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Efficacy Improvement of ZEVO (ZEzika VOlkanika) through Mineral and Organic Supplies: A Case Study of the Bean (*Phaseolus vulgaris*)

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Abstract

In Madagascar, agriculture remains largely traditional, practiced on often depleted and acidic soils, particularly ferralitic soils. This situation limits agricultural yields and undermines food security, in a context marked by the high cost and limited availability of imported chemical fertilizers. Faced with this problem, the utilization of local resources, such as volcanic scoria treated as ZEVO (ZEzika VOlkanika), represents a sustainable alternative for improving soil fertility. This study aims to evaluate the effect of ZEVO combined with manure or varying doses of mineral fertilizer on bean growth and productivity. Four treatments were compared to an unamended control (T), ZEVO + manure (Z + F), ZEVO + manure + NPK at 2.5% weight of the mixture (Z + F + NPK (2.5%)), and ZEVO + manure + NPK at 5% weight of the mixture (Z + F + NPK (5%)). The Z + F treatment yielded slightly more pods with larger seeds, while the Z + F + NPK (2.5%) treatment produced a greater number of seeds but of smaller size and lower mass. Applying a 5% dose of NPK did not improve the results, demonstrating that an excess of NPK can hinder crop development due to nutritional imbalances. The combination of ZEVO and manure already provides a balanced and effective supply of nutrients. Therefore, judicious fertilization combining natural resources with organic inputs is essential to optimize crop production.

Keywords

ZEVO, Manure, NPK, Beans, Fertility, Yield

1. Introduction

The progressive depletion of soil nutrients represents a major challenge for agricultural production. In the case of Madagascar, the chemical and physical characteristics of soil are dominated by poor ferralitic soils in nutrients and organic matter [1]. This low fertility limits the productivity of food crops. To reverse this situation, it is important to develop a sustainable farming system that enhances soil fertility and improves food security for the population. One current measure is to improve soil fertility by utilizing natural resources adapted to environmental conditions. The use of chemical fertilizers remains limited by their high cost and restricted availability, hence the interest in utilizing local natural resources. ZEVO (ZEzika VOlkanika), a fertilizer of volcanic origin, represents a promising alternative but requires improvement in its agronomic efficiency [2]. ZEVO, derived from volcanic rocks rich in minerals containing nutrients such as Ca, Mg, K, etc., is a product that meets this approach [3]. However, its slow mineralization often necessitates combining it with organic or mineral amendments to improve nutrient availability. This study aims to evaluate the effect of different combinations of ZEVO with manure and varying doses of NPK on bean growth and production. Can the application of mineral or organic amendments combined with ZEVO improve bean plant development?

2. Literature Review

2.1. Volcanic Rock Potential for Soil Remineralization [4]

The development and improvement of techniques and agricultural products capable of providing a variety of macro and micronutrients to crops with the least negative environmental impact have been intensified. Soil remineralization through the addition of ground rocks represents a low-negative environmental impact alternative and clean food production, aligning with the second goal of sustainable development proposed by the United Nations Agenda 2030. The publication aimed to determine the viability of outcropping andesitic in the municipality of Jaguarão, in the extreme south of Brazil, for soil remineralization. For this purpose, mineralogical and geochemical characterization, as well as an analysis of availability of nutrients using citric acid as an extracting solution indicated a significant availability of macro-nutrients (Ca, K, Mg, and Mn) and micronutrients (Fe and Cu), essential for the development of various crops, were performed. The free quartz content and the levels of K_2O, MgO, As, Cd, Hg, and Pb comply with the parameters established by Normative Instruction No. 5 of 2016 from the Ministry of Agriculture, Livestock, and Supply (MAPA), which regulates the commercialization of soil remineralizers. The analysis of availability of nutrients using citric acid as an extracting solution indicated a significant availability of macronutrients

(Ca, K, Mg, and Mn) and micronutrients (Fe and Cu), essential for the development of various crops.

2.2. Suitability of Volcanic Ash, Rice Husk Ash, Green Compost and Biochar as Amendments for a Mediterranean Alkaline Soil [5]

Today's agriculture has the challenge of ensuring food supply for a growing population while human activity has already deteriorated about 40% of the world's soils, reducing productive capacity and increasing reliance on mineral fertilizers. In this context, valorizing and recycling mineral and agricultural waste for use as substrates or soil supplements enhance a sustainable economy, as well as the development of activities focused on finishing the soil nutrients' cycle. Looking for an effective solution to the massive waste generation and to enhance the agronomic qualities of soils, this study investigates the agronomic impact of contrasting inorganic and organic materials such as green compost (GC), wood biochar (WB), rice husk ash (RA), and volcanic ash (VA) as amendments to an alkaline Luvisol under controlled conditions. In this sense, barley seeds were planted and grown in a greenhouse under controlled conditions for 60 days on a soil amended with the aforementioned materials. The amendments demonstrated appropriate attributes for improving soil agronomic properties, enhancing the soil's nutritional content with no effect on barley germination. The WB showed high aromaticity and abundance of refractory organic C. Both ash-rich amendments showed high P and K contents, which are important elements for plant development.

