The Effects of Eggshell and Egg Membrane Amendments on Soil and Plant Growth

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Abstract
The management of eggshell waste poses a considerable challenge, given its contribution to environmental pollution and the squandering of valuable soil nutrients. Traditional synthetic fertilizers have resulted in soil deterioration and environmental pollution, underscoring the urgency for more sustainable alternatives. Organic fertilizers and soil enhancements present promising options by augmenting soil quality and fostering plant growth. This investigation scrutinizes the feasibility of utilizing eggshells as organic fertilizers to tackle these concerns. Through the assessment of diverse concentrations of eggshells on the development of green bean, okra, and cucumber plants, along with their impact on soil characteristics, this study advances our comprehension of the potential of eggshells in sustainable agriculture. Three different masses of eggshell amendments (20g, 40g and 60g) along with a control group (0g) are added into the soil of three plants (green bean, okra, cucumber). Findings indicate that specific eggshell concentrations exert a positive influence on plant growth, underscoring their promise as an alternative fertilizer source. Correlation analyses ($0.920 < r < 0.974$) underscore the robust significance of eggshell concentrations on plant height, emphasizing the importance of precise application for optimizing plant maturation. The optimized results from the study is 9.61cm, 6.83cm and 3.11cm for cucumber, okra and green bean plants respectively. While there may be constraints related to experimental procedures and resources, this study underscores the significance of eggshell amendments in sustainable agriculture, opening the door for forthcoming research and more environmentally friendly farming techniques.

Keywords: Eggshell, Soil properties, Green bean, Okra, Cucumber

Introduction

Malaysians have a substantial daily egg consumption of 20 million, making them the global leaders in egg consumption (Doh & Chin, 2014). A significant proportion of eggshell waste is routinely sent to landfills without prior treatment (Tsai *et al*., 2008). Given stricter environmental regulations, it is imperative to find efficient methods for handling food waste, particularly in the face of the food industry's notable contribution to pollution. Eggshells, categorized as bio-waste, emit odors and attract flies, adding to environmental concerns. Additionally, the agriculture sector holds crucial roles in ensuring food security for the burgeoning global population and driving economic

growth in emerging economies. However, more than a billion people worldwide lack access to sufficient nourishment, underscoring the imperative to double anticipated agricultural production by 2050 (Karne *et al.*, 2023). Soil organic fertility, stemming from the intricate interplay of organic constituents, significantly bolsters worldwide soil fertility and productivity. While fertilizers are indispensable for augmenting agricultural yield, chemical alternatives are costly, environmentally detrimental, and diminish organic content and microbial activity in the soil, leading to ecological imbalances and water pollution (Karne *et al.*, 2023). In pursuit of more eco-friendly fertilization practices, alternative sources like eggshells are being explored for agricultural applications. Eggshells, rich in vital nutrients like calcium carbonate, hold promise as an excellent soil amendment, enhancing soil conditions and supplying essential nutrients for plant development. The substantial quantity of discarded eggshells arising from egg consumption presents an invaluable opportunity for recycling and augmenting soil fertility. In summary, the integration of eggshells as soil amendments can advance sustainable agriculture, curbing waste, fortifying soil vitality, and reducing reliance on harmful chemical fertilizers, thus fostering a more environmentally conscious approach to farming.

The objectives of this study are stated below:

I. To evaluate the effect of the use of eggshells as an organic fertiliser on the growth of green bean, okra and cucumber plants.
II. To evaluate the effect of the use of eggshells as an organic fertiliser on the pH of the soil.
III. To identify the differences in compatibility when applying different concentrations of eggshells as an organic fertiliser on green bean, okra and cucumber plants respectively.

The hypotheses of this study are as stated below:

Ho1: There is no significant correlation between the use of eggshells as an organic fertiliser and the growth of green bean, okra and cucumber plants.

Ha1: There is a significant correlation between the use of eggshells as an organic fertiliser and the growth of green bean, okra and cucumber plants.

Ho2: There is no significant correlation between the use of eggshells as an organic fertiliser and pH soil.

Ha2: There is no significant correlation between the use of eggshells as an organic fertiliser and pH soil.

Ho3: There is no significant difference between the compatibility when applying different concentrations of eggshells as an organic fertiliser on green bean, okra and cucumber plants respectively.

