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Growing *Curcuma longa* for Rhizome Production on Diverse Arable Soil Types in Cameroon: Agronomic and Microbial Parameters

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Abstract

The aim of this work is to assess soil types' effect on the growth and production of *Curcuma longa* rhizomes. The Rhizome of *Curcuma longa* was grown in a greenhouse in pots for seven months on different soil types. Physico-chemical analyses of the different soils were carried out. Collar diameter, the height of the plants, and yield of rhizome were measured. Total microbial density, number of spores, and root colonization of arbuscular mycorrhizal fungi (AMF) from these soils were assessed. Results show that soils are sandy clay loam, clay sandy, clay, acidic (pH 4.16 to 6.62), and have a C/N ratio from 6.10 to 19.83. Nitrogen (N) is between 0.49 to 2.41 g/kg, available phosphorus (P) between 2 to 16 ppm, Organic matter (OM) from 14.6 to 51.4 g/kg. Total microbial density is between 2 to 16 × 10^6 Cell/mm^3, number of AMF spores *in situ* between 4 to 67 spores/g of soil. The frequency of root colonization is between 47% to 78%. The average growth and rhizome production are between 5 to 15 g/plant. All the results obtained show that the soils with clay to sandy clayey loam texture, medium acidity (pH 5.5 - 6.6), low C content (7.3 - 9.6 g/kg), low N content (0.49 - 1.13 g/kg), good C/N ratio (<14), low to medium AMF sporulation (28 - 41 spores/g) and AMF root colonization between 55% to 78% are the most suitable for the cultivation and rhizome production of *Curcuma longa* in Cameroon.

Keywords

Production, *Curcuma longa*, Soils, Agronomic, Microbial

1. Introduction

Turmeric (*Curcuma longa*) is a rhizomatous herbaceous perennial plant belonging to the family *Zingiberaceae*, widely used as a spice and extensively applied in the traditional systems of Ayurveda, Unani, and Siddha, the various folk medicines [1]. Turmeric is a perennial therapeutic spice that can reach a height of about 1 m. Its palmated leaves are oblong in shape, alternate, and arranged in two rows, which are further divided into leaf sheath and later form false stem, petiole (50 - 115 cm long), and leaf blade (76 - 115 cm long) [2]. Plants have roughly segmented, yellow to orange, cylindrical, and aromatic rhizomes that measure 2.5 - 7.0 cm in length and nearly 2.5 cm in diameter [2]. The primary rhizome is mostly pear-shaped known as "bulb" while the secondary one is cylindrical [3].

Turmeric requires heavy nutrients for higher yields [4]. Especially, higher nitrogen (N) application is effective for rhizome production [5]. Soil microorganisms and their activities play important roles in the transformation of plant nutrients from unavailable to available forms and have many metabolic qualities related to soil fertility improvement [6]. Some studies [7] [8] have shown the place of arbuscular mycorrhizal fungis (AMfs) and endophytes in the culture and production of *Curcuma longa*.

Several factors like nutrition, cultivation practices, and plant genotype affect morphological parameters of turmeric, such as leaves, shoots rhizomes, and rhizomes yield. Plantation time varies with climatic conditions, turmeric varieties, and planting materials. It requires a warm and humid climate and can be grown in diverse tropical conditions within a temperature range of 20˚C - 30˚C and with a rainfall of 1500 mm or more per annum. Turmeric thrives in different soil types ranging from light black loam, red soils to clay loams and rich loamy soils having natural drainage and irrigation system [8]. Leaf spot disease and rhizome rot are the main diseases of *Curcuma longa*. Pests of turmeric include shoot borers, leaf-eating insects, sucking insects, and nematodes [9]. At the establishment of the culture, it's taken from two to six weeks for the germination of the turmeric plants; after which comes a period of active vegetative growth. Flowering and rhizome development begins about five months after planting. The vegetative growth period takes place 7 - 10 months after the seedlings of germination. Once this period has elapsed, the leaves turn yellow and the harvest is ready [10].

In Cameroon, there are two production campaigns (March and August). The culture is carried out mainly on ridges 20 - 25 cm high and 45 - 50 cm wide separated by channels 25 - 30 cm wide. Usually between 900 and 1300 kg of seed is used per ha. We used rhizomes with 3 to 5 eyes as seeds and planted 30 to 40 cm within and between the rows. Large amounts of manure (10 tons/ha) are applied. In addition, NPK is applied at an amount of 100 kg/ha of nitrogen, 175 kg/ha of phosphorus, and 100 kg/ha of potassium. The main pests encountered are shoot borers, leaf-eating insects, and nematodes. Generally, the rhizomes are harvested from the 8th month after sowing.

