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Analyzing the Critical Magnesium Concentrations for Optimal Tomato Production in Calcareous Soils

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Abstract

Plant growth depends heavily on Magnesium (Mg), particularly for crops like tomatoes (Solanum lycopersicum), which are particularly vulnerable to nutritional imbalances in soil science. Magnesium availability can be changed by calcareous soils that are typically found in agricultural areas, depending on their mineral composition, pH, and organic matter in plant science. Understanding the ideal magnesium concentrations for recently transplanted tomato seedlings to thrive in these soils is crucial for boosting crop production and reducing nutrient deficiencies in plant science. To maximize tomato production in calcareous soils, the research looks into the necessary magnesium concentrations in soil science. It also develops potential fertilizing techniques to improve tomato production in these types of soils. The experiment was set up in a controlled greenhouse environment to eliminate any outside influences like weather and pest activity. Positional bias was avoided by randomly assigning calcareous soil to pots that were similar in volume and texture. Mg levels varied throughout the five treatment groups: Group 1 as low (20 mg/kg), Group 2 as medium-low (40 mg/kg), Group 3 as medium (60 mg/kg), Group 4 as medium-high (80 mg/kg), and Group 5 as high (100 mg/kg). The tomato seed was demonstrated to be grown in a controlled environment concerning temperature, humidity, and lighting in each pot. Among the several metrics used to evaluate the impact of magnesium on plant growth were plant height, fruit yield, and chlorophyll content. The content of magnesium and plant growth is strongly positively correlated. The plants that grew and produced the most fruit had magnesium levels between 50 and 70 mg/kg. Reduced magnesium concentration (less than 50 mg/kg) was accompanied by decreased fruit yield. Mg's function in photosynthesis is demonstrated by the greatest concentration of chlorophyll, which was 50–70 mg/kg Mg.

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According to research, magnesium levels in calcareous soils should be kept below the recommended critical range to increase tomato yield in soil science. It implies that for higher yields in tomato growing, targeted magnesium fertilization is crucial in plant science.

Keywords:

Calcareous soils, tomato production, crop yields, plant growth, plant science, soil science.

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Introduction

One of the fundamental biological components required for plant growth is magnesium, which is termed as an essential agricultural element. As the most important component of the chlorophyll system, magnesium is essential in plant science for photosynthesis (Song et al., 2024). Because it permits the growth of roots, blooms, and fruits, as the energy produced by this specific system is crucial for biological processes. Because proteins and enzymes are necessary for plant health, and magnesium is necessary for their synthesis (Bakki et al., 2024). Magnesium increases the enzymes that make proteins, lipids, and carbohydrates, which activates plant metabolic processes in soil science. Magnesium enables plants to transport essential minerals, their constituents, amino acids, and carbohydrates across different plant sections. Plants with a magnesium deficit exhibit chlorosis, or yellow leaves, aberrant growth patterns, and undeveloped roots as a result of low soil magnesium levels. Effective management is necessary to meet sustainable agricultural targets as crop output is significantly reduced by inadequate magnesium content in plant science (Kebria, 2017). For tomato crops growing in calcareous soils, knowing the magnesium levels becomes essential as the high pH of the soil prevents the plants from using this element (Mustapha et al., 2017; Du et al., 2021). Maintaining appropriate magnesium concentrations is a crucial procedure for growing the most high-quality tomatoes possible (He et al., 2021). Magnesium is necessary for plant health and productivity because it enables chlorophyll to work efficiently for photosynthesis, which produces energy for plant science. As magnesium facilitates protein synthesis and improves glucose metabolism and nucleic acid production, it is necessary for the activation mechanism of vital enzymatic processes in soil science (Radmanović et al., 2018). As magnesium stimulates the production of proteins, nucleic acids, and glucose, it is essential for the activation mechanism of essential enzymatic processes. Figure 1 illustrates the life cycle of a tomato.