Ha3: There is a significant difference between the compatibility when applying different concentrations of eggshells as an organic fertiliser on green bean, okra and cucumber plants respectively.

Eggshells and Egg Membrane

Chicken eggshells and their accompanying membranes constitute plentiful waste resources possessing distinctive attributes that hold potential for diverse applications. Comprising predominantly of calcium carbonate ($CaCO_3$), eggshells find extensive use as a fertilizer. A single chicken eggshell contains 2.07±0.18g of Ca of which 90% of it is absorbable. Calcium is essential for biochemical and metabolic activities in plants such as root and shoot tissue development as well as cell wall membrane development (Ma'mor *et al.*, 2023). Analysis of organic constituents reveals that both eggshells and their membranes are chiefly constituted of proteins, with minor amounts of carbohydrates and lipids. Research has identified glycosaminoglycans, including hyaluronic acid and chondroitin sulphate-dermatan sulphate copolymer, as integral components of eggshell organic matter (Nakano *et al*., 2003). Additionally, eggshell membranes contain sialic acid, a type of carbohydrate. Despite the potential applications of eggshells and their membranes, there remains limited exploration of their chemical composition, particularly regarding variations in nitrogen concentrations, amino acid composition, and sialic acid levels between the inner and outer membranes. Given their status as non-edible by-products with restricted commercial value, a deeper comprehension of their chemical constitution is of paramount importance. The abundance and cost-effectiveness of chicken eggshells and their membranes hold promise for a range of applications. Continued research in this realm has the potential to augment soil microbial vitality and fertility, thereby benefiting agricultural practices and advancing environmental sustainability.

Soil pH and Fertility

Soil degradation, encompassing reduced fertility and heightened erosion, is a significant apprehension within global agriculture. Soil degradation is the decline in soil quality, which encompasses physical, chemical, and biological deterioration, caused by its improper use, usually for agricultural, pasture, or urban purposes (Wang *et al.*, 2023). Additionally, the decline in organic matter content diminishes the stability of soil aggregates. Thus, it is imperative to address soil degradation through uncomplicated and sustainable approaches.

The vital indicator to represents soil fertility is soil pH (Wang *et al.*, 2024). Soil pH assumes a pivotal role in influencing an array of biogeochemical processes in soil, which in turn impact plant growth, biomass yield, and ecosystem functions. Numerous soil properties, both biological and chemical, as well as physical attributes, are influenced by soil pH. The pH level of soil is regulated by processes like cation leaching, CO_2 dissolution, humic residue presence, nitrification, and other factors. This intricate interplay between soil pH and biogeochemical processes governs nutrient accessibility, substance behavior, and translocation (Neina, 2019). This underscores the necessity to account for soil pH's significance in environmental investigations and strategic planning. A grasp of how soil pH affects substance availability and the fate of pollutants can lead to more effective nutrient management and enhanced strategies for environmental sustainability.

Methodology

Experimental Design

This study utilises three different masses of eggshell amendments (20g, 40g and 60g), along with a control group without any eggshell amendment (0g). To ensure reliability and validity, each concentration has 3 replicates, resulting in 12 pots for each plant. The different types of plants chosen for this study are green bean, okra, and cucumber plants, which are 36 plants in total.

Procedure

In this experiment, the eggshells undergo a meticulous process of collection and thorough cleaning to eliminate potential contaminants. Subsequently, they are left to dry under direct sunlight. Once dried, the eggshells together with its membrane are finely crushed and powdered using a blender. Each pot is then uniformly filled with 200g of soil, ensuring uniform soil mass across all experimental groups. Prior to introducing the eggshell amendments, the initial pH of the soil in each pot is measured using a RCYAGO 4 in 1 soil pH meter and documented. The finely powdered eggshells are meticulously integrated into the soil of their respective pots, adhering to the specified masses of 20g, 40g, and 60g. Pots in the control group remain free from any eggshell amendments. Green bean, okra, and cucumber seeds are sown in each pot at a depth of approximately 0.5 to 1.5 cm. Following the planting process, each pot receives a daily watering of 20 ml of water for a duration of 10 days to maintain consistent moisture levels.

Observation and Data Collection

Over the course of 10 days, observations were recorded regarding the growth and development of the green bean, okra and cucumber plants. Various parameters such as plant height, root and shoot growth, and soil pH were measured and recorded daily. After the observation period, the mass of each plant was measured and recorded for further analysis.