Currently, India is the world's largest producer, consumer, and exporter of

turmeric followed by China and several other subcontinent countries [11]. Turmeric is one of the spices whose demand on the international market is exponential. Indeed, it benefits from strong demand on the natural product markets whether it is as a colorant or as a spice or medicine. These exchanges are intended for a multitude of countries (Malaysia; Japan; United States, etc.). We can deduce that the turmeric market is internationalized and there is no monopolization of production by a dominant importing country. However, the production of this spice in the tropics, especially in central Africa and particularly in Cameroon, is still low and little rarely known too.

With such great economic potential, it would be important to increase the production of *Curcuma longa* in the tropics, where there are all conditions required for its growth. Thus, ameliorate the knowledge about *Curcuma longa* production, and particularly determine the most suitable type of soil for its production might create an interest in this promising culture for the major producers across the country, enabling this one to increase the production and to become competitive in the international market

The present work aims to contribute to the increase in the production of *Curcuma longa* in Cameroon and to assess the effect of soil types on the growth and production of *Curcuma longa* in greenhouses. The idea is to use different soil to produce *Curcuma longa* in order to determine the best soils for rhizome production.

2. Materials and Methods

2.1. Soil Sampling

Experiments were conducted with soils collected from five agroecological (I, II, III, IV, and V) zones of Cameroon. Djarengol in the far north region; Touboro in the North region; Bini in the Adamawa region; Dschang in the West region; Nkometou in the Centre region; Bertoua in the East region; Douala in the Littoral region and Ebolowa in the South region labeled Dj, Tb, Bi, Ds, Nk, Be, Dl and Eb respectively. All the soils come from fallow soils with particular crop history. Maize on the soils of Nk, Be, and Eb; bean for the soil of Ds; Plantain for the soils of Dl; Onion from Tb and Dj soils; Yam for the soil of Bi. Each site was randomly sampled (0 - 20 cm) at 30 different places of approximately 0.2 ha, and bulked. Once arrived at the laboratory the soils were sieved (<2 mm), air-dried, and their physical and chemical parameters were determined. Soil reserved for the greenhouse experiments was sieved and mixed with sand in the proportions 1:2 or ¾:¼ depending on the cases that have been prepared then homogenized using a shovel to obtain the substrate.

The experiment was carried out in the greenhouse of the soil microbiology laboratory of the University of Yaoundé I. The device was on wooden shelves specially designed to support the experimental devices in order to reduce contamination from Earth. It consists of 96 pots divided into 8 lots of 12 pots, which represent the 8 treatments containing the soil samples from the agroecological

zones. We introduced substrate into each pot for 288 plants (3 plants/pot). We did not add fertilizer during the growth of the plants and they were not protected against diseases or pests.

2.2. Soil Physico-Chemical Analyses

The physicochemical parameters of each soil were determined before the growth of Turmeric plants. Particle size (three fractions) was determined by the hydrometer method [12]. pH was measured in a 1:2.5 (soil: demineralized water) ratio using a glass electrode. Organic C (C), and total N (N) were determined by dry combustion at 950˚C in a C, N, H analyzer. Available phosphorus (P) was determined after wet digestion by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Organic matter (OM) was determined according to the formula of [13].

2.3. Biological Analyses

The analysis of microbial density was carried out by using the suspension-dilution technique. 10 g of dry compost was aseptically added to a 250 ml Erlenmeyer flask containing 90 ml of sterile distilled water (after drying at 30˚C overnight). This mixture is stirred mechanically using magnetic bars for 30 minutes. The suspension obtained corresponds to the 10^{-1} dilution. A series of dilutions were carried out until dilution 10^{-3}. A drop of 1 ml of 10^{-3} dilution was deposited on a Malassez cell for observation under a microscope at objective 40. The cells were counted on five rectangles arranged diagonally in the Malassez cell and the number of cells was determined using the following formula: $N = (n \times Fd)/a \times v$. With n the number of cells per unit of volume; a number of counting units counted; Fd the dilution factor; v the volume of a metering unit (0.01 mm^3).

Endophytes were isolated from *Curcuma longa* rhizomes according to a method described by [14].

The number of spores was evaluated before sowing and after harvesting the rhizomes. Using a sieve with mesh sizes between 0.2 mm and 0.04 mm, the spores were extracted according to the protocol of [15]. 300 ml of water were poured into a jar containing 100 g of soil and then homogenized; then poured into the sieve. This maneuver was repeated three times, rinsed with a water hose, then, the soil was retained on the mesh of the sieve until all the water had drained out and cleared water was obtained after which was poured in a box, beforehand labeled, and finally counted using a stereomicroscope.

