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Remineralization of a Dystric Ferralsol Using Basalt and Tephra Dusts, Effective Microorganisms Manure and NPK 20-10-10 for Radish (*Raphanus sativus*) Production in Bamougoum (Cameroon Western Highlands)

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ARTICLE INFO

Article history

Received: 6 November 2020

Accepted: 7 February 2021

Published Online: 12 February 2021

Keywords:

Raphanus sativus

Soil remineralisation

Micronutrients

Revenue-to-cost ratio

Cameroon Western Highlands

ABSTRACT

This paper studies the effect of basalt and tephra dusts, as alternatives to chemical fertilizers, on soil fertility and Radish (*Raphanus sativus*) production. The experiment was conducted in the field and in the laboratory in the years 2017 and 2018 on two separate plots so as to annul residual effects of fertilizers. The experimental design in the field was a randomized complete block design (56 m²), including five treatments and three replications: control (T₀), basalt dust (T₁), tephra dust (T₂), effective micro-organism (EM) fertilizer (T₃) and NPK 20-10-10 (T₄). The main results show the following decreasing trend based on yield: T₁>T₃>T₀>T₄>T₂. The best yields appear in T₁ and T₃ probably because they supplied the highest levels of soil nutrients to match the needs of the crops. Although T₂ plants performed poorly, soil properties like pH.H₂O (6.14 to 6.49), sum of exchangeable bases, base saturation, available phosphorus and cation balance were improved after tephra treatment. T₂ plants might have performed poorly due to intrinsic properties of the tephra dust like low availability of trace elements compared to T₁ and T₃. T₄ plants show the highest number of leaves, leaf area index and plant height. The Fe, Mn, Cu and Zn levels in bulbs and leaves will not pose danger of toxicity to human upon consumption and could serve as nutrient supplement for children and expectant mothers. The most profitable treatment is T₁ permitting to recommend the popularization of basalt dust for radish cultivation as an alternative to chemical fertilizers.

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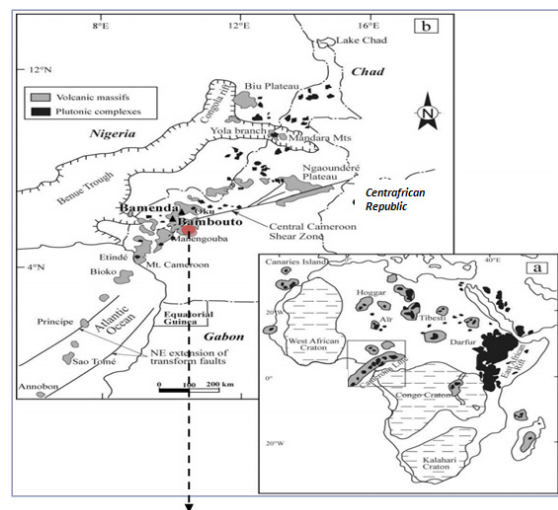
1. Introduction

Natural geologic materials are suitable for restoring soil fertility as alternatives to chemical fertilizers that instead destroy beneficial soil bacteria and pollute the environment [25,29]. The present state-of-knowledge on the use of rocks as fertilizers reveals that modern agricultural and agro-forestry practices often cause nutrient depletion in soils leading to nutrient deficiencies [12,35]. Soil remineralization is an economically and ecologically sustainable alternative to chemical fertilizers based on its capacity to regenerate nutrient depleted soils [21,24]. Rock dusts of volcanic origin like basalt and diabase are most recommended due to their high contents of silicon necessary for proper cell structure, and a well-balanced array of calcium, magnesium and micronutrients [15]. Crops grown on mineralized soils generally show higher vitamin and mineral salt contents, thus favouring better human health and resistance to diseases than those produced with synthetic fertilizers [22]. The use of rock dust to improve soil quality and crop yields has been reported [1,3,5,16,31]. In Cameroon, research activities on the use of rock dust as fertilizers remain timid. This might be explained by the lack of awareness on the use of rock dust for soil amendment despite large reserves of volcanic, sedimentary and metamorphic rocks in Cameroon. There is need for a detailed investigation of rock dusts as soil amenders for crop production. Recently, measurements by [3,16] revealed many advantages of rock dusts compared to chemical fertilizers: they are environmentally friendly and crops grown with rock dusts usually show higher resistance to disease, and higher levels of vitamins and micronutrients [3,31]. Their exploitation is relatively cheap and the only expenses come from excavation, loading, transportation and crushing into power form. Various types of volcanic rocks are abundant along the Cameroon Volcanic Line [31]. These rocks are highly demanded as building material and road construction. Most farmers are not aware of the use of these materials as fertilizers but rather resort to chemical fertilizers. Soils are regularly been fertilized with chemical fertilizers often causing soil acidification and destruction of soils organisms [15]. Very few scientific works have also been dedicated to rocks as fertilisers [4,10,30]. These works have revealed the importance of basalt and pyroclasts as fertilizers to many crops but none of these findings have been dedicated to Radish (*R. Sativus*) cultivation; this crop is highly cultivated, demanded and lucrative in Cameroon as a source of vitamins and micronutrients [30]. Numerous questions remain without answers: what is the effect of basalt dust on the performance of Radish? What is the implication of rock dust on soil quality relative to mineral

and organic fertilizers? What is the economic implication of rock dust treatment relative to chemical and organic fertilizers? What is the micronutrient level of edible parts (roots and leaves) of Radish cultivated with rock dusts? The aim of the present study was to examine the effects of basalt and tephra dusts as amenders of degraded soils on the growth, yield and micronutrient composition of *R. sativus*. The results obtained will supplement the available data on the use of natural geological materials as fertilizers for cultivation of crop in Cameroon and beyond.

2. Geographical and Geological Settings

The study site was selected in Bamougoum Sub-division (Cameroon Western Highlands), at longitude 10°21'00"-10°24'00" East, latitude 5°30'00"-5°32'00" North and a mean altitude of 1300 m (Figure 1). The mean annual rainfall is 1707.4 mm and the mean annual temperature is 21.5°C, typical of a Cameroon type equatorial climate. The relief is hilly and undulating, and ends down as deep U- and V-shaped valleys. River Mifi is the most important river in the study area that flows across the Bafoussam town and together with its tributaries forms a dendritic drainage pattern. The vegetation is tropical grassland (mostly shrubs, stunted trees, grasses on slopes and raffia bushes in valleys) strongly modified by human activities. The soils are mainly Ferralsols, with minor andosols and Gleysols. Although not very popular in Cameroon, Radish is a garden crop whose fast harvest cycle, high yield and lucrativeness have fostered its market gardening especially near major city markets like Yaoundé, Douala and Bafoussam. It is easily planted as a companion crop or intercrop between rows of the other vegetables. It is often planted on beds separating one plot from another. It is cultivated when all year round, but intensified in the dry season as it is more lucrative.



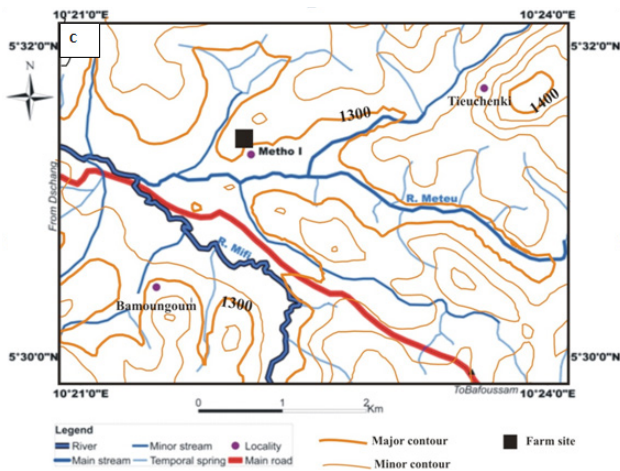


Figure 1. Location of the Cameroon Volcanic Line (CVL) and position of the studied site. (a) Location of CVL in Africa [6]; (b) Situation of CVL and studied site in Cameroon; (c) studied site in Bamougoum

The studied area is located along the Cameroon Volcanic Line (CVL). This CVL is divided into an oceanic and a continental sector [8]. Within the continental sector, the composition of the rocks range from picro-basalt and basalt through intermediate compositions to phonolite and rhyolite. Basanites, trachytes, tristanites, phonolites, basalt, nephelinites, tristanite and trachy-phonolites are found mostly in the oceanic sector. The Bamougoum area is composed mainly of basalt that overlies a granite-gneissic basement [6].