2.3. Tripled Plant Productivity and Soil Microbiome Restructuring in a Greenhouse Volcanic Ash Fertilization Experiment [6]

Volcanic ash is widely held responsible for fertilizing soils, but the processes and conditions leading to volcanic soil fertility remain poorly understood. The results of a greenhouse volcanic ash fertilization (VAF) experiment aimed to explore the impact of basaltic ash addition (0 - 10 weight%) to soil on plant growth, nutrient uptake, and the soil microbiome. Four-month experiment with the *Coleus* species *Plectranthus scutellarioides* on forest soil revealed a non-linear growth response with distinct growth patterns below and above 3 weight% ash addition, respectively. Low ash VAF (<3 weight% ash) had a negligible growth impact, while high ash addition yielded a threefold increase in biomass production, reproductive effort, and total nutrient uptake in aboveground plant biomass. Volcanic ash fertilization is a complex process that does not act by simple nutrient addition from its chemical inventory but rather by restructuring the soil growth environment.

3. Materials and Methods

3.1. Methodology

To carry out our study, the methodology consists of collecting and processing the raw materials and then proceeding to the chemical analysis of the soil and the

ZEVO product, then we used the fertilizers on the bean crop, evaluating the development and yield of the bean.

3.2. Materials

The field experiments were conducted in Ambohitratrimo using ZEVO, sometimes enriched with manure or NPK 11-22-16 chemical fertilizers, on bean crops grown on ferralitic soil.

This ZEVO is obtained from the physico-chemical treatment of volcanic products from Itasy, composed mainly of volcanic scoria and ash.

The bean (*Phaseolus vulgaris*) is a common food crop in Madagascar. Its short growing cycle allows for rapid observation of results. Furthermore, it is a good biological indicator.

3.3. Chemical Analyses

These chemical analyses were carried out at the FOFIFA soil laboratory in Tsimbazaza. The methodologies applied to determine the characteristics of these chemical elements are as follows:

- Nitrogen (N) by the Kjeldahl method [7].
- Phosphorus (P) by the Olsen method or the methylene blue method [8].
- Potassium (K) by the flame photometry method [9].
- Calcium (Ca) and magnesium (Mg) by observation using an atomic absorption spectrometer [10].
- Carbon (C) by the oxidation method of a potassium dichromate solution [11].
- pH of the water using a pH meter.

3.4. Application to Bean Cultivation

3.4.1. Experimental Site

The trial was conducted on an experimental plot located in the Analamanga region, in the district and commune of Ambohidratrimo, on depleted ferralitic soil.

3.4.2. Experimental Setup

The study was conducted using a Fisher block design with four treatments and three replicates. Observations were performed on randomly selected plants within each 1 m^2 experimental plot, subdivided into 9 equidistant planting holes, with 3 bean seeds sown per hole, for a total of 27 plants per plot. However, in our research, only two seedlings per hole were retained.

The treatments applied were as follows:

T: Control (no input)

Z + F: ZEVO (2 t/ha) + manure (5 t/ha)

Z + F + NPK (2.5%): ZEVO (2 t/ha) + manure (5 t/ha) + NPK at 2.5% of the mixture

Z + F + NPK (5%): ZEVO (2 t/ha) + manure (5 t/ha) + NPK at 5% of the mixture

The following **Table 1** summarizes the number of plots replicated for each treatment and the number of plants sampled per plot.

Table 1. Summary of the bean-growing experiment.

treatment	Seeds sown per hole	Number of seedlings kept	Number of pockets per plot	Number of repeated plots	Number of plants per plot for each treatment	Number of plants sampled per plot	Number of plants sampled from each treatment
T	03	02	09	3	54	06	18
Z + F:	03	02	09	3	54	06	18
Z + F + NPK (2.5%)	03	02	09	3	54	06	18
Z + F + NPK (5%)	03	02	09	3	54	06	18

3.4.3. Measured Parameters

Observations focused on the following indicators:

Vegetative growth: average plant height, number of leaves Yield components: average number of pods, number of seed and dry weight of seeds per plant.

3.4.4. Statistical Data Analyses

Statistical data analysis was processed using Fisher method. Analysis of variance (ANOVA) is a statistical method used to compare the means of three or more groups to determine if at least one significant difference exists between them. It is based on the F-test, which compares the between-group variance to the within-group variance.