Calculate the number of spores/g according to the formula: $N = n \times 27.76/100$ with n the average of the number of spores of the three repetitions.

Root fragments of 1 to 2 cm are harvested in each treatment 40 days after sowing according to the devices. They are then introduced into test tubes and treated according to the method of [16]. The harvested roots were cut and then washed with tap water; they were then cleared in 10% KOH for 30 min at 90˚C in a water bath. The roots were washed again 3 times with tap water, then acidi-

fied in 1% HCl for 30 min at 90˚C. in a 0.05% acid fuchsin solution added to the solution consisting of lactic acid-glycerol-water (4-1-1), then the coloring solution was emptied from the test tube and discoloration was done in a solution of lactic acid-glycerol-water (4-1-1) for at least 24 hours. The colored root fragments (30 fragments/treatment) were mounted in parallel on slides and covered with coverslips in groups of 10 and observed under the microscope. 3 repetitions were carried out.

2.4. Growth Parameters and Yield

The height of the stem and the diameter of the collar were measured from the seventh week after sowing until the sixteenth week. Production of the rhizomes was evaluated at the end of the test with an automatic balance.

2.5. Statistical Analysis

The data obtained were subjected to a one-way analysis of variance (ANOVA) followed by Duncan-test at 5% level. Spearman's rho correlation test at the 1% cutoff was performed between the results of the growth parameters and those of the rhizome yield. The data were analysed using SPSS Software Package 16.0.

3. Results

3.1. Soil Physico-Chemical Analyses

Table 1 reports the physical properties of the soil. The particle size analysis of the soil samples studied demonstrated the presence of sand, clay and loam in

Table 1. Physical properties of soils used for *Curcuma longa* growth in greenhouse.

Localities (Region)	Physical properties (%)			Soil type
	Sand	Loam	Clay	
Bertoua (East)	50.96	11.35	37.69	Clay-sandy
Bini (Adamawa)	26.96	17.35	55.69	Clay
Djarengol (Far North)	24.96	29.35	45.69	Clay
Douala (Littoral)	60.96	3.35	35.69	Clay-sandy
Dschang (West)	56.89	9.42	33.69	Sandy-clay-loam
Ebolowa (South)	60.89	9.42	29.69	Sandy-clay-loam
Nkometou (Centre)	50.96	5.35	43.69	Clay-sandy
Touboro (North)	24.96	17.35	57.69	Clay

different proportions. In the localities of Bini, Bertoua, Djarengol and Dschang the percentage of sand was 26.96%, 50.96%, 24.96%, 58.89%, that of clay 55.69%, 37.69%, 45.69%, 33.69% and that of loam 17.35%, 11.35%, 29.35%, 9.42% respectively. In addition, in the localities of Douala, Ebolowa, Nkometou and Touboro, the percentage of sand was 60.96%, 60.89%, 50.96%, 24.96%, that of clay 35.69%, 29.69%, 43.69%, 57.69% and that of loam 3.35%, 9.42%, 5.35%, 17.35% respectively. Finally, the USDA triangle for the classification of soils allows us to classify them as follows: sandy clay loam such as the soils of Dschang and Ebolowa; clay-sandy soils such as Nkometou, Bertoua, and Douala; clay soils, notably those of Djarengol, Touboro, and Bini.

Table 2 presents the results of the chemical parameters of the soils studied. Overall, the soils of Ebolowa, Nkometou, Bertoua and Bini are the most acidic with respective values of pH 4.16, 4.92, 5.4 and 5.5. These are followed by the soils of Douala, Djarengol, Dschang, and Touboro with respective values of pH 6.45, 6.6, 6.6, and 6.62 which are moderately acidic. In summary, the soils studied are not very acid with pH values ranging from 4.16 to 6.62, with low nitrogen contents for Bertoua, Dschang, Djarengol, Ebolowa, and Touboro soils, but also with average (Bertoua and Douala soils) and high (Nkometou soils) nitrogen contents. As a result, the amount of nitrogen in the soils of Nkometou is 4.9 times (about 5 times) higher than that of Touboro. As the amount of nitrogen, the amount of organic matter (as well as the amount of organic carbon) is lower in Touboro with a value of 14.60 g/kg of soil (7.30 g/kg of soil) and higher in Nkometou with the value of 51.4 g/kg of soil (25.7 g/kg of soil). The available phosphorus

Table 2. Chemical properties of soils used for *Curcuma longa* growth in greenhouse.