3. Methodology

The experiment was conducted in the field and in the laboratory in the year 2017, repeated in 2018. This was done on two separate plots so as to prevent the residual effects of fertilisers.

3.1 Land Preparation, Sample Collection and Pre-treatment

3.1.1 Sample Collection and Pre-treatment

The basalt and tephra were sampled in Bamougoum at latitude 05°30'25" N, longitude 10°23'17" E and altitude 1315 m for basalt, and at latitude 05°35'16" N, longitude 10°26'42" E and altitude 1307 m for tephra. The rock transformation to powders was done at Mbuy and Family Industry at Nkwen (Cameroon). Effective microorganisms manure (EM) was composed of microorganisms extracted from nature using Molasse carbon sources under anaerobic conditions at pH below 3 for seven days [28]. This involves a thorough mixture of rice husk and wheat brand using chlorine-free water, sugar solution and EM. The

mixture was then put in a tightly closed plastic tank and left to ferment for seven days. Red skin variety of radish (*R. sativus*) seeds and granular NPK 20-10-10 fertilizer were bought in the Bafoussam Main market (Marché B). Soil samples for laboratory analysis were collected in two phases: after each treatment (BS) and after harvest (AH). The soil samples were dried, sieved, placed in labelled airtight plastic bags and sent to the laboratory for analysis.

3.1.2 Land Preparation

In the field, an 8 m by 7 m plot was selected and ploughed on a Dystric Ferralsol, the most dominant soil type in the area. A randomized complete block design (RCBD) was used with five treatments (T_0 = Control soil, T_1 = basalt powder, T_2 = tephra dust, T_3 = effective micro-organism manure (EM) and T_4 = NPK fertilizer 20-10-10) and three replications (T^I , T^{II} and T^{III}). Altogether, the plot was composed of 15 experimental units. The plot was then designed into three columns with each having five similar 2 m by 1 m ridges. The surfaces of the ridges were flattened and holes of 8 cm depth by 6 cm width were dug at 40 cm and filled with the rock dusts. The ridges were then watered daily for one month to permit to leach into soil. The basalt and tephra dusts were applied at a rate of 10 tons per hectare for optimum crop Radish performance according to [9]. The spotted areas were marked with sticks and soil samples were collected after one month for laboratory analyses. Sowing of the radish seeds was done on 20th April (first and second years of experimentation). EM manure was applied one week before sowing. The application of NPK 20-10-10 fertilizer on respective beds was done after two weeks of germination, with banding of the fertilizer 5 cm away from the radish stems. The EM manure and NPK 20-10-10 fertilizer were applied at the rate of 1 ton ha⁻¹. In order to keep the soil porous and free from weeds, mulching was done twice, on the 20th and the 35th days after sowing. Harvesting was done on the 15th of June for each planting year.

3.2 Plant Data Collection

Ten radish plants were selected per experimental unit and data on growth parameters were collected on the 2nd, 4th and 6th weeks after planting. Thus, plant height was measured using a measuring tape. The leaf area index (LAI) was obtained as the product of leaf length (cm), leaf width (cm) and a constant (0.75) [18]. The number of leaves per plant was recorded. Six weeks after planting, the 10 bulbs per experimental unit were harvested and their weights were recorded using an electronic balance. The growth and yield parameters of each treatment were

obtained as the mean of the three replicates of each treatment.

3.3 Laboratory Analysis

Laboratory work included petrographic, geochemical and physico-chemical analyses. Petrographic analysis involved the cutting of rock thin sections (basalt only since tephra was powdery in the field) at the Institute of Geologic and Mining Research (IRGM) in Yaoundé (Cameroon). The chemical analysis of rock powder was done in the “Laboratoire de Géochimie Appliquée” of “Université Technique de Berlin” (Germany). The major elements of basalts and were performed by Inductively Coupled Plasma-Atomic Emission Spectrometry ICP-AES meanwhile trace and rare earth elements were dosed by FI-ICP-Mass spectrometry. The loss on ignition (LOI) was determined by ignition of samples at 1050°C for two hours. Elemental contents were reported in %oxide for major elements and mg.kg⁻¹ for trace and REE. Relative errors are <3% for major elements and 5-10% for trace elements, except for Ni and Cr with a relative error of 15-20%. Relative errors of REEs are <10% for Sc and Y, and about 25% for Hf. The CIPW norm was calculated by assigning cations of major elements within the basalt to silica anions in the modal proportions to form solid solution minerals in the idealised mineral assemblage^[4].

The physico-chemical and micronutrient analysis were performed in the Laboratory of Soil Analysis and Environmental Chemistry in the University of Dschang (Cameroon) according procedures reported by^[37]. Thus, bulk density was determined using the paraffin method and the particle density was measured by pycnometer method. The soil porosity was deduced from bulk density and particle density. The particle size distribution was measured by Robinson’s pipette method. The pH.H₂O was measured in a soil/water suspension of 1:2.5 using a glass pH-meter. Available phosphorus was determined by concentrated nitric acid reduction method. Exchangeable cations were analysed by ammonium acetate extraction method. Cation exchange capacity was measured by sodium saturation method.

Analysis of soil and plant micronutrients was done by total digestion method^[10]. For soils, one composite sample of the control soil was analyzed. Thus, aliquots of 0.5 g of dried soil samples were digested with HNO₃ acid, H₂O₂ and HCl acid mixture in the ratio 5:1:1 at 80°C until a clear solution was obtained. The solution was filtered with Whatman no. 42 filter paper and diluted to 50 ml with distilled water. The filtrates were analyzed for Fe Mn Cu Fe, Mn, Cu and Zn using atomic absorption spectrophotometry PG-900 Model, equipped with an air-acet-

ylene flame and a hollow cathode lamp, under standard conditions using wavelengths and slit-widths specified for each element.

Dried crushed leaves and root (bulb) of beetroot were digested with HNO₃ acid, H₂O₂ and HCl acid mixture (5:1: ratio), filtered, diluted to 50 ml and then analyzed for Fe, Mn, Cu and Zn by atomic absorption spectrophotometry (PG-900 Model spectrometer)^[10].

All soil and plant tissue samples were analyzed along with a blank solution. Calibration was performed with standard solutions while precision and accuracy were controlled by repeated analyses of sub-samples of the standards. The micronutrient concentrations in soils and vegetables were expressed in mg .kg⁻¹. The metal transfer factors were calculated as the concentration of the metal in the plant to the ratio of its concentration in the soil.

3.4 Data Analysis

The data were analysed using the SPSS software (SPSS Inc., Version 16.0). Analysis of variance was used to determine significant differences in the means between treatments. Means were separated by Duncan’s Multiple Range Test (DMRT) at 5% significance level.

3.5 Economic Analysis

The results of the experiment were subjected to economic evaluation in order to test the economic viability of the different soil treatments used for radish cultivation^[11]. The Average yield, average costs and average prices were used in the economic evaluation. Net profit (NP), marginal net return (MNR), revenue -to- cost ratio (RCR), and marginal rate of return or profit rate (MRR or PR) were calculated for different soil treatments. For RCR >1, profit is expected, but if RCR <1, no profit is expected. However, under the humid tropics, a RCR ≥2 implies that a 100% MRR of the total investment is expected and that the application method or fertilizer type can be popularized. The gross benefit (GB) of a fertilizer treatment is obtained by multiplying the yield per treatment by the field price per kg of radishes. 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 is obtained by multiplication of the unit price of the radishes and the difference between the yield with fertilizer use and yield without fertilizer use. The MNR is obtained as the difference between the GR (gross revenue) and the RCF (revenue cost of fertilizers). The MRR (or PR) was calculated using the following expression:

$$PR(\text{or } MRR) = \frac{MNR - RCF}{RCF} \times 100$$

4. Results

4.1 Petrography

The two main rock types studied are basalts and tephra. The basalt from Bamougoum occurs as lava flows and vertical prismatic columns which are either tetragonal or hexagonal in shape. The tephra outcrops are composed of clay-sized particles to decimetre-sized blocks of basaltic lavas.