For the measurement of height and number of leaves, six samples were measured for each plot, for a total of 18 samples per treatment. The data obtained were then analyzed using an analysis of variance (ANOVA) performed in Excel.

Yield data were aggregated by treatment. In the absence of independent replicates for these variables, no analysis of variance (ANOVA) could be performed. The average number of pods or seeds as well as the seed mass per plant was then calculated by dividing the total number of pods, seed or seeds mass by the total number of plants. Based on the total pod and seed counts, a comparative study with the control was performed by calculating the gain using the following formula:

$$Gain(\%) = \frac{Tx - T}{T} * 100$$

T: control treatment

Tx: Z + F or Z + F + NPK (2.5%) or Z + F + NPK (5%)

4. Results

This section presents the physico-chemical characteristics of the ZEVO product, the chemical characteristics of the soil, the statistical data analyses and the effects of ZEVO on the development, number of pods and weight of the bean seed.

4.1. Chemical Properties of the ZEVO Product

After processing the volcanic rocks, a chemical analysis of the ZEVO product was carried out at the FOFIFA laboratory. Table 2 presents the relevant results.

Table 2. Results of chemical analysis of ZEVO.

Total elements (%)							
pH	C	N	CaO	MgO	K_2O	P_2O_5	P (Olsen) (ppm)
6.8 - 7.0	1.5 - 1.6	0.70 - 1.40	10.2 - 17.1	4.6 - 6.8	0.92 - 1.95	1.2 - 3.0	102.08
Trace elements				%			
Fe	Cu	Mn	Zn	Si			
53.1	4.5	103.1	2.9	39.2			

4.2. Results of Soil Chemical Analysis

Table 3, obtained from the FOFIFA laboratory, summarizes the chemical analyses of the soil from Ambohidratrimo.

Table 3. Results of chemical analysis of soil.

Acronyms	(H_2O)	(ppm)	(%)				(m(g)/100)		(meq/100g)
	pH	P	N	C	M.O	C/N	K	Na	C.E.C
Soil	5.48 ± 0.02	4.0 ± 0.1	0.154 ± 0.03	2.72 ± 0.03	4.68 ± 0.03	17.7± 0.03	0.135± 0.03	0.092 ± 0.03	8.8 ± 0.1

4.3. Results of Vegetative Growth

4.3.1. Height

1) Statistic by ANOVA

Table 4, detailed report for the height of plants in each group and mean calculation and variance analysis.

Table 4. Height of plants, mean and variance analysis.

Groups	Number of samples	Sum	Mean	Variance		
T	18	221.00	12.28	11.15		
Z + F	18	408.00	22.67	3.41		
Z + F + NPK (2.5%)	18	426.00	23.67	19.06		
Z + F + NPK (5%)	18	414.00	23.00	31.06		
Source of variation	*Sum of squares*	*Degrees of freedom*	*Mean squares*	*F*	*Probability*	*Critical value for F*
Between Groups	1593.71	3.00	531.24	32.85	0.00	2.74
Within Groups	1099.61	68.00	16.17			
Total	2693.32	71.00				

Analysis of variance (ANOVA) shows a highly significant difference between the means of the four groups.

The Fisher statistic obtained is F = 32.85, well above the critical value F = 2.74.

The associated probability is very low ($p = 3.06 \times 10^{-13}$), well below the 5% significance level ($p < 0.05$).

Thus, the null hypothesis that the group means are equal is rejected. The applied treatments therefore have a significant effect on the parameter studied.

2) Mean comparison test (Tukey)

Table 5 shows the comparison test of mean plant heights.

Table 5. Comparison test of mean plant heights (Tukey) significance groups can be presented as follows.

Treatment	Mean	Group
Z + F + NPK (2.5%)	23.67	a
Z + F + NPK (5%)	23.28	a
Z + F	22.67	a
T	12.28	b

The three fertilized treatments belong to the same group (a) and do not differ significantly from each other.

The control (b) is significantly inferior to the other three treatments.

3) Average plant height

The average height of the plants was measured one month after sowing. The results obtained are presented in Figure 1.

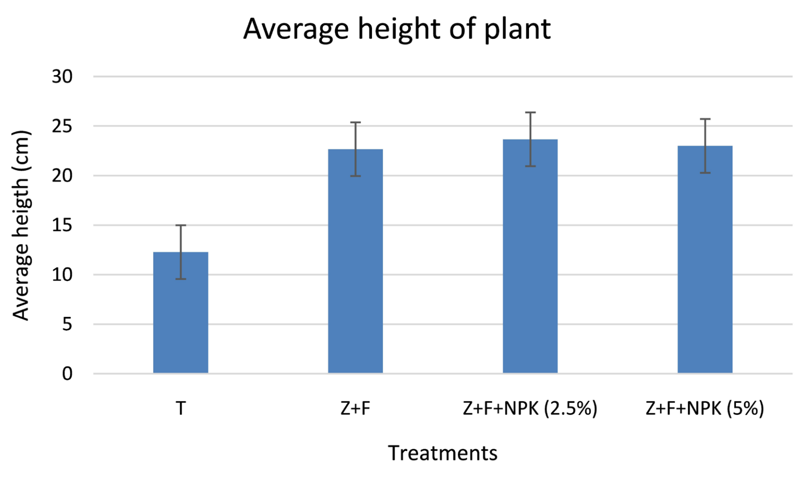

Figure 1. Average plant height.