Localities (Region)	Chemical properties (%)					
	N (g/kg)	P (ppm)	C (g/kg)	pH	OM (g/kg)	C/N
Bertoua (East)	1.40	5.30	15.30	5.40	30.60	10.93
Bini (Adamawa)	0.98	8.90	7.50	5.50	15.00	7.70
Djarengol (Far North)	0.56	16.10	6.10	6.60	12.20	10.90
Douala (Littoral)	1.24	4.60	7.50	6.45	15.00	6.10
Dschang (West)	1.13	2.57	9.60	6.60	19.20	8.50
Ebolowa (South)	1.19	5.16	23.60	4.16	47.20	19.83
Nkometou (Centre)	2.41	6.04	25.70	4.92	51.40	10.70
Touboro (North)	0.49	13.80	7.30	6.62	14.60	14.90

content is lower in Dschang with a value of 2.57 ppm, higher in Touboro, and in Djarengol with values of 13.8 ppm and 16.1 ppm *i.e.* 5.4 times and 6.3 times higher respectively. C/N ratio is poor for Ebolowa and Touboro soils; good for Bertoua, Djarengol, and Nkometou soils; and very good for Bini, Dschang, and Douala soil.

3.2. Biological Properties

Table 3 presents the characteristics of AMF morphotypes extracted from *Curcuma longa* rhizosphere. A total of seven AMF morphotypes were obtained after observation of the spores isolated from the collected soil samples.

Table 3. Characteristics of AMF morphotypes extracted from *Curcuma longa* rhizosphere.

AMF morphotypes	Color	Shape	Size (µm)	Frequency *in situ* (%)	Frequency *ex situ* (%)
I	Black	Round	200	100	100
II	Brown	Round	200	100	100
III	White	Oval	100	88	100
IV	Bright	Irregular	100	50	87.5
V	Yellow	Round	100	81	75
VI	Orange	Round	100	75	50
VII	Grey	Irregular	48	6.25	12.5

Table 4. Soil microbial density, AMF diversity, morphotypes and root colonization of soils used for *Curcuma longa* growth in greenhouse.

Localities (Region)	Soil microbial density ($\times 10^6$ cell/mm^3)	Rhizome endophytes	AMF diversity *in situ* (spores/g sol)	AMF morphotypes *in situ*	Root colonization (%)
Bertoua (East)	15 ± 0.03^{d}	19	36 ± 0.06^{e}	I, II, III, IV, V, VI, VII	57 ± 0.14^{d}
Bini (Adamawa)	4 ± 0.01^{a}	8	41 ± 0.09^{f}	I, II, III, IV, V, VI	72 ± 0.14^{g}
Djarengol (Far North)	6 ± 0.07^{c}	14	67 ± 0.03^{h}	I, II, III	47 ± 0.17^{a}
Douala (Littoral)	16 ± 0.11^{h}	13	24 ± 0.04^{b}	I, II, III, IV, V	60 ± 0.00^{e}
Dschang (West)	14 ± 0.10^{g}	13	28 ± 0.09^{c}	I, II, III, IV, V	78 ± 0.17^{h}
Ebolowa (South)	2 ± 0.01^{b}	13	4 ± 0.03^{a}	I, II, III, IV	63 ± 0.14^{f}
Nkometou (Centre)	9 ± 0.12^{e}	11	44 ± 0.03^{g}	I, II, III, IV, V, VI	50 ± 0.00^{b}
Touboro (North)	9 ± 0.07^{f}	14	32 ± 0.06^{d}	I, II, III, IV, V, VI	55 ± 0.00^{c}

The means followed by the same alphabetical letter and in the same column are not significantly different from each other at the 5% threshold according to the Duncan-test.

Table 4 presents some microbial parameters of different soils. The analysis of total microbial density of soils reveals that Dschang, Bertoua and Douala soils have a greater microbial density with respectively 14×10^6; 15×10^6 and 16×10^6 cell/mm^3 while soils from Djarengol, Bini and Ebolowa have the smallest microbial density. In addition, 105 endophytes were isolated from rhizomes of *Curcuma longa*. It was found that endophyte number was higher for rhizomes from Bertoua soil (19) followed by those of Touboro (14) and Djarengol (14) and these were lower for Bini soil (8). Sporulation was determined at T *in situ*. The results obtained show that the largest number of spores was observed from soils of Bini (41 spores/g soil), Nkometou (44 spores/g soil) and Djarengol (67 spores/g soil). Bini, Nkometou and Touboro soils have six morphotypes (I; II; III; IV; V; VI), Douala and Dschang soils have five morphotypes (I; II; III; IV; V), Djarengol soil (I; II; III) have three morphotypes; Ebolowa soil (I; II; III; IV) have four morphotypes while all morphotypes (I; II; III; IV; V; VI; VII) were obtained in Bertoua soil.

