Journal of Plant Biota
Original Research Article
ISSN: 3048-4863
Journal homepage: https://plant.researchfloor.org/

Enriched compost with vivianite and pyroclastite powders: suitable fertilizer for better maize growth under the High Guinean Savanah climate of Cameroon

Mohamed Awal, Tchuenteu Tatchum Lucien*, Simo kuate David and Megueni Clautilde

Department of Biological Sciences, Faculty of Science, University of Ngaoundere, Cameroon

Abstract

This study aims to improve maize production in Adamawa-Cameroon without using chemical fertilizers. Field experiments were carried out during two cropping seasons (2023 and 2024). A randomized complete block experimental design with 16 treatments (unfertilized plant (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14), chemical fertilizer (T15) was used with 03 replications. Physico-chemical properties of growth substrates (soil, composts), maize growth, and production parameters were evaluated. Results show that the growing soil is acidic and poor in mineral elements necessary for better maize growth. T12 fertilizer improves significantly ($p < 0.05$) the studied parameters (plant height, foliar production, plant dry biomass, seed yield) compared to other fertilizers. T12 fertilizer increased maize seed yield by 244 % and 37 % compared to unfertilized plants and chemical fertilizer, respectively. T12 fertilizer is more economic profitable than chemical fertilizer The supply of the following combination, compost derived cow dung manure enriched with vivianite and pyroclastite powders at a ratio (50-1-1), was found to be very promising in improving maize plant growth and therefore, can be used as an alternative of the mineral fertilizers usually employed for the cultivation of this cereal.

Keywords: *Zea mays L., compost, vivianite, pyroclastites, productivity, Adamawa-Cameroon*

INTRODUCTION

Zea mays L., also known as maize, is a food crop of the grass family. This cereal is one of the most important crops for human consumption, with an annual world production of approximately 2.80 billion tons. It is one of the world's main cereal crops, and thus a mainstay of global food security [1]. Maize is rich in starch (around 70%), fat, protein, ash, mineral elements (potassium, magnesium, and phosphorus), and crude fiber [2].

Cameroon produced 2 million tons of maize in 2020, ranking 14th in Africa [3]. Despite the high level of maize production, requirements are constantly increasing because of the combined effects of rising human and animal consumption. Cameroon is both a maize importer and exporter, depending on the season. In seasonal abundance times (October to mid-January), the maize prices on local markets are low, and Cameroon exports maize to West African markets and even to Europe. When stocks run out from January to February onwards, prices on local markets generally rise until September. The price relationship with the international market then reverses, then Cameroon increases its maize imports [4].

Maize production in Africa increases, and in general, there is still great potential to increase productivity. However, its production is limited in the Adamawa-Cameroon region by many abiotic and biotic constraints that affect the yields. These include soil poverty.

In this respect, maize growers in the Adamawa-Cameroon region generally use chemical fertilizers to solve the problem of soil deficiency in mineral elements, in order to optimize the yield of this cereal crop. However, several authors [5] [6] revealed that chemical fertilizers have an immediate positive effect on plant growth potential, but present serious environmental risks and do not maintain soil fertility. In this respect, it is urgent to consider management methods in local farming that can increase agricultural production while protecting the environment.

Growing maize using compost combined with rock powders would contribute to improving the seed yield, cleaning up the environment, as well as adding value to our local material in agriculture while protecting the environment. Compost has physicochemical and biological properties that improve soil structure [7] [8]. Compost is an organic amendment that improves soil biodiversity through the contribution of microorganisms, combats mineral depletion, improves physicochemical qualities, and helps reduce the need for industrial nitrogen fertilizers [9]. The Adamawa region is rich in rock deposits, including vivianite in the Hangloa village and basaltic pyroclastites around Lac Tison. Vivianite is rich in phosphorus, then it can be used to improve soil fertility, consequently enhancing plant growth and yields [10]. Pyroclastites are characterized by their mineralogical composition rich in exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}) that

17 February 2025: Received | 17 March 2025: Revised | 17 April 2025: Accepted | 16 May 2025: Available Online

Citation: Mohamed Awal, Tchuenteu Tatchum Lucien, Simo kuate David and Megueni Clautilde (2025). Enriched compost with vivianite and pyroclastite powders: suitable fertilizer for better maize growth under the High Guinean Savanah climate of Cameroon. *Journal of Plant Biota.* **89 to 98. DOI: https://doi.org/10.51470/JPB.2025.4.1.89**

Tchuenteu Tatchum Lucien | tatchumlucien@gmail.com

can improve soil chemical properties [11].
This study aims to improve the maize productivity under the High Guinean Savannah climate of Adamawa-Cameroon without using chemical fertilizers. Specifically, it consists to: (1) evaluate growth substrates (soil, composts) for maize growth; (2) determinate determining the effects of the combination of composts and rock powders on maize production; (3) estimate the economic value of fertilizers.

MATERIALS AND METHODS

Study site

The study was conducted during two cropping seasons (2023 and 2024) in the experimental field of the University of Ngaoundere (Cameroon) located at Darang locality. The area belongs to the agroecological zone II of Cameroon and is characterized by a Sudano-Guinean Savannah with six month's dry season (November to April) and six months rainy season (May to October). The Adamawa Regional (Cameroon) Meteorological Service provided the meteorological data (precipitation and temperature) for both cropping years. Precipitation is higher in 2023 than in 2024, with an average of 197.11 mm per month and an annual total of 2365.30 mm in 2023, compared with 116.97 mm per month and an annual total of 1403.70 mm in 2024. May and June are the wettest months in 2023, with 415.30 mm and 493.10 mm of precipitation, respectively. In 2024, May and September are the wettest months, with 240.30 mm and 332.20 mm of precipitation, respectively. Average temperatures are higher in 2024 than in 2023, with an average of 24.25°C in 2024 versus 22.10°C in 2023. March and April are the hottest months in 2024, with average temperatures of 29°C and 28°C, respectively. In 2023, March and May are the hottest months, with mean temperatures of 24.20°C and 23.60°C, respectively (figure 1). The vegetation of the area is an herbaceous savannah dominated by *Imperata cylindrica*, *Annona senegalensis*, and *Piliostigma thonningii*. The following are the geographical parameters of the field: 07°23' latitude North, 13°29' longitude East, and 1125 m altitude.

