# Statistical Analysis of Zeolite Concentration Effects on Germination and Growth of Cucumber Seedlings

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***Abstract:*** *Zeolite is widely applied in agriculture due to its high cation-exchange capacity, ability to improve soil fertility, and effectiveness as a slow-release carrier of nutrients. Inaddition, its porous structure allows it to retain and purify water, thereby enhancing soilmoisture balance and reducing nutrient leaching. The present study examines the influence of varying Zeolite concentrations in soil on the germination and subsequent growth dynamics of Cucumber (Cucumis sativus L.) seedlings. Experimental data were subjected to Correlation Analysis, Analysis of Variance (ANOVA), and Statistical Hypothesis testing in order to evaluate the relationship between Zeolite content and plant growth rate. The findings indicate statistically significant effects of Zeolite percentage on both germination and vegetative development, highlighting the potential of Zeolite as a soil amendment for improving Cucumber cultivation practices.*
***Keywords****: ZEOLITE, ANALYSIS OF VARIANCE (ANOVA), CORRELATION ANALYSIS, CORRELATION COEFFICIENT, STATISTICAL HYPOTHESIS*

## *1. Introduction*

Zeolites are crystalline aluminosilicates of natural or synthetic origin, characterized by a three-dimensional open structure, high cation exchange capacity, large specific surface area and significant porosity. These physicochemical properties make them highly efficient sorbents of water and nutrients, which explains their wide application in industrial, environmental and agricultural practices [1].

In agriculture, Zeolites – particularly natural clinoptilolite are recognized for their potential to improve soil structure by increasing it's water-holding and ion-exchange capacity. Moreover, they stabilize soil pH and reduce fertilizer losses due to evaporation and leaching [2]. This is especially important for sandy soils, which are naturally low in organic matter and easily lose water and nutrients. In such soils, Zeolite acts as a buffer, retaining moisture and fertilizers and gradually releasing them to plant roots [3].

Numerous studies have shown the positive effect of Zeolite application on the growth and yield of various crops, including wheat, maize and vegetables. Nevertheless, the duration and intensity of this effect largely depend on the mineral concentration, soil type and growing conditions. For example, the use of small amounts of Zeolite (up to 0.8 kg/m²) in spring wheat cultivation under field conditions initially increases yield, but without lasting improvement of soil properties [4]. In contrast, laboratory studies using higher Zeolite concentrations have shown increased nutrient retention, higher pH and greater plant biomass accumulation [5]. Cucumber (Cucumis sativus L.) is a crop highly sensitive to soil moisture and nutrient availability, making it suitable for assessing the short-term effects of Zeolite application on germination and early growth processes. Understanding the influence of different Zeolite concentrations on seedling development is crucial for optimizing it's use in vegetable production, especially under limited water and nutrient resources.

Cinnamon Forest Soils (Chromic Luvisols) generally have good structure and water permeability, but are often poor in organic elements such as nitrogen and phosphorus, with pH typically in the slightly acidic to neutral range. The addition of Zeolite, with it's pronounced porous structure, allows such soils to retain water effectively. This helps reduce irrigation needs and protects plants from water stress, which is critical for water-demanding cucumbers. It also increases the soil's cation exchange capacity, allowing it to retain more nutrients (nitrogen, potassium, phosphorus, calcium, magnesium) and release them slowly to the roots instead of washing away during watering or rainfall. Zeolite can also slightly increase and stabilize soil pH, creating a more favourable environment for nutrient uptake by cucumbers.

The present study aims to perform a Statistical Analysis of the effect of Zeolite concentration on cucumber seedling germination and early growth. Specifically, it investigates how different Zeolite concentrations influence key physiological parameters – germination percentage, stem length, and biomass accumulation. The results obtained can contribute to a clearer understanding of the role of Zeolite as a soil amendment and help determine optimal concentrations to achieve maximum positive effect without adversely affecting plant development.

## *2. Experimental conditions*

For the purpose of conducting the study and performing a Statistical Analysis to monitor the effect of different Zeolite content on the germination and initial growth of the used vegetable crop, in this case Cucumber, four samples with varying ratios of Zeolite and soil were prepared. Before placing the required amount of the mixture into the samples, they were thoroughly homogenized.