The observed means show that:

Treatment T has the lowest mean height (12.28);

Treatments Z + F, Z + F + NPK (2.5%), and Z + F + NPK (5%) have higher mean heights, respectively 22.67; 23.67 and 23.

The Z + F + NPK (2.5%) treatment has the highest average, while the control treatment T stands out clearly from the other groups.

Analysis of variance revealed a highly significant effect of the treatments on the parameter studied (ANOVA, $F = 27.79$; $p < 0.001$). Treatments Z + F, Z + F + NPK (2.5%), and Z + F + NPK (5%) had significantly higher mean values than the control. Tukey's test at the 5% significance level showed that the three amended treatments belonged to the same statistical group and did not differ significantly from each other, while the control constituted a distinct group characterized by the lowest mean.

4) Gain compared to the control

Table 6 displays the average plant height gain compared to the control.

Table 6. Average plant height gain compared to the control.

Treatment	Gain (%)
Z + F	+84.6%
Z + F + NPK (2.5%)	+92.8%
Z + F + NPK (5%)	+89.6%

These results indicate that the application of Z + F alone already leads to a significant improvement in the measured parameter, while the addition of NPK does not result in a statistically significant increase compared to Z + F alone.

4.3.2. Number of Leaves

1) Statistic by ANOVA

Table 7, detailed report for the number of leaves in each group, mean calculation and variance analysis.

Table 7. Number of leaves per plant, mean and variance analysis.

Groups	Number of Samples	Sum	Mean	Variance		
T	18	66	3.67	1.65		
Z + F	18	145	8.06	5.23		
Z + F + NPK (2.5%)	18	127	7.06	2.06		
Z + F + NPK (5%)	18	136	7.56	4.85		
Source of variation	*Sum of squares*	*Degrees of freedom*	*Mean squaress*	*F*	*Probability*	*Critical value for F*
Between Groups	213.17	3.00	71.06	20.62	0.00	2.74
Within Groups	234.33	68.00	3.45			
Total	447.50	71.00				

The one-way analysis of variance (ANOVA) indicates a highly significant difference between the means of the four groups studied.

The calculated Fisher value is $F = 20.62$, greater than the critical value $F = 2.74$.

The associated probability is extremely low ($p = 1.31 \times 10^{-9}$), well below the 5% significance level ($p < 0.05$).

Therefore, the null hypothesis that the group means are equal is rejected. The factors studied thus has a significant effect on the measured parameter.

2) Number of leaves par plant

Treatment T has the lowest mean (3.67);

Treatments Z + F, Z + F + NPK (2.5%), and Z + F + NPK (5%) showed higher mean values, 8.06, 7.06, and 7.56, respectively. Treatment Z + F had the highest mean value, while the control treatment T stood out significantly from the other groups. The number of leaves per plant is given in Figure 2. These results suggest that the ZEVO treatments applied in the Z + F treatment significantly improved the studied variable compared to the treatment without any additions.

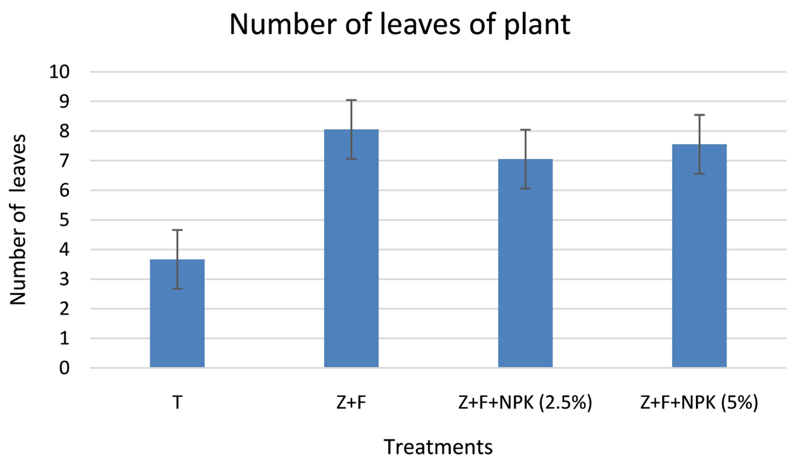

Figure 2. Number of leaves of plant.