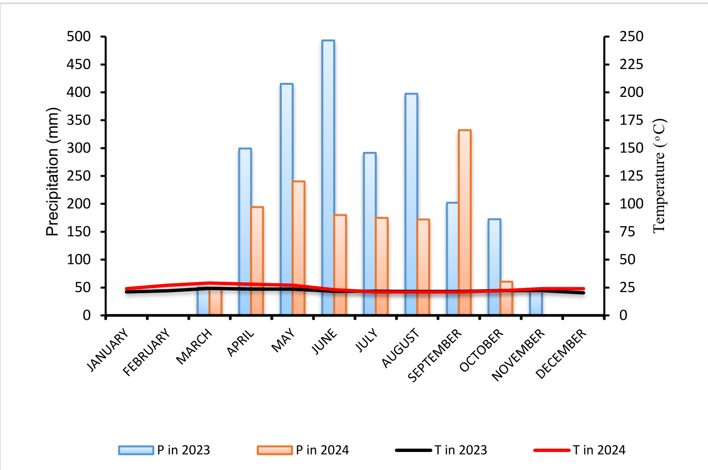


Figure 1: Umbrothermal diagram for the Adamawa region in 2023 and 2024
P: precipitation, T: temperature

Material

Maize seeds

The seeds of the SHABA maize variety are used (Figure 2). These seeds were supplied by the Institute of Agricultural Research for Development of Wakwa (Ngaoundere, Cameroon). This variety was chosen for its great adaptability to the rainy season, early germination, and it has short reproduction cycle. Its development cycle varies between 100 and 120 days.
These seeds are white, they are oval-shaped and medium-sized, with an average length of 10.50 mm and an average width of 8.5 mm, average weight is between 250 and 300 mg.

Figure 2: Seeds of the SHABA variety of Zea mays L.

Fertilizers

The fertilizers (figure 3) used in the trials include: 03 different types of compost (compost derived from poultry litter, cow dung manure, and goat droppings manure), rock powders (pyroclastites and vivianite), and chemical fertilizers (NPK 20-10-10 and Urea 46 % N).
Animal wastes (poultry litter, cow dung, and goat droppings) were collected from livestock buildings located near the campus of the University of Ngaoundere. The composting method, according to [5], was used. The composting process lasted 04 months.
Vivianite was collected in the Hangloa locality located between 7°20' and 7°30' North latitude and 13°20' and 13°25' East longitude. The chemical composition of vivianite powder is the following: Fe_2O_3 (68.72%), P_2O_5 (9.17%), Al_2O_3 (7.72%), and SiO2 (9.67%) [10]. Thus, the total phosphorus content was estimated at about 671.50 mg/kg, while the assimilated phosphorus content was around 81.13 mg/kg. Phosphate contained in this mineral can be solubilized. Pyroclastites were collected around Lake Tyson (Adamawa, Cameroon) located at 7°15' North latitude and 13°34' East longitude. Their geochemical composition is similar to that of the Tombel graben, rich in total agronomic bases: CaO > 8%, MgO > 6%, K_2O > 1% [11]. These rocks were ground to powder using a hammer, then sieved (2 mm mesh) before being used.
The main nutrients of used chemical fertilizers are N, P, and K. They are referred to as urea (46% N) and NPK (20-10-10) chemical fertilizer, meaning that it contained 20% N, 10% P_2O_5, and 10% K_2O.

3a: Compost

3b: Pyroclastite powder

3c: Vivianite powder

3d: NPK (20-10-10) chemical fertilizer

3e: Urea (46% N)

Figure 3: Fertilizers

Methods

Physicochemical analysis of soil and compost

Soil samples were collected from the study site using a five-point randomization system (1 Kg per point). All these samples were mixed to form a composite sample representative of the study site (5 Kg of soil) [12]. The physico-chemical analyses of soil and composts were carried out in the Laboratory of Research Unit in Soil Analysis and Environmental Chemistry at the University of Dschang (Cameroon), using standard methods.

Evaluation of the responses of maize to rock powders and composts

Land preparation, experimental design, and sowing

Field experimentation was carried out during two cropping seasons (2023 and 2024). The experimental site measured 504 m^2 area (28 m × 18 m). The experimental field was ploughed at 30 cm depth, and the elementary plots of 5 m^2 area (5 m × 1 m) were formed. 48 experimental units were formed. Space between two consecutive elementary plots in a block was 80 cm, and two consecutive blocks were spaced 1.5 m. A randomized complete block experimental design with 16 treatments (unfertilized plant (T0), compost derived poultry litter (T1), compost derived goat dung manure (T2), compost derived cow dung manure (T3), vivianite powder (T4), pyroclastite powder (T5), compost derived cow dung manure + vivianite powder (T6), compost derived cow dung manure + pyroclastite powder (T7), compost derived goat dung manure + vivianite powder (T8), compost derived goat dung manure + pyroclastite powder (T9), compost derived poultry litter + vivianite powder (T10), compost derived poultry litter + pyroclastite powder (T11), compost derived cow dung manure + vivianite powder + pyroclastite powder (T12), compost derived goat dung manure + vivianite powder + pyroclastite powder (T13), compost derived poultry litter + vivianite powder + pyroclastite powder (T14), chemical fertilizers (NPK (20-10-10) + urea 46%N) (T15)) was used with 03 replications. Two plants are consecutive in an elementary plot spaced 50 cm apart. 500 g of compost and 10 g of rock powder were applied per hole at sowing time. 10 g of NPK (20-10-10) chemical fertilizer and 5 g of urea (46% N) were applied to the base of plants, respectively, at 15 days after plant emergence and at flowering.

Data collection, sampling, and statistical analysis

During the vegetative phase, 15 plants were randomly selected, and plant height and number of leaves per plant were evaluated at a regular interval of 14 days starting from the 14th day after sowing. At flowering, the diameter of the stem at collar was evaluated, also development parameters (male flowering and heading dates) were assessed.

At maturity, the number of ears per plant, ear size, diameter at the middle of the ear, ear weight, and number of seeds per ear are evaluated. Seeds yield (t/ha) from different treatments was estimated. 15 plants are sampled. For the economic analysis of the treatments, the value-to-cost ratio (VCR) was used. The VCR compares the profitability of the various fertilizers with that of unfertilized plants. It is therefore the ratio between the yield increase of a treatment and the fertilizer cost of the same treatment: VCR = value of yield increase/fertilizer cost. If the VCR exceeds 1, the fertilizer is profitable, but profitability is excellent when VCR ≥ 3 [13] [14].

All the data were statistically analyzed using the Statgraphics Plus Program version 5.0. The significance of differences was determined using the Duncan test.

Results and Discussion

Physicochemical properties of growth substrates

Growing soil for this study was acidic and presented a clay texture (Table 1). A pH value below 5.50 indicates probable deficiencies in Ca, K, N, Mg, Mo, P, and S, and possible excesses in Al, Co, Cu, and Fe [15]. C/N ratio ≤ 9 indicates good humification, while values ≥12 are indicative of difficulties in mineralizing organic matter [16]. C/N ratio of the used growing soil in the present study is 19. This indicates a very low degree of organic matter mineralization. Increasing the organic matter content appears to be an unavoidable solution to most of these problems. This is because organic matter not only increases cation exchange capacity (CEC) and releases nitrogen and phosphorus through mineralization, but also blocks anionic uptake sites, which can hold phosphorus too tightly for it to be taken up by plants [17] [18]. The relatively high organic matter content of the various composts (Table 1) could correct the deficiencies of this soil by stimulating the growth and activity of micro-organisms, leading to greater availability of soil nutrients for the benefit of crops [19]. Globally, growing soil is acidic and poor in the essential mineral elements (N, P, K, Ca) for maize growth. Produced composts derived cow dung manure and poultry litter enriched by rock powders (vivianite and pyroclastites basaltic) contain various mineral elements (N, P, K, Ca, Mg) that would improve growing soil fertility for maize better growth and development.