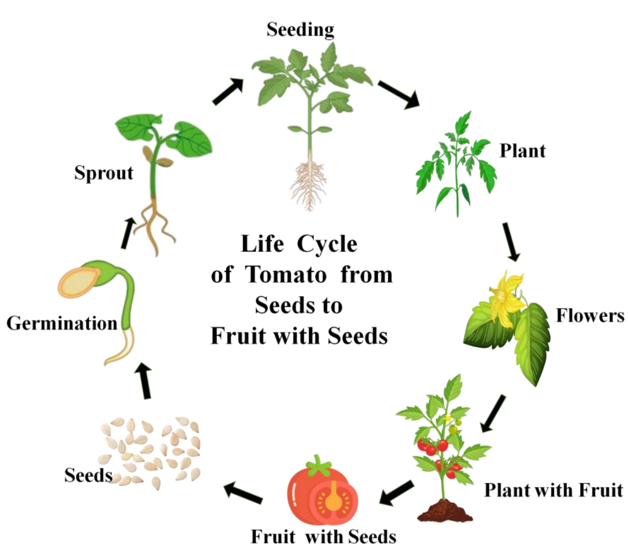

Figure 1. Presentation of the life cycle of tomato

The development of crop plants and tomato yield output is directly impacted by the advantages of magnesium. By regulating both enzyme activity and vital nutrient absorption mechanisms, magnesium maintains nutritional equilibrium (Bouizgarne et al., 2023). Magnesium increases the spread ability of nutrients when it is absorbed by plants because it facilitates the movement of phosphorus, potassium, and sulfur from roots to other plant components. Secondary plant cell wall strength and stress tolerance depend on maintaining the right concentration of the magnesium system (Ma et al., 2022). Plants with inadequate magnesium content exhibit three main physiological symptoms: chlorate leaves between veins, poor fruit development, and short overall plant height in soil science. Higher calcium concentrations in calcareous soils restrict the amount of magnesium that can be found there, according to (Sediqui et al. 2024). To maximize agricultural productivity under these mineral conditions, tomato soil cultivation requires effective management of magnesium levels in soil science. Understanding the biology of magnesium plants can lead to improved fertilization methods that produce tomato crops high in nutrients (Hazman et al., 2022).

Tomatoes have hard time absorbing magnesium, and calcareous soils give too much calcium. Research is required to make nutrient management systems efficient because that can attain sufficient amounts of magnesium along with other essential minerals. For these specific soil types, it establishes the optimal magnesium amounts to improve tomato production. To overcome the above, the research determines the essential Mg thresholds in calcareous soil, which are categorized into five treatment groups: Group 1 as low (20 mg/kg), Group 2 as medium-low (40 mg/kg), Group 3 as medium (60 mg/kg), Group 4 as medium-high (80 mg/kg), and Group 5 as high (100 mg/kg) to analyze the higher outcomes in production of tomato growth. Among the shortcomings identified in these particular soil types, it establishes Mg concentrations appropriate for plant growth in conjunction with production enhancements and quality preservation in soil science (Tarek & Abood, 2014). The research leads to practical recommendations for magnesium-deficient locations that improve fertilization tactics with crop management approaches.

Yan et al., (2020) investigated tomato Mg deficit using soil and leaf samples with varying Mg concentrations and four different fertilizer amounts. Higher magnesium fertilizer application was found to promote the uptake of both calcium and magnesium, boost tomato yield, and lessen the potassium/magnesium (K/Mg) imbalance in the soil. Seifi & Souri (2021) Sulfur application has a major effect on soil pH, electrical conductivity, nutrient availability, and plant tissue concentrations, according to Western Iran. According to the findings, adding up to three grams of sulfur per kilogram of calcareous soil improved nutrient uptake, which in turn enhanced tomato yield and growth. Saha et al., (2025) discovered that, in comparison to foliar B spray, soil-applied boric acid (B) enhanced tomato yield by 2-12%. Fruit and shot B content also increased. In B-deficient calcareous soils, cultivars NS-812, NS-512, and B-9-2 exhibited the maximum usage efficiency. Cheraghi et al., (2023) determined the effects of several fertilizers on tomato plants were investigated in a greenhouse experiment (Kanagala et al., 2023). The findings demonstrated that the soil microbial population, zinc and silicon concentrations, and dry weight were all considerably raised by F4, BF4, and BF3. While BF4 and BF3 treatments enhanced plant growth and nutritional status, F2-BF3 and F2-BF4 boosted the rate of soil microbial respiration. Mal et al., (2023) evaluated 94 tomato-growing fields' Gangetic alluvial soils were evaluated for B concentration using second-order polynomial curve fitting. It was discovered that the best extract for identifying B insufficiency was hot calcium chloride. Rehman et al., (2021) discovered the bio chars in nutrient-depleted alkaline soil greatly enhanced tomato growth, soil organic carbon concentration, and soil biogeochemical quality. The biochars improved the characteristics of the soil below ground; and raised the pH, electrical conductivity, and Cation exchange capacity of the soil. Thiyagarajan et al., (2021) found that crop productivity and yields are impacted by zinc deficiency, a prevalent abiotic stressor throughout the world (Toraman et al., 2020). Soil parameters such as pH and organic carbon content have an impact on low zinc utilization efficiency. In calcareous soils, zinc sulfate is utilized, however, because of its greater solubility, leaching loss occurs. Santoro et al., (2024) suggested that phosphorus was considered essential for plant growth; soil processes such as co-precipitation, adsorption, and precipitation can reduce its bioavailability, which can result in stunted growth and overuse of fertilizer. In response, plants modify their development and metabolism, with strigolactones becoming hormones for adaptation tactics.