Under the microscope, the rock is composed of olivine phenocrysts (25%), plagioclase (60%) and opaque minerals (15%). The texture is porphyritic (Figure A1). The main chemical constituents are silicon (45.36-46.42% SiO₂), aluminium (15.66-17.08% Al₂O₃) and iron (12.08-12.92% Fe₂O₃). Basic cations are also well represented, with calcium (8.43-9.40% CaO) as the most abundant element, followed by magnesium (4.58-6.68%MgO), sodium (3.69-3.86% Na₂O) and potassium (1.65-1.70% K₂O) (Table 1). Based on its silica content, the rock is classified as a basic rock. The trace elements in the rocks appear in two groups based on their concentrations; elements whose average concentrations in the rock are above 100 mg kg⁻¹ (Ba, Cr, Ni, Sr, V and Zn and those whose mean concentrations are below 100 mg kg⁻¹ (.Co, Rb, Be, Ga, Nb, Sc, Th and Y) (Table 1). The trace element composition compositions of the basalt and tephra are quite similar. The CIPW norms reveal that both basalt and tephra are olivine and diopside normative and quartz free (Table 1). For the REE concentrations of basalt and tephra, the light REE are far more abundant (ΣLREE: 247.7-317.28 ppm) compared to the heavy REE (ΣHREE: 12.07 to 13.65 ppm), giving a LREE/HREE ratio of 19.88 to 25.33. La is the most concentrated REE followed by Ce and Nd, while Lu is the least concentrated in the rocks.

Table 1. Major and trace elements and CIPW weight norm (%) composition (%) of basalts and tephra from Bamougoum Sub-division

Rock samples Composition	Basalt 1	Basalt 2	Tephra 1	Tephra 2
Major elements (%Oxide)				
SiO ₂	45.92	45.56	42.40	45.76
Al ₂ O ₃	17.42	13.91	14.51	14.81
Fe ₂ O ₃	12.10	13.28	13.58	13.41
MgO	3.47	8.14	8.50	7.78
CaO	9.10	10.05	10.14	9.71
Na ₂ O	4.33	2.97	3.22	3.69
TiO ₂	2.88	2.70	3.08	2.97

K ₂ O	1.77	1.01	1.22	1.45
P ₂ O ₅	1.23	0.64	0.64	0.68
MnO	0.22	0.17	0.19	0.19
LOI	1.14	0.76	1.40	0.38
Total	99.62	98.82	98.98	100.15
Trace elements (mg kg⁻¹)				
Ba	759	594	776	491
Co	48.8	44.7	39.9	47.7
Cr	466	201	207	340
Cu	42.8	53.9	36	45.8
Ni	109	124	90.5	179
Sr	949	965	1142	744
V	258	246	224	237
Rb	44.8	38.8	42.3	35
Be	1.13	1.22	1.63	1.2
Ga	19.5	20.1	21.5	20.5
Nb	95	77.9	96.4	64.5
Sc	22.3	19.6	18.6	19.3
Th	8.42	5.28	8.92	4.96
Y	28.9	25.9	28.10	24.3
Zn	119	112	130	131
Zr	286	234	276	213
Rare earth elements (mg kg⁻¹)				
La	76.13	58.04	76.65	64.03
Ce	141.5	109.1	142.30	121.40
Pr	15.3	12.33	15.74	13.22
Nd	59.08	48.45	60.65	51.72
Sm	10.70	9.07	10.31	9.61
Eu	3.51	3.03	3.28	3.52
Gd	8.87	7.88	8.35	7.93
Tb	1.17	1.09	1.17	1.13
Dy	6.01	5.17	5.73	6.14
Ho	1.13	1.04	1.12	1.08
Er	2.55	2.31	2.59	2.47
Tm	0.35	0.29	0.35	0.34
Yb	2.09	1.88	2.07	2.18
Lu	0.31	0.29	0.24	0.31
ΣREE	328.7	259.97	330.55	285.08
LREE	315.09	247.9	317.28	271.43
HREE	12.44	12.07	13.27	13.65
LREE/HREE	25.33	20.54	23.91	19.88
Norm composition (%)				
Apatite	2.75	1.43	1.45	1.50
Ilmenite	5.54	5.22	5.22	5.67
Magnetite	2.73	2.99	2.99	2.98
Orthoclase	10.64	6.08	6.08	8.56
Albite	24.68	21.71	21.71	17.77
Anorthite	23.24	21.91	21.97	19.61
Diopside	12.09	19.95	19.95	19.78
Olivine	16.41	17.46	17.46	16.32
Nepheline	3.82	2.08	2.08	7.33
Total	98.90	98.87	98.66	99.53

4.2 Soil Characteristics

Physically, the studied soils are dark brown (10YR3/3) at the surface to reddish brown (7.5YR5/8) at depth and clayey in texture. Other soil properties are presented in Table 2.

The soils of the experimental units, after treatment, show a slightly acidic pH, low exchangeable Ca, medium exchangeable Mg, low exchangeable K, low exchangeable Na, low sum of exchangeable bases, medium CEC, low available phosphorus (Table 3A). The base saturation is low and, apart from Ca/Mg ratio, all the other nutrient ratios are unbalanced (Table 3A). The soil pH globally increases from slightly acidic to alkaline following the different treatments. However, for all treatments, only T₄ shows a significant difference in pH compared to T₀ after harvest (AH). The exchangeable Ca of T₃ is less concentrated in the treated soils after sowing (BS) as compared to the control (T₀) and varies from 0.35 (T₃) to 9.74 cmol_ckg⁻¹ (T₄) (Table 3A). After harvest, the exchangeable Ca ranges from 9.74 (T₃) to 11.18 cmol_ckg⁻¹(T₁). Apart from T₃, there is no significant difference in exchangeable Ca disparity among the different treatments. The Exchangeable Mg ranges from 1.91 to

2.98 cmol_ckg⁻¹, showing no significant difference among BS treatments and control. The Mg values of AH range from 2.24 (T₂) to 29.83 (T₁), and only T₁ fall below the control. The exchangeable K ranges from 0.68 to 2.66 cmol_ckg⁻¹, and all treatments of BS were significantly different (P<0.05) from the control (T₀). Exchangeable K of AH ranges from 0.1 to 1.36 cmol_ckg⁻¹, with a significant (P<0.05) decrease for T₃. The exchangeable Na is low for BS and AH, and there is no significant difference (P<0.05) between treatments. The sum of bases of BS ranges from 6.17 (T₃) to 13.15 cmol_ckg⁻¹ (T₄). The sum of bases of AH ranged from 12.42 (T₃) to 42.47 cmol_ckg⁻¹ (T₁). The available phosphorus varies from 1.02 to 14.06 ppm for BS and 7.22 to 69.43 ppm for AH. Apart from T₂, available phosphorus is relatively for all AH treatments compared to BS. The CEC varies between 13.76 cmol_ckg⁻¹ (T₁) and 18.30 cmol_ckg⁻¹ (T₄) at the start of the treatment, between 16.09 (T₂) and 18.30 cmol_ckg⁻¹

Table 2. Physical properties and micronutrient composition of a composite soil sample from the studied plot in Bamougoum

Horizon (cm)	Physical properties	Munsell colour (code)	Bulk density (g cm ⁻³)	Particle density (g cm ⁻³)	Porosity (%)	Particle size distribution (%)				Micronutrient concentration (mg kg ⁻¹)					
						sand	silt	clay	Textural class	Fe	Mn	Zn	Cu	Al	Fe/Mn
A1 (0-20)		dark brown (10YR3/3)	1.5	2.5	40	25	30	45	Clay	119.2	62.2	21.0	05.2	0	1.92
B1 (20-100)		reddish brown (7.5YR5/8)	1.6	2.6	38.5	19	25	54	Clay	-	-	-	-	-	-

Notes: Permissible limits for agricultural soils in mg kg⁻¹ (Pesquini, 2006): Fe (50-250); Mn (15-500); Zn (150-300); Cu (50-140); Critical limits for normal plant growth in mg kg⁻¹[38]: Fe (<50); Mn (<20); Zn (150-300); Cu (50-140); Fe/Mg ratio [38]: Fe/Mn>2.5 (Fe toxicity); Fe/Mn<1.5 (Mn toxicity); 1.5<Fe/Mn<2.5 (Normal ratio for plant availability)

Table 3. Soil physico-chemical properties (A) and nutrient ratios (B) after treatment (BS) and after harvest of *R. sativus*.