Table 1: Physico-chemical properties of growth substrates

Parameters		Sol	Composts			Chemical fertilizer	
			CD	GD	PL	NPK	Urea
Texture	Clay textural		/	/	/	/	/
Clay (%)		43	/	/	/	/	/
Silt (%)		26	/	/	/	/	/
Sand (%)		31	/	/	/	/	/
pH		5,0	7.20	7,20	6.80	/	/
OM (%)		4.02	21	44	59	/	/
CO (%)		2.33	11	22	30	/	/
C/N (%)		19	20	15	10	/	/
N (%)		0.12	0.54	1.46	3.04	20	46
P (mg/100g)		/	127.12	307.89	365.36	10	/
K (mg/100g)		1.96	223.58	905.79	2619,17	10	/
Ass. P (mg /Kg)		9.42	/	/	/	/	/
Ca (mg/100g)		140.76	520	1280	1480	/	/

Mg (mg/100g)		54.74	558.9	874.8	2075.80	/	/
Na (mg/100g)		1.17	43.32	81.19	198.46	/	/
Humidity. (%)		/	16	33	14	/	/
Ash (%)		/	79	56	41	/	/

CD: cow dung manure, GD: Goat dung manure, PL: Poultry litter, DM: dry matter

Flowering and emergence dates

Male flowering dates (Table 2) range from 60 days after sowing (DAS) in 2023 to 78 DAS in 2024 for treated plants using compost-derived poultry litter + pyroclastite powder (T11) and unfertilized plants (T0), respectively. Similarly, emergence ear dates ranged from 69 DAS in the first crop season 2023 for T11 and T12 plants (compost derived cow dung manure + vivianite powder + pyroclastite powder) to 82 DAS in the second crop season 2024 for T0 plants. Flowering and emergence ear were early for T11 and T12 plants, whereas they were late for T0 maize plants. T11 and T12 plants flowered at 18 days and 16 days before T0 plants, respectively, and the emergence ear is observed at 13 days before T0 plants. Moreover, T0 plants in 2023 flower and form ears 7 days before those in 2024.

These results obtained on maize flowering differ from those obtained by [20], who found that flowering days range from 54 to 59 DAS. T11 and T12 treatments stimulate male flowering and ear emergence compared to T0 plants. Early flowering and ear emergence reduce disease risk and insect attack, allow plants to complete their growth cycle before extreme weather conditions, and improve yields [21] [22] by improving the plant's physiological parameters.

Table 2: Flowering and ear emergency according to fertilization and study year

Fertilizers	Cropping season 2023				Cropping season 2024			
	Flowering date		Emergency date		Flowering date		Emergency date	
	50%	100%	50%	100%	50%	100%	50%	100%
T0	64	71	67	75	74	78	75	80
T1	60	66	65	74	71	76	75	80
T2	60	66	68	75	74	78	75	81
T3	60	66	68	75	72	76	76	80
T4	63	70	71	78	72	78	80	83
T5	65	71	70	77	73	76	79	82
T6	58	66	64	71	72	77	77	79
T7	57	62	65	72	72	76	77	82
T8	60	65	69	76	72	77	76	80
T9	59	65	68	75	71	76	76	82
T10	57	62	64	71	72	76	75	79
T11	55	60	60	69	73	76	76	80
T12	57	62	60	69	75	77	77	82
T13	58	63	65	72	73	77	78	81
T14	57	63	63	71	74	77	72	78
T15	61	67	67	75	72	77	74	79

unfertilized plant (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14), chemical fertilizer (T15). 50%F: Mid-male flowering; 100% F: Total male flowering; 50% EF: Mid ear formation; 100% EF: Total ear formation.

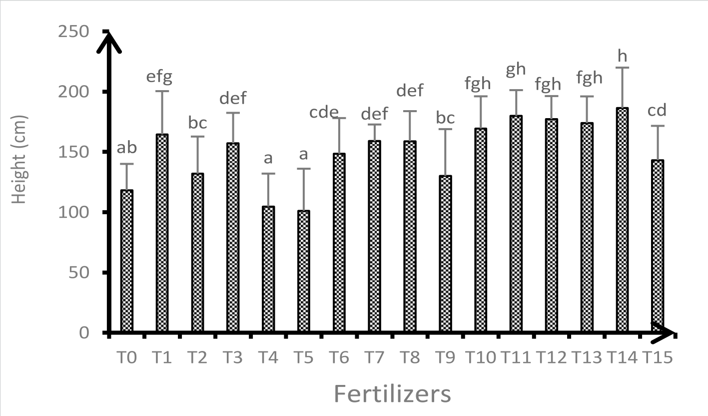
Growing parameters

Statistical analysis revealed a significant difference ($p < 0.05$) between treatments on the number of leaves per plant. There is a highly significant difference ($p < 0.01$) in plant height and, diameter of stem. In addition, a highly significant interaction ($p<0.001$) between fertilizers and study years was recorded on plant height, diameter of stem and foliar production.

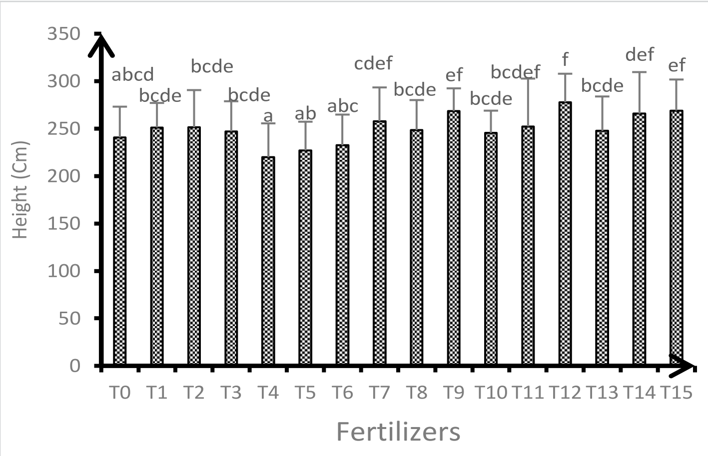
Plant height

Plant heights at male flowering time vary from 101.2±34.86 cm for pyroclastites powder treated plants and 118.13±21.91 cm for unfertilized plants (T0) in 2023 to 277.66±30.13 cm for compost derived cow dung manure enriched with vivianite and pyroclastites powders (T12) in 2024 (Figure 4). In a second cropping season in 2024, T12 fertilizer increased maize height by 15% compared to T0. Moreover, T0 plants in the 2nd crop year 2024 were 2.03 times taller than those of the same plants in the first crop year 2023.

These results recorded on plant height are different from those found by [23], who reported that maize plants ranged between 123 cm and 180 cm. [24] showed a fairly strong positive correlation between maize plant height and leaf production, and between plant height and yield parameters, which are also positively correlated with each other.