3) Mean comparison test (Tukey)

The results of the significance grouping are presented in Table 8.

Table 8. Comparison test of number plant leaves (Tukey).

Treatment	Mean	Group
Z + F	8.06	a
Z + F + NPK (5%)	7.67	a
Z + F + NPK (2.5%)	7.11	a
T	3.72	b

The three fertilized treatments belong to the same group (a) and do not differ significantly from each other.

The control (b) is significantly inferior to the other three treatments.

4) Gain compared to the control

Table 9 shows leaf number gain per plant compared to the control.

These results indicate that the application of Z + F alone already allows a significant improvement of the measured parameter, while the addition of NPK does not lead to a statistically significant increase compared to Z + F alone.

Table 9. Leaf number gain per plant compared to the control.

Treatement	Gain (%)
Z + F	116.67
Z + F + NPK (2.5%)	91.13
Z + F + NPK (5%)	106.18

4.4. Result of Yield Components

4.4.1. Number of Pods

1) Number of pods

Table 10 displays the comparison of the number of pods in each treatment and the control.

Table 10. Comparison of pod numbers across treatments relative to the control.

	Number of pods	Gain compared to control treatment T in%
T	44	
Z + F	308	600
Z + F + NPK (2.5%)	297	575
Z + F + NPK (5%)	302	586

The Z + F or Z + F + NPK (2.5%) or Z + F + NPK (5%) treatments greatly increase the number of pods, and the Z + F treatment shows the best improvement.

2) Average number of pods per plant

The average number of pods per plant was counted at maturity, and the results are presented in Figure 3.

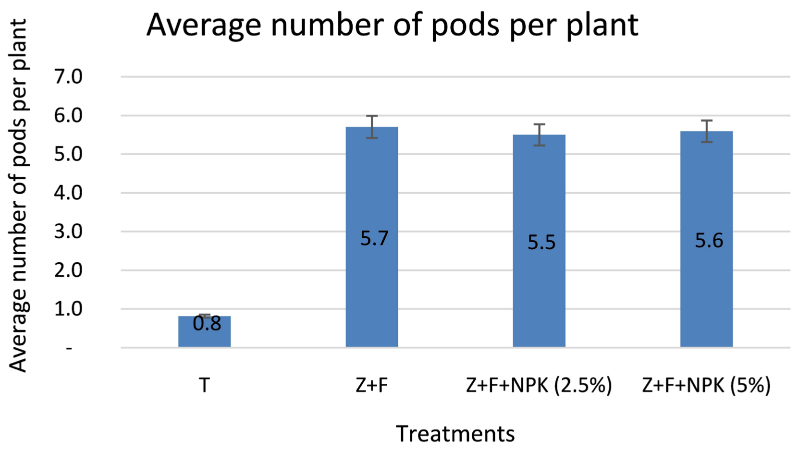

Figure 3. Average number of pods per plant.

The number of pods per plant was influenced by the application of the Z + F fertilizer. The control treatment recorded the lowest number of pods per plant (0.8), while the Z + F, Z + F + NPK (2.5%), and Z + F + NPK (5%) treatments yielded 5.7, 5.5, and 5.6, respectively. The observed differences are small, indicating that the application of NPK, regardless of the dose used, in the combination with Z + F fertilizer has no significant effect on the number of pods.

4.4.2. Seeds

1) Number of seeds

Table 11 displays the comparison of the number of seeds in each treatment relative to the control.

Table 11. Comparison of seed numbers across treatments relative to the control.

	Number of seeds	Gain compared to control treatment T in%
T	83	
Z + F	920	1008.4
Z + F + NPK (2.5%)	1448	1644.5
Z + F + NPK (5%)	780	839.7

Although Z + F + NPK (2.5%) produced the highest number of seeds, visual assessment showed that many were incompletely developed.

2) Average number of seeds per plant

The average number of seeds per plant was determined after harvest, and the corresponding data are shown in Figure 4.

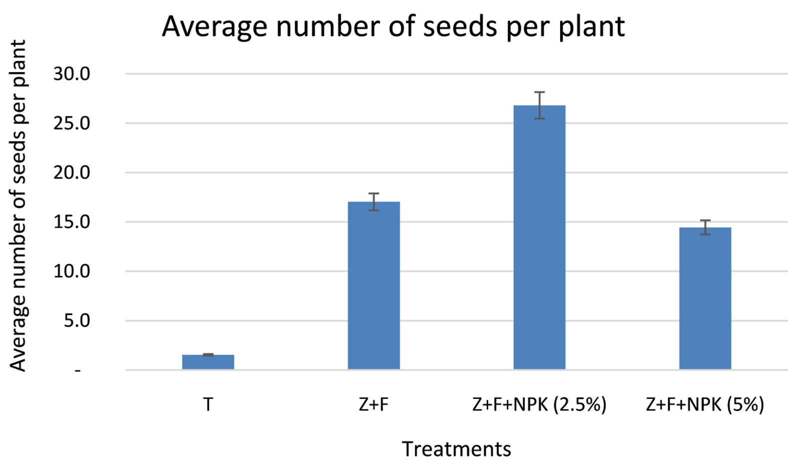

Figure 4. Average number of seeds per plant.

