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# Cultivar and Soil Fertilizer Treatment Affect Seed Production of Sweet Yellow Yam (*Dioscorea dumetorum*) on Highly Acidic Soils of the Western Highlands Region of Cameroon

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## Abstract

The popularization of *Dioscorea dumetorum* (Dioscoreaceae), a nutritious yam species is still marginal due to constraints such as the low interest of research, poor cultural practices, insufficient and expensive seeds, pests, and diseases. The latter pushes producers to use about 50% of their harvest as seed for the next planting season. The lack of a specific fertilizer formulation for yam production on the oxysols of Cameroon is another constraint. This study was aimed at enhancing the availability of quality seeds through the characterization of five yam accessions. One experiment was performed to determine the effect of cultivar and origin of tuber sets on their germination rate. The second concerned the evaluation of cultivars and soil treatment effects on agronomic parameters of yam seedlings. Yam cultivars were subjected to nine fertilizer formulations as follows: T0: no fertilizer; T1: mycorrhizal fungi (MF) + 150 g manure + peanut waste; T2: 25 g chemical fertilizer (20.10.10); T3: MF + peanut waste; T4: 16 g chemical fertilizer (12.6.20); T5: 25 g (20.10.10) +100 g CaO + 150 g manure; T6: 100 g CaO + 150 g manure; T7: 20 g tropicote + 2 g DAP (Diammonium phosphate, a reference starter fertilizer coded N18P46) + 100 g CaO + 150 g manure; and T8: mycorrhiza. These treatments were tested in a factorial design. Results show that Ibo sweet 3 and Mabondji sweet white 1 yam accessions were less affected by anthracnose disease on the aerial parts. Guzang 1 showed the best germination rate and yield, making it appropriate for cultivation in the region. Soil treatments, T2, T5, T7 and T8

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significantly increased the yield of yam cultivars. Mycorrhiza treatment alone gave a better response to seed weight, indicating the interest of this biofertilizer as a solution for good seedling production. These fertilizer treatments can be recommended to farmers for more seed production with optimum seed weight (300 g).

## Keywords

*Dioscorea dumetorum*, Mini Set, Yam Seed Production, Mycorrhiza, Fertilizer, Soil Acidity

## 1. Introduction

Yams are cultivated in tropical and temperate zones. They belong to the family Dioscoreaceae which consists of 8 genera *Avetra*, *Borderea*, *Dioscorea*, *Nanarepentia*, *Rajania*, *Stenomeris*, *Tamus* and *Trichopus* and about 880 species. The genus *Dioscoreae* is the largest with more than 600 species [1] [2]. It is a staple food source in countries in Africa, the Caribbean and Oceania and is also consumed in Southwest Asia and Latin America [3]. More than 90 percent of world production is concentrated in West Africa, in coastal countries of the Gulf of Benin known as the "yam belt". In contrary to West African countries, yam production remains secondary in Cameroon with a production of 685,426 tons. Cameroon is the sixth largest yam producer in the world far behind Nigeria (50 052 977 tons), Ghana (8 288 198 tons), Ivory Coast (7 176 762 tons), Benin (3,088,498 tons) and Togo (874 267 tons) [4]. In volume, it represents the third root and tuber plant produced in Cameroon after cassava (2 349 171 tons) and macabo/taro (1 156 919 tons). The species cultivated in Cameroon are: *D. dumetorum*, *D. esculenta*, *D. bulbifera*, *D. schimperiana*, *D. semperflorens*, *D. alata*, *D. burkilliana* and *D. cayenensis*; they are often region-specific. They are cultivated in all agro-ecological zones of Cameroon. The high production zone is the Highland region of Western Cameroon where in most cases, it is associated in the field with other crops such as maize, potato and groundnut [5]. *D. dumetorum* is of great socio-economic [6] and medicinal values. It has a higher nutritional value than other cultivated yams, and can be an important source of vitamin A due to its carotenoid content [7]. It is characterized by relative ease of cultivation (optional staking, mechanizable harvesting), high yields (40 tons/ha in agronomic stations), good protein content (9.6 g/100g dry matter) with a balanced composition of essential amino acids. It has easily digestible starches due to their crystalline structure close to that of cereal starch [8].

Despite of all these advantages, yam cultivation is neglected in favour of relatively less nutritious plants such as cassava and potato. *D. dumetorum* is thus a more neglected crop among orphan crops [9]. Its popularization is still very marginal because of the various constraints it faces such as low interest of research compared to other yam species, poor cultivation practices, pests, plant pathogenic

diseases, post-harvest hardening [10] [11], and insufficient seeds [5] [12] [13] [14] [15]. The latter could be due to the low rate of tuber multiplication compared to cereals, which is associated with the low yield on the acid soils of Cameroon. In spite of this, farmers save seeds in an effort to maintain the crop. A significant part of the harvest (25% - 50%) is used as seed for the following year, which reduces the amount available for food [16]. The insufficiency and high cost of seeds is thus a major constraint to yam production.

As mentioned earlier, another cause for concern in yam production is poor soil fertility and acidity. Among the microorganisms living in the rhizosphere, arbuscular mycorrhizal fungi are very essential components for sustainable agriculture [17] [18] [19] [20] [21], for increasing agricultural and horticultural production in water-scarce areas of sub-Saharan Africa and on acid soils in Cameroon [22] [23]. Mycorrhizal fungi might alleviate aluminum toxicity. The same is true for agricultural lime, which, through its capacity to reduce soil acidity, increases the yield of crops requiring high pH. It thus benefits only from the fertilizers (12-6-20 and 20-10-10) applied to these other crops. The results of the impact of fertilizers on the taste of yam are crucial in deciding on the best formula to be used for extension. Even if farmers prefer cultivars with good germination rate, good soil cover and high yield [24], their final choice is influenced by the culinary quality of the variety [25]. This is all the more relevant as some farmers in Baham think that fertilizer spoils the yam taste. There is a genetic interest in finding poor soil tolerant cultivars such as those in Baham for yam production [26].

This study exploited the scientific approach used in West Africa for the cultivation of species of the *D. roundata-cayennensis* complex to assess *D. dumetorum*, in its local cultivation context, the Upper Plateau region of West Cameroon, which is mainly characterized by acidic soils with aluminium toxicity, on which yam is cultivated with a low use of fertilizers in association with other crops. The overall objective of this work was to improve the production of sweet yellow yam seeds in West Cameroon through the assessment of the germination of *D. dumetorum* fragments during vegetative propagation by the mini-set method, evaluation of the effect of cultivar and fertilizer treatment on the agronomic traits, growth and tuber yield of the yam fragments.

## 2. Material and Methods

### 2.1. Site Characteristics and Plant Material

Two trials were carried out; the first dealt with the germination of fragments and the second, a factorial trial combining the 5 cultivars evaluated and the 8 soil treatments (plus the control). This study was carried out in the Ferme École de Bokoue (FEBO) in the West region of Cameroon, Upper-plateaux Division, Baham district. It is at high altitude (1634 m above sea level) with the following geographical references: latitude 05˚20.040'N, longitude 010˚22.572'E. The climate is of the "Cameroonian" type, marked by two seasons of unequal duration: a dry season that lasts from mid-November to mid-March and a rainy season

that lasts from mid-March to mid-November. Average temperatures are low (19˚C), and heavy rains (1500 - 2000 mm) fall in a monomodal pattern. The experimental plot is a slightly steep slope, frequently colonized by a grass (*Imperata cylindrica*). It is perfectly exposed to light. The soil of the experimentation site is clay, acidic, with low cation exchange capacity and aluminium toxicity. The experimental design was a Randomized Complete Block with 2 factors (cultivars (Cult) and soil treatments (SoilT)) in 9 repetitions. The soil physico-chemical properties of the experimental field are presented in Table 1.