4a: Plant height from 2023



4b: Plant height from 2024

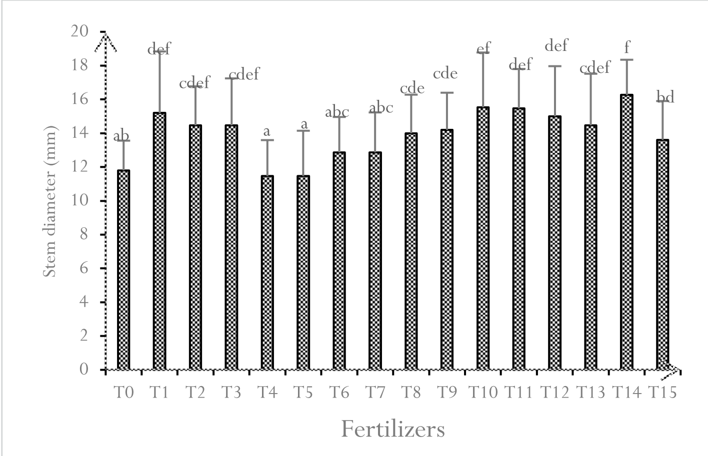
Figure 4: Maize plant height as a function of fertilization in 2023 (4a) and 2024 (4b)

unfertilized plant (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14), chemical fertilizer (T15). Values of bands affected by the same letter are not significantly different.

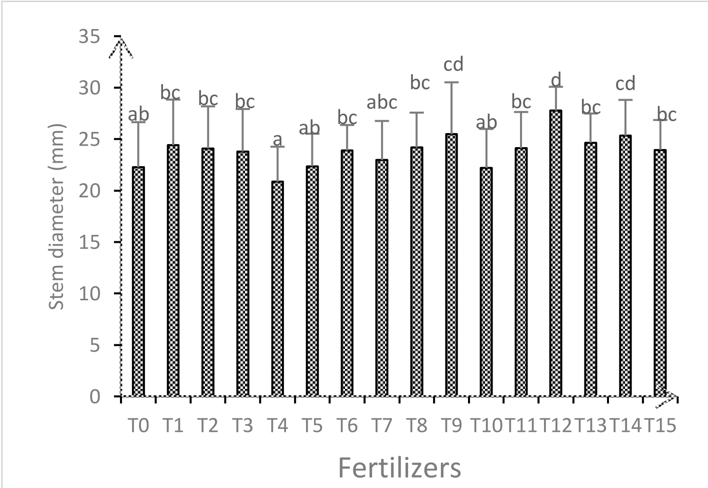
Diameter of stem at collar

Regarding the first cropping season, treated plants using vivianite powder and unfertilized plants exhibited the smallest stem radial growth (11.47±2.77 mm and 11.8 ± 1.76 mm, respectively). The highest diameter (27.77 mm) was recorded on treated plants using compost-derived cow dung manure enriched with vivianite and pyroclastite powders (T12) during the second crop year 2024 (Figure 6). The average radial growth of T12 plants was 1.25 times greater than that of unfertilized plants. The radial growth of unfertilized plants in 2024 is 1.88 times greater than that of the same plants in 2023.

These results obtained on stem diameter differ from those reported by [20], who found that the maize diameter varies from 16.3±5.60 mm to 19.9±2.10 mm. Maize plant diameter is a key indicator of plant vigor and health, resistance to harsh weather conditions, and maize productivity.



6a: Stem diameter from 2023



6b: Stem diameter from 2024

Figure 6: Stem diameter at collar as a function of fertilizers in 2023 (6a) and 2024 (6b)

unfertilized plant (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14), chemical fertilizer (T15). Values of bands affected by the same letter are not significantly different.

Production parameters

Statistical analysis revealed a highly significant ($P < 0.01$) difference on ear size (length, diameter), weight, seed weight per plant, and seed yield. However, this interaction was not significant for biomass, number of rows per ear, and number of ears per plant. In addition, a highly significant interaction ($P<0.001$) between fertilizers and study years was observed on ear size (length, diameter), ear weight, seed weight per plant, and seed yield. However, this interaction between treatments and study ear was not significant for biomass ear, number of rows per ear and number of ears per plant (tables 3 and 4).

Number of ears per plant

The highest number of ears per plant (1.46±0.5) (Tables 3 and 4) was observed on treated plots using compost-derived cow dung manure enriched with vivianite and pyroclastite powders

(T12), while the lowest value of this parameter (1.00±0.23) was recorded on unfertilized plots. The T12 treatment increased the number of ears per plant by 46% compared to unfertilized plants, and by 25% compared to chemical fertilizer.
These results on ear production per plant are similar to those of [25], who found that the number of ears per plant ranged from 1.00±0. to 1.40 ± 0.50. The number of ears of maize per plant is an important factor influencing seed yield. Maize plants with a higher ear number tend to produce more seeds than plants with a lower ear number. [26] found that maize plants with two ears per plant produced an average of 250 seeds per ear, while plants with one ear per plant produced an average of 150 seeds per ear.

Ear length

Average ear length ranged from 12.02±1.91 cm for unfertilized plants in 2023 to 24.53±1.16 cm for treated plants using compost-derived cow dung manure enriched with vivianite and pyroclastite powders (T12) in 2024. T12 treatment increased ear length at 35.02% compared to unfertilized plants in 2023 (Figure 7). The average length ear of unfertilized plants in 2024 was 1.59 times greater than that of the same plants in 2023.
Our results on ear length differ from those of [23] who reported that ear length varies from 10.16 cm to 14.26 cm. These differences may be explained by the "Musangana" maize variety used by [23]. Maize ear size is an important factor influencing seed yield. Larger maize ears tend to produce more seeds than smaller ears, and maize ear size can influence the number of seeds per ear.

7a: Ear from T0 *7b: Ear from T12* *7c: Ear from T15*

Figure 7: Ear length of unfertilized plants (7a), treated plants with compost-derived cow dung enriched with vivianite and pyroclastites powders (7b) and treated plants with chemical fertilizers (7c) in 2024 cropping season.
T0: unfertilized plant, T12: cow dung-based compost + vivianite + pyroclastite, T15: chemical fertilizer.

Ear weight

T12 plants exhibited the highest ear weight (0.16±0.02 kg) in 2024, while the lowest ear weight (0.06±0.02 kg) is recorded on unfertilized plants in 2023 (figure 8). Ear weight from T12 fertilizer is 1.14 and 1.23 kg higher than that from unfertilized plants and chemical fertilizer, respectively in 2024.

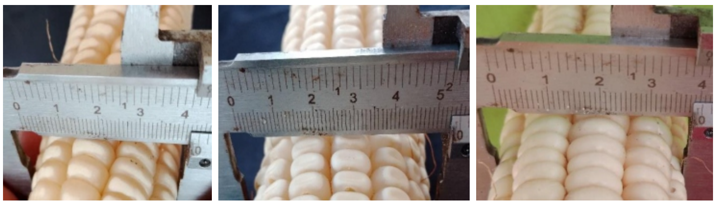
Our results on ear weight differ from those of [23], who reported that maize ear length varies from 0.12 kg to 0.15 kg for ears with spathes and from 0.11 to 0.14 kg for ears without spathes. [26] revealed a significant positive correlation between maize ear weight and seed yield.

