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Effect of Amending Acid Oxisols Using Basalt Dust, *Tithonia diversifolia* Powder and NPK 20-10-10 on Garlic (*Allium sativum*) Production in Bafut (Cameroon Volcanic Line)

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PAT, PW, AHC and MNMP designed the study, performed the petrography, soil and statistical analyses, wrote the protocol and the draft of the manuscript. Authors AM, DGKN, DGN and DB managed the analyses of the study and the literature review. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To compare the effects of basalt dust, *Tithonia diversifolia* (*T. diversifolia*) powder and NPK 20-10-10 on the growth and production of Garlic (*Allium sativum,* softneck variety) in Bafut (Cameroon Volcanic Line).

Study Design: A randomized complete block design (RCBD) with three replications in the field was used. The treatments were T_0 (control), T_1 (0.7 tons ha^{-1} NPK 20-10-10), T_2 (0.4 tons ha^{-1} basalt), T_3 (0.6 tons ha^{-1} basalt) and T_4 (0.5 tons ha^{-1} *T. diversifolia* powder).

Place and Duration of Study: The study conducted in Bafut (Cameroon) from 2nd August 2017 to 24th February 2018.

Methodology: Fieldwork involved land preparation, planting and collection of growth and yield parameters as well as rocks and soil sampling. Laboratory work involved soil physicochemical analysis and cutting of rock thin sections for microscopic observations. The plant data were subjected to statistical and economic analyses.

Results: The control soil (T_0) showed a sandy clayey loamy texture, acidic pH (5.1), very high organic carbon (6.4%), low total nitrogen (0.2%) and moderate available phosphorus (19.42 mg kg^{-1}). The exchangeable complex revealed high K^+ (0.88 cmol (+).kg^{-1}), very low Ca^{2+} (0.63 cmol (+).kg^{-1}) and Mg^{2+} (0.21 cmol (+).kg^{-1}), low Na^+ (0.07 cmol (+). kg^{-1}), very low sum of exchangeable bases (1.79 cmol (+).kg^{-1}), moderate cation exchange capacity (CEC) (22.7 cmol (+). kg^{-1}) and a very low base saturation (7.88%). C/N ratio was very high (35>17) indicating very poor quality organic matter and a potentially very slow mineralization rate. Growth and yield parameters, except fruit number, were such that $T_2>T_3>T_4>T_1>T_0$. T_2, T_3 and T_4 plants gave high yields while T_1 recorded the lowest yields below the control. The net yield showed that $T_3>T_4>T_2>T_0>T_1$ suggesting that basalt dust and *T. diversifolia* powder improved soil fertility that in turn boosted yields. Economically, T_1 had a BCR (benefit-to-cost ratio)<1 indicative of no profit, while T_2, T_3 and T_4 showed a BCR>2 indicating more than 100% profit of the investment and a possibility of popularization of these treatments.

Conclusion: Natural basalt dust and *T. diversifolia* powder treatments gave better garlic yields indicating a better soil fertilizing capacity compared to synthetic NPK 20-10-10. Basalt dust and *T. diversifolia* can be popularized to local inhabitants.

Keywords: Garlic; basalt dust; soil remineralisation; Tithonia diversifolia powder; NPK 20-10-10; crop production; Benefit-to-Cost Ratio.

1. INTRODUCTION

Soil remineralization has many advantages in agriculture as it provides slow and natural release of elements and trace minerals [1]. Soil remineralisation increases nutrient uptake of plants, raises soil pH, increases activities of earthworm and micro-organisms. It also helps to build humus complex, prevents soil erosion, increases soil water storage capacity and resistance to insects, disease and drought [2,3]. Moreover, it promotes more nutritious crops, enhances flavor as well as decreases dependence on fertilizers, pesticides and herbicides [3]. Results of soil remineralization by Hamaker and Weaver [1] revealed up to 150% yield improvement and nutritional value increase of crops. The effect of rock dust on plant growth is of importance in biologically orientated agriculture [2-4]. It recently enabled up to date developments in the use of rock dust to be described as “Stone Age” farming [5]. Remineralization has the potential to lower global atmospheric CO_2 to safe levels, revitalize soil and biological life as well as increase human nutrition and health levels [6]. In Cameroon, various rock dusts from the Cameroon Volcanic Line (CVL) have been used as fertilizers and conclusions drawn on their gradual, continuous and long-term nutrient release to soils, enabling to recommend these rocks for soil remineralization [7-11]. A survey conducted in Bafut Sub-division (Northwest Cameroon) has revealed that, although the soils of this area are very humiferous at the surface, their productivity is low even upon chemical fertilizer application, notably NPK. Garlic is a common lucrative crop in the neighbouring villages to Bafut -, but its cultivation or farm trial in Bafut is not reported. The Canadian Sunflower (*T. diversifolia)*, a locally abundant green manure, was shown to contribute to reversing declining soil fertility and to increase yield in small-scale farms in many countries [12-19]. The benefits are both environmental to cub pollution with chemical fertilizers as well as economical to reduce importation of chemical fertilizer and to popularise the cultivation of garlic in Bafut by local farmers. The use of *T. diversifolia* as a green manure has not been tested on garlic (*Allium sativum*) in Cameroon. The objective of this work was to study the actual fertility level of Oxisols in Bafut Sub-division and to compare the effects of basalt dust, *T. diversifolia* powder and NPK 20-10-10 on garlic production. The soft neck variety of garlic was selected as it is more lucrative and more appreciated by the local population as a result of its commonness, high yield, longer storability, stronger flavour and its various medicinal virtues. The results obtained will serve as a benchmark for the use of natural local fertilizers for remineralization of degraded soils as well as encourage the cultivation of garlic in this locality.

2. MATERIALS AND METHODS

2.1 Study Site Description

Bafut Sub-division is located in Mezam Division in the North West Region of Cameroon (Fig. 1). Bafut is located in the South East of Mount Bamenda that rises at 2621 m altitude [20]. The climate of the area is the Cameroon type equatorial climate, with two seasons: a rainy season of eight months (mid-March to mid-November) and a dry season of four months (mid-November to mid-March) [21]. The total annual rainfall is 2372 mm and the mean annual temperature is 25ºC. The study site, Njimbee, is located in the East of Bafut, between latitude 10º05” 00” to 10º12”00”E and latitudes 05º55” 00” to 05º62”00” N. Njimbee is more or less on a plain and the peak is at 1400 m.

