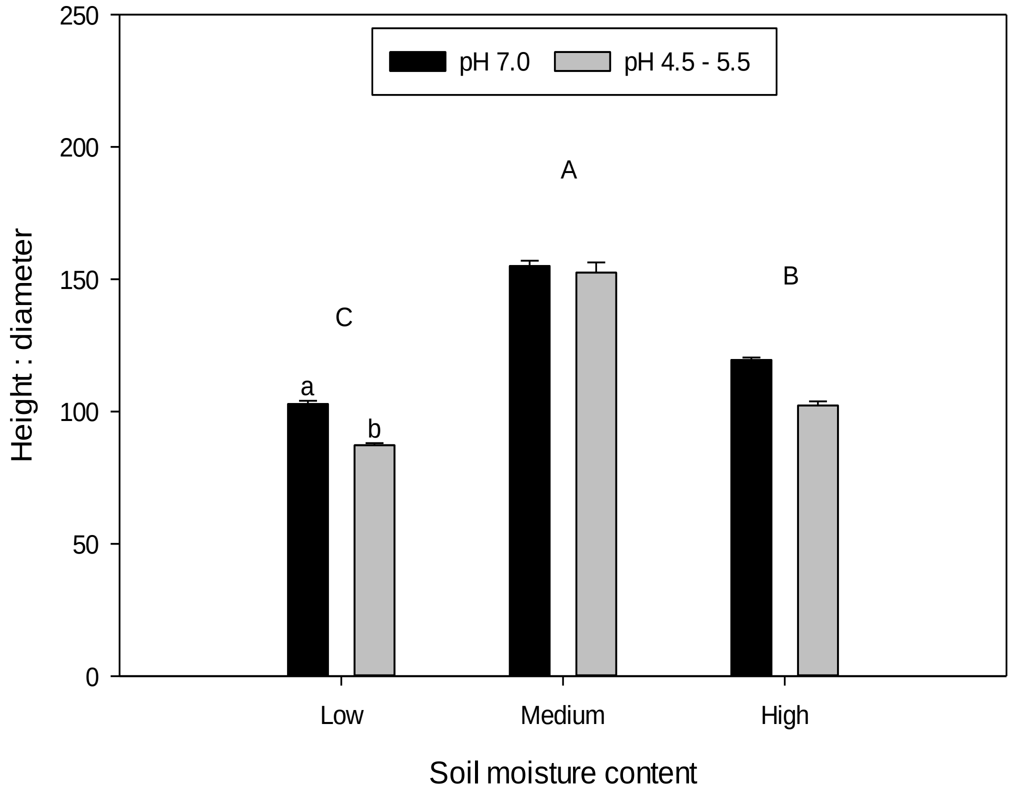


**Figure 4: Effects of soil moisture (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 % field capacity) and pH (pH 7.0; pH 4.5-5.5) on height:diameter of *Canarium schwienfurthii* seedlings. Bars represent Mean±SE. The upper- and lower-case letters above the bars indicate significant effects of moisture and pH, respectively. Means carrying different letters are different from each other.**

## NUMBER OF LEAVES

Number of leaves was neither affected by moisture nor pH as main factors. There was, however, a significant response of the parameter to moisture×pH interaction (Table 1). Number of leaves increased from low to high moisture regime exclusively at the pH 7.0 treatment level. However, the difference between the medium and either the low or high moisture regimes was not significant at this pH level. Similarly, there were no significant differences in number of leaves between any of the moisture treatments at pH 4.5 – 5.5 (Figure 5).

## LEAF AREA

Moisture as well as its interaction with pH significantly affected leaf area. The parameter was unaffected by any other treatment alone or combined (Table 1). Values of leaf area were highest at pH 7.0 and lowest at pH 4.5 – 5.5 both at the high moisture regime. The same pattern was maintained at the other moisture levels with rather a narrower gap in response between the pH treatments. Leaf area declined from the high to the low moisture regime at pH 7.0, with responses being comparable between the medium and either the low or high moisture treatments. At pH 4.5 – 5.5, on the other hand, leaf area increased only from the low to medium moisture level (Figure 6).