8a: Ear from T0 *8b: Ear from T12* *8c: Ear from T15*

Figure 8: Ear weight of unfertilized plants (8a), treated plants with compost-derived cow dung enriched with vivianite and pyroclastites powders (8b) and treated plants with chemical fertilizers (8c) in the 2024 cropping season.

Diameter of the ear at the middle

Ear diameter at middle varies from 33.93±4.51 mm for unfertilized plants in 2023 to 49.93±2.08 mm for treated plants using compost-derived cow dung manure enriched with vivianite and pyroclastites powders (T12) in 2024 (Table 3 and Table 4). T12 treatment increased the diameter of the ear in the middle by 22.98% compared to unfertilized plants in 2024 (figure 9). The average ear diameter from unfertilized plants in the second cropping season was 1.20 times greater than that of the same plants in the 1st season cropping. These results on ear diameter differ from those obtained by [20], who reported that ear diameters of maize plants vary from 32.4±8.3 mm to 39.6±3.30 mm.
The mid-ear diameter of maize is an important factor influencing seed yield. Indeed, [26] revealed a significant positive correlation between the ear diameter of ear and seeds yield, number of lines per ear and seeds yield, and between number of seeds per ear and seeds yield.



9a: Ear from T0 *9b: Ear from T12* *9c: Ear from T15*

Figure 9: Ear diameter at middle of unfertilized plants (9a), treated plants with compost derived cow dung enriched with vivianite and pyroclastites powders (9b) and treated plants with chemical fertilizers (9c) in 2024 cropping season.

Table 3: Maize production according to fertilization in the first cropping year 2023

F	NE/P	EL (cm)	EW (Kg)	ED (mm)	NL/E	NS/E
T0	1.13±0.34^{a}	12.02±1.91^{a}	0.06±0.02^{a}	33.93±4.51^{ab}	12.40±1.96^{ab}	245.00±73.95^{a}
T1	1.27±0.40^{abcd}	15.37±2.80^{ef}	0.12±0.05^{def}	42.07±5.63^{ef}	14.53±1.86^{fg}	383.53±116.98^{cd}
T2	1.27±0.44^{abcd}	13.07±2.34^{abcd}	0.09±0.04^{abc}	39.13±4.19^{de}	13.20±1.22^{abcde}	296.00±57.74^{ab}
T3	1.40±0.49^{cd}	15.11±2.62^{ef}	0.11±0.04^{cde}	39.53±4.36^{de}	13.60±2.33^{bcdefg}	349.73±90.00^{bc}
T4	1.07±0.25^{ab}	12.11±2.39^{ab}	0.07±0.04 ^{ab}	33.27±7.90^{a}	13.33±1.19^{abcdef}	271.00±101.07^{a}
T5	1.07±0.25^{ab}	12.57±2.21^{abc}	0.06±0.02^{a}	34.60±5.29^{abc}	12.27±1.91^{a}	289.47±79.63^{ab}
T6	1.40±0.49^{cd}	15.05±2.69^{ef}	0.12±0.04^{de}	40.13±3.96^{de}	13.07±1.44^{abcd}	373.20±96.58^{cd}
T7	1.33±0.47^{bcd}	14.68±2.37^{def}	0.13±0.03^{ef}	42.33±2.18^{ef}	14.67±1.58^{g}	426.40±91.43^{de}
T8	1.20±0.4^{abc}	13.54±1.81^{abcde}	0.09±0.02^{abc}	37.47±2.85^{bcd}	13.73±1.77^{cdefg}	340.80±63.95^{bc}
T9	1.47±0.50^{cd}	12.84±3.15^{abcd}	0.07±0.03^{ab}	34.27±5.36^{abc}	13.07±1.91^{abcd}	298.80±68.51^{ab}
T10	1.20±0.40^{abc}	14.42±3.70^{cdef}	0.12±0.06^{def}	40.00±5.30^{de}	13.87±1.36^{defg}	403.60±126.22^{cde}

T11	1.27±0.44^{abcd}	15.27±2.62^{ef}	0.12±0.04^{def}	41.67±4.28^{ef}	14.27±2.29^{defg}	389.67±70.37^{cd}
T12	1.53±0.50^{d}	16.23±2.01^{f}	0.14±0.03^{ef}	42.73±2.59^{ef}	14.13±1.71^{defg}	401.73±66.10^{cde}
T13	1.53±0.44^{d}	12.51±2.05^{ab}	0.09±0.04^{bc}	37.80±6.32^{cd}	12.53±1.36^{abc}	265.13±106.50^{a}
T14	1.40±0.49^{cd}	15.87±2.33^{f}	0.15±0.05^{f}	43.80±5.37^{f}	14.40±2.22^{efg}	461.27±139.96^{e}
T15	1.07±0.25^{ab}	13.93±2.57^{bcde}	0.10±0.04^{cd}	40.13±4.60 ^{de}	13.20±1.6^{abcde}	349.33±98.19^{bc}

Table 4: Maize production according to fertilization in the second cropping year 2024

F	NE/P	EL (cm)	EW (kg)	ED (mm)	NL/E	NS/E
T0	1.07±0.3^{a}	19.13±1.75^{a}	0.14±0.01^{e}	40.6±1.8^{ab}	12.38±1.9^{ab}	258.00±36.11^{de}
T1	1.47±0.5^{d}	24.33±2.84^{efg}	0.13±0.01^{abc}	48.73±5.6^{gh}	14.5±1.8^{fg}	257.93±46.95^{de}
T2	1.2±0.4^{abcd}	24.07±2.35^{def}	0.14±0.00^{de}	45.27±3.3^{def}	13.18±1.2^{abcde}	219.93±35.98^{ab}
T3	1.2±0.5^{cd}	22.40±1.54^{cde}	0.14±0.00^{cd}	47.2±1.9^{fg}	13.59±2.3^{bcdefg}	253.8±38.96c^{de}
T4	1.07±0.2^{ab}	22.33±3.44^{cde}	0.14±0.01^{cd}	42.2±3.9^{bc}	13.33±1.1^{abcdef}	225.6±29.34^{abc}
T5	1.33±0.2^{ab}	23.93±2.95^{def}	0.14±0.01^{bc}	43.8±2.5^{cd}	12.26±1.9^{a}	239.33±45.89^{bcd}
T6	1.2±0.5^{cd}	21.53±3.67^{bc}	0.13±0.01^{a}	44.2±3.7^{cde}	13.08±1.4^{abcd}	214.4±8.52^{ab}
T7	1.27±0.5^{bcd}	21.2±4.48^{abc}	0.13±0.01^{ab}	45.13±4.5^{def}	14.65±1.6^{g}	231.13±37.19^{bcd}
T8	1.33±0.4^{abc}	21.2±2.90^{abc}	0.14±0.01^{bcd}	46.93±3.9^{fg}	13.71±1.8^{cdefg}	198.73±31.01^{a}
T9	1.13±0.5^{cd}	19.47±3.22^{ab}	0.13±0.01^{abc}	46.33±2.5^{defg}	13.08±1.9^{abcd}	230.73±36.37^{bcd}
T10	1.33±0.4^{abc}	21.2±3.64^{abc}	0.14±0.01^{cd}	46.87±4.2^{fg}	13.88±1.4^{defg}	250.27±56.06^{cde}
T11	1.27±0.4^{abcd}	22.47±2.70^{cdef}	0.14±0.00^{cde}	45.73±4.3^{def}	14.24±2.3^{defg}	287.4±57.37^{f}
T12	1.40±0.5^{d}	24.53±1.16^{fg}	0.16±0.02^{e}	49.93±2.0^{h}	14.11±1.7^{defg}	338.6±38.62^{g}
T13	1.40±0.4^{abcd}	20.93±2.32^{abc}	0.15±0.01^{e}	46.67±3.5^{efg}	12.50±1.4^{abc}	288.4±36.43^{f}
T14	1.27±0.5^{cd}	21.93±2.54^{cd}	0.13±0.01^{abc}	39.67±2.3^{ab}	14.39±2.2^{efg}	269.4±33.28^{ef}
T15	1.27±0.2^{ab}	22.67±1.74^{cdef}	0.13±0.01^{abc}	39.53±3.05^{a}	13.21±1.6^{abcde}	268.73±30.21^{ef}