(A)																
Treatment	pH		Ca		Mg		K		Na		Sum of bases		CEC		Available P	
	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH
T ₀	6.17		1.74		2.32		0.16		0.19		4.41		17.76		5.72	
T ₁	6.07	6.49	8.92	11.18	2.57	29.83	0.89	0.95	0.28	0.51	12.54	42.47	16.58	16.68	1.02	29.79
T ₂	6.14	6.39	7.86	9.45	1.91	2.24	0.68	1.36	0.16	0.26	10.61	13.31	13.76	16.09	14.06	14.24
T ₃	6.01	6.5	0.35	9.74	2.98	2.46	2.66	0.10	0.17	0.12	6.17	12.42	17.47	16.70	4.83	69.43
T ₄	6.14	8.56	9.74	10.35	2.22	2.44	1.03	1.01	0.16	0.22	13.15	14.02	18.30	18.95	2.60	7.22

(B)																
Treatment	S/T ratio		Ca/Mg		Mg/K		Na/T (%)		Ca/Mg/K		CRC					
	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH				
T ₀	24.83		0.75		14.5		1.06		41.23/54.94 [*] /3.83			3.05				
T ₁	75.63	255	3.47	0.37	2.88	31.40	1.68	3.06	72.05/20.76/7.19 [*]	26.64/71.09 [*] /2.26	1.20	3.94				
T ₂	77.10	82.67	4.12	13.89	2.81	1.65	0.16	1.62	75.21/18.28/6.51 [*]	72.41/17.16/10.43 [*]	1.09	1.74				
T ₃	35.31	74.61	0.12	3.95	1.12	24.60	0.97	0.69	5.84/49.75/44.41 [*]	79.19/20.3 [*] /0.51	7.40	1.13				
T ₄	71.86	73.98	4.38	2.24	2.15	2.41	0.87	1.16	74.98/17.09/7.93 [*]	75.22/17.68/7.10 [*]	1.32	1.20				

Notes: BS = soil sample after treatment; AH = Soil sample after harvest; T₀= Control beds; T₁= Basalt treatments; T₂= Tephra treatments; T₃= Effective microorganism (E.M.) treatments; T₄= NPK fertilizer 20-10-10). Each value is a mean of 3 replicates. The critical values of the soil nutrients are summarized in Tabi et al. (2013). S/T = Base saturation; * = Most concentrated element that determines the direction of equilibrium; CRC = coefficient of relative concentration.

(T₄) at the end.

The soil nutrient ratios are compiled in Table 3B. The S/T ratios of BS soils vary from 24.83 (T₀) to 77.10% (T₂) while values of the AH soils range from 73.98% (T₃) to 255% (T₁). The Ca/Mg ratios indicate normal to optimum cation balance for BS, AH and the control, except for T₁ of BS and T₃ of AH with a cationic imbalance. The Mg/K ratios indicate a cationic imbalance for T₀ for those cations. Most of the treatments show a normal to optimum equilibrium, except for T₁ of BS and T₂ of AH that show low cation imbalance, as well as T₁ and T₃ of AH beds with a very strong cationic balance. The exchangeable sodium percentage (%Na/T) is very low (<5%) for all BS, AH and T₀. The Ca/Mg/K ratios indicate a cationic imbalance for T₀. Most of the BS beds are close to the optimum ideal condition (76% Ca, 18% Mg and 6% K) required for best plant absorption. Also, T₁ of AH, T₃ of BS and T₀ show a cationic imbalance.

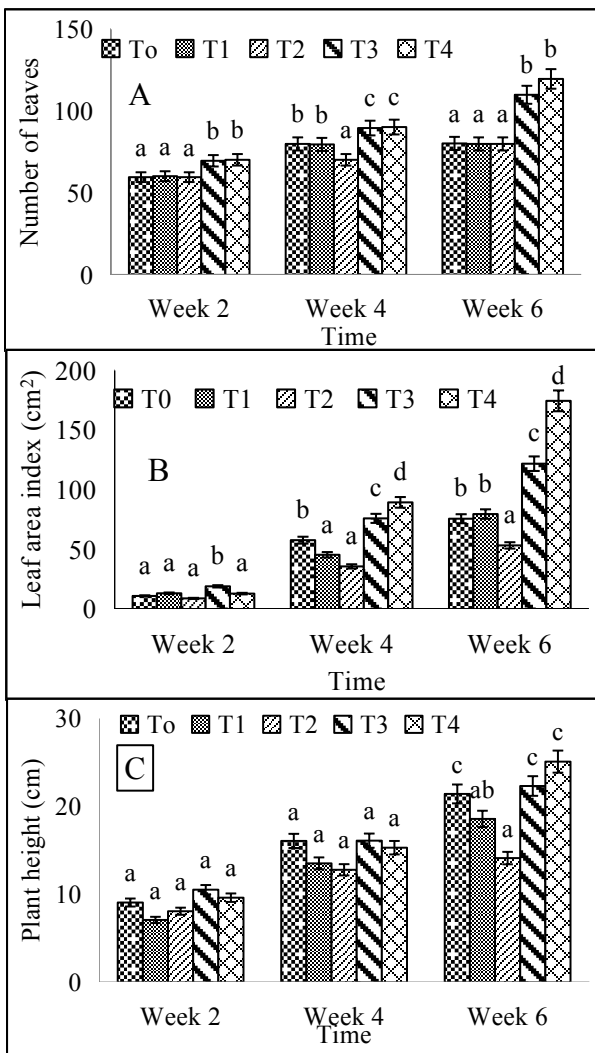


Figure 2. Weekly variation of number of leaves (A), leaf area index (B) and height (C) of *R. sativus* with time for different soil treatments and mean yield (D) per treatments (n = 10)

4.3 Growth and Yield Parameters

The Number of leaves increase gradually with time for all the soil treatments (Figure 2A). The number of leaves in week 2 reveals a significant difference (P<0.05) with those of the other weeks; the highest number of leaves is observed for T₄ (70.30 ± 0.15) and the lowest for T₂ (59.70± 0.12). Among the treatments, the number of leaves are significantly different (P<0.05) in week 4. The highest number of leaves are recorded for T₄ (90.3±0.35) and the least for T₂ (70.30 ± 0.55). There is also a significant difference in the number of leaves in week 6 (P<0.05). Meanwhile, T₄ (119.70±0.15) is significantly high and T₀ (80.30 ± 0.75), T₁ (80.00 ± 0.26) and T₂ (80.00 ± 0.17) show the lowest values.

The LAI increases progressively with time (Figure 2B). Among the treatments, the LAI is not significantly different (P<0.05) in weeks 2 and 4. The highest LAI is noted in T₄ (89.42 ± 6.64 cm²) and the lowest one for T₂ (35.73 ± 4.84 cm²). A similar trend is observed after week 6, where the highest LAI value is 174.54 ± 18.46 cm² (T₄) and the lowest one is 53.35 ± 5.49 cm² (T₂).

