The Effectiveness of Volcanic Ash in Manipulating pH Level and Enhancing Macronutrients of Garden Soil

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Abstract: Volcanic ash soils have been widely underutilized due to their perceived toxicity. However, the ash's agricultural viability has yet to be put to the test. This study aims to determine the agricultural viability of volcanic ash by understanding the ash's influence on the soil's macronutrients and pH level by answering the questions: (i) What are the acidity and macronutrients concentrations in the soil sample after the volcanic ash is introduced? and (ii) is there a significant difference between the pH level and macronutrients of the volcanic ash soil sample across the different setups? Soil-ash mixtures with different ash concentrations were prepared and tested using soil testing kits. The collected data was analyzed using MANOVA. The volcanic ash evidently lowered the pH level of the soil; however, its effect on the macronutrient content is unclear based on the test data obtained. Future studies ought to include the ash's containment period as a variable that affects nutrient composition. Numerous crop species set-ups may also be tested.

Key Words: volcanic ash; pH; nitrogen, phosphorus, potassium

1. INTRODUCTION

1.1 Background of the Study

Volcanic ash soils are severely underutilized in the agricultural field due to their perceived toxicity (Nanzyo, Shoji, & Dahlgren, 1993a). However, literature focusing specifically on the pH level or macronutrient content of volcanic ash is sparse. Most that pertain to these specific aspects of volcanic ash do not actually conduct experiments on its viability, as they merely review its characteristics (Nanzyo, Shoji, & Dahlgren, 1993a; Shoji, Nanzyo, & Dahlgren, 1993b; Shoji & Takahashi, 2002). Moreover, no study has produced a viable prediction on the extent to which the volcanic ash is able to manipulate the pH level of the soil, nor its effects on the macronutrient composition.

Most reviewed studies also focused on a limited variety of crop species (Fageria & Zimmerman, 1998; Soti et al., 2015), which may have affected the results in determining the ash's effectiveness in enhancing soil productivity as certain crop species are more tolerant of certain soil acidities. Additional research on the effects of the treatments on a wider range of crop species was recommended.

Ensuing the 2020 Taal volcanic eruption, the present study proposes to repurpose volcanic ash for agricultural use. The success of the study will not only provide a solution to food insecurity through sustainable agriculture, but also mitigate future ashfall cleanup efforts. The volcanic ash's agricultural viability will be assessed by examining the pH and Nitrogen, Phosphorus, and Potassium (NPK) levels of the soil when ash is introduced.

1.2 Literature Review

1.2.1 Soil Acidification

Shoji, Nanzyo, & Dahlgren (1993b) initially believed the high acidity of andisols soil is unsuitable for vegetation while Matsumoto et al. (2017) contested that acidic soils indicated successful revegetation. Kom et al. (2018) also found out that as the volume of solution (KCI, CaCl2 and distilled deionized water) added to Mt Kupe's volcanic ash increases, the acidifying effects of Mt Kupe's volcanic ash is diluted.

1.2.2 Macronutrients Present in Volcanic Ash Soils and their Effect on Soil Productivity

Shoji & Takahashi (2002) reviewed the volcanic ash soils' physical and chemical properties and found Nitrogen in subsurface samples in the form of inorganic nitrates. Elemental phosphorus was produced by Apatite, a phosphate mineral, in the ash (Nakamaru et al., 2000, as cited in Shoji & Takahashi, 2002), while the Potassium content was dependent on the mineralogy of the parent material. Nanzyo, Shoji, & Dahlgren's (1993a) reported that volcanic ash soils also have a highly porous soil structure, low bulk density, as well as a high water-holding capacity. They are also rich in non-crystalline materials which provide excellent enhancements in the root growth of a plant.

1.2.3 Effects of NPK and pH levels on Soil Productivity

Soil acidity enhances the plant's nutrient uptake, and subsequently its productivity (Fageria & Zimmerman, 1998; Soti et al., 2015). Certain crop species have unique acidity tolerances that distinctly determine their ability to absorb nutrients from the soil. Macronutrients facilitate the plant's metabolism and growth by increasing the available nutrients. Compost treatments are the most common as the microbial activities enrich and fertilize the soil over time (Adekayode & Ogunkoya, 2011).