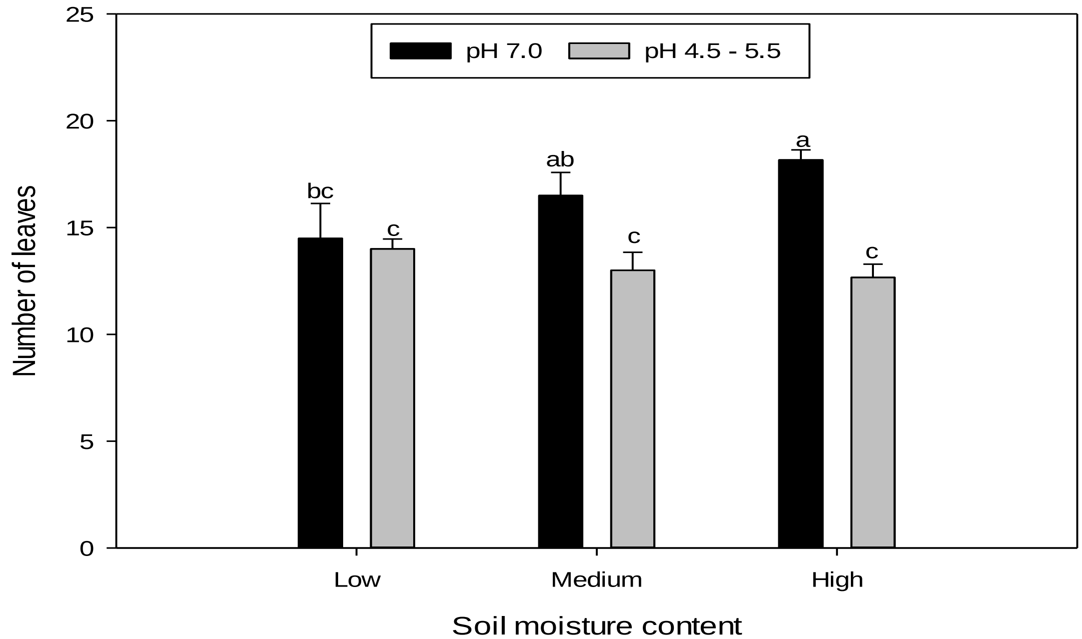


**Figure 5: Effects of soil moisture (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 % field capacity) and pH (pH 7.0; pH 4.5-5.5) on number of leaves of *C. schwienfurthii* seedlings. Bars represent Mean±SE. The letters above the bars indicate significant moisture × pH interactions. Means carrying different letters are different from each other.**