The soils of localities of Ebolowa, Bini and Dschang have the highest percentages of colonization with respectively 63%, 72% and 78% (Table 4 and Figure 1).

3.3. Growth Parameter

Table 5 presents the evolution of collar diameter of *Curcuma longa* growing on eight soil types. It appears that collar diameter of *Curcuma longa* increased from the 7th to 13th week for all soils except that of Djarengol. The collar diameter of the Bini soil has the highest diameter on the 10th week with a value of 0.94 cm. In the 13th week, it always has the largest diameter (1.07 cm) followed by soils of Touboro (1.05 cm) and Dschang (0.98 cm). In addition, there is a reduction in collar diameter for all soils between the 13th and 16th weeks except that of Djarengol.

Table 6 presents the evolution of plant height of *Curcuma longa* growing on height soil types. *Curcuma longa* height varies according to the weeks. Thus, at the 13th week, the heights of Touboro soil plants is the best and records the greatest value 10.5 cm followed by Dschang 10 cm, then come Bini (9.46 cm), Bertoua (8.70 cm), Ebolowa (7.50 cm), Nkometou (6.90 cm), Douala (6.75 cm) and finally Djarengol (6.30 cm). In the 16th week, there is a decrease in plants height of Bertoua soil, unlike that in Ebolowa, which increases and reaches the height of 9 cm. In addition, the height of *Curcuma longa* in Touboro, Dschang and Bini soils remains the best (Figure 2).

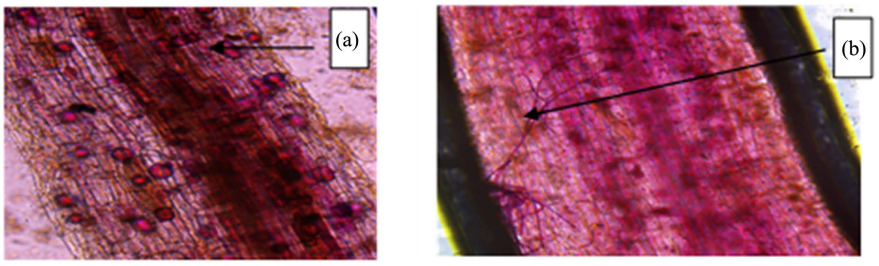

Figure 1. Structure of AMFs in the roots of *Curcuma longa*, stained using acid fuchsin method. Vesicle (a); Hyphae (b).

Table 5. Evolution of collar diameter of *Curcuma longa* growing on eight soil types.

Localities (Region)	Collar diameter (cm)			
	7th	10th	13th	16th weeks
Be (East)	0.52 ± 0.07^{b}	0.82 ± 0.04^{de}	0.76 ± 0.11^{c}	0.70 ± 0.05^{b}
Bi (Adamawa)	0.71 ± 0.09^{c}	0.94 ± 0.09^{e}	1.07 ± 0.12^{f}	1.01 ± 0.07^{c}
Dj (Far North)	0.44 ± 0.12^{ab}	0.67 ± 0.07^{bc}	0.64 ±0.09^{b}	0.67 ± 0.04^{b}
Dl (Littoral)	0.36 ± 0.09^{a}	0.44 ± 0.08^{a}	0.54 ± 0.08^{a}	0.45 ± 0.04^{a}
Ds (West)	0.64 ± 0.10^{c}	0.90 ± 0.16^{e}	0.98 ± 0.08^{ef}	0.86 ± 0.12^{c}
Eb (South)	0.46 ± 0.05^{ab}	0.76 ± 0.06^{cd}	0.86 ± 0.10^{cd}	0.67 ± 0.08^{b}
Nk (Centre)	0.53 ± 0.04^{b}	0.64 ± 0.08^{b}	0.92 ± 0.08^{de}	0.70 ± 0.08^{b}
Tb (North)	0.67 ± 0.09^{c}	0.84 ± 0.16^{de}	1.05 ± 0.07^{f}	0.91 ± 0.10^{c}

The means followed by the same alphabetical letter and in the same column are not significantly different from each other at the 5% threshold according to the Duncan-test.

Table 6. Evolution of plant height of *Curcuma longa* growing on eight soil types.