1.3 Framework

The concentration of macronutrients and non-crystalline materials in the ash could potentially improve root growth when paired with the ash's high water-holding capacity (Shoji & Takahashi, 2002; Nanzyo, Shoji, & Dahlgren, 1993a; Shoji, Nanzyo, & Dahlgren, 1993b, Cochran et al., 1983). As such, the volcanic ash's nutrient composition and structural properties are strong proponents of its agricultural viability.

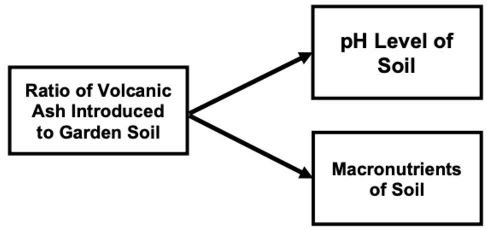

Figure 1 - Framework of the study

The present study is anchored on the assumption that the overall pH and macronutrient content of the garden soil is dependent on the concentration of volcanic ash introduced. Evidence suggests that introducing volcanic ash to the soil could manipulate soil acidity to match the requirements of the crop species, hence improving its nutrient uptake. The researchers hypothesized that an increased concentration of ash relative to soil would effectively lower the base pH level and increase macronutrient content.

The study aims to answer the following questions:

1. What are the acidity and macronutrients concentrations in the soil sample after the volcanic ash is introduced?
2. Is there a significant difference between the pH level and macronutrients of the volcanic ash soil sample across the different setups?

2. METHODOLOGY

2.1 Research Design

The study falls under the experimental research design as it compares two or more groups following the results of specific tests and includes an independent variable that can be manipulated to observe its effects on the dependent variable(s) ("Experimental Research Designs", 2020). The effect of the different volcanic ash ratios (the independent variable) on the pH and NPK contents (the dependent variables) are recorded for each setup.

2.2 Procedures

The Letter of Approval to conduct the study and the Research Ethics Checklist were submitted and approved. Data gathering was conducted by researchers wearing appropriate PPEs. The soil testing kit was bought online and volcanic ash was collected from the 2020 Taal 2020 Volcanic Eruption ashfall. The collected soil was air-dried and sieved according to Kome et al.'s (2018) methodology to best preserve the soil's nutrient composition. The ash and soil were precisely measured in different volcanic ash to soil ratios (0%, 20%, 40%, 60%, 80%, 100%) using a weighing scale, and shaken to incorporate well.

The tests (pH, N, P, K) were administered as per Luster Leaf 1601 Rapitest Test Kit packaging instruction. A specified portion of the ash-soil mixture from each set-up was diluted with distilled water in the pH level test chamber; whereas the remaining unused ash-soil mixtures were diluted with equal parts 100 ml distilled water in preparation for the NPK tests respectively. The solutions were left undisturbed until the soil sediments settled. The respective test capsules provided in the kit were applied to all solutions.

Within ten minutes, the hue of all samples changed corresponding to the numerical scale as provided in the soil testing kit. The pH level follows the scale: (4.5 - 5.4) Very Acid; (5.5 - 6.0) Acidic; (6.1-6.5) Slight Acid; (6.6-7.0) Neutral; and (7.1-7.5) Alkaline. The remaining tests for N, P, and K all follow the scale : (4) Surplus; (3) Sufficient; (2) Adequate; (1) Deficient; and (0) Depleted.

2.3 Data Analysis

The data was processed with IBM SPSS v.24. Descriptive Analysis identified the pH and macronutrient content of the setups. Multivariate analysis of variance (MANOVA) analyzed the difference in the pH and macronutrients across different ash concentrations.