It has a subdendritic drainage system with all streams flowing into the Mezam River (main drainage basin of the area). The area belongs to the tropical grasslands, dominated by palm bushes and eucalyptus meanwhile the raffia bushes are limited to swampy valleys. This natural vegetation is strongly modified by human activities [22]. The area lies within the CVL and is covered by granitic rocks that overlie the granite-gneissic basement. The dominant soils are red Oxisols with a dark and thick surface horizon. Gleysols are located in the swampy valleys [23]. The main activity of the population is farming, but few practice small scale business.

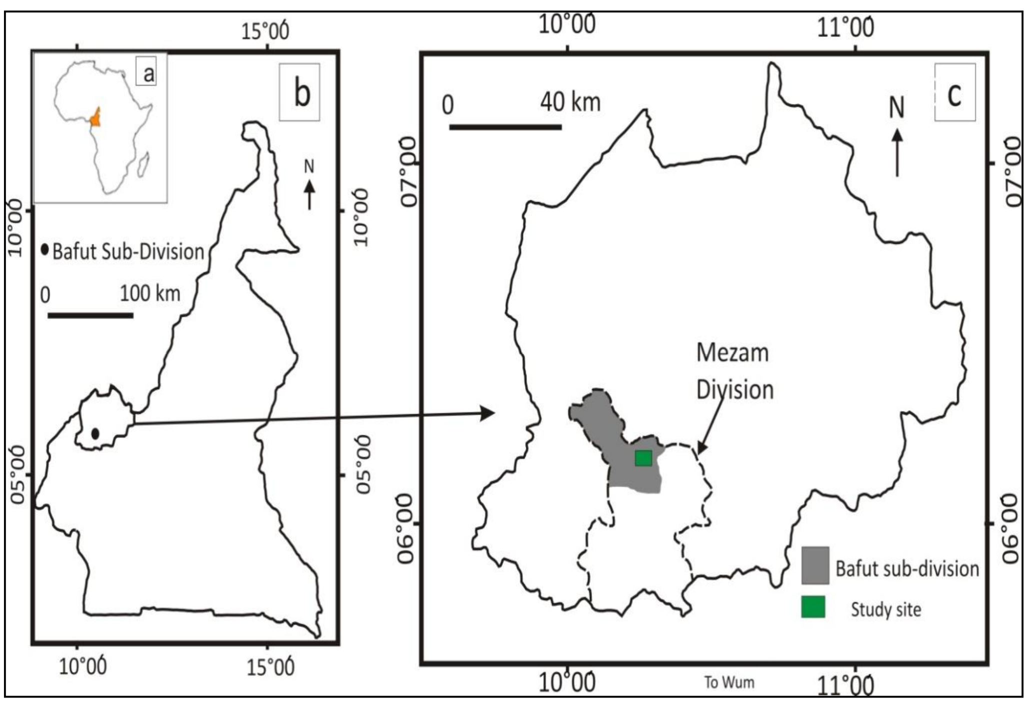

Fig. 1. Location map showing: a) the location of Cameroon in Africa; b) the location of the North West region in the Cameroon map; c) the location of the studied site in Bafut Sub-division, Mezam Division and in the North West Region

2.2 Field and Laboratory Methodology

A plot of 77 m^2 was cleared and tilled. It was divided into three blocks and each block further sub-divided into five experimental units (EU) or ridges (Fig. 2). The ridges were 1 m by 1 m with a furrow of 1 m separating them. The experimental layout was a randomized complete block design with five treatments replicated three times: T_0 (control), T_1 (0.7 tons ha^{-1} NPK), T_2 (0.4 tons ha^{-1} basalt), T_3 (0.6 tons ha^{-1} basalt) and T_4 (0.5 tons ha^{-1} dry *T. diversiforia* leaves). Five circular holes of 5 cm depth and 10 cm diameter were dug on T_2 and T_3 ridges. Basalt dust was put into these holes, mixed with soil. This was done on the 2nd of August 2017.These ridges were watered lightly after every three days for one month. On the 2nd of December 2017, identical holes were made on the T_4 ridges but this time filled with dry crushed *T. diversifolia* powder. The holes were made at 25 cm between the rows on a ridge and 10 cm between the holes on a row [24]. Planting was done on the 3rd of September 2017 by directly burying one garlic clove per hole at a depth of 2.5 cm. The cloves germinated 14 days after sowing and the NPK 20-10-10 treatment was applied 7 days after germination on the T_1 ridges by making a small ring round the plant with a radius of 7 cm to avoid direct contact with the plant. Weeding and mulching were done every 3 weeks to keep the experimental units free from weeds and to keep the soil porous.

2.3 Sampling and Laboratory Analysis of Rocks and Soil

Before land preparation, four soil samples were randomly collected in the experimental plot between 0 and 25 cm depth (humiferous layer), mixed thoroughly to form a composite sample, stored in a clean plastic bag and sent to the laboratory for analysis. In the laboratory, the composite soil sample was air-dried for one week. Afterwards, it was lightly crushed in an agate mortar, passed through a 2 mm sieve and then stored in a glass container under ambient conditions pending analysis.

The Petrographic analysis involved the cutting of thin sections (basalt and granite) at the Institute of Geologic and Mining Research (IRGM) in Yaoundé (Cameroon). Microscopic observations were done in the Geology Laboratory of the University of Bamenda.

The soil physico-chemical analyses were done at the "Laboratory of Soil Analysis and Chemistry of the Environment" (LABASCE) of the University of Dschang (Cameroon). The bulk density was determined by paraffin coating method and particle density was measured by pycnometer method [25]. Soil porosity was deduced from bulk density and particle density [25]. The particle size distribution was measured by Robinson´s pipette method [25]. The pH-H_2O was determined in a soil/water ratio of 1:2.5 and pHKCl was measured in a soil/KCl ratio of 1:2.5 [25]. The organic carbon (OC) was measured by Walkley-Black method [26]. The total nitrogen (TN) was measured by the Kjeldahl method [27]. Available phosphorus was determined by concentrated nitric acid reduction method [28]. Exchangeable cations were analyzed by ammonium acetate extraction at pH7 [29]. The CEC was measured by sodium saturation method [30]. The base saturation was calculated as the percentage of the sum of exchangeable cations (S) divided by the CEC [31].