Localities (Region)	Plant height (cm)			
	7th	10th	13th	16th weeks
Be (East)	6.80 ± 0.11^{d}	7.10 ± 0.07^{d}	8.70 ± 0.11^{d}	7.50 ± 0.00^{b}
Bi (Adamawa)	8.16 ± 0.12^{f}	9.56 ± 0.05^{g}	9.46 ± 0.27^{e}	9.33 ± 0.61^{c}
Dj (Far North)	6.00 ± 0.11^{b}	6.80 ± 0.11^{c}	6.30 ± 0.11^{a}	6.60 ± 0.11^{a}
Dl (Littoral)	5.40 ± 0.13^{a}	6.20 ± 0.10^{a}	6.75 ± 0.17b	6.70 ± 0.09^{a}
Ds (West)	7.50 ± 0.03^{e}	9.10 ± 0.00^{f}	10.00 ± 0.00^{f}	9.90 ± 0.07^{d}
Eb (South)	6.20 ± 0.11^{c}	7.30 ± 0.12^{e}	7.50 ± 0.00^{c}	9.00 ± 0.00^{c}
Nk (Centre)	6.80 ± 0.11^{d}	6.70 ± 0.11^{b}	6.90 ± 0.10^{b}	7.50 ± 0.10^{b}
Tb (North)	8.94 ± 0.17^{g}	9.44 ± 0.00^{g}	10.50 ± 0.18^{g}	10.50 ± 0.12^{e}

The means followed by the same alphabetical letter and in the same column are not significantly different from each other at the 5% threshold according to the Duncan-test.

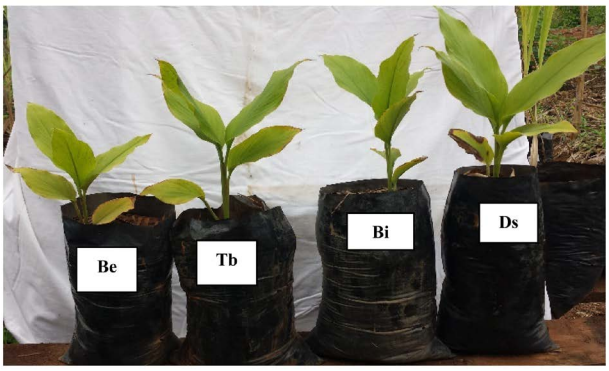

Figure 2. *Curcuma longa* growing on diverse soils from Bertoua, Touboro, Bini and Dschang after seven months.

3.4. Production Efficiency

The rhizomes of *Curcuma longa* were harvested on the 7th month. We note that soils play a very important role in the good development of plants. **Figure 3** presents *Curcuma longa* rhizome production according to soil types after trapping. It clearly appears that the masses of rhizomes from Bini (11.16 g/plant) and Dschang (11.44 g/plant) soils are the highest followed by that of Touboro (10.84 g/plant) and Bertoua (9.58 g/plant) soils. Statistical analysis reveals significant difference between rhizomes mass from the different soils. According to the histogram we see that Dschang soil is the best and Douala soil the worst.

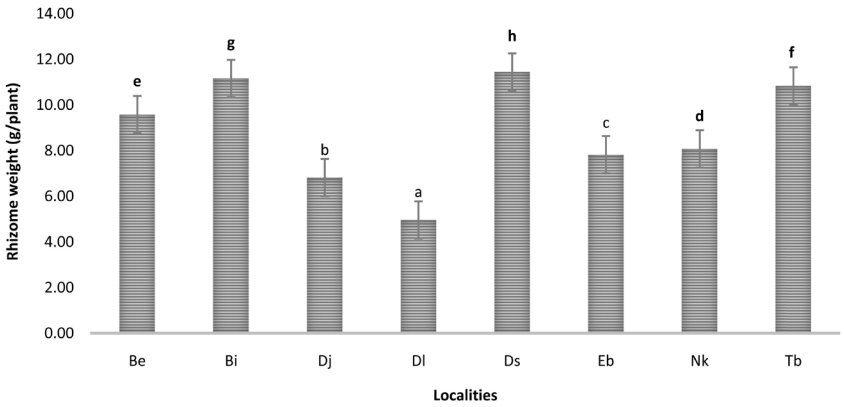

Figure 3. *Curcuma longa* rhizome production according to soil types after trapping. Bars with the same alphabetical letter are not significantly different from each other at the 5% threshold according to the Duncan-test.

3.5. Evaluation of Correlations

The results obtained from the correlation tests between rhizomes weight and growth parameters at the 16th week show that there is a weak correlation between rhizomes weight and the *Curcuma longa* height with a correlation coefficient of 0.44 on the one hand; and on the other hand, between rhizomes weight and collar diameter with a correlation coefficient of 0.54 with a p-value slightly above the threshold of 1%.

In addition, average correlations are noted between leaf area and collar diameter and between height and collar diameter of *Curcuma longa*.