Four samples with varying Zeolite concentrations were prepared, using the following materials:

• Natural Zeolite – Clinoptilolite, obtained from the Rhodope region;

• Chromic Luvisol soil;

• Cucumber seeds, variety "Gergana".

The first sample – Container I is a control sample, containing no Zeolite. The second sample – Container II – contains 25% Zeolite and 75% Soil, the third sample – Container III – contains equal amounts of Zeolite and Soil (50% Zeolite, 50% Soil) and the fourth sample – Container IV – contains 75% Zeolite and 25% Soil (Table 1).

***Table 1:*** *Zeolite/soil ration in the samples.*

| Sample | Total content (g) | Zeolite (g) | Zeolite % | Soil (g) |
|---|---|---|---|---|
| 1 | 1300 | 0 | 0 | 1300 |
| 2 | 1300 | 325 | 25 | 975 |
| 3 | 1300 | 650 | 50 | 650 |
| 4 | 1300 | 975 | 75 | 325 |

To each of the samples (containers), 100 ml of distilled water was added, and six seeds were sown – each planting spot containing one seed. During sowing a precisely defined distance between the seeds was not maintained (Fig. 1).

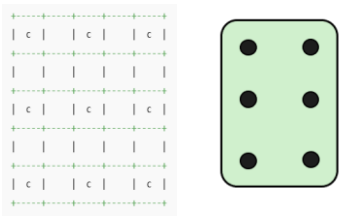

***Fig. 1*** *Sowing layout of cucumber seeds.*

The first seedlings from the sown Cucumber seeds were observed a few days after sowing. The germination process and the initial growth of the plants varied depending on the Zeolite content in the soil mixture. The control sample, containing only soil without Zeolite, exhibited the slowest germination and a limited number of plants, likely due to lower aeration and reduced water-holding capacity of the soil. In the sample with 25% Zeolite content, the highest germination rate was observed. Initial growth in this sample was the most vigorous and the plants showed a healthy and robust appearance, indicating optimal moisture conditions and nutrient availability.

In the sample with 50% Zeolite content, plants also germinated well, with stable development, though slightly slower compared to the sample with a lower Zeolite concentration. Nevertheless, the plants showed good resilience and uniform growth, suggesting that this ratio maintains an appropriate balance between air and water permeability of the mixture. In the sample with the highest Zeolite content (75%), plants germinated more slowly and developed shorter stems during the initial period. Leaf development was weaker, which may be due to reduced nutrient availability in the mixture, resulting from the lower proportion of soil and organic matter.

Watering was carried out regularly with distilled water – usually daily or every other day, depending on the plants needs and soil moisture.

Throughout the experiment, the plants in all variants continued to grow and develop leaf mass, with the samples containing 25% and 50% Zeolite maintaining an advantage in terms of height and leaf density. However, in the control sample, weak and uneven growth was observed, and at a certain stage of the experiment, all plants died. This is probably due to the less favourable moisture regime and the lower ability of the soil without Zeolite to retain water and nutrients, which leads to periods of drought or physiological stress. Additionally, the lack of improved aeration and weaker pH buffering may create conditions unfavourable for the early development of the seedlings.

## *3. Statistical Analysis*

Statistical Analysis is a set of methods for collecting, processing, summarizing and interpreting data in order to identify patterns and relationships between the variables under study. It is a fundamental tool for assessing the significance of experimental results and for testing scientific hypotheses.

In the present study, the height of the first-emerged plant in each sample was used for Statistical Analysis. The choice of this approach is motivated by the need to compare plants that developed under the most similar initial conditions, as the first emergence usually reflects the most favourable interaction between the seed and the environment. This allows minimizing differences related to the individual viability of the seeds and reducing variability that is not the result of the experimental factor.

The first-emerged plant serves as a representative indicator for the early response of plants to different Zeolite concentrations, as it's development most quickly reflects the presence of favourable or unfavourable physicochemical conditions in the soil environment.

To evaluate the influence of different Zeolite concentrations on the height of the first-emerged plant, a one-way Analysis of Variance was applied.