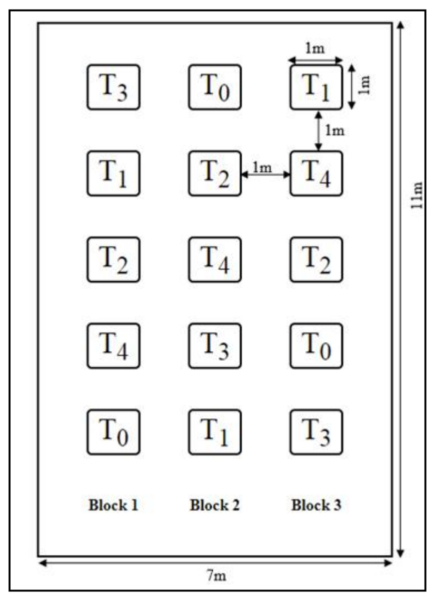

Fig. 2. Experimental layout

2.4 Data Collection

Data collection started three weeks after planting and one week after application of NPK 20-10-10. Measurements were taken every two weeks for a period of four months, from 24th of September 2017 to 24th January 2018. Growth parameters were collected after every two weeks for thirteen weeks (up to 24th December 2018) and the yield parameters were completed on 24th January. The growth parameters (germination rate, number of leaves, plant height, stem diameter, leaf length and leaf diameter) and yield parameters (number of fruits, fruit length, fruit diameter and fruits weight) were collected on 10 plants selected at the middle of each EU. At harvest, garlic was weighed immediately for the fresh yield, fruit length and fruit width, and after one week for the dry yield (~70% moisture content). The drying of garlic was done in shade (to minimize excessive weight loss).

2.5 Land and Climate Evaluation

Land evaluation was intended to evaluate climate and land suitability for garlic cultivation in the study area. The climatic index (CI) was obtained by the square root formula [32]:

$$CI=R_{min}(A/100\times B/100\ldots)^{1/2} \quad (1)$$

where R_{min} is the lowest parametric value of all groups and A, B, …etc are the remaining parametric values. The parametric value of climate or climatic rating (CR) was obtained by the conversion of CI [32]:

$$\text{If } 25<CI<92.5\text{----}CR=16.67 + 0.9\times C \quad (2)$$

$$\text{If } CI<25\ldots\ldots\ldots\ldots CR=1.6\times CI \quad (3)$$

The limitation approach was used for land evaluation. A limitation is a deviation from the optimal condition of a land characteristic/land quality, which adversely affects a kind of land use. If a land characteristic is optimal for plant growth, it has no limitations. On the other hand, when the same characteristic is unfavourable, it is said to show severe limitation. The final assessment was performed by calculating the earth index (IT) which combines climatic and soil characteristics [32]:

$$IT= R_{min}(A/100\times B/100\times\ldots)^{1/2} \quad (4)$$

where IT is the Earth Index, R_{min} is the lowest parametric value and A, B … etc are the other parametric values. The IT value obtained was corrected to the corrected earth index (ITc) as:

$$\text{If } 0 <IT \leq 25 \ldots\ldots\ldots ITc=IT \quad (5)$$

$$\text{If } 25 <IT \leq 50\ldots\ldots ITc=25+ (IT-5)\times 0.455 \quad (6)$$

$$\text{If } 50< IT \leq 75\ldots\, ITc = 50 + (IT-5)\times 0.41 \quad (7)$$

$$\text{If } 75< IT \leq 100\ldots\ldots ITc=50 + (IT-60)\times 0.625 \quad (8)$$

Suitability classes were defined based on ITc [33].

2.6 Statistical Analysis

Statistical analysis was performed using the SPSS software program (SPSS Inc., Version 12.0). The data were analyzed by one-way analysis of variance (ANOVA). The means of the different treatments were compared using Tukey's test at P<.05.

2.7 Economic Analysis

In order to test the economic viability of each soil treatments, garlic yields were subjected to economic evaluation according to FAO [34]. Thus, mean yields, mean cost and unit price per kg were used. Net profit (NP), marginal net return (MNR), benefit-to-cost ratio (BCR), and marginal rate of return or profit rate (MRR or PR) were calculated. For a BCR>1, profit is expected, but if BCR<1, no profit is expected. Nevertheless, for a BCR≥2, at least 100% profit rate of the total investment is expected and the fertilizer (treatment) is worth popularizing. The gross benefit (GB) of a fertilizer treatment is obtained by multiplying the yield per treatment by the field price per kg of garlic. The operation cost (OC) on the other hand is comprised of the fertilizer cost (FC), transport cost (TC), fertilizer spreading cost (FSC), marginal net return (MNR) and the investment interest (II) during the planting period. The MNR was obtained by multiplying the unit price of garlic by the difference between the yield with fertilizer use and yield without fertilizer use. The MNR was obtained as the difference between the GR (gross revenue) and the RCF (revenue cost of fertilizers). The MRR (or PR) was calculated as:

$$\text{PR}(or MRR) = \frac{MNR-RCF}{RCF}\times 10 \quad (9)$$

3. RESULTS

3.1 Petrography

Granite was the main outcrop in Njimbee-Bafut. The basalt used for treatment was also studied.

3.1.1 Granite

The granite is a compact leucocratic rock that outcrops in blocks of various sizes and shapes (Fig. 3a and b). The visible minerals in hand specimen were quartz, feldspars and biotite. The microscopic structure is shown in Fig. 3b, c and d. Microcline, about 45% of the rock, was subhedral with lengths of 0.3-1.2 mm and widths of 0.2-0.9 mm. It showed cross-hatched twins and a greyish white colour. It was at times perthitic with inclusions of quartz. Plagioclase feldspars (about 12% of the rock) showed subhedral grains easily identifiable by their polysynthetic twinning. Their mean length intervals were 0.2-1.8 mm and width intervals were 0.1-0.7 mm. Orthoclase was rare (2%) and subhedral with lengths of 0.2-0.8 mm and width of 0.2-0.4 mm. Myremekite was very rare (<1% of the rock volume). It was generally localized between quartz and feldspar and was <0.3 mm long. Quartz constituted about 30% of the rock; it was colourless in plane polarized light with a very weak relief. It occurred extensively in a massive form, globally 0.2-1.5 mm long and 0.1-0.8 mm wide. Biotite made up about 6% of the rock, with lengths of 0.2-1.5 mm and widths of 0.1-0.3 mm. It occurred as flakes and at times frayed at the extremes (Fig. 2d). It was dark brown in plane polarized light with a moderate relief. Muscovite represented about 4% of the rock. It appeared as flakes at times associated with biotite. It was kinked and more or less oriented. The dimensions were 0.3 to 3 mm by 0.1 to 1 mm. It was colourless in plane polarized light with a moderate relief. The mineral association gave a heterogranular texture.