NE/P: number of ears per plant, EL: ear length, EW: ear weight, ED: ear diameter at middle,
NL/E: number of lines per ear, NS/E: number of seeds per ear, unfertilized plant (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14), chemical fertilizer (T15). Values of columns affected by the same letter are not significantly different.

Maize seeds yield

The highest estimated seed yield (6.70 t/ha) was recorded on treated plots with compost derived cow dung manure enriched with vivianite and pyroclastites powders (T12) in the cropping season 2024, while the lowest seeds yield (1.60 and 1.80 t/ha) were from treated plots with pyroclastites powder (T5) and unfertilized plants (T0) in 2023 respectively. T12 treatment increased maize seed yield by 118.24% compared to the T0 treatment, and by 21.60% compared to chemical fertilizer in 2024 (Table 5).

Similarly, the estimated seed yield of unfertilized plants in the 2nd cropping year 2024 (3.07 t/ha) was higher than that of the 1st cropping year 2023 (1.80 t/ha). Maize seeds yield from the second cropping year is 1.70 times higher than that from the first cropping year, 2023. These results on estimated maize seed yield as a function of fertilizer corroborate the work of [27], who reported that maize seed yields vary from 1.80 to 6.40 t/ha. Assessing maize seed yield in an experimental field is important for improving productivity and seed quality, identifying factors influencing productivity, and taking steps to improve it, as well as for predicting maize seed yields under similar conditions. Maize seeds are one of the most important crops for human consumption [1], it is rich in starch, protein, fat, ash, crude fiber, and mineral elements (magnesium, potassium, and phosphorus) [2]. This study reveals that enriched compost with vivianite and pyroclastite powders improves maize growth and seed yield. However, several authors [5] [28] [29] found that crops nutritive value varies depending on fertilizer. In this context, seeds nutritive value from fertilizers used in this work needs to be assessed.

Table 5: Seeds yield from 2023 and 2024

Fertilizers	Yield 2023	Yield 2024
T0	1,8±0,37^{a}	3,07±0,43^{a}
T1	3,95±0,26^{d}	3,88±0,32^{de}
T2	2,9±0,41^{b}	3,19±0,31^{ab}
T3	4±0,17^{d}	4,05±0,27^{efg}
T4	1,93±0,38^{ab}	3,59±0,41^{cd}
T5	1,6±0,35^{a}	3,39±0,25^{bc}
T6	4,48±0,23^{def}	4,19±0,27^{fg}
T7	4,67±0,31^{def}	3,91±0,21^{ef}
T8	3,22±0,42^{bc}	3,15±0,38^{ab}
T9	2,8±0,46^{b}	3,92±0,46^{ef}
T10	4,75±0,30^{def}	3,96±0,36^{ef}
T11	4,15±0,28^{d}	4,3±0,37^{g}
T12	6,22±0,24^{f}	6,7±0,29^{i}
T13	4,33±0,36^{de}	5,61±0,28^{h}
T14	5,83±0,39^{ef}	5,53±0,35^{h}
T15	4±0,42^{cd}	5,51±0,29^{h}

unfertilized plant (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14), chemical fertilizer (T15). Values of columns affected by the same letter are not significantly different.

Profitability of fertilizer use

Compost-derived cow dung manure enriched with vivianite and pyroclastite powders (T12) presented the highest seed yield in both 2023 and 2024 cropping years. T12 fertilizer generated the highest net profits in 2023 ($1307.1/ha) and 2024 ($1038.6/ha) compared to treated plots using chemical fertilizer (T15) ($365.33/ha and $446.89/ha in 2023 and 2024, respectively). The value of yield increase/fertilizer cost (VCR) is very attractive for T12 treatment, with 6.33 in 2023 and 7.70 in 2024. T12 fertilizer is the most profitable and economically efficient treatment. The VCR relative to T12 fertilizer is 2.92 and 3.93 times higher than that for chemical fertilizer in 2023 and 2024, respectively. Thus suggesting that T12 fertilizer is more economically profitable than chemical fertilizer.

In the present study, the VCR ranged between 1.96 and 7.90, this result corroborates partially the data found in the literature. Indeed, [14] studied the economic evaluation of maize in the Republic of the Congo and reported that the VCR varied from 2.47 to 5.01. In addition, [30] studied the influence of planting date and inorganic fertilization on the yield of maize hybrids in Lubumbashi and reported that the VCR ranged between 1.6 and 2.42. Furthermore, several studies [5] [28] have shown that organic fertilizers have positive residual effects over several growing cycles, whereas chemical fertilizers must be applied several times to maintain yields.

Table 6: Profitability of fertilizer use in 2023 and 2024

F	Yield with fertilizers (t/ha)		Control yield (t/ha)		Maize seed price ($/t)	Cost of fertilizer ($/ha)	Yield gain ($/ha)		Gross economic gain ($/ha)		Net income ($/ha)		Profitability (%)		Value/cost ratio (VCR)	
	2023	2024	2023	2024	2023	2023	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
T0	1.8	3.07	1.8	3.07	339.84	0	-	-	-	-	-	-	-	-	-	-
T12	6.22	6.7	1.8	3.07	339.84	194.98	4.42	3.63	1502.1	1233.6	1307.1	1038.6	532.69	670.38	6.33	7.70
T15	4	5.51	1.8	3.07	339.84	382.32	2.2	2.44	747.65	829.21	365.33	446.89	116.89	95.56	2.17	1.96

F: Fertilizer; T0: unfertilized plant; T12: cow dung-based compost enriched with vivianite and pyroclastites powders; T15: chemical fertilizer

Various natural fertilizers used in this study had positive effects on physiological parameters and, consequently, on maize seed yield. There are several possible explanations for these results. Indeed, the composts used have an alkaline pH, which may have improved that of growing soil [31]. Furthermore, the organic matter and macronutrient contents of composts are far higher than those of growing soil. A high level of soil organic matter content promotes phosphorus uptake [32], which plays a key role in photosynthesis [33]. The addition of organic matter to growing soil stimulates the growth of microorganisms, leading to greater availability of soil nutrients to crops [19].