Data Analysis

After completing the experiment, the results are sorted into tables, ordered by the days of observation. This helped the researchers to observe clearly the rate of growth of green bean, okra and cucumber plants respectively. The data was then saved in an Excel Spreadsheet so that it could be run in a statistical software using the IBM SPSS Statistics Data Editor Version 29.0.1.0 (171).

Descriptive statistics were done to determine distribution of samples among various types of plants and concentrations of eggshells. Pearson's correlation analysis test was used to investigate the correlation between the number of days and eggshell concentration for each plant respectively. General statistical techniques were used to analyse the data based on the level of confidence of 95% ($\alpha = 0.05$) and the level of confidence of 99% ($\alpha = 0.01$).

Results and Discussion

Overall Results

Based on our studies, below are the findings of the growth of grean bean, okra and cucumber. All plant heights remain at zero till the 3rd day, and gradually increase till the 10th day. The maximum heights achieved are 3.11cm for green bean; 6.83cm for okra and 9.61cm for cucumber (Table 1).

Table 1: Overall Results for Green Bean, Okra and Cucumber Height (cm)

Day	GB-0g	GB-20g	GB-40g	GB-60g	O-0g	O-20g	O-40g	O-60g	C-0g	C-20g	C-40g	C-60g
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0.62	1.26	1.81	1.57	0.24	1.51	1.31	2.12	1.15	1.19	3.12	3.16
5	1.27	2.19	1.99	2.01	0.9	2.62	1.63	2.7	2.43	2	5.54	6.87
6	0.22	1.28	1.17	1.17	0	0.72	0.85	1.72	0.78	2.28	5.78	6.88
7	0.28	2.22	1.84	1.78	0.22	1.11	1.17	2.45	1.11	3.05	6.5	7.45
8	0	2.61	2.55	1.78	0.22	1.11	1.39	3.33	1.55	3.61	7.72	8.83
9	0	3.19	3.44	2.06	0.22	0.33	2.11	4.33	1.72	3.78	8.61	9.44
10	0	2.83	3.11	2	0.11	0	2.89	6.83	1.22	3.78	9.61	8.61

Table 1 above displays the heights of green bean, okra and cucumber plants with different concentrations of eggshell amendments over the course of 10 days. The abbreviation used for each plant are green bean (GB), okra (O) and cucumber (C).

While for the soil pH, different concentrations of eggshell resulted in different pH. Based on our observations, a noticeable correlation emerges whereby higher eggshell concentrations correspond to elevated soil pH levels. The average soil pH for green bean, okra, and cucumber plants with 0g, 20g, 40g, and 60g eggshell concentrations are 5.42, 5.89, 6.02, and 6.28, respectively (Table 2). This is attributed to the substantial calcium carbonate content in eggshells, which enriches the soil with an excess of this compound. As a result, the soil's pH undergoes an upward shift, making it more alkaline. This transformative process offers significant benefits for optimal plant growth, as many plant species thrive in low-acidity soil conditions.

Table 2: Overall Results for Average Green Bean, Okra and Cucumber pH

Day	GB-0g	GB-20g	GB-40g	GB-60g	O-0g	O-20g	O-40g	O-60g	C-0g	C-20g	C-40g	C-60g
AVERAGE	5.37	5.92	5.99	6.23	5.34	5.95	5.99	6.1	5.55	5.8	6.08	6.52

Table 2 above displays the average soil pH values for green bean, okra and cucumber plants with different concentrations of eggshell amendments. *Descriptive Statistics*

Table 3: Descriptive Statistics for Green Bean's Mean Height and Standard Deviation

	Mean	Std. Deviation	N
DAY	5.50	3.028	10
GB-0g	.2390	.41538	10
GB-20g	1.5580	1.23261	10
GB-40g	1.5910	1.27741	10
GB-60g	1.2370	.89148	10

Based on the descriptive statistics in Table 3 above, the sample mean height and standard deviation of green bean plants with 0g eggshell concentration is 0.2390 cm and 0.41538 respectively. The sample mean height and standard deviation of green bean plants with 20g eggshell concentration is 1.5580cm and 1.23261 respectively. The sample mean height and standard deviation of green bean plants with 40g eggshell concentration is 1.5910cm and 1.27741 respectively. The sample mean height and standard deviation of green bean plants with 60g eggshell concentration is 1.2370cm and 0.89148 respectively.