3.1.2 Basalt

Basalt outcrops were identified in the Sabga old Richie quarry. The basalt was melanocratic and columnar (Fig. 4a and b). Microscopically, the basalt was composed of olivine, clinopyroxene and rarely plagioclase and an abundant groundmass. Olivine represented about 18% of the rock. Most of the olivine microphenocrysts showed anhedral to euhedral shapes with cracks. Its lengths varied between 0.2 and 0.7 mm and widths between 0.1 and 0.5 mm. Under cross polarized light, olivine was bluish pink to light brown (Fig. 4c and d). Clinopyroxene made up about 10% of the rock, with dimensions of 0.2 to 0.8 mm by 0.1 to 0.9 mm. They showed abundant microphenocrysts and few phenocrysts, with anhedral to euhedral shapes and a strong relief.

Plagioclase represented about 2% of the total rock volume and was generally corroded. The mineral surfaces exhibited a polysynthetic twin under cross polarized light. Their lengths varied between 0.5 and 0.7 mm and widths between 0.2 and 0.3 mm. The groundmass constituted about 70% of the total rock volume and was composed of plagioclase microlites, olivine and clinopyroxene microcrystals, and opaque minerals associated with volcanic glass. The mineral organisation of the basalt resulted to a porphyritic microlitic texture.

3.2 Soil Characteristics and Land Evaluation

3.2.1 Soil characteristics

The control soil was sandy clayey loamy at the surface (0-25 cm), acidic ($4.0<pH\text{-}H_2O<5.3$), with very high organic carbon (4.63%), low total nitrogen (0.2%), very high C/N ratio (35) (Table 1). The sum of bases was very low (1.79 cmo (+). g^{-1}) with very low exchangeable Ca^{2+} (0.63 cmo (+).g^{-1}) and Mg^{2+} (0.21 cmo (+). g^{-1}), high K^+

Table 1. Soil characteristics

Particle size distribution and textural class	Sand	48
	Clay	18
	Silt	34
	Textural class	Sandy clay loam
Electrical conductivity ($mScm^{-1}$)		0.07
$pH\text{-}H_20$		4.8
pH-KCl		4.3
ΔpH		0.5
OC (%)		1.32
TN (%)		0.2
C/N		35
Exchangeable bases (cmol (+).kg^{-1})	Ca^{2+}	0.63
	Mg^{2+}	0.21
	K^+	0.88
	Na^+	0.07
Sum of exchangeable base (cmol (+). kg^{-1})		1.79
CEC (cmol (+). kg^{-1})		22.7
Base saturation (%)		7.88
Available P (mg kg^{-1})		19.42

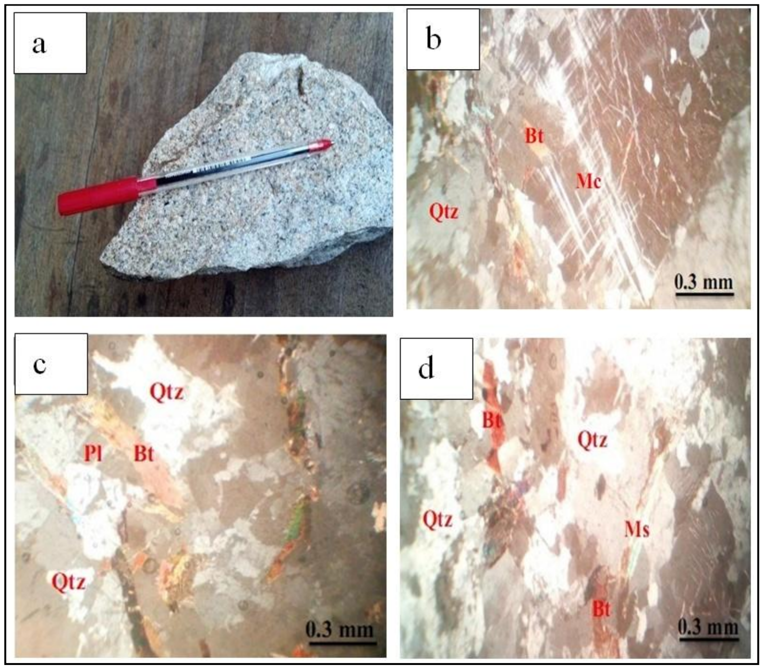

Fig. 3. Photographs (a) and photomicrographs (b, c and d) of the granite from Bafut

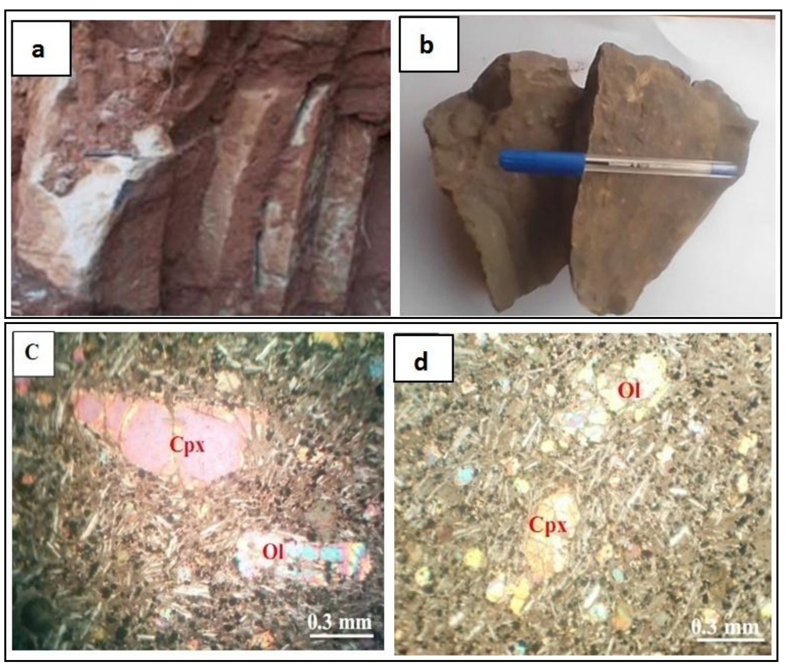

Fig. 4. Photographs (a and b) and photomicrographs (c and d) of the basalt used for soil remineralisation

(0.88cmo (+). g^{-1}) and low Na^{+} (0.07 cmo (+). g^{-1}). The CEC was very low (4.24 cmo (+). g^{-1}) and base saturation (42.42%) and available phosphorus (19.42 mg kg^{-1}) were moderate.