The addition of these composts and rock powders therefore has the beneficial effect of promoting good plant nutrition by releasing mineral elements into the soil solution, thus promoting elevated physiological parameters compared with control plants that received no amendment [34].

However, the optimum was reached with the treatment based on compost-derived cow dung manure enriched with vivianite and pyroclastite powders (T12). These results may be explained by the ionic balance of nutrients in the soil amended with this treatment. Indeed, there is a necessary ionic balance that the plant needs to absorb nutrients for proper growth. Although this compost is less rich than the other two (compost derived poultry litter and compost derived goat droppings), its enrichment with vivianite and pyroclastite powders gives it a balanced ionic content that enhances plant growth. A high cation content, for example, can inhibit potassium and ammonium uptake [35], which can slow plant development and growth. This would be the case for amended plots with compost derived from poultry litter and goat dung manure, which contain high levels of mineral elements (Table 1).

The significant difference in maize growth and development parameters observed between the 2023 and 2024 cropping years would be justified by differences in climatic conditions. Several authors [36] [37] revealed that low photosynthesis activity leads to plant growth due to water stress. Increased rainfall intensity affects crop growth and yield through waterlogging or leaching of soil nutrients. Waterlogging compact the soil, deprives roots of oxygen, and contributes to salinization. This, in turn, reduces the effective photosynthetic surface area of the leaves, the length and diameter of the ear, and consequently disrupts the accumulation of dry matter, leading to lower yields [37]. In addition, optimum temperatures for the development and filling of maize kernels are between 20 and 30°C. Temperatures above 30°C during seed filling can accelerate the ripening process, but often to the detriment of yield [38].

CONCLUSION

The soil of the locality of Darang (Cameroon) is unfavorable for growing maize because it is acidic and poor in some nutrients like N and P. The growth and maize seed yield varied significantly depending on the fertilizer and the year of experimentation. The combined application of 500 g of compost-derived cow dung manure + 10 g of vivianite powder + 10 g of pyroclastite powder (T12) generates the highest response of maize plant growth. Flowering and emergence ear are early for T12 plants compared to unfertilized plants. T12 fertilizer increased the number of ears per plant by 46% and 25% compared to unfertilized plants and chemical fertilizer, respectively. T12 fertilizer increased maize seed yield by 118.24% and 21.60% compared to unfertilized plants and chemical fertilizer, respectively. T12 fertilizer has the highest benefit/cost ratios (6.33 in 2023 and 7.70 in 2024). It is the most profitable and economically efficient fertilizer. T12 fertilizer can be employed to replace the mineral fertilizers in an attempt to boost the maize production while reducing the production cost. Our future study will focus on the effects of T12 fertilizer on the maize seed's nutritional values.

REFERENCES

1. FAO, 2024. Rapport sur l'indice FAO des prix des produits alimentaires, Rome. https://www.fao.org/wordfoodsituation/foodpricesindex/fr/

2. Semassa, A.J., Padonou, S.W., Anihouvi, V.B., Adjanohoun, A., Baba-Moussa, L. 2016. Diversité variétale, qualité et utilisation du maïs (*Zea mays*) en Afrique de l'Ouest : Revue critique. *European Scientific Journal*, vol. 12, no. 18

3. Atlasocio, 2022. Classement des Etats d'Afrique par production de maïs. http://atlasocio.com

4. Mathe, S., Dury, S., Temple, L., Ngomé, P. T., Njankouo, A. N., Otou, M. 2022. Etude d'impact socioéconomique des effets de la COVID 19 sur les stratégies paysannes et I'adaptation des filières agricoles et alimentaires au Cameroun. Rapport du Centre de coopération internationale en recherche agronomique pour le développement (CIRAD).

5. Tchuenteu, T.L., Megueni, C., Noubissie, E., Wamkoua, M.M. 2018. Study on physico-chemical properties of composts and their effects on growth, yield and fruits quality of *Capsicum Annum* L. at Dang locality (Ngaoundere-Cameroon). *Journal of Agriculture and Veterinary Science*, vol. 11, pp. 26-35.

6. Kamdem, K.F. – Tchuenteu, T.L. – Maimouna, A. – Megueni, C. 2020: The combination of arbuscular mycorrhizal fungi with rock powder and poultry litter: An appropriate natural fertiliser for improving the productivity of soybean (Glycine max (L.) MERR). *Agriculture (Poľnohospodárstvo)*, vol. 66, no. 3, pp. 108 – 117.

7. Liu, X., and Li, Q. 2018. Effects of vivianite powder on soil phosphorus availability and plant growth. *Journal of Environmental Science and Health*, Part B, 53, 235-242.

8. Bachirou, H., Tchuenteu, T. L., Maimouna, A., Megueni, C., and Njintang, Y. N. 2022. "The Combination of Compost Derived Poultry Litter and Vivianite Powder: Appropriate Biological Fertilizer to Improve the Growth and Root Yield of *Daucus Carota* L". *Journal of Experimental Agriculture International*, vol. 44, no 3, pp. 15-28.

9. Leclercy, D. 2002. Le compost: une filière de valorisation des déchets organiques à développer. Courrier de l'environnement de l'INRA no 47, octobre 2002. pp. 128-129.

10. Yaya, F., Nguetnkam, J.P, Tchameni, R, Basga, S.D., Penaye, J. 2015. Assessment of the Fertilizing effect of vivianite on the Growth and yield of the Bean ''*phaseolus vulgaris*''on Oxisoils from Ngaoundere (Central North Cameroon). *International Research Journal of Earth Sciences*, vol. 3, no 4, pp. 18-26.

11. Nkouathio, D., Wandji, P., Bardintzeff, J.-M., Tematio, P., Kagou, D. A. et Tchoua, F. 2008. Utilisation des roches volcaniques pour la reminéralisation des sols ferrallitiques des régions tropicales. Cas des pyroclastites basaltiques du graben de Tombel (Ligne volcanique du Cameroun). *Bulletin de la Société Vaudoise des Sciences Naturelles*, vol. 91, no. 1, pp. 1-14.

12. Hamza, N. 2014. Application of arbuscular Mycorrhiza in Gardening crops: Case study of water Melon (*Citrullus lanatus*), Master Thesis, University of Ferhat Abbas Setif.