Table 4: Descriptive Statistics for Okra's Mean Height and Standard Deviation

	Mean	Std. Deviation	N
DAY	5.50	3.028	10
O-0g	.1910	.27082	10
O-20g	.7400	.86667	10
O-40g	1.1350	.96139	10
O-60g	2.3480	2.16284	10

Based on the descriptive statistics in Table 4 above, the sample mean height and standard deviation of okra plants with 0g eggshell concentration is 0.1910cm and 0.27082 respectively. The sample mean height and standard deviation of okra plants with 20g eggshell concentration is 0.7400cm and 0.86667 respectively. The sample mean height and standard deviation of okra plants with 40g eggshell concentration is 1.1350cm and 0.96139 respectively. The sample mean height and standard deviation of okra plants with 60g eggshell concentration is 2.3480cm and 2.16284 respectively.

Table 5: Descriptive Statistics for Cucumber's Mean Height and Standard Deviation

	Mean	Std. Deviation	N
DAY	5.50	3.028	10
C-0g	.9960	.81630	10
C-20g	1.9690	1.59012	10
C-40g	4.6880	3.68772	10
C-60g	5.1240	3.92542	10

Based on the descriptive statistics in Table 5 above, the sample mean height and standard deviation of cucumber plants with 0g eggshell concentration is 0.9960cm and 0.81630 respectively. The sample mean height and standard deviation of cucumber plants with 20g eggshell concentration is 1.9690cm and 1.59012 respectively. The sample mean height and standard deviation of cucumber plants with

40g eggshell concentration is 4.6880cm and 3.68772 respectively. The sample mean height and standard deviation of cucumber plants with 60g eggshell concentration is 5.1240cm and 3.92542 respectively.

Correlations

Table 6: Correlations Between Number of Days and The Heights of Green Beans for Four Different Eggshell Concentrations (0g, 20g, 40g, 60g)

		DAY	GB-0g	GB-20g	GB-40g	GB-60g
DAY	Pearson Correlation	1	-.091	.935**	.921**	.846**
	Sig. (2-tailed)		.802	.000	.000	.002
	N	10	10	10	10	10
GB-0g	Pearson Correlation	-.091	1	.161	.130	.398
	Sig. (2-tailed)	.802		.657	.721	.255
	N	10	10	10	10	10
GB-20g	Pearson Correlation	.935**	.161	1	.978**	.954**
	Sig. (2-tailed)	.000	.657		.000	.000
	N	10	10	10	10	10
GB-40g	Pearson Correlation	.921**	.130	.978**	1	.942**
	Sig. (2-tailed)	.000	.721	.000		.000
	N	10	10	10	10	10
GB-60g	Pearson Correlation	.846**	.398	.954**	.942**	1
	Sig. (2-tailed)	.002	.255	.000	.000	
	N	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the correlation in Table 6 above, the correlation between the number of days and the heights of green bean plants with 0g eggshell concentration is -0.091. The correlation between the number of days and the heights of green bean plants with 20g eggshell concentration is 0.935. The correlation between the number of days and the heights of green bean plants with 40g eggshell concentration is 0.921. The correlation between the number of days and the heights of green bean plants with 60g eggshell concentration is 0.846.

Table 7: Correlations Between Number of Days and Okra's Eggshell Concentrations

		DAY	O-0g	O-20g	O-40g	O-60g
DAY	Pearson Correlation	1	.181	.101	.888**	.920**
	Sig. (2-tailed)		.617	.782	.001	.000
	N	10	10	10	10	10
O-0g	Pearson Correlation	.181	1	.884**	.409	.271
	Sig. (2-tailed)	.617		.001	.240	.449
	N	10	10	10	10	10
O-20g	Pearson Correlation	.101	.884**	1	.267	.118
	Sig. (2-tailed)	.782	.001		.456	.746
	N	10	10	10	10	10
O-40g	Pearson Correlation	.888**	.409	.267	1	.981**
	Sig. (2-tailed)	.001	.240	.456		.000
	N	10	10	10	10	10
O-60g	Pearson Correlation	.920**	.271	.118	.981**	1
	Sig. (2-tailed)	.000	.449	.746	.000	
	N	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the correlation in Table 7 above, the correlation between the number of days and the heights of okra plants with 0g eggshell concentration is 0.181. The correlation between the number of days and the heights of green bean plants with 20g eggshell concentration is 0.101. The correlation between the number of days and the heights of green bean plants with 40g eggshell concentration is 0.888. The correlation between the number of days and the heights of green bean plants with 60g eggshell concentration is 0.920.