The plant height increases gradually with time for all treatments (Figure 2C). After week 2, a significant difference (P < 0.05) is observed in plant height for all the treatments and the control. The highest plant height is recorded for T₃ (10.55 cm ± 1.43) and the lowest one for T₁ (7.11 ± 1.20 cm). A significant difference (P < 0.05) in plant height after week 4 is marked by T₃ having tallest plants (16.12 ± 1.19 cm) and T₂ (12.81 ± 2.12 cm) as shortest ones. After week 6, maximum height is recorded for T₄ (25.10 cm ± 1.46) and the lowest one for T₂ (14.14 ± 0.81 cm).

The mean yield of Radish ranges from 3200.52 ± 39.47

kg ha⁻¹ to 7775.36 ± 16.52 kg ha⁻¹. The yields increase as follows: T₁>T₀>T₃>T₄>T₂ (Figure. 2D). There is a significant difference (P <0.05) in the yield (kg ha⁻¹) between T₂ and T₄ and the rest of the treatments and the control.

4.4 Micronutrient Concentrations in Leaves and Bulbs of the Radish

The micronutrients levels of bulbs and leaves of Radish are shown in Table 4 and Figure 3A.

In bulbs, Fe contents vary from 12.2 to 129.9 mg kg⁻¹. The highest Fe contents occur in T₁ bulbs while the lowest occur in T₀ bulbs. Apart from Fe contents of T₀ and T₄ that show no significant difference, those of the rest of the treatments are significantly different (P<0.05). The transfer factors range from 0.12 to 2.09, with highest values noted for T₁ and T₂ bulbs (Figure 3B). The Mn contents of the bulbs vary from 11.2 to 29.04 mg kg⁻¹, with the highest levels noted in T₂ and the lowest ones in T₀. T₀ and T₁ bulbs do not show any significant difference in Mn levels, just like T₁ and T₂ bulbs. The transfer factors vary from 0.18 to 0.47, with highest values noted for T₁ and T₂. The Zn contents of the bulb fluctuate between 0.43 and 1.92 mg kg⁻¹ with T₂ showing the highest levels and T₄ is shows the lowest ones. Treatments T₀, T₃ and T₄ show no significant difference among themselves just like T₁ and T₂. The transfer factors of Zn vary from 0.02 to 0.9, with highest values noted for T₁ and T₂ (Figure 3B). The concentrations of Cu in the bulbs are almost similar to those of Zn (0.20 to 1.80 mg kg⁻¹), with treatments T₂ and T₁ showing the highest accumulations of the metal in the plant tissue while T₃ shows the least. Just as for Zn, treatments T₀, T₃ and T₄ show no significant difference in Cu concentrations

among themselves just like T₁ and T₂. The transfer factors vary from 0.04 to 35, with highest values observed for T₁ and T₂ bulbs.

The Zn contents vary from 0.21 to 2.1 mg kg⁻¹ and the highest concentrations appear in T₁ and T₂ plant bulbs while the lowest ones are observed in T₄ bulbs. There is no significant difference (P<0.05) between Fe contents of the T₁ and T₂ bulbs as well as bulbs of T₀, T₃ and T₄. However, Fe contents of T₁ and T₂ plant bulbs are significantly different from those of T₀, T₃ and T₄.

The microelements concentrations of the leaves are globally lower than those of the bulbs, except for Cu content of T₄ plants (Table 4). The concentrations of Fe in the Radish leaves vary from 2.2 to 18.6 mg kg⁻¹. The highest accumulations were observed in the T₁ and T₂ plants, with comparable levels without any significant difference. The Fe contents in leaves of the rest of the treatments are significantly lower than those of T₁ and T₂ but show no significant differences among themselves. The transfer factors of Fe from soil to leaves vary from 0.02 to 1.6, with highest values observed for T₁ and T₂ plants (Figure 3B). The Mn contents of the leaves vary from 1.99 to 9.2 mg kg⁻¹. The highest accumulations occur in T₂ plants followed by T₃ plants. The lowest concentrations are observed in T₄ plants followed by T₁ plants. The Mn contents of T₁ and T₄ plants show no significant difference (P<0.05), just like the concentrations of T₂ and T₃ plant leaves. The transfer factors of Mn from soil to leaves vary from 0.03 to 0.15, with highest values observed for T₂ followed by T₃, and T₁ plants attain a transfer factor of only 0.08. The lowest values are shown by T₀ and T₄ plants (Fig. 3B). The Zn concentrations in the Radish leaves vary from 0.21

Table 4. Micronutrient composition of leaves and bulbs of the mature Beetroot per treatments (n=10)

Treatment	Micronutrient	Fe		Mn		Zn		Cu	
		bulb	leaves	bulb	leaves	Bulb	leaves	bulb	leaves
Micronutrient concentration (mg kg ⁻¹)									
T ₀		12.2 ^a	2.9 ^b	11.2 ^a	2.2 ^a	0.37 ^a	0.84 ^a	0.52 ^a	0.22 ^a
T ₁		129.9 ^d	16.7 ^d	26.99 ^c	4.8 ^b	1.57 ^b	2.10 ^b	1.32 ^b	0.62 ^a
T ₂		71.8 ^c	18.6 ^c	29.04 ^c	9.2 ^c	1.92 ^b	1.34 ^b	1.80 ^b	1.03 ^a
T ₃		30.2 ^b	2.4 ^a	19.88 ^{ab}	6.3 ^b	0.63 ^a	0.42 ^a	0.20 ^a	0.19 ^a
T ₄		14.01 ^a	2.2 ^a	15.20 ^a	1.99 ^a	0.33 ^a	0.21 ^a	0.23 ^a	0.26 ^a
Micronutrient transfer factors from soil to organ									
T ₀		0.10 ^a	0.02 ^a	0.18 ^a	0.04 ^a	0.02 ^a	0.04 ^a	0.10 ^a	0.04 ^a
T ₁		1.09 ^c	0.14 ^b	0.43 ^{ab}	0.08 ^b	0.07 ^b	0.10 ^b	0.25 ^b	0.12 ^b
T ₂		0.60 ^b	0.16 ^b	0.47 ^{ab}	0.15 ^b	0.09 ^b	0.06 ^b	0.35 ^b	0.20 ^c
T ₃		0.25 ^a	0.02 ^a	0.32 ^a	0.10 ^b	0.03 ^a	0.02 ^a	0.04 ^a	0.04 ^a
T ₄		0.12 ^a	0.02 ^a	0.24 ^a	0.03 ^a	0.02 ^a	0.01 ^a	0.04 ^a	0.05 ^a
Predefined standards of micronutrients									
Normal levels in plants ^[23]		50- 500		5-20		20-1000		1-400	
Critical levels for plant growth ^[23]		50-150		20-100		300-500		100-400	
Toxicity levels in plants ^[13]		>500		20-30		>500		>400	
Sufficiency levels in food ^[17]		-		<200		-		<500	

Note: Means in the same column followed by the same letters are not significantly different (P < 0.05).

to 2.10 mg kg⁻¹. The highest levels of Zn are observed in T₁ and T₂ plants and lowest occur in T₃ and T₄ plants. The Zn levels of T₁ and T₂ plants are not significantly different (P<0.05) but significantly different from T₀, T₃ and T₄ plants which are also not significantly different among themselves. The transfer factors of Zn from soil to leaves range from 0.01 to 0.10, with highest values observed for T₁ and T₂. The Cu concentrations of the Radish leaves fluctuate between 0.22 and 1.03. The highest concentrations appear in T₂ and T₁ plants while the lowest ones are noted in T₃. The Cu contents of T₁ and T₂ are not significantly different from one another, but significantly different from the metal concentrations in the other treatments. The transfer factors of Cu from soil to leaves fluctuate from 0.04 to 0.20, with highest values in T₁ and T₂ leaves (Figure 3B).