**Table 1.** Physico-chemical characteristics of the soil (0 - 15 cm) of the experimental site and of the fowl droppings used in this study.

| Samples | Fowl droppings | Appréciation | Soil | Appreciation |
|---|---|---|---|---|
| **Texture (%)** | | | | |
| Sand | | | 21.88 | |
| Limon | | | 13.58 | |
| Clay | | | 64.54 | |
| Textural class (USDA) | | | A | A |
| **Soil reaction** | | | | |
| pHwater | 6.80 | Slightly acidic | 4.45 | Acidic |
| pHKCl | 6.40 | Slightly acidic | 4.10 | |
| **Organic matter** | | | | |
| Ntotal (%) | | | 0.14 | Medium |
| CO (%) | 22.44 | Very high | 2.57 | Very low |
| C/N | 14.31 | Poor | 17.70 | Very poor |
| **Exchangeable Cations meq/100g** | | | | |
| Calcium | 29.20 | Very high | 1.63 | Very low |
| Magnesium | 26.93 | Very high | 0.43 | Very low |
| Potassium | 4.97 | Very high | 0.06 | Very low |
| Sodium | 4.74 | Very high | 0.02 | Very low |
| Sum of the bases | 65.84 | High | 2.14 | Low |
| $Al^{3+}$ | | | 0.93 | |
| **Exchange capacity (meq/100g)** | | | | |
| Effective EQF | | | 2.49 | Very low |
| S/ECE (%) | | | 85.94 | Very high |
| **Assimilable phosphorus** | | | | |
| Phosphorus Bray II | | | 1.14 | Very low |
| **Macroelements** | | | | |
| N (%) | | | 1.76 | |
| P (%) | | | 0.66 | |
| K (%) | | | 1.03 | |

The soil of experimentation is clay, acidic with a very low cation exchange capacity and very poor biotic activity.

The plant material used consisted of five yam cultivars of the species D. dumetorum collected from the yam collection of FEBO [13]. The areas of collection and local names of cultivars are indicated in Table 2. These were Banga bakundu sweet 1, Dschang 1, Guzang 1, Ibo sweet 3, Mabondji sweet white 1 (Figure 1(a)).

## 2.2. Germination of Fragments Using the Mini-Set Method

The procedure for germinating fragments consisted of: 1) Construction of a germinator containing 10 cm of white sawdust, the roof was made up of black polystyrene paper; 2) Cuttings of the large yam tubers of the five different varieties into 75 gram fragments separated into different parts (head, middle, tail); 3) Soaking in a solution of fungicide and insecticide for 15 minutes, then left to dry in the open air; 4) Placing the fragments on the germinator, labelling them by part and by variety, and covering them with a 5 cm layer of sawdust; 5) Watering every day. 6) Counting the number of fragments that have emerged from the second week onwards (Figure 1(c)).

Table 2. Sex and geographic origin of *D. dumetorum* cultivars used in this study.

| Cultivars | Sex | Local name | Area of collection | Altitude | Latitude | Longitude |
|---|---|---|---|---|---|---|
| | | | | m asl. | (N) | (E) |
| Banga bakundu sweet 1 | M | Sweet yam | Muyuka | 62 | 04˚17.314 | 009˚24.451 |
| Dschang 1 | F | Lilio | Dschang | 1337 | 05˚26.637 | 010˚03.404 |
| Guzang 1 | F | Ndong-mbeck | Guzang | 1233 | 05˚49.983 | 009˚55.278 |
| Ibo sweet 3 | M | Ibo sweet | Banga Bakondu | 56 | 04˚24.103 | 009˚26.522 |
| Mabondji sweet white 1 | M | Sweet yam Mabondji | Mabondji | 80 | 04˚33.745 | 009˚11.806 |

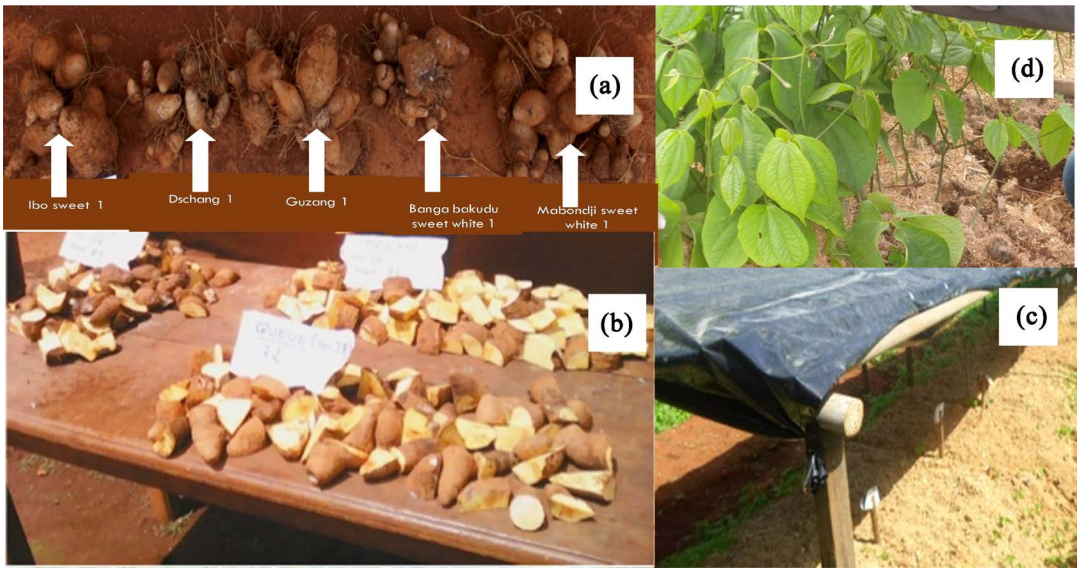


Figure 1. Photo showing (a) the five cultivars of *Dioscorea dumetorum* used in this study; (b) the 75 g fragments grouped in three origins (head, middle and tail); (c) germination board on sawdust and (d) seedling at the planting stage to obtain seeds.

### 2.3. Experimental Design

The experimental set-up is a randomized complete bloc design with 9 repetitions. It comprises eight treatments; one cultivar per replication and nine-soil treatment per replications. The distance between the replication (block) was 2 meters. The distance between plants in a block was 0.8 meters on the line and 1 meter between lines (**Figure 2(a)**).

### 2.4. Soil Fertilizer Treatments

This consisted of combinations of mineral fertilizers (N12P6K20, N20P10K10, DAP and Tropicote); biofertilizer (fowl droppings, mycorrhizal fungi) and associated legume crop (*Arahidis hypogea*). The quantities per plant were obtained on the basis of quantities habitually applied on *D. cayenensis-rotundata* complex. For example, the 25 g of NPK 20.10.10 dose was obtained from [27] cit. [28]. They [28] used 14 g of NPK 10.18.18 plus 7 g of urea (46% N) as quantity of mineral fertilizer applied per plant. Its equivalent was 25g of NPK 20.10.10; total N = 4.6 g ≈ 5 g, P = K = 2.54 g ≈ 2.5 g. Details of the eight soil treatments are indicated in **Table 3**. The use of DAP was guided by the possibility of this fertilizer to suppress nematodes in the soil [29].