13. Useni, S.Y., Chukiyabo K.M., Tshomba K.J., Muyambo M.E., Kapalanga K.P., Ntumba N.F., Kasangij K.P., Kyungu K.A., Baboy L.L., Nyembo K.L., Mpundu M.M., 2013. Utilisation des déchets humains recyclés pour l'augmentation de la production du maïs (Zea mays L.) sur un ferralsol du sud-est de la RD Congo. Journal of Applied Biosciences 66:5070 – 5081;

14. Mankoussou, M., Mialoundama, F. et Diamouangana, J. 2017 .Évaluation économique de quelques niveaux de fertilisation du maïs (Zea mays L. variété Espoir) dans la Vallée du Niari, République du Congo . Journal of Applied Biosciences 111: 10905-10915

15. Landon, J. R. 1991. Booker tropical soil [33] manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Pbk. ed. Harlow, Essex, England: Longman Scientific & Technical.

16. Baize, D. 2000. Guide des analyses en pédologie. 2ème édition, revue et augmentée. INRA édition, paris.257p.

17. Van Wambeke, A. 1992. Soils of the Tropics, Properties and Appraisal; McGraw-Hill, Inc.: New York; 343.

18. Van Ranst, E. 1995. Rational Soil Management in the Humid Tropics. Bulletin des Séances. Académie Royale des Sciences d'Outre-Mer, vol. 40, pp. 209–233.

19. Clément, M.F. et N'Dayegamiye, A. 2009. Rotation dans la culture de pomme de terre : bilans humiques et logiciel de calcul. CRAAQ, Colloque sur la pomme de terre, Québec.

20. Banza, M. J., Mwamba, K. F., Esoma, E. B., Meta, T. M., Mayamba, M. G. et Kasongo, L. M. E. 2019. Evaluation de la réponse du maïs (*Zea mays* L.) installé entre les haies de *Tithonia diversifolia* à Lubumbashi, R.D. Congo. *Journal of Applied Biosciences*, vol. 134, pp. 13643–13655

21. Liu, W., Zhang, Y., and Li, X. 2015. Effects of early flowering on maize seeds quality. *Journal of Cereal Science*, vol. 64, pp. 137-143.

22. Zhang, Y., Liu, W. & Il,2019. X. . Early flowering and seeds yield in maize under drought conditions. *Crop Science*, vol. 59, no 3, pp. 931-93.

23. Tshibingu, R. M., Mukadi, T. T., Mpoyi, M., Ntatangolo, B. M., Musenge, D. K., Tshibingu, M. I., Kazadi, J. N. Nyembo, D. N. et Mushambani, T. M. 2017. Evaluation de la production du maïs (*Zea mays* L.) sous amendement organique et minéral dans la province de Lomami, République Démocratique du Congo. *Journal of Applied Biosciences,* vol. 109, pp. 10571-10579.

24. Moussa, A.A., Salako, V.K., Charlemagne, Gbemavo, D.S.J., Zaman-Allah M., Kakaï R.G. et Bakasso Y. 2018. Performances agromorphologiques des variétés locales et améliorées de maïs au sud-ouest du Niger. *African Crop Science Journal*, vol. 26, no. 2, pp. 157–173.

25. Useni, S.Y., Baboy, L.L., Nyembo, K.L., Mpundu, M.M. 2012. Effets des apports combinés de biodéchets et de fertilisants inorganiques sur le rendement de trois varieties de Zea mays L. cultivées dans la région de Lubumbashi. *Journal of Applied Biosciences*, vol. 54, pp: 3935–3943.

26. Zhang, J., Liu, X. & Wang, Y. 2018. Effects of ear number per plant on maize yield and its components. *Journal of Agricultural Science*, vol. 156, no 3, pp. 257-265.

27. Kaho, F., Yemefack, M., Feujio-Teguefouet, P., & Tchatchouang, J.C. (2011). Effet combiné des feuilles de *Tithonia diversifolia* et des engrais inorganiques sur les rendements du maïs et les propriétés d'un sol ferralitique au Centre Cameroun. Tropicultura, 29(1), 39–45.

28. Megueni, C. – Tchuenteu, T.L. – Noubissie, E. –Maimouna, A. – Bachirou, H. 2017. Field productivity of carrot (Daucus carota L.) in Adamawa Cameroon and chemical properties of roots according to chicken manure pretreatments and vivianite powder. *Journal of Agriculture and Veterinary Science* (IOSR-JAVS), vol. 10, no. 5, pp. 16 – 23.

29. Kamdem, K. F. – Tchuenteu, T. L. – Megueni, C. 2025. The combination of poultry litter, vivianite powder and mycorrhizae: A suitable natural fertilizer for improving nutritional values of soybean (*Glycine max* Linn. Merril). *Journal of Agricultural, Food Science & Biotechnology*, vol. 3, no 1, pp. 67-75.

30. Useni, S.Y., Kayenga, L.A., Assani, B. L., Ekondo, O. A., Baboy L. L., Ntumba K.B., Mpundu M.M., et Nyembo K.L., 2014. Influence de la date de semis et de la fertilisation inorganique sur le rendement de nouveaux hybrides de maïs (Zea mays L.) à Lubumbashi. Journal of Applied Biosciences 76:6316 – 6325;

31. Ognalaga, M. et Itsoma, E. 2014. Effet de *Chrmolaena odorata* et de *Leucaena leucocephalae* sur la croissance et la production de l'oseille de Guinée (*Hibiscus sabdarifa* L.). Agronomie africaine, 26, 1-88.

32. Rabeharisoa, L. 2004. Rôle de la matière organique dans la fertilité des sols ferralitiques de Madagascar. Mémoire de DEA, Université d'Antananarivo, Département des Sciences du Sol.

33. Chapman, R. and Edmeades, D. C. 1999. Soil organic matter: Its importance in sustainable agriculture and carbon dioxide fluxes. In D. L. Sparks (Ed.), *Advances in Agronomy* (Vol. 101, pp. 1-57). Academic Press.

34. Toundou, O., Tozo, K., Amouzouvi, K.A.A., Lankondjoa, K., Tchangbedji, G., Kili, K., Gnon, B. 2014. Effets de la biomasse et du compost de *Cassia occidentalis* L. sur la croissance en hauteur, le rendement du maïs (Zea mays L.) et la teneur en NPK d'un sol dégradé en station expérimentale. *European Scientific Journal*, vol. 10, pp. 294-308.

35. Etchebest, S. 2000. Croissance foliaire du maïs (*Zea mays* L.) sous déficience en phosphore. Analyse à l'échelle de la plante et à l'échelle de la feuille. Thèse préparée à l'unité d'agronomie, INRA Bordeaux, 83p.

36. Gao, Q., Li, M., Piao, L., Yan, J.Y., Li, Q., Xiao, J.L., Jin, P. 2018. Effects of weak light and waterlogging stress at jointing stage on photosynthesis, root growth and yield of spring maize. *Jiangsu Academy of Agricultural Sciences*, vol. 34, no 6, pp. 1276-1286.

37. Chao, H., Yang, G., Anzhen, Q., Zugui, L., Ben, Z., Dongfeng, N., Shoutian, M., Aiwang, D., Zhandong, L. 2022. Effects of water logging at different stages and durations on maize growth and seeds yields, Agricultural Water Management, vol. 261.

38. Barros, M. S. L., De Souza, L.M., et Neves, D.G. 2017. *Agricultural and Forest Meteorology*, vol. 246, pp. 174-182.