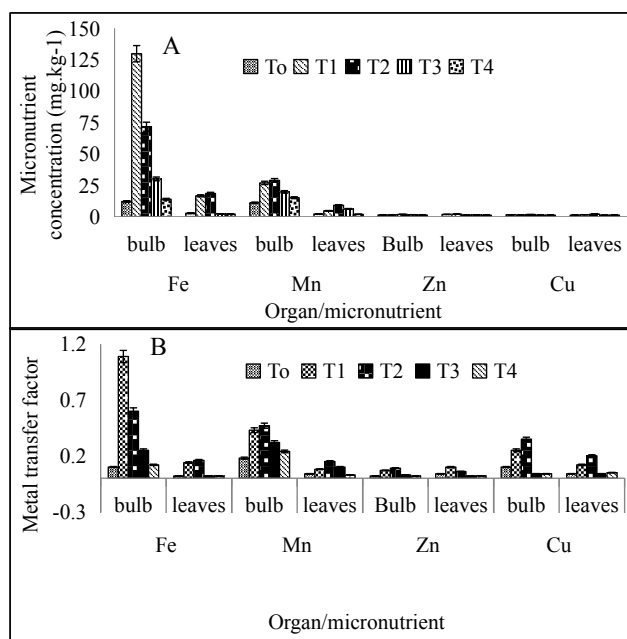


Figure 3. Micronutrient composition of bulbs and leaves (A) and soil-to-organ metal transfer factors (B) in Radish for different treatments after harvest (n=10)

4.5 Economic Analysis of the Treatments

Treatments T₃ and T₄ are very expensive relative to T₁ and T₂ (Table 5). Also, for all treatments, the total expenditure is far below the total gross return (GR) implying a positive balance sheet for all the soil treatments. However, T₁ gives the highest GR, with a substantial supplementary profit rate of 333% following the application of basalt dusts (Table 5). Compared to T₀, there is a drop in GR for the rest of the treatments. A profit reduction is thus observed as a result of those treatments as revealed by the negative yield due to treatment and marginal net return (MNR). Thus, apart from T₁, the other treatments are less profitable compared to T₀.

5. Discussion

5.1 Influence of Different Treatments on Soil Properties

In all the treatments, a slight rise in pH from slightly acidic to slightly alkaline is observed. This pH interval is best for the cultivation of radish and indicates that the different treatments amended the soil fertility by reducing its acidity [33]. This pH increment has a positive impact on other chemical properties, base saturation, cationic balance and microbial activity [14]. The fact that exchangeable bases increase after harvest for all treatments (except T₃) could imply that more basic cations have been released into the soil during plant growth as confirmed by an increase in base saturation of those treatments. Basalt and tephra dusts remineralise the soil by adding trace elements that were initially low in T₀. The fineness of the basalt dust enhanced rapid weathering and the release of nutrients into the soil. Treatment T₁ reveals the highest transfer of exchangeable bases (Ca²⁺, Mg²⁺ and K⁺) from rock powder to the soil, probably portraying a high fertilizing potential of the basalt dust [14]. This might justify why radishes from T₁ show

Table 5. Economic analysis of the different soil treatments for radish cultivation (n = 10)

Treatment	AY (Kg/ha)	EY (Kg/ha)	GR (FCFA)	FC (FCFA)	TEEY (FCFA)	FSC (CFA)	FTC (FCFA)	OC (FCFA)	II	RCF (FCFA)	MNR (FCFA)	RCR	NR (FCFA)	PR (%)
T ₀	6175.36	0	9,880,576	0	0	0	0	0	0	0	0	0	0	0
T ₁	7775.36	1600.2	12,440,576	35000	6000	30000	2000	74600.2	1865.00	76465.15	2560.32	3.34	2483854.85	333
T ₂	3200.52	-2974.6	5,120,832	35000	6000	30000	2000	70025.4	1750.63	71776	-4,759.36	-66.3	-4831136.00	-67.31
T ₃	6100.85	-74.3	9,761,360	216000	5500	30000	2000	253425.7	6335.6	259761.3	-118.88	-0.46	-378641.30	-1.46
T ₄	3550.74	-2624.4	5,680,864	490000	5500	30000	2000	524875.6	13121.89	537997.5	-4199.04	-7.80	-4737037.50	-8.80

Notes: AY: Average yield; GR: Gross return; EY: Extra yield (due to fertilizer use); FC: Fertilizer cost; TEEY: Total expenditure on extra yield; FSC: Fertilizer spreading cost; FTC: Fertilizer transport cost; OC: Total cost; II: Interest on investment (4.25% per annum in Cameroon); RCF: Revenue cost of fertilizers; MNR: Marginal net return; RCR: Revenue-to-cost ratio; NR: net return; PR (%): Profit rate (due to soil treatment); FCFA: Francs French Currency in Africa; 1US \$ 1 ≈ 600 FCFA (May 2016); Cost of radish in the market ≈ 1600 FCFA/kg. Each value is a mean of 3 replicates

the best yields; in T_1 soils, base saturation is high and the absorption complex is saturated with exchangeable bases (Ca and Mg). The available phosphorus content of the soils after harvest (AH) is such that $T_3 > T_1 > T_2 > T_4$. Hence, high phosphorus content in treatment T_3 could be linked to rapid organic matter mineralisation by biological activity from the inoculant microorganisms^[33,34]. Available phosphorus is a booster of mineral nutrient uptake and an essential element to plant organs at early growing stage^[21,24]. This could explain why T_3 plants show no morphological significant difference to T_4 plants. The Mg/K ratio shows a normal to optimum level of Mg and K for all the treatments^[26]. The Ca/Mg ratio reveals a cationic balance between exchangeable magnesium and calcium for all the treatments^[25]. The Ca/Mg/K ratio indicates a cationic imbalance for the three bases for T_0 , T_3 plants of BS, and T_1 plants of AH compared to the ideal equilibrium state of 76% Ca, 18% Mg and 6% K values necessary for optimum plant nutrient uptake by plants^[27]. This suggests that although the cations were present in sufficient amount necessary for good crop performance in these soils, their uptake might have somehow been limited due to cationic imbalance^[31].

5.2 Implications of Different Treatments on *R. sativus* Performance

In this study, the growth parameters of *R. sativus* increase gradually from the second week through the sixth week where the plant attains maturity. Mean values of plant height and leaf area index are as follows: $T_4 > T_3 > T_0 > T_1 > T_2$. T_3 and T_4 show the highest number of leaves, leaf area index and plant height certainly due to the high nitrogen and phosphorus supplied by NPK which favoured plant growth through formation of tissues. Josh and Petil^[7] and Dixon^[19] proved nitrogen fertilizers to be essential components of the chlorophyll molecule and protein synthesis. The outstanding performance of T_3 leaf count, LAI and plant height could be attributed to mechanisms like soil structural modification, changes in available water content, increased availability of macro- and micronutrients, stimulation of microbial activities and increase in critical enzyme activities necessary for tissue synthesis^[39]. The fresh yields of the radish bulbs follow this trend: $T_1 > T_0 > T_3 > T_4 > T_2$. The highest yield obtained from treatment T_1 could be attributed to a number of factors as already documented: Gillman^[14] observed that basalt dust slowly increases soil pH just as lime, although over a longer period of time, but generates less stress on plant growth. Moreover, basalt dust forms a symbiotic relationship with the microbial activity in soil which is crucial in clay-humus