Analysis of Variance (ANOVA) is one of the most commonly used methods for statistical processing of experimental data in agriculture. It is used to determine whether there is a statistical relationship between a dependent variable (e.g., plant height, yield, or biomass) and one or more independent variables (e.g., Zeolite concentration). By testing the hypothesis $H_0$: $\mu_1 = \mu_2 = ... = \mu_K$, it is established whether there is a significant difference between the mean values of the studied parameter in two or more groups defined at different levels of the input factor. If this hypothesis is true, the factor does not affect the experimental results, otherwise it's influence is significant.

The principle of the method is based on decomposing the total variation into two components:

• variation between groups, caused by the action of the studied factor,

• variation within groups, due to the influence of random disturbances accompanying each process.

The influence of the factor and the random error are compared by calculating the so-called variance ratio or F-value, which follows the Fisher Distribution (F-distribution). If the calculated F-value exceeds the tabular value determined for a given significance level ($\alpha = 0.05$), it is accepted that the factor has a statistically significant effect on the studied variable [6].

The results obtained from the Analysis of Variance are presented in Table 2.

***Table2:*** *Results of the Analysis of Variance (ANOVA).*

| Source of variance | Sums of squares | Degrees of freedom | Estimate of variance | Variance ratio |
|---|---|---|---|---|
| Factor | 184.50 | 3 | 61.50 | 2.38 |
| Residual error | 619.21 | 24 | 25.80 | - |
| Total sum | 803.71 | 27 | - | - |

The results show that the factor "Amount of Zeolite" does not have a statistically significant effect on the studied variable ($F < F_T(\alpha, 2, 24) = 3.01$).

The obtained F-value indicates that the variation between groups, caused by the different Zeolite content in the mixtures, does not differ significantly from the variation within the groups, which is due to random errors.

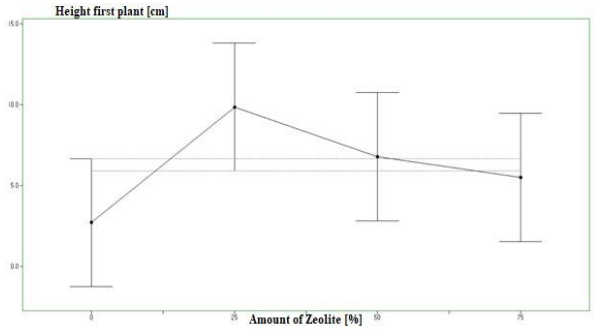


***Fig. 2*** *Confidence intervals of the mean values for height at each level of the factor.*

Fig. 2 presents a graph of the confidence intervals of the mean values for the height of the first emerged plant, calculated based on the standard deviation for each level of the factor. Partial overlap of the confidence intervals between the levels confirms that the differences between the groups are not statistically significant.

The insignificant effect of the Zeolite amount can be explained by the fact that the internal variability among the plants is high, making it difficult to detect a clearly expressed effect of the factor. It is possible that the sample of data used was not sufficiently large, which reduces the statistical power of the analysis. Additionally, plant responses are often nonlinear, so a one-way Analysis of Variance cannot capture the dependencies. Moreover, external, uncontrolled factors such as light, humidity or soil structure may have had an influence, thus masking its effect. It is also possible that Zeolite exerts an indirect effect by mainly influencing soil properties and certain physiological parameters of the plants, rather than directly affecting height, which is a morphological parameter.

For a more complete characterization of the effect of Zeolite on plant growth, a Correlation Analysis was performed between the height of the first-emerged plant and the number of days of measurement at different Zeolite concentrations. Correlation Analysis allows a quantitative assessment of the linear relationship between two variables, with the main indicator being the correlation

coefficient (r), which ranges from –1 to +1. Positive r-values indicate that as the number of days increases, height also increases, while negative values indicate an inverse relationship. Absolute r-values close to one reflect a strong linear relationship, while values near zero indicate the absence of such a relationship [7].

To determine whether the observed correlation is statistically significant, a test of the significance of the correlation coefficient is performed, $H_0$: $\rho = 0$. If this hypothesis is true, the coefficient is insignificant and no linear relationship exists between the two variables. The significance test is based on a t-statistic, which follows the Student's t-distribution and is compared with a tabular value determined at the given significance level ($\alpha = 0.05$). If $t \leq t_T$, the correlation is considered statistically insignificant [8].