The legume used in this study is a local variety of groundnut (*Arachis hypogaea*) commonly known as village groundnut. It is the most widely cultivated by Baham farmers, which justifies its use in this study. The mycorrhizal fungi which are known to enhance plant nutrition and growth [20] consisted of a mixture of four pure strains of mycorrhizae: *Glomus hoi*, *Gigaspora margarita*, *Scutellospora dipurpurescens* and *Glomus intraradices*. Their sporulation is 10 ± 3/g and root coloration is 56% ± 18%.

### 2.5. Cultivars and Soil Treatment Evaluation

The experimental design was a completely randomized block. It consisted of 5 varieties, 9 treatments and 9 replications. The distance between the blocks was 2 meters. The distance between plants in a block was 0.8 meter on the row and 1 meter between rows (**Figure 2(a)**).


**Figure 2.** Photo showing the experimental plot (a) Preparation of the plots, (b) The different cultivars in full growth

**Table 3.** Doses of mineral fertilizers combined with biofertilizers as used in this trial.

| | Fertilisant CaO | Fowl droppings | Mycorrhizal fungi | N12P6K20 | N20P10K10 | Peanuts | Tropicote | DAP |
|---|---|---|---|---|---|---|---|---|
| **Treatments** | | | | | | | | |
| Nothing | T0 | | | | | | | |
| Mycorrhize+ Fowl droppings | T1 | 150 | Yes | | | Yes | | |
| NPK (20-10-10) + Fowl droppings + CaO | T2 100 | | | | 25 | | | |
| NPK (20-10-10) | T3 | | Yes | | | Yes | | |
| Mycorrhize + Fowl droppings + CaO | T4 100 | 150 | | 16 | | | | |
| Tropicote (21% N + 25% CaO) + DAP + CaO | T5 100 | 150 | | | 25 | | 20 | 2 |
| NPK (12-6-20) | T6 | 150 | | | | | | |
| CaO + Fowl droppings | T7 | | | | | | | |
| Mycorrhize | T8 | 150 | Yes | | | | | |

Quantities are in grams. Tropicote is a liming fertilizer whose formula is 15.5N + 26.3 CaO; DAP formula is N18P46.

## 2.6. Assessment of Mycorrhization

This consisted in comparing the growth parameters (plant height and vine diameter) and the yield from the different treatments to that of the control. The expression of the response to mycorrhization (RM) in relation to the control was calculated according to [30]. Observations were done under a light microscope with a 10X objective. For each fragment, the abundance and diversity of mycorrhizal structures were noted, including arbuscules, vesicles, intra- and intercellular hyphae, extra-root hyphae, auxiliary cells and spores (**Figure 3**). The degree of endomycorrhizal colonization of each fragment was estimated according to a scale consisting of six classes scored from zero (0) to five (5) according to [31]. The frequency of mycorrhizal colonization was evaluated according to the method of [32]. Root staining was done according to the modified method of Grace and Stribley [33].

## 2.7. Inoculation of Mycorrhizae Fungi

The inoculation of *D. dumetorum* cultivars was carried out after their germination by coating with the mycorrhizal fungus solution.

## 2.8. Data Collection

*Emergence rate*, *seedling tuber weight* (*SWeight*); *vine length* (*VineL*); *crown diameter* (*VineD*), *leaves N*, *P*, *K content* 85 *days after sowing*,

The number of fragments that emerged after planting was counted every day for each of the five cultivars (**Figure 1**). The mass of the tubers was taken using an electronic scale. The diameter of the vines was taken at a distance of 2 cm below the first node using the electronic caliper. Data were taken from all plants in the trial of cultivar and soil treatment evaluation. Plant size was measured using a tape from the crown to the apex.

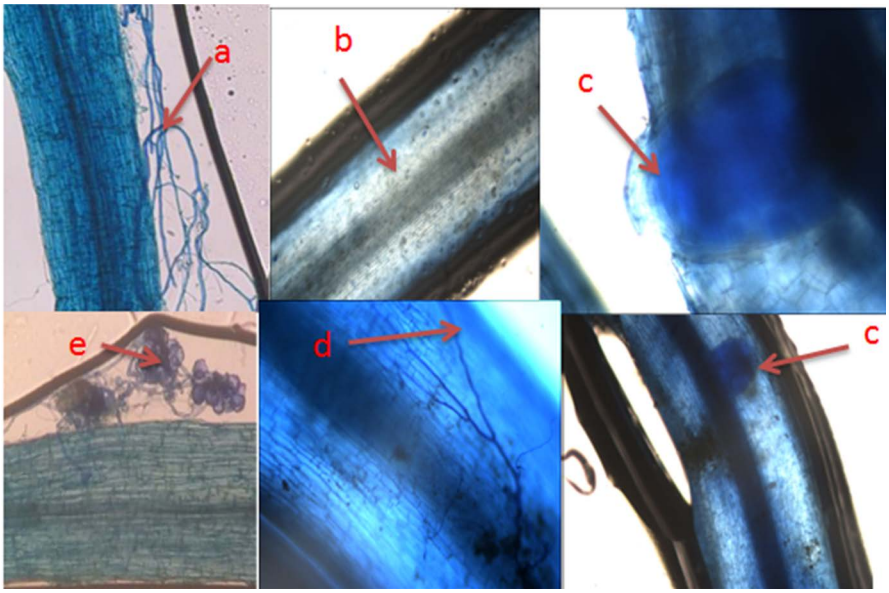


**Figure 3.** Electron microscope observation showing (b) the uncolonized root on the one hand and roots colonized by mycorrhizal fungi presenting various fungal structures on the other hand: external hyphae (a), vesicles (c), auxiliary cells (e), internal hyphae (d) observed with an electron microscope.

The N, P, K content of the leaves gives us information on the needs of the leaves in mineral elements. This was measured on harvested leaves 80 days after transplanting of yam seedlings. Here, the fourth leaf of each variety per treatment was harvested. The leaves of the different cultivars belonging to the same treatment were then mixed to form five composite samples whose N, P, K contents were determined according to the method of [34] at the Faculty of Agronomy and Agricultural Sciences (FASA), Soil Science Laboratory, University of Dschang.

*Incidence* (*DisI*) *and Severity* (*DisS*) *of anthracnose disease*

Disease incidence and severity were diagnosed visually based on the observation of the different characteristic symptoms on the aerial parts of the plants of each treatment. Incidence (I) was measured by dividing the number of diseased plants (NDP) by the total number of plants (TNP).

$$(I) = NDP/TNP \times 100.$$

Severity of the disease was measured using a notation scale from 1 to 5.

## 2.9. Data Analysis

Data analysis was performed using a linear model with interaction (Cult + SoitT + Cult x SoitT) software. Analyses of variance (ANOVA) were performed using SPSS version 16.0 software. Duncan's Multiple Range Test ($P < 0.05$) was used to judge the difference between the means of the different parameters. The ANOVA was used to see if the variability of the results for each given factor is due to differences between cultivars and soil treatment depending on the respective variance of each variable studied. The graphical representations were made using

Microsoft Excel 2014.

## 3. Results and Discussions

### 3.1. Emergence of Tuber Fragments versus Cultivars and Origin

In this study, the origin of yam and cultivar influenced the rate of emergence very highly ($p < 10^{-3}$) as shown in Table 4.