The control treatment recorded the lowest value (1.5 seeds per plant). while the treatments using Z + F significantly improved seed production. The Z + F + NPK (2.5%) treatment had the highest value at 26.8 seeds per plant. followed by the Z + F treatment (17.0 seeds per plant). In contrast, the Z + F + NPK (5%) treatment produced only 14.4 seeds per plant. These results suggest that a low dose of NPK (2.5%) combined with volcanic fertilizer and manure further promotes seed production, whereas a higher dose provides no additional benefit and may even reduce crop performance.

3) Weight of dry seeds

Table 12 shows the comparison of the weight of dry seeds across treatments and the gain relative to control.

Table 12. Comparison of weight of dry seeds across treatments relative to the control.

	Weight of dry seeds	Gain compared to control treatment T in%
T	26	
Z + F	297	1042
Z + F + NPK (2.5%)	299	1050
Z + F + NPK (5%)	266	923

The Z + F + NPK (2.5%) treatment generated a high number of seeds, but seed quality was lower, as evidenced by their small size and low weight.

4) Weight of dry seeds by fertilization treatments

Table 13 shows the comparison of seed numbers by fertilization treatments.

Table 13. Comparison of seed numbers to fertilization treatments.

Comparative treatment	Gain in%
Z + F + NPK (2.5%) and Z + F	57
Z + F and Z + F + NPK (5%)	18
Z + F + NPK (2.5%) and Z + F + NPK (5%)	86

Applying the Z + F + NPK (2.5%) treatment results in an 86% increase in the number of seeds harvested compared to the Z + F + NPK (5%) treatment. However, these seeds are not well formed.

5) Average weight of seeds per plant

The average weight of seeds per plant was measured after drying and sorting; the results are presented in Figure 5.

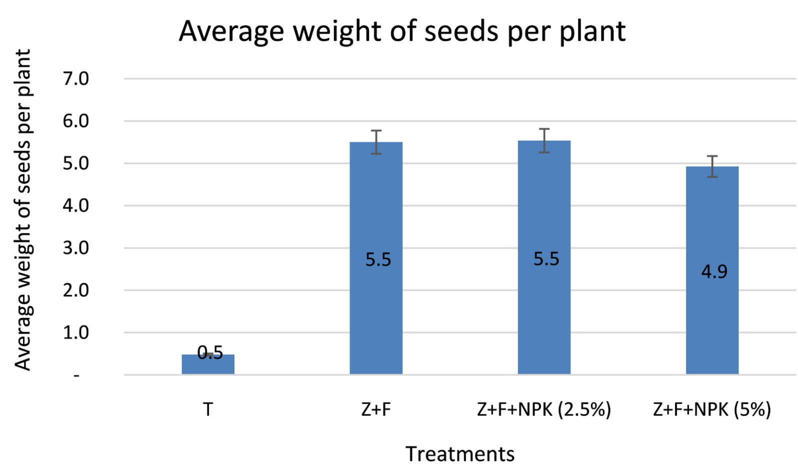

Figure 5. Average weight of seeds per plant.

The control treatment recorded the lowest value (0.5), while the Z + F and Z +

F + NPK (2.5%) treatments performed best, both with an identical weight of 5.5—a very significant increase compared to the control. The Z + F + NPK (5%) treatment slightly reduced the average seed weight (4.9) compared to the other two fertilized treatments. The addition of NPK at a low dose (2.5%) did not result in a significant improvement, whereas at a high dose (5%), a decrease in performance was observed.

4.5. Summary of the Vegetative Growth and Yield of Beans for Each Treatment

Table 14 shows the summary of the vegetative growth and yield of beans for each treatment.