3. RESULTS AND DISCUSSION

3.1 The acidity and macronutrients present in the soil sample after the volcanic ash is introduced

Table 1 presents the average pH level and macronutrient composition. The 100% ash was the most acidic (M=5.56, SD=0.320), but had a striking absence of Nitrogen and Potassium (M=0.00, SD=0.00). Alternately, 0% ash reported a neutral pH level (M=7.00,SD=.378), and an absence of Nitrogen (M=0.00,SD = .00). The pH level increased with the volcanic ash percentage as predicted by the dilution effect. It is suspected that the ash's prolonged containment (9months before experimentation) affected the volatilization of its nutrient composition, and perhaps its pH level. Exposure to weathering, despite all efforts made, was also a plausible cause. Nonetheless, Nitrogen and Potassium's absence denotes their presence in the soil as the primary influence.

Table 1. pH and Macronutrient Content of the Soil

Volcanic		pH		N		P		K	
Ash (%)	n	M	SD	M	SD	M	SD	M	SD
0	8	7.00	.378	0.00	.000	3.75	.463	3.38	.518
20	8	6.75	.463	1.25	.463	3.88	.354	3.50	.756
40	8	6.81	.530	1.38	.518	4.00	.000	1.00	.756
60	8	6.00	.598	1.63	.528	3.38	.518	0.63	.744
80	8	5.69	.458	0.00	.000	3.13	.641	0.13	.354
100	8	5.56	.320	0.00	.000	3.25	.463	0.00	.000

Note. M, Mean. SD, Standard Deviation.

Nitrogen, though absent in the ash and soil, was detected from 20% through 60% ash setups, $p>0.05$. This conforms to Bot & Benites, (2005); Adekayode & Ogunkoya, (2011) citation that microorganisms in the soil underwent microbial decomposition resulting in Nitrogen as the main byproduct. Decomposition rate is boosted in acidic conditions (Yun et al, 2016; Berenstechers et al., 2016), explaining the negligible production of organic Nitrogen in the neutral 0% ash setup. Alternatively, the 80% setup had a negligible soil content despite being the most acidic soil-containing setup.

Opposing the predicted deficiency, Phosphorus levels were maintained among most setups. Phosphorus does not volatilize when exposed to weathering; It binds with non-crystalline materials in the ash, causing Phosphorus fixation (Shoji & Takahashi, 2002; Floyd, Lefroy & D'Souza, 1998; Nanzyo, Shoji, & Dahlgren, 1993a).

Potassium, being the most susceptible to weathering and volatility, decreased as more volcanic ash was introduced in the setups. Hence, the same fundamental principle of Kome et al.'s (2018) dilution effect can be cited — as the quantity of soil decreased, its effect on the overall Potassium content also weakened. Therefore, presuming that the quantity of volcanic ash affects the Potassium levels would be inaccurate.

3.2 Difference in pH level and macronutrients of the volcanic ash soil sample across the different setups

3.2.1 Test of MANOVA assumptions

Table 2. Test of Equality of Covariance and Normality

Box's M	F	df1	df2	Sig.
5.536	.578	10	937.052	.957

	Shapiro-Wilk Test		
	Statistic	df	Sig.
Standardized Residual for pH	.985	48	.780
Standardized Residual for N	.891	48	.000
Standardized Residual for P	.959	48	.093
Standardized Residual for K	.971	48	.268

A series of tests were conducted to determine the satisfaction of assumptions for One-way MANOVA. Table 2 shows the assumption on homogeneity of variance among groups is fulfilled (Box M's 5.536, $p>0.05$) and normality of the standardized residuals is verified except for Nitrogen ($p<0.05$). Pillai's Trace was used in place of Wilk's Lambda, as it does not require a normal distribution of data (Horn, n.d.).

Table 3. Multivariate Test using Pillai's Trace

Effect	Value	F	H. df	Error df	Sig.	Partial Eta Squared[a]
Volcanic Ash (%)	2.076	9.060	20.000	168.000	.000	.519

Note. H. df, Hypothesis df.
a. *Partial eta squared can be cited as a measure of effect size: f^2 is Cohen's effect size: .02 = small, .15 = moderate, .35 = large.*

Table 3 establishes a statistically significant difference in pH and macronutrient content of the soil at different volcanic ash percentages, $p<0.05$. Approximately 52% of the multivariate variance (η^2= 0.519) of the dependent variables is associated with group factor, Pillai's Trace=2.076. This indicates a large effect according to Cohen's effect size, partial $\eta^2>0.35$.