Table 4 and Table 5 also indicate strong interaction between origins on the tuber and cultivars, origin on the tuber and the number of days after sowing and cultivar and number of days after sowing. This indicates the complexity of germination phenomenon, governed by factors including plant reserves, enzymes and light intensity and their concentration variation over time. Guzang 1 cultivar had a highly significant average emergence rate compared to other cultivars. The lowest average germination rate was observed in the Mabondji sweet white 1

Table 4. ANOVA of emergence rate with respect to origin of the tuber and cultivar of mini set fragment.

| Sources of variation | Sum of Squares | df | Mean Square | F | Sig. | |
|---|---|---|---|---|---|---|
| Model | 320,761[a] | 57 | 5627.38 | 78.65 | 0.00E+00 | *** |
| Cultivar | 32,084 | 4 | 8020.89 | 112.11 | 0.00E+00 | *** |
| Origin | 26,409 | 2 | 13,204.37 | 184.56 | 0.00E+00 | *** |
| Days After Sowing (DAS) | 40,665 | 6 | 6777.51 | 94.73 | 0.00E+00 | *** |
| Cultivar * Origin | 9957 | 8 | 1244.67 | 17.4 | 0.00E+00 | *** |
| Origin * DAS | 3789 | 12 | 315.75 | 4.41 | 0.00E+00 | *** |
| Cultivar * DAS | 6421 | 24 | 267.54 | 3.74 | 0.00E+00 | *** |
| Error | 3434 | 48 | 71.55 | | | |
| Total | 324,195 | 105 | | | | |

[a]RSquared = 0.989 (Adjusted R Squared 0 = 0.98).

Table 5. Average emergence rate in relation with different dates after sowing.

| DAS | Emergence rate |
|---|---|
| 20 | 6.93[a] |
| 26 | 27.93[b] |
| 34 | 38.00[c] |
| 46 | 50.06[d] |
| 54 | 53.20[d] |
| 82 | 62.06[e] |
| 111 | 68.40[f] |

Numbers on the same row followed by the same letter do not show a significant difference according to Duncan's test at the 5% threshold.

and Banga bakundu sweet 1 cultivars. The Guzang 1 cultivar is easily multiplied by the mini-set method and thus can be popularized among farmers. According to [35], farmers prefer cultivars with a high germination rate. These results confirm those of Zoundjihekpon [36] and Kouakou [35] according to which there is a difference in germination rate between different yam cultivars. The variability in survey rates between different cultivars could be due to the genetic diversity between these different cultivars; this hypothesis is supported by [36]. Indeed, the germination potential is possibly governed by individual genes.

There was a decreasing gradient of emergence from top to bottom of tuber in all cultivars used. As illustrated in **Figure 4**, while the fragments from the top (head) reach a germination rate of over 90%, those taken from the bottom do not exceed 65%.

These observations are similar to those of [36] on *D. cayenenses-rotundata* and of [37] on the Brazo Fuerte variety of *D. alata*. The variability in the rate of germination with respect to the different parts of the tuber probably portrays a difference in the concentration of growth hormones in the three parts of the tuber. The different concentrations of gibberellic acid (which promotes germination) in the parts (top, middle, bottom) of the same cultivar could be responsible for the different germination rates in these different parts (**Table 6**, **Table 7**).

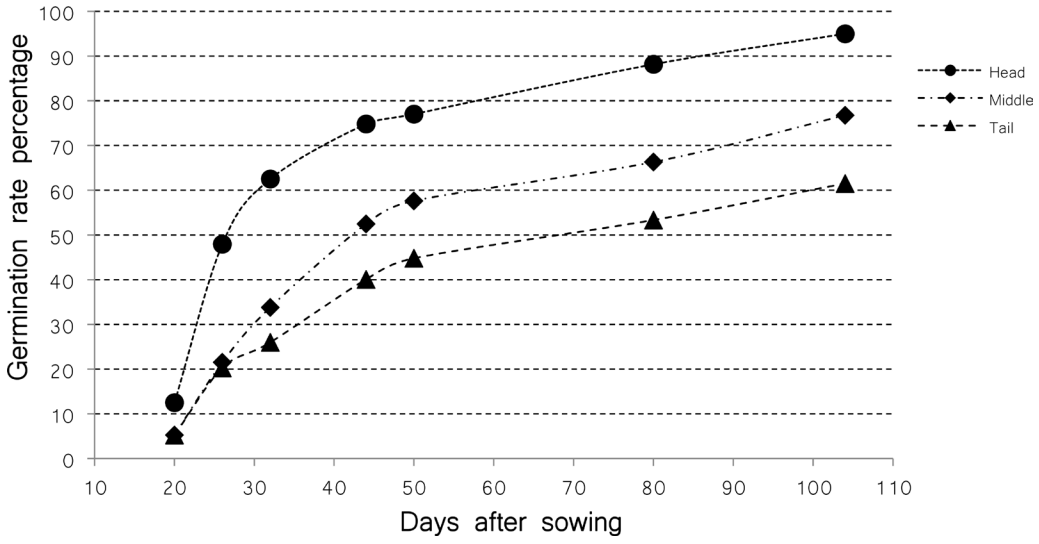


**Figure 4.** Influence of the origin of mini set fragment on the germination rate.

**Table 6.** Average emergence rate with respect to different parts of the tuber (top, median, bottom). Numbers on the same row followed by the same letter do not show a significant difference according to Duncan's test at the 5% threshold.

| Part of the tuber | GermR |
|---|---|
| Top | 27.49[a] |
| Midian | 38.62[b] |
| Bottom | 65.29[c] |

The Dschang 1 and Guzang 1 cultivars emerged earlier and can therefore be considered as early cultivars; compared to Mabondji sweet white 1, Banga bakundu sweet 1 and Ibo sweet 3 which are late cultivars (Figure 5). It has been noticed that Dschang 1 and Guzang 1 cultivars which exhibit early germination are both female plants, in contrast to Mabondji sweet white 1, Banga bakundu sweet 1 and Ibo sweet 3 which are male plants. Thus, it can be hypothesized that a high content of gibberellic acid could be correlated with the female sex of the plant in *D. dumetorum* as observed with yams of the *D. cayenenses-rotundata* group. This hypothesis remains to be tested on a larger number of plants. Therefore high content of gibberelic acid could be a sex indicator of the cultivar: This result corroborates that of Zoundjihekpon [36] who found that in *D. rotundata*, females emerge faster than males. More than half of the cultivars emerged two months after germination. This confirms the observations of [38] which stated that most seeds emerge after 2 months.

### 3.2. Soil Treatment versus Leaves' Content of N, P, K

The soil treatments showed highly significant differences for these three variables ($p = 3.46E{-}26$; $p = 6.44E{-}16$ and $p = 1.12E{-}21$ respectively for NPK) (Table 8). Leaf composition in NPK shows that nitrogen is the most abundant element in the leaves, followed by potassium and then phosphorus in all treatments. The nitrogen content of the control (T0) was lower than that of all other treatments.

Table 7. Average emergence rate in relation with different parts of the tuber (top, median, bottom).

| Parts of the tuber | Top | Midian | Bottom |
|---|---|---|---|
| Seed bearing rate (%) | 65.44[a] | 55.38[b] | 40.68[c] |

Numbers on the same row followed by the same letter do not show a significant difference according to Duncan's test at the 5% threshold.