Research Contributions

- **Optimal Magnesium Concentration Range**: The research establishes the critical magnesium concentration level (50–70 mg/kg) required for both optimal tomato fruit production and healthy growth in soil with high lime content in plant science.
- **Effect of Magnesium on Photosynthesis**: Magnesium (Mg) is essential for better photosynthesis as well as for increased plant health and productivity; research shows that higher magnesium concentration raises chlorophyll levels in plant science.
- **Fertilization Strategies for Tomato Production**: To regulate soil nutrient disparities and increase tomato yield production in calcareous soils have determined the necessary magnesium requirements for particular fertilization techniques in soil science.

Methodology

Under the particular circumstances of calcareous soil fields, which predominate in agricultural areas, it examines the impact of magnesium on tomato cultivation in soil science. It establishes the critical magnesium levels that result in maximum production and ideal tomato growth. By evaluating the impacts of magnesium on plant growth and chlorophyll status, this type of analysis helps researchers identify the best fertilization techniques that improve tomato farming. Figure 2 presents the architecture diagram of the methodology flow.

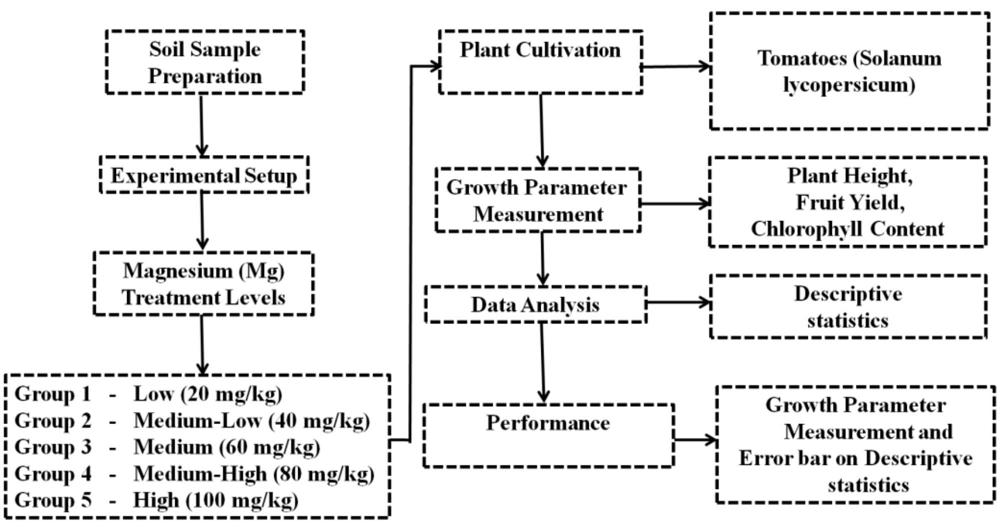

Figure 2. Architecture diagram of methodology flow

Soil Sample Preparation

The decision to employ calcareous soil with high concentrations of calcium carbonate (CaCO3) was made as these soil types are commonly found in agricultural areas and have an impact on the availability of nutrients in soil science. The high pH of these soils is a common characteristic that restricts nutrient solubility, especially for magnesium (Mg) which impacts crop output and plant growth. The research location is genuine to its natural soil environment as the researchers gathered soil from a nearby agricultural field in plant science. When scientists collected the soil sample for analysis of the organic matter contents, pH levels, and important element readings of potassium, phosphorus, and nitrogen, a thorough baseline analysis of essential soil nutrients was conducted. When magnesium sulfate (MgSO4) was systematically mixed with soil, different concentrations were obtained that replicated diverse soil magnesium conditions. To adequately investigate how plant development would react to varying magnesium concentrations, multiple magnesium treatment levels were established by properly mixing MgSO4 into the soil. The broad range of magnesium levels found in calcareous soils across agricultural regions was replicated by the experimental setting.