3.2.2 Meteorological and land characteristics

The meteorological and land characteristics of the studied area are compiled in Table 2. Thus, IT was 25.12 while ITc was 34.16. This value indicates marginally suitable land class (S3cf) for Garlic cultivation due to soil fertility and climate. The Climatic index (CI) was 53.34 (25<53.34 92.5. The climatic rating (CR) was 48.55 typical of a marginally suitable climate for garlic cultivation due to precipitation.

3.3 Growth Parameters

The data on growth parameters are summarized in Table 3. These data include germination rate, number of leaves, plant height and stem diameter.

3.3.1 Germination rate (%)

A total of 125 seeds (25 seeds per m^2 or EU) were planted and 117 germinated (93.6% mean germination rate). The mean values per treatment range between 90 and 98% and are such that $T_3>T_1>T_4>T_2=T_0$. There is no significant difference (*P*>.05) in germination rate amongst the different treatments.

3.3.2 Number of plants germinated (Plants per m^2)

The mean number of plants germinated ranged between 225000 and 245000 plants per hectare (Table 3). There was no significant difference (*P*>.05) between different treatments for this parameter.

3.3.3 Number of leaves per plant

The mean number of leaves ranged from 2.88 (T_1) to 4.44 (T_3); they were differed as follows: $T_3>T_4>T_2>T_0>T_1$ (Table 3). Nevertheless, there was no significant difference (*P*>.05) in mean number of leaves for different treatments. From week three to week nine, there was a general increase in the number of leaves. After week nine, the number of leaves started reducing (Fig. 5). At week nine, T_3 plants scored the highest mean number of leaves (8.4) while T_1 plants scored the lowest value (3). From week three to five after planting, there was no significant difference (*P*>.05) between the treatments. Multiple comparisons between treatments from week nine to 13 showed that T_3 and T_4 were significantly different from T_2, T_0 and T_1 but in week nine, the difference between T_3 and T_4 is significant.

3.3.4 Plant height (cm)

The highest mean plant height was recorded by T_4 (61.2 cm), followed by T_3 (60.8 cm).

Table 2. Land and climatic characteristics for the cultivation of garlic

Land characteristics	Values	Class	Number of limitations	Parametric values
Topography (t)				
Slope (%)	10.00	S_2	2	75.00
Wetness (w)				
Flooding(i)	F_0	S_{1-0}	0	100.00
Drainage (d)	Good	S_{1-0}	0	100.00
Soil physical characteristics (s)				
Texture	SCL	S_{1-1}	1	95.00
Coarse fragments (%)	None	S_{1-0}	0	100.00
Soil depth (cm)	None	S_{1-0}	0	100.00
Soil fertility (f)				
Apparent CECclay (cmol (+).kg^{-1}_)	12.85	S_2	2	80.00
Base Saturation (%)	7.88	S_3	3	60.00
Organic Carbon (%)	4.63	S_{1-0}	0	100.00
pH-water	5.10	S_3	3	56.00
Salinity (n)				
ECe (ms/cm)	0.11	S_{1-0}	0	99.82
Exchangeable Sodium %	3.9	S_{1-0}	0.	97.05
Climatic characteristics (c)				
Length of growing period (days)	90.00	S_{1-0}	0	100.00
Precipitation of growing period (mm)	233.30	S_3	3	53.34
Mean temperature (°C) of growing period	18.53	S_3	3	54.70
Relative Humidity (%) of growing period	81.75	S_2	2	80.63
Suitability class				
Class	/	S3	/	82.41

Table 3. Means of growth and yield parameters measured in the study

Treatment	Growth parameters					Yield parameters			
	Germination rate (%)	No. of plants germinated (plants/m^2)	No. of leaves	Plant height (cm)	Stem diameter (cm)	Bulb length (cm)	Bulb diameter (cm)	Fresh bulb (tons ha^{-1})	Dry bulb (tons ha^{-1})
Control	90^a	22.5	3.57^a	39.35^{ab}	3.99^a	3.38^a	2.70^a	0.96^a	0.87^a
0.7 tons ha^{-1} NPK	96^a	24.0	2.88^a	28.05^b	3.34^a	3.14^a	2.62^a	0.76^a	0.69^a
0.4 tons ha^{-1} of basalt	90^a	22.5	3.82^a	43.50^a	4.27^a	3.76^a	2.79^a	1.70^b	1.63^b
0.6 tons ha^{-1} of basalt	98^a	24.5	4.44^a	50.20^a	5.46^a	5.41^a	3.32^a	2.97^c	2.90^c
0.5 tons ha^{-1} *Tithonia*	94^a	23.5	3.95^a	46.83^a	4.85^a	5.83^a	4.33^a	2.89^c	2.76^c

The lowest mean value was recorded by T_1 plants (11.6 cm). There was no significant difference (*P*>.05) in mean plant height amongst the different treatments. There was a general increase in plant height from week three to week nine (Fig. 6). Here, all the treatments showed a similar variation from week five to week 13, except for T_1, with a perceptible reduction in leaf number. There was no significant difference between the treatments in week three and five but from week seven to 13, there was a significant difference between the treatments. Comparisons showed that, at week 11, T_4 was significantly different from T_3 and T_2 whereas in week two, there was no significant different among treatments.