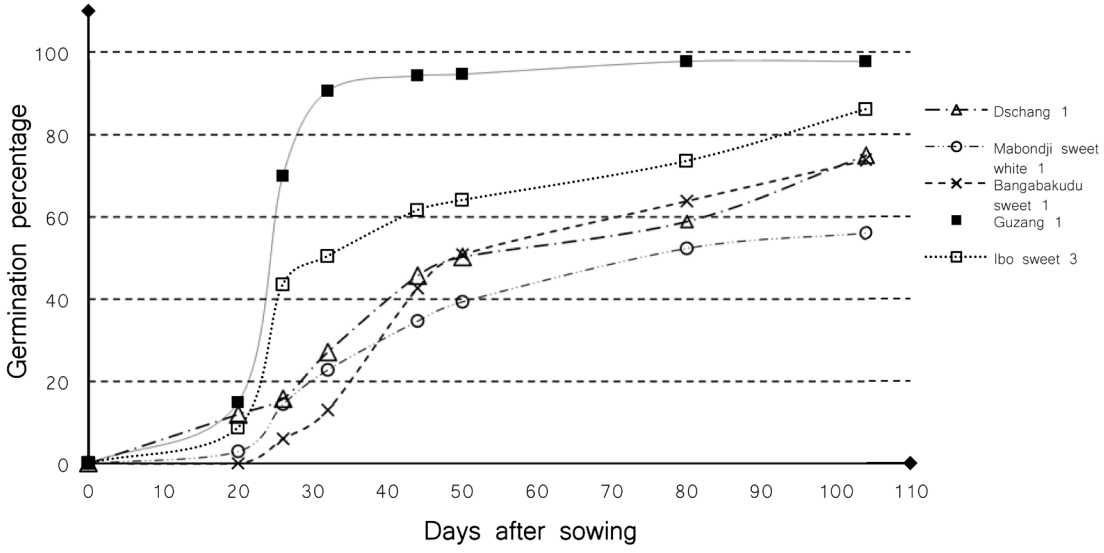


Figure 5. Influence of cultivar on the germination rate.

**Table 8.** ANOVA of leaves NPK content with respect to soil treatment.

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Model | N | 149.26 | 11 | 13.569 | 2 046.97 | 5.22E−23*** |
| | P | 2.75 | 11 | 0.250 | 137.14 | 1.14E−13*** |
| | K | 14.19 | 11 | 1.290 | 669.90 | 3.90E−19*** |
| SoilT | N | 8.44 | 8 | 1.054 | 159.07 | 9.02E−14*** |
| | P | 0.29 | 8 | 0.036 | 19.63 | 6.81E−07*** |
| | K | 4.44 | 8 | 0.556 | 288.46 | 8.18E−16*** |
| Rep | N | 0.01 | 2 | 0.004 | 0.57 | 5.75E−01ns |
| | P | 0.00 | 2 | 0.000 | 0.05 | 9.47E−01ns |
| | K | 0.00 | 2 | 0.002 | 0.91 | 4.21E−01ns |
| Error | N | 0.11 | 16 | 0.007 | | |
| | P | 0.03 | 16 | 0.002 | | |
| | K | 0.03 | 16 | 0.002 | | |
| Total | N | 149.36 | 27 | | | |
| | P | 2.78 | 27 | | | |
| | K | 14.22 | 27 | | | |

a. R Squared = 0.99 (Adjusted R Squared = 0.99); b. R Squared = 0.99 (Adjusted R Squared = 0.98); c. R Squared = 0.99 (Adjusted R Squared = 0.99).

The N, P, K contents of the T8 treatment was higher than that of T1.

T1 also had a higher N, P, K content than T3 (Table 8). The leaves being photosynthetic organs of the plant, their composition in N, P, K gives information on the absorption of nutrients in the plant. Thus, the high concentrations of nitrogen can lead to the conclusion that yam needs important quantities of nitrogen for its vegetative growth. The potassium contents directly followed those of nitrogen showing that yam could also need high quantities of potassium (possibly for tuberization). The phosphorus contents are low; yam probably needs relatively low quantities of phosphorus for vegetative growth and tuberization. However, flowering seems to require high phosphorus concentrations. These ideas are in line with those of [39], who, after analysis of the tubers of *D. cayenenses-rotundata* noted that the nitrogen (N) and potassium (K) requirements of yam are high. Dognimeton *et al.* [40] mentioned an increase of NPK content of leaves following mineral fertilization. On the other hand, phosphorus (P) requirements are relatively low.

The NPK content of the T8 treatment (mycorrhizal fungi) is higher than that of T3 (mycorrhizal fungi + peanut). This suggests that there is nutrient competition between peanut and yam in their combination in the T3 treatment. This competition was also demonstrated by [41] in maize in association with soybean or bean after comparison of the NPK content of the leaves in pure culture and associated with each legume. This competition could be overcome by the con-

tribution of fowl droppings in the T1 treatment (mycorrhizal fungi + droppings + peanut). Mycorrhizal fungi alone show their effectiveness in solubilizing soil phosphorus, which is trapped in acidic soils, and making it available to the plant. The addition of other fertilizing elements to mycorrhizal fungi reduces their effectiveness. This result is in accordance with those obtained by [42], in succhini squash. The response of mycorrhyzal treatment is also correlated with a high root colonization index noted for treatment 8 and Guzang 1 cultivar (**Figure 6**).

### 3.3. Cultivars versus Agronomic Parameters and Disease Evaluation

Cultivars very highly influenced growth parameters and disease. Seedling tuber weigh (SWeight, p = 4.71E−07); vine diameter (VineD, p = 6.12E−03) and Disease severity (DisS, p = 6.21E−03). There were no significant differences between the sizes of the five cultivars evaluated in this study and vine length (VineL, p = 0.64) as indicated in **Table 9**.

The Guzang 1 cultivar had the highest yield (452 g) (**Table 10**, **Figure 7**). Kouakou *et al.* [35] working on the *D. cayenenses-rotundata* complex highlighted differences in yield among yam cultivars. These differences were also observed in the results of [25] who worked on *cayenenses-rotundata* and *D. alata* species.

With respect to disease severity, Ibo sweet 3 had the lowest disease severity. In Guzang 1 and Mabondji sweet white 1, the severity was medium. In the Dschang 1 cultivar, the severity was high and in the Banga bakundu sweet 1 cultivar, the disease severity is very high (**Table 10**). The disease severity was different in the cultivars probably because of the genetic diversity between them. Indeed, the genotypic variability of the cultivars implies a difference in the quality and quantity

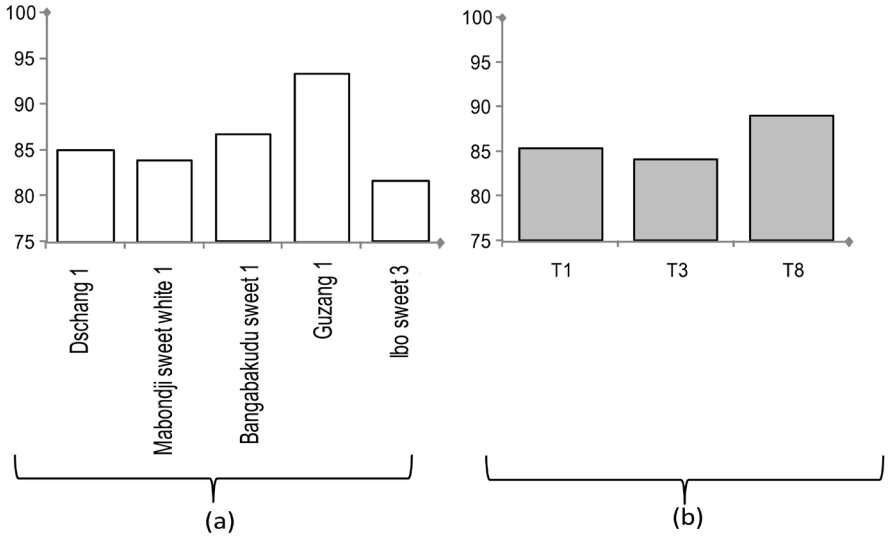


**Figure 6.** Frequency of root colonization by mycorrhizal fungi according to (a) cultivars and (b) treatments involving the use of mycorrhizal fungi. Guzang 1 and treatment 8 show the best response to root colonization, indicating that the response to root colonization depends on the cultivar; mycorrhizal fungi work best in low nutrient environments.

of defense molecules in them. Ibo sweet 3 could therefore be a good genitor for plant breeding. This result is in accordance with that of [43] who worked on six yam genotypes and demonstrated that genotype accounts for 85% of the total variation observed of the resistance with respect to viral disease severity of water yam (*Dioscorea alata* L.) in Nigeria.