Table 4 depicts the analysis of variance accounted for by the model and each variable. The percentage of volcanic ash has a large statistical significance in the pH and the individual macronutrient contents (NPK), $p<0.05$, partial $\eta^2>0.35$. By order of the greatest effect, the percentage of volcanic ash significantly affected the Potassium content (partial η^2=0.874), Nitrogen content (partial η^2=0.825), pH (partial η^2=0.632), and lastly the Phosphorus content (partial η^2=0.376).

Table 4. Tests of Between-Subject Effects

Source	DV	Type III SS	df	MS	F	Sig.	Partial Eta Squared[a]
Volcanic Ash (%)	pH	15.715	5	3.143	14.1416	.000	.632
	N	24.667	5	4.933	39.467	.000	.835
	P	5.188	5	1.038	5.052	.001	.376
	K	101.188	5	20.238	58.118	.000	.874

Note. DV, Dependent Variable. SS, Sum of Squares. MS, Mean Square.
a. *Partial eta squared can be cited as a measure of effect size: f^2 is Cohen's effect size: .02 = small, .15 = moderate, .35 = large.*

3.2.2 Differences between pairs

Table 5 displays the post-hoc test using Bonferroni analyzing the pairwise comparison of mean differences. A significance was only observed when the more neutral setups (0%, 20%, and 40%) were compared against the more acidic setups 60%, 80%, and 100% setups, $p>0.05$.

Kome et al.'s (2018) dilution effect is further proven as the setups with higher concentrations of ash were significantly different to lower concentrations. A minimum increment of 60% ash can be established in manipulating the pH level of the soil.

A significant difference was only observed when the non-Nitrogen-bearing setups (0%, 80%, 100%) were compared against the Nitrogen-bearing setups (20%, 40%, 60%). Though it should be noted that the diminishing quantity of soil influenced the results as much as, if not more, than the volcanic ash's presence. Yun et al., (2016) and Berenstechers et al. (2016) form a direct relation between the pH level and Nitrogen content of the soil due to microbial decomposition rates — the more acidic the environment, the more Nitrogen will be produced by the microorganisms in the soil. The non-Nitrogen-bearing setups had neither an acidic environment nor adequate soil concentration.

Nonetheless, the Nitrogen-bearing setups suggest increments greater than 40% to observe a substantial difference in manipulating the soil's Nitrogen content.

Table 5. Pairwise Comparison of the Mean Difference

Volcanic Ash (%)		Sig.[a] of MD			
(I)	(J)	pH	N	P	K
0	20	1.000	0.000	1.000	1.000
	40	1.000	0.000	1.000	0.000
	60	0.002	0.000	1.000	0.000
	80	0.000	1.000	0.128	0.000
	100	0.000	1.000	0.493	0.000
20	40	1.000	1.000	1.000	0.000
	60	0.038	0.598	0.493	0.000
	80	0.001	0.000	0.029	0.000
	100	0.000	0.000	0.128	0.000
40	60	0.018	1.000	0.128	1.000
	80	0.000	0.000	0.006	0.074
	100	0.000	0.000	0.029	0.023
60	80	1.000	0.000	1.000	1.000
	100	1.000	0.000	1.000	0.602
80	100	1.000	1.000	1.000	1.000

Note. MD, Mean Difference (I-J), *At 95% Confidence Interval for Difference* [a]

a. *Adjustment for multiple comparisons: Bonferroni.*

Phosphorus results were erratic; 0% and 60% ash unexpectedly failed to detect any differences among all other setups. 20% and 40% were also both significantly different to 80%, though the former did not detect a significant difference to 100% when the latter did.