3.3.5 Stem diameter (cm)

The mean stem diameter varied from 3.34 cm (T1) to 4.85 cm (T4) and there was no significant difference (*P*>.05) between treatments. There was a general increase in stem diameter from week three to 11, and a general drop from week 11 to 13 (Fig. 7). T_3 plants scored the highest mean stem diameter of 9 while T_1 plants showed the lowest mean value of 2. From week three to week13, there was no meaningful difference between treatments. The comparison of plant stem diameter in week nine was such that $T_3>T_4>T_2>T_0>T_1$.

3.4 Yield Parameters

3.4.1 Fresh weight and dry bulb weight (tons ha^{-1})

The fresh weight of the Garlic immediately after harvest varied from 0.76 tons ha^{-1} (T_1) to 2.97 tons ha^{-1}(T_3) (Table 3; Fig. 8). The fresh bulb weight of T_1 and and T_3 were not significantly different (*P*>.05) from each other but significantly different from T_0, T_1 and T_2. Also, T_0, T_1 and T_2 were not significantly different from one another. The different treatments increased as $T_3>T_4>T_2>T_0>T_1$. The dry bulb weight of the gralic (70% moisture content) varied between 0.69 (T_1) and 2.76 tons ha^{-1} (T_4), following a similar trend as for the fresh weight (Fig. 8).

3.4.2 Mean bulb length (cm)

The mean bulb lengh of the garlic ranged from 3.14 cm (T1) to 5.83 cm (T4). There was no significant difference (*P*>.05) between the treatments. The variation was such that $T_4>T_3>T_2>T_0>T_1$ (Table 3).

3.4.3 Mean bulb diameter (cm)

The mean bulb diameter ranged from 2.62 (T_1) to 2.97 (T_4). There was no significant difference between means of bulb diameter for the different treatments. The variation between treatments was such that $T_4>T_3>T_2>T_0>T_1$ just as for bulb weight.

3.4.4 Correlation between growth and yield parameters

The correlation coefficients between growth and yield parameters are shown in Table 4. Thus, all the growth parameters showed a strongly positive linear correlation with the yield parameters, with coefficient ranging between 0.53 and 0.95. Also, yield parameters showed a strong positive linear correlation among themselves, with coefficient ranging between 0.91 and 0.97.

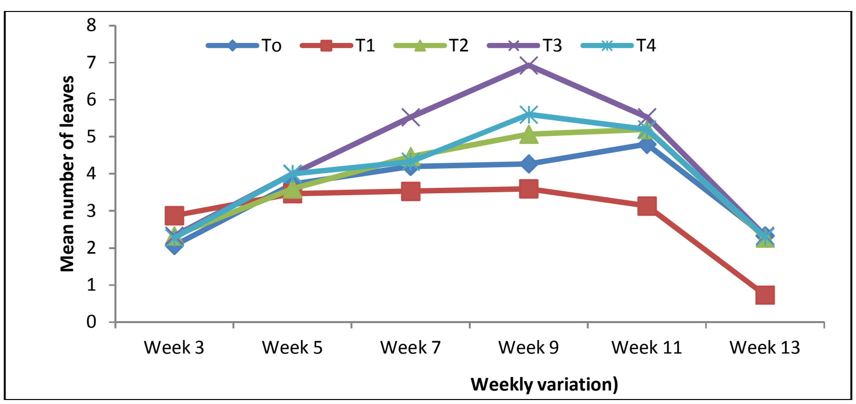

Fig. 5. Mean weekly variation of number of leaves per treatment

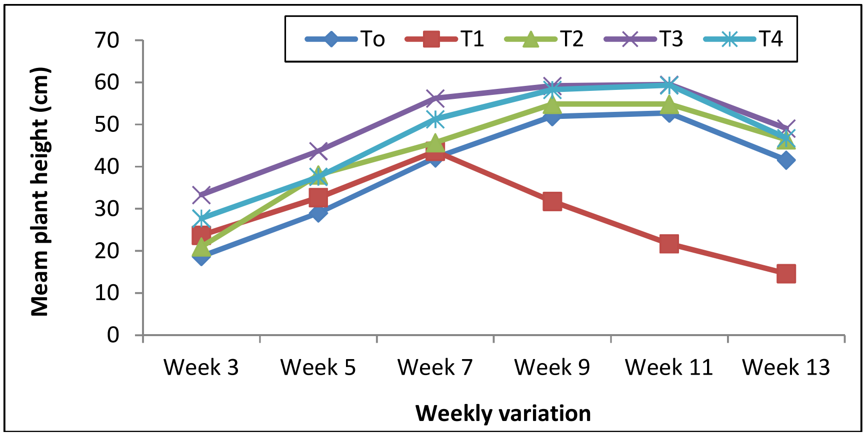

Fig. 6. Mean weekly evolution of plant Height per treatment (n=10)

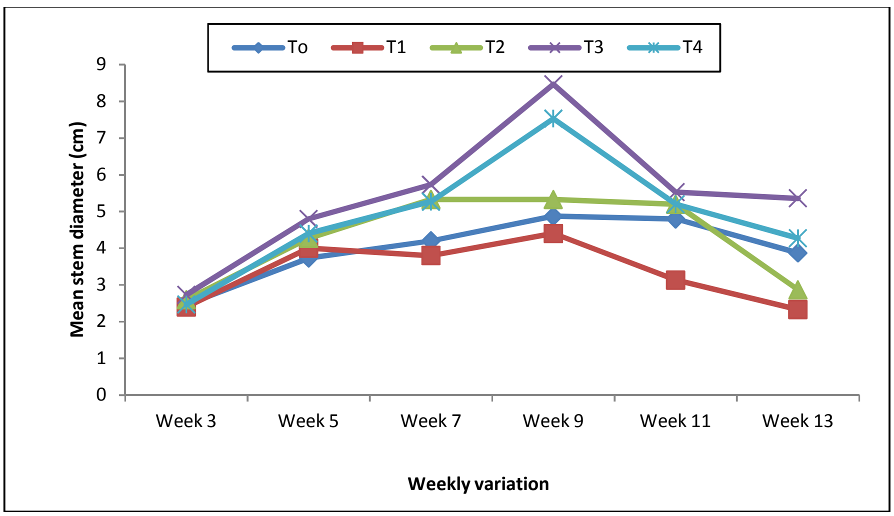

Fig. 7. Mean weekly evolution of stem diameter per treatment (n=10)