4. Discussion

Statistical analysis (ANOVA) of plant height measurements did not show any significant difference at the 16th week regardless of the soil type. However, *Curcuma longa* height grown in Bini, Dschang, and Touboro soils is significantly higher than those measured in other soils. This better growth in plants height cultivated in these soils is due to their physical (clayey and sandy-clay-loam soils) and chemical composition (pH (5.4 - 6.6); N (0.49 - 1.13 g/kg); P (2.57 - 13.8 ppm); OM (14.6 - 19.2 g/kg); and C/N (7.70 - 14.90)). In addition, statistical analysis of collar diameter measurements showed significant differences at the 16th week of growth. We observed a larger collar diameter for the Bini and Touboro soils.

Indeed, the results obtained show that in order to facilitate the growth of *Curcuma longa* rhizomes, stony soils, as well as alkaline soils should be avoided because they induce root asphyxia. Fertile or clayey loams, well-drained, loose with a pH 5.0 - 7.5, and partial shade exposure are recommended [10]-[17]. The correlation test showed that there is a correlation between the weight of the rhizomes and the height of the plants on the one hand as has been observed by [18], which showed that plant height is a significant character in the *Temulawak* plant because it has a live effect on the character of the rhizome weight per clump and on the other hand between the weight of the rhizomes and the diameter at the root collar. In fact, we obtained the highest rhizome masses for the plants of Dschang, Touboro, and Bini soils where the highest values of collar diameter and height of the plants were observed at the 16th week. Rhizomes weight of *Curcuma longa* would be proportional to their collar diameter and to their height. Indeed, reference [17] has shown that large shoot biomass of Turmeric on dark-red soil resulted in a higher yield.

Physical and chemical analyzes of the different soils reveal that all the soils have a pH between 5.0 and 6.62 except Nkometou and Ebolowa soils (4.92 and 4.16 respectively) where average rhizome yields were obtained (7.82 g/plant for Ebolowa and 8.08 g/plant for Nkometou). Physical properties of the soils studied show that the sandy-clay-loam soil of Dschang is the best for the growth of *Curcuma longa* in Cameroon. In fact, it is a type of porous soil with good water retention [19]. The pH of this soil is 6.6 (slightly acidic). This pH can influence other chemical properties of the soil. The lower the pH is the lower the absorption of nutrients by plant roots.

On the other hand, Douala soil, which shows the lowest yield, is a sandy-clay soil, a poorly ventilated impermeable soil, forming an obstacle to the penetration of the roots [19] with a slightly acidic pH and very low available phosphorus. In addition to being a very unsuitable soil for growing turmeric [20], its chemical properties are weak and therefore nutrients are hardly accessible to plant roots.

Among the nutrients provided to crops, the most important is often nitrogen, which can be attributed in some cases to 75% of the observed increase in yields [21]. Indeed, it participates in the development and growth of all parts of the plant: leaves, stems, and roots. Nitrogen is an essential element for cell constitution and photosynthesis (chlorophyll) [21]. It is the main factor in plant growth and a quality factor that influences the protein level of plants. A substrate with a C/N ratio of less than 20 is mineralized and can release significant amounts of nitrogen [22]. The different substrates have low ratios, indicating that nitrogen was available in large quantities. Reference [23] demonstrated that the leaching of nitrogen is considerable and its immobilization remains weak for soils where the ratio is less than 25. Furthermore, for Touboro soil, a very low amount of nitrogen of the order of 0.49 g/kg of soil was obtained, but a high production yield. This will show that nitrogen is not the only essential element for the growth and production of *Curcuma longa*.

Despite the fact that most of the soils possess high amount of total phosphorus, available P pool of in the soil is quite limited [24]. Phosphorus is fixed into soil as stable complexes with metal ions like Al, Fe and Ca that make substantial amount (up to 75% - 90%) of P unavailable for plant uptake [25]. Therefore, a higher amount of P is required than that actually needed for crops [26]. It plays essential roles in the biological functioning of plants since it participates in many physico-chemical, biological and enzymatic processes. It is one of the main constituents of nucleic acids in joining nucleotides [27]. It is also one of the constituents of phospholipids in plant membranes [28]. Reference [29] demonstrated that at low pH (<7), phosphorus is present in the form H_2PO^{4-}. It is more easily absorbed by the roots in this form than the HPO_3^{4-} form presents in alkaline soils (pH > 7). In our study, all substrates have an acidic pH (pH (<7)), thus promoting the absorption of phosphorus by rhizomes roots, so stimulating rooting.

In addition, high levels of phosphorus can decrease the plant's photosynthetic capacity to limit the mobility of certain nutrients and cause a slowdown in the growth of the plant [29]. This was not the case in our study because for very low levels of P we firstly observed a low yield of the plant (Douala soil) and secondly an increase of the yield (Dschang soil). As with high levels of P, we obtained a low yield of the plant (Djarengol soil) and on the other hand an increase in yield (Touboro soil). Microorganisms are able to stimulate plant nutrient uptake through several mechanisms that are acting directly or indirectly on the plants [30].