Table 14. Summary of the vegetative growth and yield of beans for each treatment.

treatment	Average height per plant	Average number of leaves per plant	Number of pods per plant	Number of seeds per plant	Mass of seeds per plant	Comments
T	12.28	3.67	0.8	1.5	0.5	Control treatment exhibiting the lowest values for all vegetative and productive parameters.
Z + F: ZEVO (2 t/ha) + manure (5 t/ha)	22.67	8.06	5.7	17.0	5.5	Marked improvement in vegetative growth (height and number of leaves) as well as pod production. Higher seed mass compared to other treatments.
Z + F + NPK (2.5%): ZEVO (2 t/ha) + manure (5 t/ha) + NPK at 2.5% of the mixture	23.67	7.06	5.5	26.8	5.5	Significant improvement in plant height and seed count. Seed mass per plant is similar to the Z + F treatment.
Z + F + NPK (5%): ZEVO (2 t/ha) + manure (5 t/ha) + NPK at 5% of the mixture	23.00	7.56	5.6	14.4	4.9	Significant improvement in plant height, number of leaves and number of pods. Seed production is higher than the control but lower than the Z + F and Z + F + NPK (2.5%) treatments.

The control treatment showed the lowest performance parameters for vegetative growth and bean productivity. Treatments based on ZEVO and manure, with or without added NPK, significantly improved the agronomic performance of the bean compared to the control. The Z + F treatment and the Z + F + NPK (2.5%) treatment yielded similar results in terms of height and number of leaves, and number of seeds per plant, while Z + F produced the greatest number of pods. All three fertilized treatments also resulted in a seed mass approximately ten times greater than that of the control.

5. Interpretations and Discussions

5.1. On the Chemical Properties of the Soil

The control soil is ferralitic and highly acidic, with a pH of 5.48. Chemically, it is poor in nutrients. Although the carbon-to-nitrogen ratio is satisfactory, the soil should be enriched with nutrients and its acidity corrected. Acidity slows the activity of microorganisms responsible for nutrient availability. This is one reason for adding various inputs. Soil fertility depends on all nutrients, not just the carbon-to-nitrogen ratio.

5.2. On the Chemical Properties of ZEVO

ZEVO is significantly rich in essential elements: Ca, Mg, K, Si, and trace elements that are lacking in this control soil. It reduces soil acidity, promoting the activity of microorganisms.

5.3. Effect on Bean Development

5.3.1. On Vegetative Growth

The results indicate a marked improvement in bean growth following the application of Z + F and NPK compared with the unamended control.

Plant height almost doubled across all fertilized treatments. According to Tukey's significance test, the amended treatments were not significantly different from each other. This increase reflects an improvement in vegetative growth compared with the control. It can be explained by a better supply of nutrients provided by the different inputs: Zevo, manure, and NPK. According to the study carried out by Rakotondrafara H. *et al.*, this height of the bean reached 35 cm [12] compared to 23.67 cm in the present study, this difference can be explained by the characteristics of the soil of the present work, by a very acidic soil and poor in nutrients.

5.3.2. On the Number of Pods

The number of pods increased considerably, with a maximum for the Z + F treatment. The manure contains microorganisms that help the availability of the nutrients contained in Z; there is a significant effect of organic matter.

5.3.3. Number of Seeds per Plant

The Z + F treatment yielded a slightly higher number of pods per plant than the other treatments. However, the number of seeds per plant remained lower than that obtained with the Z + F + NPK 2.5% treatment. Nevertheless, the average seed weight produced under the Z + F treatment was higher than that of the Z + F + NPK 2.5% treatment, indicating that the seeds were larger and better developed. This result suggests that the application of volcanic fertilizer combined with manure, without additional NPK, promoted not only pod formation but also better seed filling, leading to higher-quality seed production.

The Z + F + NPK 2.5% treatment produced the highest number of seeds per plant compared to the Z + F treatment. However, the average seed weight per plant differed only slightly between these two treatments. This result indicates that the increase in the number of seeds under the Z + F + NPK 2.5% treatment was accompanied by a decrease in their individual weight, suggesting incomplete seed formation or less efficient seed filling.

On the other hand, increasing the dose by 5% did not improve the results in terms of either development or yield. This can be explained by a nutrient imbalance that can disrupt the vegetative cycle.

Therefore. the Z + F combination appears to be an effective one: it improves yield and reduces the costs and negative impacts of excessive use of chemical fertilizers.

ZEVO, relatively rich in fertilizing elements, acts not only as a source of nutrients but also improves the physical and chemical properties of the soil. With its significant levels of calcium, Magnesium, potassium, and trace elements, it contributes to neutralizing acidity and improving soil structure. Manure stimulates microbial activity, promoting the availability of nutrients. A reasoned fertilization approach combining natural resources with mineral and organic inputs is therefore essential to optimize crop production. This approach is also a way to improve food security while limiting the use of chemical fertilizers to preserve our environment.

5.3.4. Toxicity

Volcanic rocks can contain significant amounts of potentially toxic elements that are released into the environment through weathering or erosion.

These elements include Arsenic (As), lead (Pb), mercury (Hg), nickel (Ni), chromium (Cr), cadmium (Cd), nickel (Ni), zinc (Zn) and copper (Cu), can accumulate in soil, water, and plants, posing potential health risks to local populations.