Table 8: Correlations Between Number of Days and Cucumber's Eggshell Concentrations

		DAY	C-0g	C-20g	C-40g	C-60g
DAY	Pearson Correlation	1	.652*	.974**	.974**	.938**
	Sig. (2-tailed)		.041	.000	.000	.000
	N	10	10	10	10	10
C-0g	Pearson Correlation	.652*	1	.727*	.760*	.810**
	Sig. (2-tailed)	.041		.017	.011	.005
	N	10	10	10	10	10
C-20g	Pearson Correlation	.974**	.727*	1	.990**	.981**
	Sig. (2-tailed)	.000	.017		.000	.000
	N	10	10	10	10	10
C-40g	Pearson Correlation	.974**	.760*	.990**	1	.983**
	Sig. (2-tailed)	.000	.011	.000		.000
	N	10	10	10	10	10
C-60g	Pearson Correlation	.938**	.810**	.981**	.983**	1
	Sig. (2-tailed)	.000	.005	.000	.000	
	N	10	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the correlation in Table 8 above, the correlation between the number of days and the heights of cucumber plants with 0g eggshell concentration is 0.652. The correlation between the number of days and the heights of green bean plants with 20g eggshell concentration is 0.974. The correlation between the number of days and the heights of green bean plants with 40g eggshell concentration is also 0.974. The correlation between the number of days and the heights of green bean plants with 60g eggshell concentration is 0.938.

Line Chart

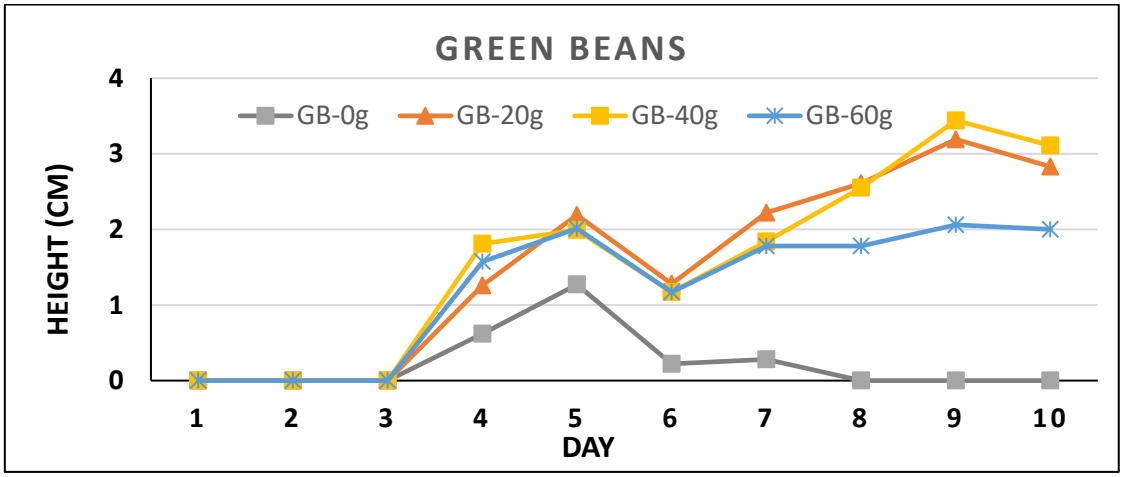

Figure 1: Growth of Green Beans

Figure 1 showed the rate of green bean plant growth for four different concentrations of eggshells over a period of 10 days. It can be observed that heights for 20g and 40g eggshell concentrations rise steadily after the 6th day, emerging as the two most suitable eggshell concentrations for green beans.

The experimental data demonstrates that 20g and 40g eggshell concentrations prove most effective for green bean growth. In green bean plants with a 20g eggshell concentration, there is a correlation of 0.935 (significant at the 0.01 level) between the number of days and plant height, with a mean height of 1.5580cm. For green bean plants with a 40g eggshell concentration, the correlation is 0.921 (significant at the 0.01 level), with a mean height of 1.5910cm.