Microbial density measurements have been widely used [31] to assess the impacts of different disturbances in agrosystems and the level of soil fertility. Results show that microbial density is higher in Bertoua (15×10^6 cell/mm^3 soil) and Douala (16×10^6 cell/mm^3) soils. However, yields of *Curcuma longa* rhizomes were obtained from other soils, notably those of Touboro, Bini, and Dschang. This proves that even if microbial density remains a good bioindicator

of soil quality [32], microbial density suffers from a lack of resolution and needs to be supplemented by more informative methods on the processes studied. Indeed, this measurement, which takes into account all of the microorganisms present (living or not), does not make a difference between the domains of microorganisms (archaea-fungi-bacteria) and gives only a quantitative and not qualitative measurement. The presence of endophytes in the rhizomes shows that the growth of *Curcuma longa* plants is not only a function of the microbial density but especially microbial quality. The study shows that Bini, Dschang, and Touboro soils have neither the greatest microbial densities nor the greatest numbers of isolated endophytes, but the greatest growths of *Curcuma longa* plants have been obtained on these soils. This better growth would be due to the properties of the endophytes present in these soils. Indeed, reference [14] has demonstrated the link between endophyte microorganisms, secondary metabolites production, and plant growth.

AMFs represent an abundant and functionally important group of soil microorganisms, which form symbiotic associations with their hosts [33]. Mycorrhizae represent an asset for agriculture, through their associations [34] with their hosts. Hosts more often benefit from increased access to nutrients, improved growth, and yield [35]. In addition, they provide better protection against a number of pests and diseases by inducing local and systemic resistance [36]. The symbiotic parameters of these soils tell us that the number of spores is variable when moving from one type of soil to another at T *in situ*. At T *in situ*, Bini (41 spores/g soil), Nkometou (44 spores/g soil) and Djarengol (67 spores/g soil) treatments multiply the greatest number of spores. The higher number of spores in Djarengol soil could be explained by its low nitrogen content. Indeed, reference [37] has shown that the high phosphorus and nitrogen contents reduce mycorrhization of plants**.** Several trials have been carried out with AMFs in Cameroon on various crops such as cereals, legumes, tubers, fruit trees, cash crops, or vegetable crops [38]. They show that the yield increased by mycorrhiza inoculation was between 33% - 66% in maize grown in an Oxisol/Ultisol under field conditions and on the other hand, mycorrhiza inoculation increased P biomass content from 40% to 280% for cowpea and 40% to 390% for pearl millet, compared to the control. They clearly show the interest of these beneficial microorganisms for agriculture, forestry, environment conservation, and tropical soils' health. In Cameroon, the AMFs selected increased productivity by around 48% to 478% in more than 12 crops (peanut, banana, yam, maize, mucuna, cowpea, oil palm, chilli, leek, sorghum, soybean, and tomato) alone or in combination with other agricultural inputs that stimulate their effects such as phosphorus solubilizing microorganism (PSM) and bacteria nodulating legumes (BNL) [38]. The results obtained show that frequency of root colonization is relatively high. However, In Djarengol soils, frequency of root colonization was low (47%). Reference [39] suggested that the level of root colonization was probably more dependent on the environmental conditions than on the plant variety.

Dschang (78%) and Bini (72%) soils have the highest frequency of root colonization. In addition, root colonization is higher for plants from Dschang soil where the yield was also the highest among all the treatments, which confirms the results of numerous authors who have shown that the AMF structures presence in plant roots contributes to better production of the latter. In fact, reference [40] shows that AMF is able to increase the fresh weight of *Temulawak* rhizomes; [41] shows that AMF colonization improved positively the overall growth and development of both cultivars of potato plants. These results also prove that *Curcuma longa* has a relatively strong response to mycorrhization.

5. Conclusion

The evaluation of the effect of height representative soils on growth and production of *Curcuma longa* in Cameroon permitted to obtain after 7 months of production, average growth, and rhizome production between 5 to 15 g/plant. The best rhizome production was obtained from Bini (11.16 g/plant), Dschang (11.44 g/plant), and Touboro (10.84 g/plant) soils. Cultivation of *Curcuma longa* is adequate on clay-sandy and sandy-clay-loam textured soils. *Curcuma longa* prefers slightly acid soils; rich in organic matter and whose C/N ratio is between 7 - 14.9. The degree of mycorrhiza infection appears to depend on the physical and chemical characteristics of the soil. It also depends on the content of elements in the soil such as phosphorus and nitrogen. A study on the effect of each endophyte of *Curcuma longa* would be interesting.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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