**Table 9.** ANOVA of Seedling weight (SWeight), Vine length (VineL), Vine diameter (VineD) and Disease severity index (DisS), vinelength (VineL) and vine diameter (VineD).

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. | |
|---|---|---|---|---|---|---|---|
| **Model** | SWeight | 42,934,373 | 53 | 810,083 | 14.47 | 9.31E-52 | *** |
| | DisS | 26,654 | 53 | 503 | 5.83 | 2.35E-22 | *** |
| | VineL | 1,606,460 | 53 | 30,311 | 14.41 | 1.36E-51 | *** |
| | VineD | 3973 | 53 | 75 | 47.33 | 1.40E-104 | *** |
| **Cultivars** | SWeight | 2,090,157 | 4 | 522,539 | 9.33 | 4.71E-07 | *** |
| | DisS | 2694 | 4 | 673 | 7.81 | 6.00E-06 | *** |
| | VineL | 5292 | 4 | 1323 | 0.63 | 6.42E-01 | Ns |
| | VineD | 23 | 4 | 6 | 3.69 | 6.12E-03 | ** |
| **SoilTreatment** | SWeight | 2,529,779 | 8 | 316,222 | 5.65 | 1.31E-06 | *** |
| | DisS | 3929 | 8 | 491 | 5.69 | 1.15E-06 | *** |
| | VineL | 43,579 | 8 | 5447 | 2.59 | 9.79E-03 | ** |
| | VineD | 18 | 8 | 2 | 1.45 | 1.78E-01 | ns |
| **Cultiv * SoilT** | SWeight | 1,205,757 | 32 | 37,680 | 0.67 | 9.11E-01 | ns |
| | DisS | 3346 | 32 | 105 | 1.21 | 2.09E-01 | ns |
| | VineL | 152,223 | 32 | 4757 | 2.26 | 2.59E-04 | *** |
| | VineD | 172 | 32 | 5 | 3.39 | 3.08E-08 | *** |
| **Repetition** | SWeight | 551,699 | 8 | 68,962 | 1.23 | 2.81E-01 | ns |
| | DisS | 1446 | 8 | 181 | 2.10 | 3.67E-02 | * |
| | VineL | 22,576 | 8 | 2822 | 1.34 | 2.23E-01 | ns |
| | VineD | 14 | 8 | 2 | 1.13 | 3.44E-01 | ns |
| **Error** | SWeight | 14,219,983 | 254 | 55,984 | | | |
| | DisS | 21,914 | 254 | 86 | | | |
| | VineL | 534,326 | 254 | 2104 | | | |
| | VineD | 402 | 254 | 2 | | | |
| **Total** | SWeight | 57,154,356 | 307 | | | | |
| | DisS | 48,568 | 307 | | | | |
| | VineL | 2,140,786 | 307 | | | | |
| | VineD | 4376 | 307 | | | | |

[a]RSquared = 0.75 (Adjusted R Squared = 0.70); [b]RSquared = 0.54 (Adjusted R Squared = 0.45); [c]RSquared = 0.75 (Adjusted R Squared = 0.70); [d]RSquared = 0.91 (Adjusted R Squared = 0.89).

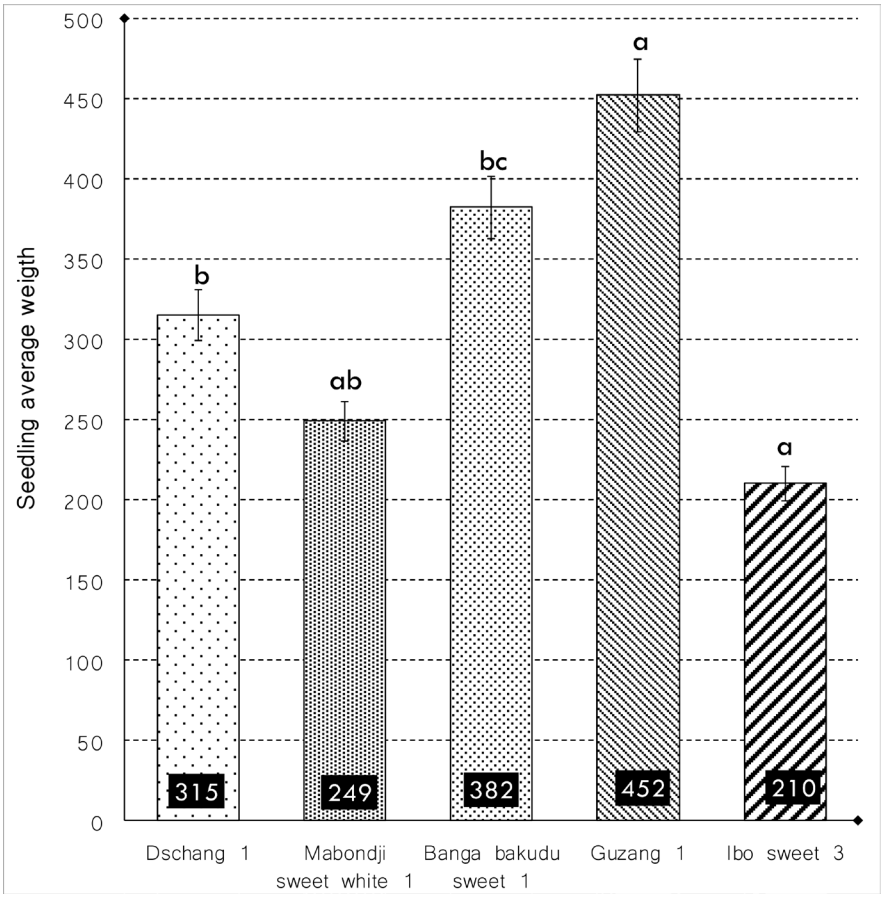


**Figure 7.** Influence of cultivar on the seedling average weight

**Table 10.** Classification of emergence rate, Seedling weight (SWeight), Vine diameter (VineD), Vine length (VineL) and Disease severity index (DisS), in response to cultivars.

| Cultivars | SWeight (g) | DisS | (VineD) (mm) | DisS | Lifing rate |
|---|---|---|---|---|---|
| Dschang 1 | $315^{b}$ | $4.74^{a}$ | $3.59^{ab}$ | $4.73^{a}$ | $40.68^{c}$ |
| MabondjiSweet White 1 | $249^{ab}$ | $2.73^{a}$ | $3.29^{ab}$ | $2.77^{c}$ | $31.82^{d}$ |
| Banga bakundu Sweet 1 | $382^{bc}$ | $10.53^{b}$ | $3.95^{c}$ | $10.53^{b}$ | $35.77^{d}$ |
| Guzang 1 | $452^{c}$ | $9.10^{b}$ | $3.06^{bc}$ | $9.10^{b}$ | $79.97^{a}$ |
| Ibo Sweet 3 | $210^{a}$ | $3.61^{a}$ | $3.48^{abc}$ | $3.61^{a}$ | $55.38^{b}$ |

Numbers in the same row followed by the same letter do not show a significant difference according to Duncan's test at the 5% threshold.