complex formation. Also, the fine particle size of this basalt might have hastened the dissolution of essential minerals needed for plants growth^[5]. In this study, basalt dust shows a better performance than tephra despite their similar chemical and mineralogical compositions. Basalt dust, unlike other rocks, is paramagnetic and some samples are more paramagnetic than others^[5]. One theory holds that this energy is ferromagnetic and is emitted by magnetite within rocks originating from deep within the mantle. This ferromagnetism is beneficial to plant growth as it encourages strong growth of soil microbes, fungi and plant roots, thereby increasing crop yield^[15]. Possible differences in paramagnetism between basalt and tephra might explain the differences in performance of the two rock powders recorded in radish growth and yield. Works of^[9] showed that basalt dust with the highest magnetic intensity exhibits the best radish performance. Callahan^[5] showed the disparity in performance between two quarry materials; one was hydrated basalt having flown into freshwater and its nutrients were more available to plants than basalt that cooled on land. The increased weathering of minerals in the rhizosphere has the tendency to induce changes in the abundance and the forms of metals at soil-root interface^[39]. Although T_3 and T_4 plants record the most expressed morphological parameters, they however show lower yields compared to T_1 , T_0 and T_2 . Potential sources of reduction of fertilizer efficiency and hence yield reduction are poor land preparation (10-25%), inappropriate crop variety (20-40%), poor timing (20-40%), improper seeding (5-20%), poor planting density (10-25%), poor irrigation (10-20%), weed infestation (15-50%), insect attack (5-50%), imbalanced fertilizer application (20-50%), improper fertilizer application (5-10%)^[3]. For T_1 , although exchangeable cations (Mg^{2+} , Ca^{2+} and K^+) were released into the soil, yields remained low probably because the quantity was not enough to meet the plant needs^[31] or due to cation imbalance that impeded nutrient uptake^[30]. The plant needs K for photosynthesis, carbohydrate translocation, water regulation, protein synthesis and proper root development while calcium plays a role in proper root development^[39]. Some authors^[29,34] reported the important role played by silicon in protecting crops against diseases and micronutrient toxicities; it improves root growth, plant structural strength as well as soil properties like soil aggregation and water holding capacity. Rock dust has been described as more "intelligent" than most chemical fertilizers as their positive effects increase with time of application^[14]. In the present work, time of rock dust application was short and it is possible that yields could increase in subsequent planting seasons

due to residual effect of the weathered rock. This agrees with [32,36] whose rock dust trials on plants show significant effects five times stronger than untreated controls a few years after application. The effects of rock dust on plant growth and subsequent soil remineralisation are of importance in biologically orientated agriculture [21], this enabled recent developments in the use of rock dust as fertilisers to be described as “Stone Age” farming [5]. Complex ferromagnesian silicates (olivine, pyroxene and amphiboles, etc) in basalt release Ca, Mg, K, P and micronutrients on weathering which are essential for plant growth [16]. It is thus a recommended additive to leached soils. The use of rock dust also seems environmentally friendly than chemical fertilizers [36]. The nutrients released by rock dust are directly related to weathering rate, thus, their beneficial effect may last for many years before needing replacement, if combined with sustainable farming techniques [20].

5.3 Micronutrients Concentrations in the Soil, Leaves and Bulbs

In T_0 , the micronutrients Fe and Mn are within the permissible limits for agricultural soils meanwhile Zn and Cu are below these limits [20]. Fe and Mn are above the critical limits for normal plant growth while Zn and Cu are below these limits [20]. These results agree with those of [3] for some arable soils in the Cameroon Western Highlands. In effect, micronutrients tend to be available in soils under strongly acidic conditions but become less available as pH gets closer to neutrality [21].

The Fe contents in the bulbs vary from 12.2 to 129.9 mg kg⁻¹: concentrations of T_1 and T_2 plant bulbs fall within the normal levels in plants and above the critical levels for plant growth, while the Fe contents of bulbs from the rest of the treatments are below these standards [23]. In the leaves, the Fe contents of all the treatments fall below normal levels in plants and below the critical levels for plant growth [23]. The Fe contents of bulbs and leaves fall below toxicity levels in plants [13].

Mn concentrations of bulbs and leaves are below the sufficiency levels in food [17]. In the bulbs, Mn levels of the T_1 and T_2 bulbs are above normal levels in plants and above the critical range for plants as well as above the toxicity level in plants [13]. In leaves, except for T_2 and T_3 , Mn levels are below normal levels in plants and below critical levels for plant growth as well as below toxicity levels in plants [13].

The Zn concentrations of the bulb and leaves of the Radish fluctuate between 0.43 and 1.92 mg kg⁻¹ and 0.21 to 2.10 mg kg⁻¹. These ranges are below normal levels in plants and below the critical levels for plant growth [23] as

well as below the toxicity levels in plants [13].

The concentrations of Cu in the bulbs are 0.20 to 1.80 mg kg⁻¹ while those in the leaves are 0.19 to 1.03 mg kg⁻¹. The Cu contents of T_1 and T_2 in bulbs and T_2 in leaves fall within the normal levels in plants while the rest of the treatments gave leaves and bulbs with Cu levels below this standards [23]. All the Cu concentrations in leaves and bulbs are below critical levels for plant growth [13] and below toxicity levels in plants and below sufficiency levels in food [17].

The application of rock dusts enables to improve the micronutrients levels in the radish leaves and bulbs. This is further confirmed by the transfer factors of micronutrients of T_1 and T_2 leaves and bulbs which are significantly higher than in leaves and bulbs of T_0 , T_3 and T_4 plants. The plant tissues present micronutrient concentrations which will not pose any danger of heavy metal toxicity to humans. The radish plants might therefore serve as nutrient supplement especially for children and expectant mothers.

5.4 Economic Outcomes of the Different Treatments

The most economically viable soil treatment in terms of yield is attained by T_1 with a profit rate (PR) of 333% and a RCR value of 3.34. According to [12], a RCR value greater than 2 implies that at least 100% of the investments will be recovered from the yields. Basalt dust can thus be popularized for the cultivation of radish. Compared to T_0 , there is a sharp drop in PR for the rest of the treatments as revealed by the negative extra yield (EY) obtained from fertilizer application and marginal net return (MNR) values. Similarly, [14] revealed that after applying basalt dust on radish at a rate of 10 tons ha⁻¹ on clayey soils, a reduction in available phosphorus requirements by 70 kg ha⁻¹, equivalent to 38 US dollars ha⁻¹, was realized. Oldfield [29] used rock dusts at 10 tons ha⁻¹ to substitute for the equivalence of 25% fertilizer requirements for the same yields; after applying 4 tons ha⁻¹ of basaltic dust on radish, yields did not vary much but crops showed reduced diseases.

5. Conclusions

The present study was focused on the evaluation of the fertilizing potentials of basalt and tephra dusts on the growth and productivity of radish (*Raphanus sativus*) compared to organic manure and chemical fertilizers. The results show that the highest radish yields were recorded basalt (T_1), followed by control soil (T_0), effective micro-organisms manure (T_3), then NPK 20-10-10 (T_4) and lowest yields were shown by tephra dust (T_2). Instead, T_4 showed the highest number of leaves,

LAI and plant height after six weeks. Soils treated with basalt dust showed the highest levels of exchangeable bases of BS soils. Also, after treatment with basalt and tephra dusts, the soils exhibited a more balanced cationic equilibrium compared to control making it easier for the plant to absorb nutrients from the soil. Although tephra treatment showed the least yield of radish, soil fertility parameters like pH, cation exchange capacity, sum of exchangeable bases, base saturation, available phosphorus and cation balance were improved after tephra dust addition. The most economically viable soil treatment in terms of yield was attained on soils treated with basalt dust (T₁) probably portraying a high fertilizing potential of this rock powder. The micronutrient (Fe, Mn, Cu and Zn) levels of leaves and bulbs were significantly higher in basalt and tephra treated plants compared to the plants fertilized with NPK 20 20 20, effective micro-organism manure. The micronutrient levels in bulbs and leaves will not pose any danger of heavy metal toxicity to humans and could thus be recommended as nutrient supplement, especially to children and expectant mothers. These results reveal that basalt dust could be popularized as an alternative to chemical fertilizers for radish cultivation.

Acknowledgments

This research did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors confirm that this article content has no conflict of interest

Appendixes

Table A1. Yield of *R. sativus* per treatment (n=10)

Treatment	Mean yield (g)	Yield ± SD (kg ha ⁻¹)	Relative yield (%)
T ₀	124	6175.15± 62.41 ^b	23.04
T ₁	156	7775.36± 16.52 ^c	29.01
T ₂	64	3200.52± 39.47 ^a	11.94
T ₃	122	6100.85± 54.48 ^b	22.76
T ₄	71	3550.74± 48.96 ^a	13.25

Notes: Means in the same column followed by the same letters are not significantly different (P < 0.05). T₀ = Control beds; T₁ = Basalt treatments; T₂ = Tephra treatments; T₃ = Effective microorganism (E.M.) treatments; T₄ = NPK fertilizer 20-10-10; SD = Standard deviation. Each value is a mean of 3 replicates.