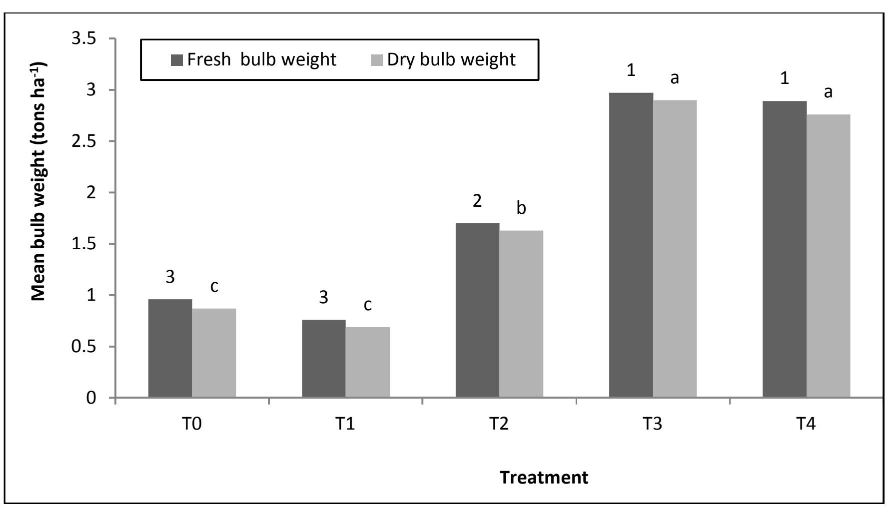

Fig. 8. Fresh and dry bulb weights (in tons ha^{-1}) of Garlic for the different treatments

Table 4. Correlation coefficients between growth and yield parameters of Garlic (n=10)

Parameters / Yield parameters	Number of leaves	Plant height	Stem diameter	Bulb length	Bulb diameter	Dry bulb weight
Bulb length	0.87**	0.88**	0.95**	1	0.96**	0.97**
Bulb diameter	0.73**	0.76**	0.83**	0.96**	1	0.91**
Bulb weight	0.53*	0.62*	0.65**	0.94**	0.81**	1

***Significant at the 0.01 level; *Significant at the 0.05 level*

Table 5. Economic value of garlic per treatment

Economic parameters / Treatment	AY (kg ha^{-1})	EY (kg ha^{-1})	GR	FC (FCFA)	FSC (FCFA)	FTC (FCFA)	FTC (FCFA)	II (FCFA)	MNR (FCFA)	TCF	BCR	PR (%)
Control	870	0	652500	0	0	0	0	0	0	0	0	0
0.7 tons ha^{-1} NPK	690	-180	517500	266000	35000	2800	303800	7595	-135000	311395	-0.43	-143
0.4 tons ha^{-1} basalt	630	760	1222500	4000	35000	2000	41000	1025	570000	42025	13.56	1256
0.6 tons ha^{-1} basalt	900	2030	2175000	6000	35000	2000	43000	107a5	2175000	44075	49.34	4834
0.5 tons ha^{-1} *Tithonia*	2760	0	2074550	15000	35000	0	50000	1250	2070000	51250	40.39	3939

AY: Average yield, EY: Extra yield, GR: Gross return, FC: Fertilizer cost, TEEY: Total expenditure on extra yield, FSC: Fertilizer spreading cost, FTC: Fertilizer transport cost, OC: Operation cost, II: Interest on investment, RCF: Revenue cost of fertilizer, MNR: Marginal net return, BCR: benefit-to- cost ratio, NR: Net return, PR: Profitability rate; Cost of Garlic= 750 Francs CFA (1.25 USD)

3.5 Economic Analysis of the Treatments

The economic analysis of the different treatments is shown in Table 5. T_2, T_3 and T_4 were very profitable with respective BCR values of 13.56, 49.34 and 40.39. Also, T_1 with a BCR value of -0.43 was not profitable and instead showed a negative extrayield value following treatment with NPK 20-10-10.

4. DISCUSSION

4.1 Pedo-climatic Conditions of the Study Area and Garlic Production

The experiment was conducted from 2nd August 2017 to 24 February 2018 for the cultivation of garlic. During this period, the soil and climatic environment showed a current inability for garlic cultivation due to climate and soil fertility [31]. The expected yield on the control plots are expected to vary between 0 and 25% of the optimum yield of garlic (0 to 25 tons ha^{-1}), that is, between 0 and 6.25 tons ha^{-1} of Marketable biomass [35]. The mean dry yield of the control was 0.87 tons ha^{-1}, thus corroborating the interval pre-defined by Sys et al. [35]. Similar findings have been confirmed by [36,37]. Local variations in garlic yields have been attributed to soil fertility level and climatic constraints [38,39]. This often requires soil amendments and irrigation to step up production [40-42]. Theoretically, garlic likes slightly moist, fertile, well drained soil with a pH range from 6.5 to 7.0 and high nitrogen fertilizers. September and October are the best months. The suitable temperature range is 13-24ºC and a flat topography is desirable.