In the field, we observed three groups of symptoms on the aerial part of the yam: The "a" group consists of black spots surrounded by a yellow halo on the leaves; in this case it could be anthracnose. The group "b" consists of continuous black spots on leaves and vines. The group "c" consists of deformations of the leaves that make us think of the yam mosaic. Disease incidence was greatly reduced by T8 treatment (mycorrhizal fungi) because mycorrhizal fungi can increase the production of phytoalexins in the plants they infect. These results confirm those of [44]. T5 treatment had a low disease incidence because it pro-

vided good hydromineral nutrition to yam plants, thus allowing their good development and thus their synthesis of defense substances. T8 and T5 treatments have the lowest disease severity compared to the control and other treatments. Disease severity was greatly reduced by T8 treatments (mycorrhizal fungi) because mycorrhizal fungi can increase the production of phytoalexins in the plants they infect [45] [46]. These results confirm those of [44]. T5 treatment had a low disease severity because it provides good hydro-mineral nutrition to yam plants, allowing their good development and thus their synthesis of defense substances. Mabondji sweet white 1 and Ibo sweet 3 cultivars had a low disease incidence. The Banga bakundu sweet 1 and Guzang 1 cultivars had the highest disease incidence. These results confirm those of [25] who showed the difference in susceptibility of *D. cayenenses-rotundata* cultivars to disease. This variability in susceptibility is thought to be due to a genotypic difference between cultivars. These inter-varietal gene differences can influence the quality and quantity of defense molecules synthesized by each of the different cultivars.

The average vine diameter of the T3 treatment (3.71 mm) exceeded that of the T8 treatment. This could be due to atmospheric nitrogen fixation by Rhizobium and the transfer of this nitrogen to the plant, which increased its vegetative growth (vine diameter). These results are similar to those of [47] who report the transfer of nitrogen from the fixing plant to a non-fixing plant. The average diameter of the plants in the T1 treatment (4.03 mm) was greater than that of the plants in the T3 treatment (3.71 mm). This result shows the importance of manure for yam growth. The T7 treatment had plants with a larger vine diameter (3.51 mm) than the control (3.23 mm). This could be due to its high nitrogen content, which promotes vegetative growth. This supports the idea of [27] that N appears to be of great importance in yam cultivation.

### 3.4. Disease Evaluation with Respect to Soil Treatment and Growth Parameters

Soil treatment had a highly significant effect on, seedling tuber weight (SWeight; p = 1.31E−06); vine length (VineL; p = 9.79E−03); and disease severity (DisS; p = 1.15E−06). The first lesson here is that it is impossible to produce yam seedlings in the study region without applying fertilizer. The mean seed weight is 142 g, far from the objective of 300 g which is the optimal tuber weight [13]. The second important result is that by applying only mineral fertilizer as it is of practice today by Baham farmers, the objective of 300 g cannot be achieved. On acid soil with low ion exchange capacity, fertilizer is not retained in the soil. After fertilizer application, the first rain will leach all the fertilizer. However, under the conditions of this trial, where the mineral fertilizer applied contained more potassium (T6; 3.2 g of K) the response of tuber formation is better than that of a fertilizer with more T3 nitrogen (2.5 g K).

Four treatments emerged as indicated in **Table 11**, NPK (20-10-10) + fowl droppings + CaO (T2), Tropicote (21% N + 25% Cao) + DAP + CaO (T5), Mycorrhiza (T8) and CaO + fowl droppings (T7). These treatments all have a

**Table 11.** Classification of Seedling weight (SWeight), Vine length (VineL), Vine diameter (VineD) and Disease severity index (DisS), N P K leaves content in response to soil treatments.

| | SWeight (gr) | DisS | VineD (mm) | N | P | K |
|---|---|---|---|---|---|---|
| **Soil Treatments** | | | | | | |
| Nothing (T0) | 142$^{a}$ | 14.66$^{c}$ | 3.52$^{ab}$ | 1.2$^{a}$ | 0.13$^{a}$ | 0.003$^{a}$ |
| Mycorrhize + Fowl droppings (T1) | 365$^{bc}$ | 2.50$^{a}$ | 3.57$^{ab}$ | 2.36$^{c}$ | 0.42$^{cd}$ | 0.21$^{b}$ |
| NPK (20-10-10) + hen droppings + CaO (T2) | 463$^{c}$ | 8.50$^{b}$ | 3.13$^{a}$ | 2.56$^{d}$ | 0.35$^{c}$ | 0.21$^{b}$ |
| NPK (20-10-10) (T3) | 280$^{b}$ | 8.69$^{b}$ | 3.24$^{ab}$ | 1.67$^{b}$ | 0.22$^{b}$ | 0.25$^{b}$ |
| Mycorrhize + Fowl droppings + CaO(T4) | 246$^{ab}$ | 7.78a$^{ab}$ | 3.66$^{ab}$ | 2.28$^{c}$ | 0.38$^{c}$ | 0.77$^{c}$ |
| Tropicote (21% N + 25% Cao) DAP + CaO (T5) | 458$^{c}$ | 2.11$^{a}$ | 3.48$^{ab}$ | 3.36$^{e}$ | 0.2$^{ab}$ | 0.91$^{d}$ |
| NPK (12-6-20) (T6) | 346$^{bc}$ | 6.39$^{ab}$ | 3.57$^{ab}$ | 2.35$^{c}$ | 0.44$^{d}$ | 0.91$^{d}$ |
| CaO + Fowl droppings (T7) | 405$^{c}$ | 7.93$^{b}$ | 3.19$^{ab}$ | 2.35$^{c}$ | 0.23$^{b}$ | 0.94$^{d}$ |
| Mycorrhiza (T8) | 409$^{c}$ | 1.77$^{a}$ | 3.94$^{c}$ | 2.42$^{cd}$ | 0.35$^{c}$ | 1.2$^{e}$ |

Numbers in the same row followed by the same letter do not show a significant difference according to Duncan's test at the 5% threshold.

common role of correcting soil acidity with CaO and fowl droppings, thereby increasing cation exchange capacity, in addition to NPK fertilizer inputs, except for T8 which has a different mechanism of action. These results are in accordance with those obtained by [40] in Ivory Coast. These authors registered an increase in yam production following a mineral fertilizer application on four local yam cultivars.

Agbede *et al.* [48], working on a sandy loam soil with a pH of 5.4, reported that mineral fertilizer has a highly significant effect on yam tuber yield. The results of [48] also showed that organic fertilizers significantly increased tuber weight and growth of yam, soil and leaf N, P, K compared with the control. The oil palm bunch ash + poultry manure treatment increased tuber weight, vine length, of yam by 66% and 25%, respectively, compared with inorganic fertilizer (NPK) and 37%, 22% respectively, compared with poultry manure alone. The success of T2 and T7 treatments confirms the idea of [27], which nitrogen seems to be of great importance in yam cultivation.

The T7 treatment which was higher than T0 shows the importance of CaO and fowl droppings which increased the pH by 4.45 (towards 7) and which is optimal for yam cultivation; thus favouring the removal of nutrients from the soil for its growth. It also shows the importance of the droppings which possibly increased the CEC of the soil and thus its capacity to retain the nutrients provided by the droppings.