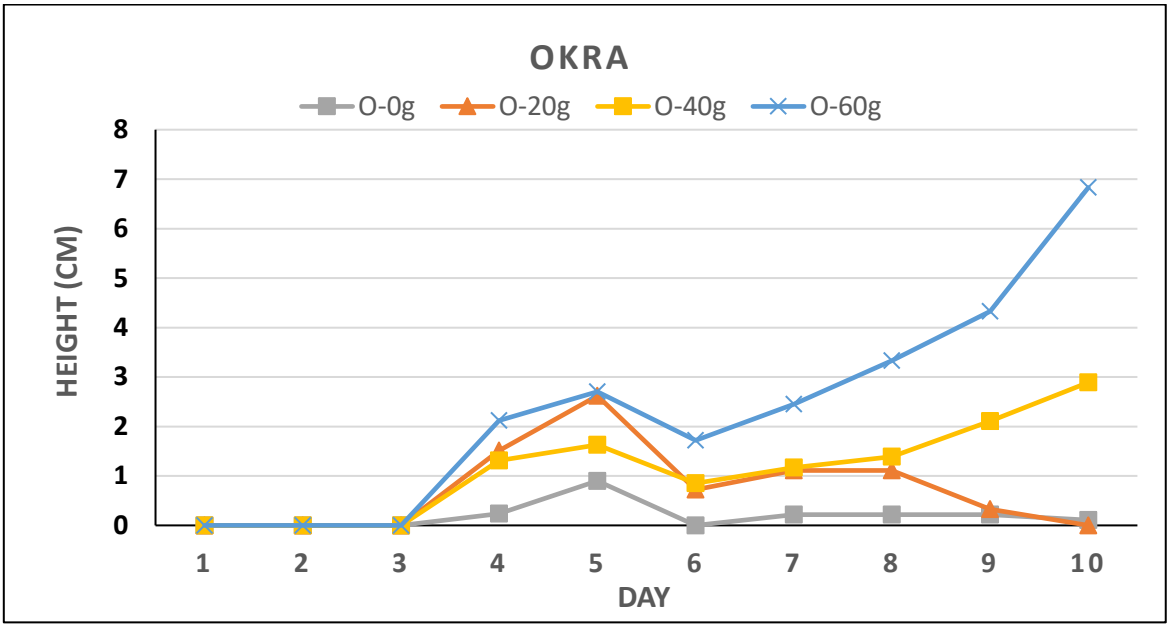

Figure 2: Growth of Okra

While for Okra, it shows that the rate of okra plant growth showed that the heights for an eggshell concentration of 60g follow a steep upward trajectory after the 6th day, emerging as the most suitable eggshell concentration for okra (Figure 2)

This suggests that a 60g eggshell concentration is most conducive for the growth of okra plants. For okra plants with a 60g eggshell concentration, there is a correlation of 0.920 (significant at the 0.01 level), with a mean height of 2.3480cm.