Table 3 presents the summarized results of the Correlation Analysis, showing a strong positive correlation between height and the number of days for all tested Zeolite concentrations. The coefficient values are close to 1 and the t-values significantly exceed the critical values, with the highest values observed in Sample 3 – Zeolite 50%. This means that at this Zeolite amount, the increase in height over time is the most pronounced.

***Table 3:*** *Results of the Correlation Analysis.*

| Content of Zeolite % | Correlation coefficient | t-value | Critical t-value | Coefficient significance |
|---|---|---|---|---|
| 0 | 0.9428 | 6.3226 | 2.5706 | $t > t_T \rightarrow H_1: \rho \neq 0$ |
| 25 | 0.9738 | 14.1936 | 2.2010 | $t > t_T \rightarrow H_1: \rho \neq 0$ |
| 50 | 0.9809 | 16.7273 | 2.2010 | $t > t_T \rightarrow H_1: \rho \neq 0$ |
| 75 | 0.9776 | 15.4229 | 2.2010 | $t > t_T \rightarrow H_1: \rho \neq 0$ |

The Scatter Plot provides a visual representation of the direction and strength of the linear relationship, in which each pair of observations of the two variables is represented as a point in a coordinate system. The shape and arrangement of the points allow an assessment of how linear the relationship is and whether it is strongly or weakly expressed. A regression line is often added to the plot, which facilitates visual interpretation – with a strong correlation, the points are closely arranged around it, while with a weak correlation, they are scattered without a clearly expressed trend.

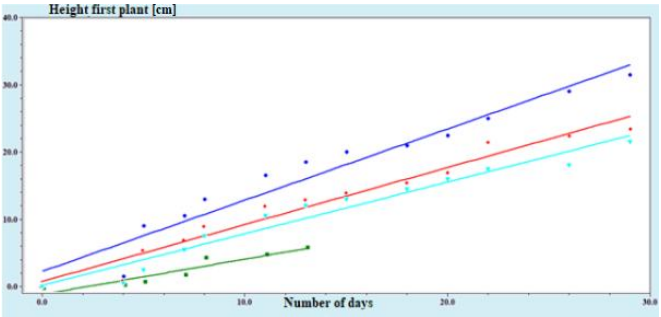


***Fig. 3*** *General scatter plot between the number of days and the height of the first-emerged plants for each smaple, where: dark blue – 25% Zeolite; red – 50% Zeolite, light blue – 75% Zeolite, green – 0% Zeolite.*

In Fig. 3, a General Scatter Plot is presented, visualizing the relationship between the number of days and the height of the first-emerged plants for each sample at different Zeolite concentrations. Each colour represents a separate experimental group:

- green – 0% Zeolite (Control sample),
- dark blue – 25% Zeolite,
- red – 50% Zeolite,
- light blue – 75% Zeolite.

The plot clearly shows a positive linear relationship between the number of days and height for all Zeolite levels. With increasing Zeolite concentration, a steeper slope of th e regression lines is observed, indicating more intensive plant growth. The lowest growth rate is in the control group (0% Zeolite), while the groups with 25%, 50%, and 75% Zeolite show a significantly higher dynamics of height increase. The most pronounced growth is observed at 50% Zeolite.

## *4. Conclusions*

The influence of different amounts of Zeolite on plant growth was investigated by evaluating the height of the first-emerged plant in each sample. Statistical Analysis using one-way Analysis of Variance showed that the factor "Amount of Zeolite" does not have a statistically significant effect on plant height. The insignificant effect of the concentration can be explained by the high internal variability among the plants, the possibly insufficient sample size, and the potential influence of external uncontrolled factors, such as light, humidity, or soil structure. Correlation Analysis shows a strong positive relationship between height and the number of days for all tested Zeolite concentrations, with the most intensive growth observed at 50% Zeolite.

In future studies, it is recommended to use a larger sample, to control the influence of external factors, and to assess the effects of Zeolite on soil properties and the physiological parameters of the plants, in order to more clearly determine its influence on growth.

## *Acknowledgements*

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