According to analyses of these elements from Itasy volcanic rocks [13]. The maximum allowable limit was met for these pollutants with few exceptions.

Volcanic rocks in the Itasy region, Madagascar, show moderate arsenic (As) content in solid rock (around 17 - 41 ppm), primarily associated with iron oxyhydroxides (FeOOH), which act as host minerals, especially in tuff samples.

The concentration of lead (Pb) ranges from approximately 4.3 to 28.4 ppm.

Mercury (Hg) is highly volatile and the concentration in the volcanic rock is very small between 0.2 to 42 ppb.

The nickel (Ni) content in basaltic lavas and associated tephra varies depending on the degree of differentiation, typically ranging from 16 to 89 ppm.

Cadmium (Cd) is a natural, toxic trace element found in volcanic rocks, typically at low concentrations (0.1 - 0.5 ppm).

Copper (Cu) ppm values are rarely highlighted in summary literature, typical arc and intraplate basalts contain roughly 50 - 90 ppm of copper. In more evolved, silica-rich rocks like the trachytes found in Itasy, these levels can drop significantly (often below 30 ppm) due to sulfide fractionation. **Table 15** summarizes the pollutant concentrations with the maximum allowable limit for amendment in ppm.

Table 15. Concentration of pollutant from Itasy volcanic rock samples [13].

Elements	As	Cd	Cr	Cu	Ni	Pb	Zn
Maximum allowable limit	40	2	100	300	50	120	800
Itasy volcanic rock samples	17 - 41	0.1 - 0.5	0 - 194	4 - 48	16 - 89	4.3 - 28.4	13.8 - 212

5.3.5. Example of Nickel, Arsenic and Chromium Elimination

Almost all toxic substances from volcanic rock are below the maximum allowable limit but there are few exceptions like nickel. arsenic and chromium. Zevo was combined with manure during the treatment process. which facilitated the removal of nickel and prevented its contamination of plants.

Humic substances derived from manure such as humic acids, fulvic acids, and humin are formed during the aerobic decomposition and composting of animal waste.

Nickel ions (Ni++) bind to functional groups (e.g. carboxyl and phenolic groups) on humic substances. forming stable organic complexes. This process typically reduces the activity of free ions, often decreasing their immediate toxicity [14].

$2(RCO_2^-) + Ni^{2+} \rightarrow$ complexe $[RCO_2Ni\ RCO_2]$

For the case of arsenic, the soil treated with zevo is a ferralitic soil meaning that iron oxides are present with certain quantity. Iron oxides are highly effective for the elimination and long-term fixation of arsenic from soil through a process of adsorption and surface complexation, rather than a simple reaction that neutralizes it. The arsenic chemically binds to the iron oxide material and is thus immobilized, preventing it from contaminating groundwater or being absorbed by plants [15].

$As(V)^+ + FeO/Fe_2O_3 \rightarrow$ complexes $[FeOAsO_3$ or FeO_2AsO_2 or $FeOAsO_2FeO]$

For chromium elimination, humic substances and fulvic acids in compost or farm-yard manure form stable chelates with free chromium, reducing its bioactivity [16].

$2(RCO_2^-) + Cr^{6+} \rightarrow$ complexe $[Cr(RCO_2)_6]$

6. Conclusions

This experiment showed that volcanic fertilizer combined with manure at varying doses or without NPK has a positive effect on bean vegetative growth and yield. The Z + F. Z + F + NPK 2.5%. and Z + F + NPK 5% treatments showed generally similar performance in terms of plant height, number of leaves, and yield, suggesting that NPK application is not essential in this fertilization system. The results thus indicate that volcanic rock powder represents a promising alternative to conventional crop fertilization.

The experiment showed that Z + F has a very positive effect on bean growth and productivity. This combination proved to be the most effective, demonstrating that a judicious application of organic fertilizer can enhance the effectiveness of Z while limiting chemical inputs. Adding 2.5% NPK to the Z + F combination increased the number of seeds produced. However, these seeds are generally smaller and not well-formed. The 5% dose did not yield better results, confirming that fertilization must be balanced.

These results confirm the principle of integrated combination of fertilization (Z + F) to improve soil fertility and crop yields. These trials will be applied to other food crops such as rice, our staple food, to ensure our food security.

Author Contributions

Conceptualization, E.A. and L.R.; methodology, S.R., H.R.; software, S.R., H.R.; validation, H.R., E.A., and L.R.; formal analysis, H.R., E.A.; investigation, L.R., S.R. and E.R.; resources, E.R.; data curation, E.A., H.R.; writing—original draft preparation, L.R.; writing—review and editing, E.A., H.R.; visualization, W.F.; supervision, W.F.; all authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

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

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