4.2 Effect of Different Treatments on the Growth and Yield of Garlic

Concerning the effect of different treatments, during the first three week after planting, all growth parameters almost showed a similar evolution trend with time for all treatments. Afterwards, the growth and yield parameters were very different for each treatment. All plants attained their maximum performance in terms of growth at week nine before a growth reduction was experienced. This is explained by the partial desiccation of the aerial part of the plant causing the stem to bend downwards as garlic matures and gets ready for harvesting [35]. The yields were comparatively higher for T_2, T_3 and T_3 than for T_0 and T_1. The fresh bulb weight and dry bulb weight of garlic were recorded as this crop is sold either in the fresh or dry form, but more preferably in dry form, at 70% moisture for best storability [35]. The classification of treatments according to their positive influence on the yield was such that $T_3>T_4>T_2>T_0>T_1$. T_1 revealed the lowest performance of all growth and yield parameters among all treatments probably because the amount of NPK 20-10-10 applied was insufficient to supply the plant needs or because of inappropriate fertilizer choice. Nevertheless, these results agree with those of Tankou [24] where inorganic fertilizers are not suitable for garlic cultivated on acid soils. Thus, basalt and *T. diversifolia* powder could be a good alternative to chemical fertilizers. Also, some studies [34,43,44] have revealed that, the decomposition rate of organic matter and increase in yields are closely related to the synchronization between the release of the nutrients and their assimilation by the crops. Finely ground basalt dusts and *T. diversifolia* powders incorporated into the soil therefore appeared to have a suitable decomposition rate which enabled the garlic to assimilate a large proportion of the released nutrients. The high performance of T_2, T_3 and T_4 needs not be overemphasized. The benefits of basalt dust to restore degraded soils have been reported in the Cameroon Volcanic Line [11,44]. In effect, basalt dust containing high proportions of olivine, pyroxene and amphiboles show naturally fast weathering rates [45]. The weathering rates are increased through grinding into fine powder. The petrographic analysis of the basalt dust showed a high proportion of olivine which might have contributed some Ca^{2+}, Mg^{2+} and trace elements upon weathering. The major initial limitation of the soil was acidity but after basalt treatment, there might have been an improvement in soil acidity according to Azinwi Tamfuh, et al. [44]. Basalt dust slowly increases soil pH just as lime, except over a longer period of time, but generates less stress on plant growth [46]. The nutrients released by rock dust are directly related to weathering, thus, their beneficial effect could last for many years before needing replacement and even longer if used in conjunction with sustainable farming techniques [47,48]. T_1 scored the lowest yield because the soil was very acidic. Under such low pH conditions, availability of nitrogen, phosphorus and exchangeable cations are compromised [49,50]. Besides, basalt, unlike other fertilizers, has an advantage of being paramagnetic [51]. One theory holds that this energy is ferromagnetic and is emitted by magnetite within rocks which originated deep within the mantle. Ferromagnetism in rocks is beneficial to plant growth as it encourages proliferation of soil microbes, fungi and plant roots, thereby increasing crop productivity [51,52].

The high performance of T_4 crops in terms of growth and yield might be due to the fact that *T. diversifolia* is rich in nutrients, averaging about 3.5% N, 0.37% P and 4.1% K on a dry matter basis [53]. Dry *T. diversifolia* powder decomposes very fast after application and can be an effective source of N, P and K for crops [54-56]. The lower yields from T_1 compared to T_4, although both fertilizers are rich in N, P and K, have already been reported [53]; these authors obtained higher yields of maize with *T. diversifolia* compared to commercial mineral fertilizer at equivalent rates of N, P and K. In addition to providing nutrients, *T. diversifolia* applied at 5 tons dry matter ha^{-1} can reduce P sorption and increase soil microbial biomass [55]. The transfer of *T. diversifolia* to fields constitutes the redistribution of nutrients within the landscape rather than a net input of nutrients. Studies in the western Kenyan highlands [56, 57], Malawi [58] and Zimbabwe [59] report that *T. diversifolia* is an effective nutrient source for crops. The quantities of green biomass available from *T. diversifolia* growing beside smallholder agricultural fields, however, are typically insufficient to supply all the nutrients required to eliminate nutrient deficiencies over large areas [60]. Consequently, the integration of *T. diversifolia* biomass with mineral fertilizers or nitrogen-fixing legumes is believed to have supplementary advantages as compared to sole use of mineral fertilizers or *T. diversifolia*.

The growth parameters all showed a strongly positive linear correlation with the yield parameters as documented in rent investigations [11,52]. These results showed that any factor that favours growth performance will also reinforce yields.

4.3 Economic Implications of the Treatments

Net economic return is a good indicator for assessing or evaluating the performance of a fertilizer treatment [61]. Results from the various treatments revealed that T_2, T_3 and T_4 were very profitable, with respective BCR values of 13.56, 49.34 and 40.39 meanwhile T_1 showed a negative BCR (-0.43) and was thus unprofitable according to [34]. In such acid Oxisols, NPK 20-10-10 seems inappropriate for Garlic cultivation as it gave even lower yields compared to T_0. A BCR≥2 is considered to be cost-effective and can be popularized or recommended in a farming environment. Similar trends have already been published [8,11,44]. Attaining higher yields with increased productivity is only economical when increased yields are not affected by increased costs of farm inputs [62]. This was the case of high cost of NPK 20-10-10 in T_1. High productivity values with high yields have important implications for the crop management for achieving efficient fertilizer use. Also, due to the high labour involved in cutting and carrying *Tithonia* biomass to the fields, the use of *Tithonia* biomass as a nutrient source has been mostly recommended for high-value crops such as vegetables rather than relatively low-valued crops like cereals [63].

5. CONCLUSION

The objective of this survey was to study the soil fertility status and the effects of application of basalt dust, dry *T. diversifolia* powder and NPK 20-10-10 on the performance of garlic in Bafut (NW Cameroon). The natural soils were sandy clayey loamy, very acidic, very humiferous, with low total nitrogen and moderate available phosphorus. Exchangeable bases revealed low K^+ (0.88 cmol (+). kg^{-1}), very low Ca^{2+} (0.63 cmol (+). kg^{-1}) and Mg^{2+} (0.21 cmol (+). kg^{-1}) and low Na^+ (0.07 cmol (+). kg^{-1}). The sum of exchangeable bases (1.79 cmol (+). kg^{-1}) was low, while CEC (22.7 cmol (+). kg^{-1}), available P (19.42 mg kg^{-1}) and base saturation (7.88%) were moderate.

The growth and yield parameters of all treatments, except number of fruits, were such that $T_2>T_3>T_4>T_1>T_0$. Also, basalt and *T. diversifolia* powder had a positive influence of the garlic growth and yield parameters: T_3 (0.6 tons ha^{-1} Basalt dust) yielded 2.90 tons ha^{-1} of garlic followed T_4 (0.5 tons ha^{-1} *T. diversifolia* powder) that yielded 2.76 tons ha^{-1}, then T_2 (0.4 tons ha^{-1} basalt dust) with 1.63 tons ha^{-1} of garlic and T_0 with a yield of 0.87 tons ha^{-1} of garlic. T_1 (0.7 tons ha^{-1} NPK 20-20-20) gave the lowest result in terms of plants height, number of leaves and diameter as well as in terms of yield (0.69 tons ha^{-1}). Net benefit following various treatments revealed that T_1 had a benefit-to-cost ratio or BCR<1 (not profitable) while T_2, T_3 and T_4 revealed a BCR>2 (profitable and implying that at least 100% profit was recovered from the investment. Treatments T_2, T_3 and T_4 are worth popularization to farmers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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