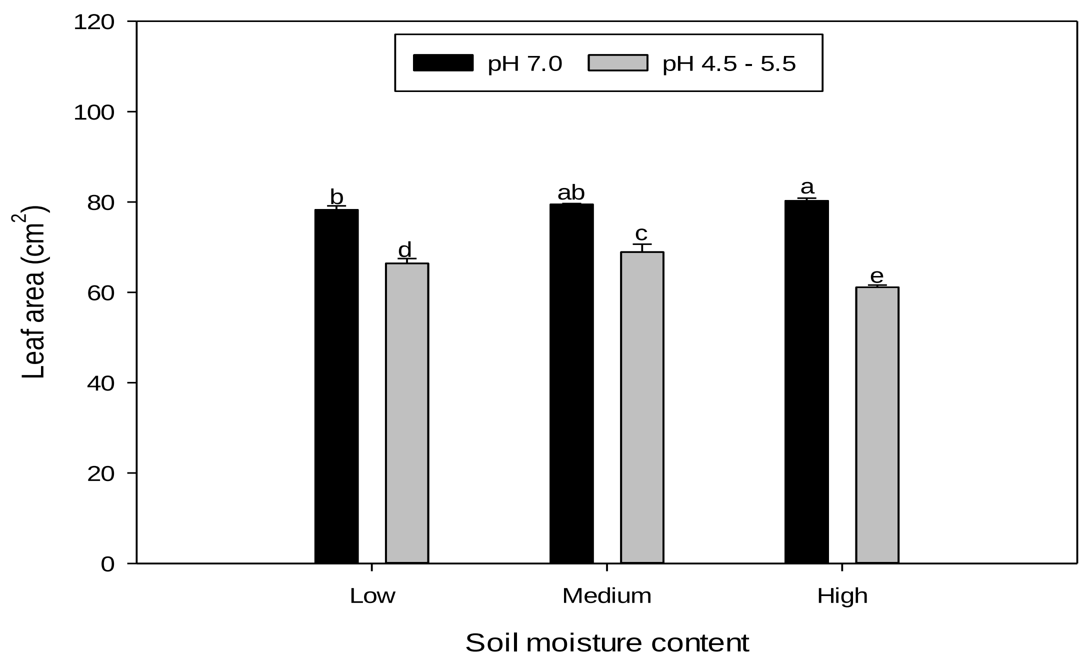


**Figure 6: Effects of soil moisture (low: 20 – 30 %; medium: 40 – 50 %; high: 60 – 70 % field capacity) and pH (pH 7.0; pH 4.5-5.5) on leaf area of *Canarium schwienfurthii* seedlings. Bars represent Mean±SE. The letters above the bars indicate significant moisture × pH interactions. Means carrying different letters are different from each other.**

## DISCUSSION

In this study, increasing soil moisture had a positive significant effect on the height, stem diameter, stem volume, leaf area and number of leaves of *Canarium schweinfurthii*. Souza *et al*. (2012); Ambebe and Tanwie (2020) and Muriithi *et al*. (2022) have also reported increases in height, stem diameter, stem volume, and number of leaves of plant species following augmentations in soil moisture availability. Increasing soil moisture levels helps increase nutrient uptake by roots leading to increased levels of photosynthesis and consequently increased plant height. Although the higher pH level was generally more beneficial to growth than its lower counterpart in this, study there were variable moisture x pH interactions corroborating the view that interactive effects of treatments may be more suitable that main effects in drawing conclusions on plant responses to ecosystem conditions (Ambebe, 2014; Lee *et al.,* 2017). Furthermore, pH positively interacted with increasing moisture levels, enhancing plant height, stem volume, number of leaves, and leaf area. One intriguing finding of this investigation is that the beneficial impact of increased moisture availability on the growth of *Canarium schweinfurthii* is confined to plants growing under favorable pH conditions. The pH is influenced by the ratio of water to soil in a suspension; as this ratio increases, pH also tends to rise. In soils with higher pH values, dilution helps maintain pH stability through the hydrolysis of basic cations (Thomas, 1996). Soil pH significantly impacts the availability, transport, and solubility of minerals essential for plant nutrition. In acidic soils (pH $\leq$ 5.5), key nutrients such as phosphorus (P), potassium (K), and nitrogen (N) become less accessible, leading to nutrient deficiencies. Conversely, certain microelements like aluminum (Al), iron (Fe), and manganese (Mn) become more bioavailable and potentially toxic (Ginocchio et al., 2009; Soti et al., 2015).

These findings explain why plant height, stem diameter, number of leaves and leaf area were reduced in the acidic pH when compared to the neutral pH soil in this study. The results that stem diameter was least under the medium moisture treatment cannot be fully explained; it must have, however, resulted from some yet unidentified error in the collection of data. The latter contention is supported by the fact that there were significant effects of replication and replication related interactions exclusively for this particular parameter but no other.

## CONCLUSION

Although increasing soil moisture and pH enhanced the growth of *Canarium schweinfurthii* seedlings, significant interactions were found between these factors, indicating a dependence on each other's effects. For certain variables, the extent of increase due to high soil moisture availability was higher at neutral pH levels rather than acidic ones, while for others, the increases were only observed at neutral soil pH. The findings of this study emphasize the importance of improving soil moisture and pH conditions in the drier and more acidic areas of the species' range in order to maximize the growth potential of seedlings.

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