Table A2. Mean variation (± standard deviation) of leaf count, leaf area index and plant height (n=10 plants)

Treatment	Week 2	Week 4	Week 6
Leaf count			
T ₀	59.70 ± 0.32 ^a	80.00 ± 0.78 ^b	80.30 ± 0.75 ^a
T ₁	60.30 ± 0.12 ^a	79.70 ± 0.55 ^b	80.00 ± 0.26 ^a
T ₂	59.70 ± 0.12 ^a	70.30 ± 0.55 ^a	80.00 ± 0.17 ^a
T ₃	69.70 ± 0.21 ^b	89.70 ± 0.32 ^c	110.00 ± 0.30 ^b
T ₄	70.30 ± 0.15 ^b	90.30 ± 0.35 ^c	119.70 ± 0.15 ^b
Leaf area index (cm ²)			
T ₀	10.95 ± 2.75 ^a	57.73 ± 17.56 ^{ab}	75.71 ± 5.47 ^b
T ₁	13.19 ± 4.94 ^a	45.47 ± 9.95 ^{ab}	79.61 ± 2.10 ^b
T ₂	8.92 ± 0.40 ^a	35.73 ± 4.84 ^a	53.34 ± 5.49 ^a
T ₃	19.03 ± 2.89 ^b	76.00 ± 17.63 ^{bc}	121.85 ± 5.96 ^c
T ₄	12.92 ± 4.28 ^a	89.42 ± 6.64 ^c	174.54 ± 1.06 ^d
Plant height (cm)			
T ₀	9.09 ± 1.66 ^a	16.09 ± 1.56 ^a	21.43 ± 4.45 ^c
T ₁	7.11 ± 1.20 ^a	13.54 ± 0.74 ^a	18.59 ± 1.13 ^{ab}
T ₂	8.10 ± 1.31 ^a	12.81 ± 2.12 ^a	14.14 ± 0.81 ^a
T ₃	10.55 ± 1.43 ^a	16.12 ± 1.19 ^a	22.33 ± 1.66 ^c
T ₄	9.64 ± 0.73 ^a	15.32 ± 2.43 ^a	25.10 ± 1.46 ^c

Note: Means in the same column with the same superscripts are not significantly different according (P < 0.05).

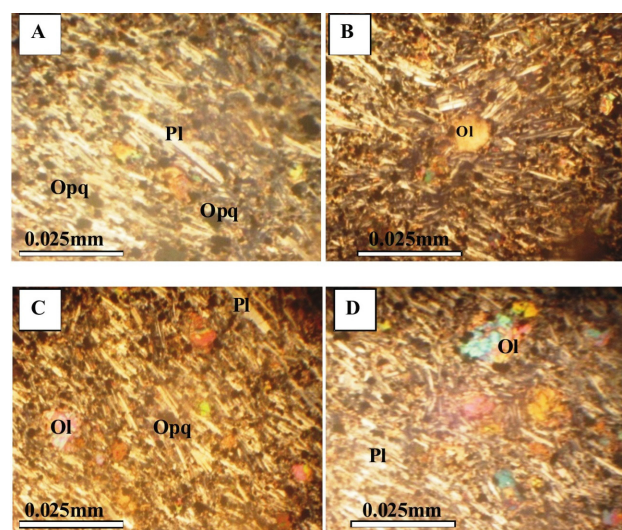


Figure A1. Photomicrographs (A-D) of basalt in Bamougou. Pl = Plagioclase; Opq = Opaque mineral; Ol = Olivine

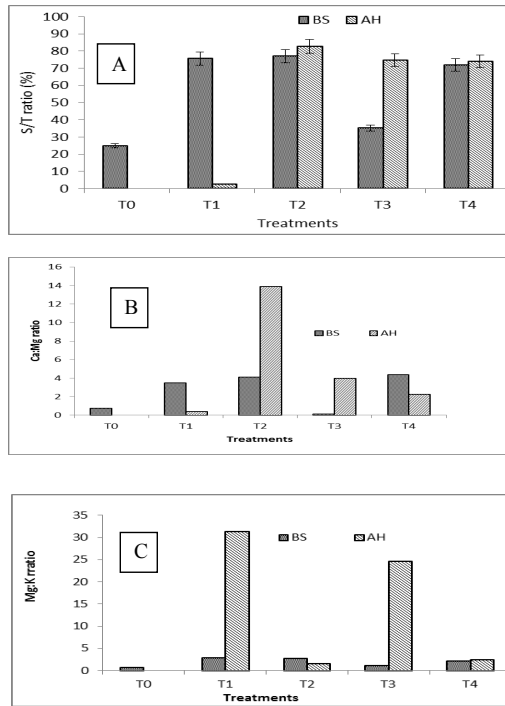


Figure A2. Nutrient ratios for the different treatments (n = 10). BS = Treated soil after treatment; AH = Treated soil after harvest; T₀ = Control bed; T₁ = Basalt treatments; T₂ = Tephra treatments; T₃ = Effective microorganism (E.M.) treatments; T₄ = NPK fertilizer 20-10-10)

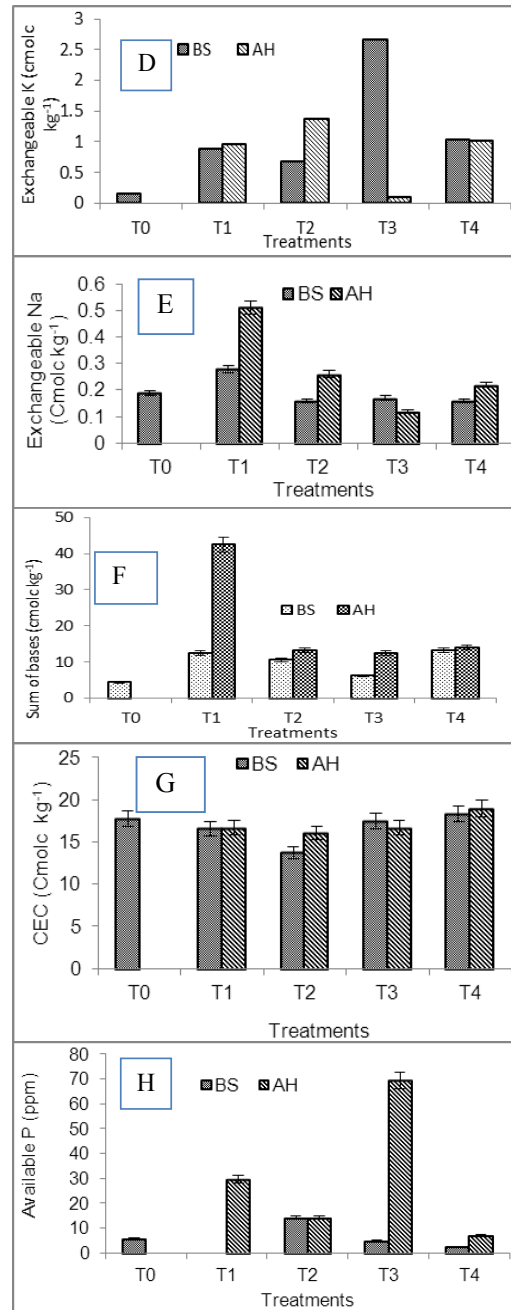


Figure A3. Mean (± standard deviation) variation of soil characteristics for different treatments. BS: Soil after treatment; AH: soil after harvest; T₀ = Control bed; T₁ = Basalt treatments; T₂ = Tephra treatments; T₃ = Effective microorganism (E.M.) treatments; T₄ = NPK fertilizer 20-10-10)

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