Notably, the ash and soil had somewhat similar Phosphorus content. As such, it was speculated that as the ash concentration increased, the Phosphorus contributed by the ash compensated for the soil's diminishing contribution. Hence, causing the overall Phosphorus content to fluctuate. It is also unclear whether or not the Phosphorus detected from the volcanic ash would be suitable for plant nutrient uptake, due to possible fixation caused by weathering (Shoji & Takahashi, 2002; Floyd, Lefroy & D'Souza, 1998; Nanzyo, Shoji, & Dahlgren, 1993a). The lack of consistency suggests no clear trend in the Phosphorus, as manipulated by the volcanic ash.

Potassium yielded a significant difference when 0% and 20% were compared against 40% and up. The data initially implies an observed significance at increments of 40%. Unfortunately, 40% had an unexpected significance against 100%. Particularly, 100% was the only setup to lack Potassium. As such, the principle of the dilution effect (Kome et al., 2018) can be applied with regard to the soil's concentration — as the concentration of soil diminished, as did its effect on the Potassium content. Among the Potassium-producing setups, 0% and 20% had higher Potassium concentrations by a large margin. 60% and 80% had almost depleted levels of Potassium, making it barely insignificant to that of 100%. 40% on the other hand, had deficient levels of Potassium. Hence, 40% was still significantly different to both 0% and 20%, and 100% individually. Due to the unexpected difference between 40% and 100%, the minimum increment of observing a significant difference was pushed to 40% or greater.

4. CONCLUSIONS

Volcanic ash's ability to manipulate the pH level of the garden soil was successfully demonstrated. Higher concentrations of ash in the mixture yielded lower pH levels due to the ash's acidic nature. However, there is insubstantial evidence to support the volcanic ash's enhancement of macronutrients. The prolonged storage of the ash, and possible exposure to weathering have been identified as confounding factors that affected the macronutrient composition, and perhaps pH level.

The presence of Nitrogen and Potassium in the soil served as the main contributor in lieu of their absence in the ash. Nitrogen levels accumulated with the acidity of the environment due to microbial decomposition by microorganisms in the soil. Phosphorus fixation is highly likely due to the possibility of weathering, hence limiting its suitability for plant nutrient uptake. Potassium solely depended on the soil's influence in that as the quantity of soil diminished, as did its effect on the overall Potassium content.

Fundamentally, the volcanic ash is able to manipulate the soil's pH level at 60% increments or greater. Conversely, the results of the macronutrients depict the influence of external factors due to the unsubstantial evidence to support the ash's effect on the macronutrients. Regardless, the Nitrogen-bearing setups imply a significant difference at increments greater than 40%. Phosphorus did not seem to report a clear trend due to the sporadic results. Lastly, Potassium can be manipulated at 40% and greater increments.

4.1 Limitations & Recommendations

Overall, the agricultural viability of volcanic ash was proven in terms of its effect in acidifying the soil's pH level. In hindsight, since the contribution of the ash to the overall macronutrient composition was negligible, the methodology limited the observation of the soil's macronutrients in reaction to the volcanic ash introduced. Additional research is required in exploring volcanic ash's effects on enhancing the macronutrient content.

In pursuing similar studies, the researchers recommend using non-commercial tests on the soil's pH level and nutrient content to garner more precise data. The Luster Leaf Rapitest kit used in this study, though garnering the required data, is not recognized as a scientific test but rather as a commercial product for hobby gardeners. As such, much information, such as the forms of NPK detected, are unavailable. The kit als relies on the use of a color chart scale, which produces subjective data as per the researcher's perception. A larger sample size with additional replicates could also provide more descriptive information on the subject matter. Lastly, the volcanic ash should be securely contained for no more than nine months to reduce the influence of external factors such as weathering.

5. ACKNOWLEDGMENTS

We express our appreciation to our mentors, Mr. Lee Gerard Macabali, Mr. Fritz M. Ferran, and Mr. Gerald B. Gamboa. Our most heartfelt thanks to our parents, for their financial support. Lastly, we offer our deepest gratitude to the Lord, our God for without whom nothing is possible.

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