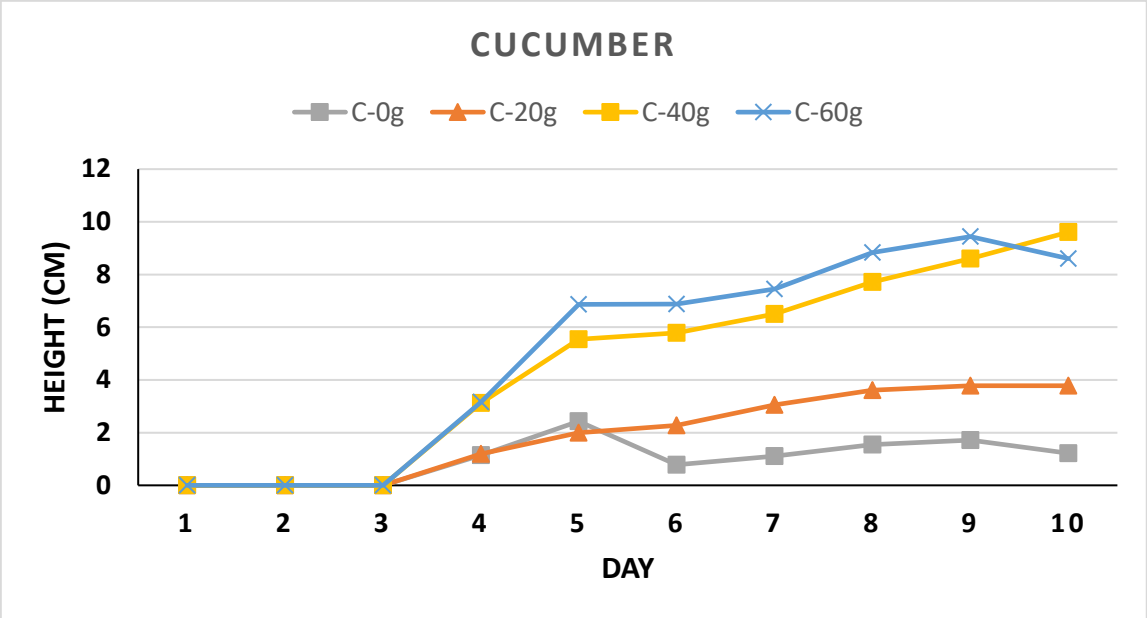

Figure 3: Growth of Cucumber

As for cucumber, the rate of cucumber plant growth for four different concentrations of eggshells over a period of 10 days. If we look at the trends over time, we can see that the mean heights for 40g and 60g eggshell concentrations follow a steep upward trajectory after the 3rd day, then rise steadily after the 5th day, emerging as the two most suitable eggshell concentrations for cucumber plants (Figure 3).

This indicates that 40g and 60g eggshell concentrations are most favorable for cucumber plants. For cucumber plants with a 40g eggshell concentration, the correlation is 0.974 (significant at the 0.01 level), with a mean height of 4.6880cm. For cucumber plants with a 60g eggshell concentration, the correlation is 0.934 (significant at the 0.01 level), with a mean height of 5.1240cm.

In general, alcium carbonate found in eggshells enhances soil fertility by helping the survival of microbial community in the soil (Buntaro & Avicenna, 2023). The reason behind the varying plant responses to different eggshell concentrations lies primarily in the alteration of soil pH. Given that green beans exhibit the highest mean growth with 20g and 40g eggshell concentrations, which maintain average soil pH levels of 5.89 and 6.02 respectively, it can be inferred that green beans favor slightly acidic soil with a pH of approximately 5.96. This is supported by Oplinger *et al*. (2023), where green bean also known as mung bean grow best in slightly acidic soil. Considering okra's highest mean growth with a 60g eggshell concentration, which results in an average soil pH of 6.28, it can be deduced that okra thrives in slightly acidic to neutral soil with a pH around 6.28. This discovery is parallel with the finding from Brandenberger *et al.* (2018), okra prefers slightly acidic soil ranging from pH 6.0 to 6.8. Lastly, as cucumber plants show the highest mean growth with 40g and 60g eggshell concentrations, resulting in average soil pH levels of 6.02 and 6.28 respectively, it can be concluded that cucumber plants prefer a pH of around 6.15, positioning it between the preferences of green bean and okra plants. This finding is similar with the result found by Brandenberger *et al.* (2018) where the best pH suitable for cucumbers are between 6.0 -6.8. Result reported by Tang *et al*., 2023, the cucumber yields increase by 28.8% when the soil is slightly acidic.

Limitations of This Research and Future Following Research

The limitations of this research include time constraints and financial constraints. Time constraints of the research resulted in the inability to conduct a soil microbial activity test to further investigate the effects of different eggshell concentrations on soil chemical properties. Moreover, financial constraints and lack of resources limited the types of plants we can conduct our research on to only three types of plants. For further research, it is suggested to implement measures to explore different soil chemical properties and expand experimentation to a larger variety of plants.

Conclusion

These results indicate a substantial influence of varying eggshell concentrations on the growth of green bean, okra, and cucumber plants. It is evident that when formulating gardening strategies to enhance overall plant development, the choice of eggshell concentration plays a crucial role. This insight can be invaluable for gardeners and farmers aiming to optimize their harvests. A comprehensive understanding of the preferred soil pH and fertility for different plant species is essential for achieving success in gardening endeavors. This knowledge can pave the way for the formulation of sustainable soil management techniques and the promotion of eco-friendly waste disposal practices, contributing to a greener world.

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