Mycorrhyza fungi were included in three treatments, in association (T1 and T4) or alone T8. Treatment with mycorrhyza alone gave highly significant results on yam yield. This treatment is in the top class of yield alongside soil treatments combining mineral fertilizer associated with organic fertilizers and min-

eral liming fertilizer. The mycorrhiza certainly increased the surface area for root's absorption of the yam, by solubilizing the phosphorus and fixing the nitrogen for the good nutrition of the yam plants. They certainly increased the tolerance of yam plants to aluminium toxicity and high soil acidity, and also limited the losses caused by pathogens (**Figure 7**). Similar performance of mycorrhyza fungi was reported by [42]. They found that inoculated plants under acidity and Al toxicity conditions had higher total, marketable yield, and total biomass than non-inoculated plants. Mycorrhized zucchini plants grown under acidity and Al conditions had a higher macronutrient concentration in leaf tissue compared to non-inoculated plants. The superiority of over T1 and T4 as presented on **Figure 8** and **Figure 9** is an indication that mycorrhyza fongi perform better when utilized in poor soil conditions (T1 = T8 + fowl droppings; T4 = T1 + CaO). The poorer the soil, the better is the response to mycorrhiza fungi symbiosis (**Figure 3(b)**), and the higher the yield response. Phosporus is known to modulate the level of symbiosis; the higher the P concentration in the soil, the lower the response to mycorhyzation. Similar results were reported by [49] who

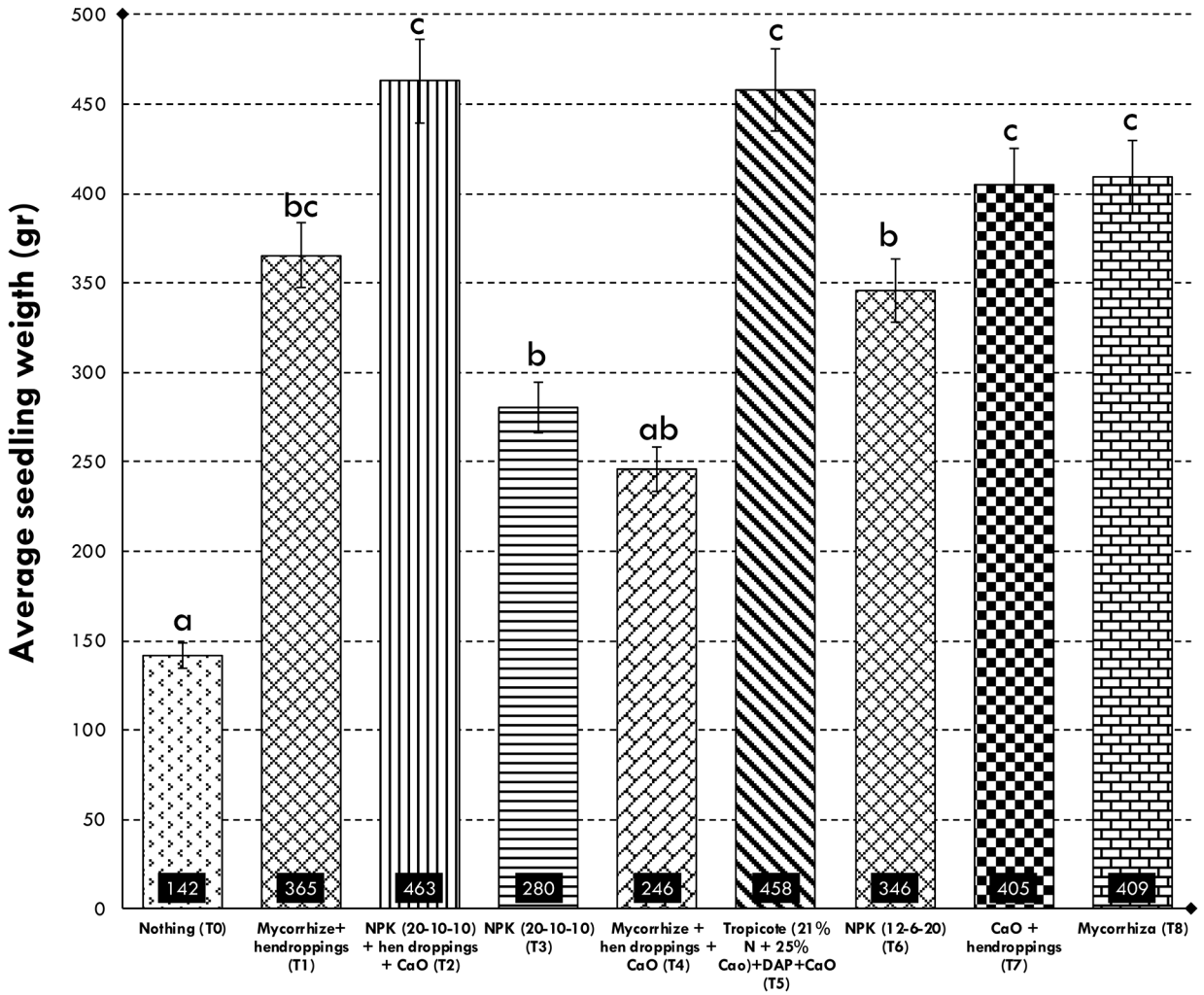


**Figure 8.** Influence of soil treatment on the average seedling weight.


**Figure 9.** Different *Dioscorea dumetorum*,yam seedlings harvested according to soil treatment. V01, V05, V07, V28, V38 represent respectively Dshang 1, Mabondji sweet white 1, Banga bakudu sweet white 1, Ibo sweet 3 and Guzang 1.

tested the effect of phosporus on asparagus (*Asparagus officinalis* L.) root colonization and obtained the highest root colonization (76%).

## 4. Conclusion

This work had two objectives. The first was to evaluate the effect of the cultivars on the aptitude for multiplication by the mini set technique, which in West Africa serves as a lever for the intensification of yam cultivation by making the seeds available. This result showed that the origin (section) of the mini set on the tuber strongly influences its germination rate. Different cultivars had different germination abilities. Genetic traits have a differential influence on germination and tuber weight. From this point of view, the cultivar Guzang 1 collected in Guzang, locally called "Ndong-mbeck", showed the best aptitude for multiplication by the mini set technique. This cultivar produced seedlings with an average weight of 453 g, well above the optimal seedling size of 300 g for this yam species [13]. Guzang 1 is also favourable to mycorrhization; a biological treatment that produced seedlings of a size comparable to those produced when fertilized with mineral and organic fertilizers. The second objective was to determine the effect of fertilizer application on yam seed production. Results showed that it is impossible to produce optimal seed size on the acidic and aluminium-toxic soil of the study area without external fertilizer inputs; soil amendment had a significant influence on seed size [50]. Alongside the mycorrhiza fungus treatment, three fertilizer formulae produced satisfactory results: T2 (25 g of NPK 20-10-10 + 150 g of fowl droppings), T5 (46 g of CaO + 150 g of fowl droppings + 25 g of

NPK 20-10-10 + 20 g of Tropicote (21% N + 25% Cao) + 2 g of DAP) and T7 (46 g of CaO + 150 g of fowl droppings). With constraints related to the strategic choice of cultivar and appropriate fertilization removed, yam farmers could benefit from the advantages of this technique as enunciated by [51], for better yam production in the Western Highlands region of Cameroon.

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## Conflicts of Interest

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

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