Experimental Setup

Insect populations and other external variables that typically affect plant growth are effectively blocked in a controlled greenhouse environment of plant science. Throughout the sixty-day development period, all treatments received standard pot sizes for routine soil management. As it offered the regularity required for plant development, the chosen arrangement became essential. The haphazard placement of the pots in the greenhouse provided all plant specimens with equal exposure to light and temperature, as well as regulated climatic conditions, effective water systems, pest control, enhanced nutritional management, and soil preservation.

Magnesium Treatment Levels

To assess the impact of varying soil magnesium concentrations on tomato plant growth, a research design comprised five treatment groups. Five treatments made up the experimental groups: Group 1 received low doses of 20 mg/kg, Group 2 received medium-low doses of 40 mg/kg, Group 3 received medium measurements of 60 mg/kg, Group 4 received medium-high doses of 80 mg/kg, and Group 5 received high concentrations of 100 mg/kg. To precisely assess how magnesium affects the availability of soil nutrients, the experiment treated five different magnesium solutions to find the ideal magnesium level needed for tomato growing in calcareous soils in plant science.

Plant Cultivation

To maintain a consistent number of specimens in each container and safeguard the other plants during the period until seedlings emerged, will keep a safety practice on plant development. While all other development nutrients stayed constant, the experimental plants were routinely watered to maintain the ideal amount of soil moisture, thereby mitigating the impacts of magnesium changes in plant science.

Growth Parameter Measurement

Plant height is an essential part of tomato culture growth research, along with fruit production and chlorophyll assessment, as these parameters show the overall health of the plant. Magnesium and all other nutrients are evaluated using performance indicators to examine plant development. Plant height measurements work as a vertical development status indicator, and fruit yield records monitor manufacturing output. The efficiency of the plants' chlorophyll-based processes is measured using Soil Plant Analysis Development (SPAD) meters to determine their photosynthetic efficiency. The effects of magnesium on tomato development and yield are thoroughly examined by the results of regularly assessing these research variables during the growing season in soil science.

- **Plant Height Measurement:** Plant growth can be easily tracked by measuring the height of the plants with a measuring tape or ruler. Starting from the root stem, the measurement process advances toward the tallest point of the plant. The plant's growth is tracked weekly during its developmental cycle to evaluate its general health. One-millimeter (mm) resolution devices are required for measuring tapes and rulers to produce accurate measurements. Regular measurement helps scientists to examine the impacts of magnesium on plant development and performance rates, which in turn helps better to understand plant growth rates. Physician indicators of plant health and the appropriate growth rate are tracked by the measurement program in plant science.

- **Fruit Yield Measurement:** The entire crop of mature fruit from the plants under examination is gathered after the measurement processes are finished. Fruits are picked with care, paying particular attention to preventing damage during the harvesting process. It utilizes high-precision digital scales to calculate the overall weight of the collected fruits. Fruit Yield Measurement can be used to ascertain the actual productivity rate of the plants. Only completely ripe fruits are assessed upon harvest to ensure measurement accuracy. The measurement technique provides a trustworthy expression of plant responses to varying magnesium levels, supporting the assessment of the impact on tomato agriculture in calcareous soils of soil science.
- **Chlorophyll Content Measurement:** By measuring light transmission across leaf surfaces, the SPAD meter can be used to determine the amount of chlorophyll. Plant health and photosynthetic capacity are positively correlated with chlorophyll levels, making the SPAD sensor a suitable tool for tracking these levels. With the non-destructive method of measuring chlorophyll using SPAD meters, the plant can be left undisturbed for multiple tests. Experts use this apparatus sometimes to measure changes in chlorophyll levels at different phases of plant development. It can use chlorophyll, which indicates the nutritional state of the plants, to link magnesium levels to photosynthesis, yield, and growth. Research organizations frequently conduct these kinds to comprehend how specific nutritional resources affect plant health and yield in soil science.

Data Analysis

All statistical analyses were performed using IBM SPSS software version29. Descriptive statistics across the different treatment conditions are required to determine the effects of magnesium concentrations and therapy on tomato development parameters in soil science. Therefore, based on the descriptive statistics, the suggested models of high or low magnesium can always anticipate its quantitative relationship with plant features. It can assist in creating efficient fertilization plans based on the descriptive statistical model that displays relationships, significant magnesium thresholds, and patterns of plant responses.

Results

It examines the effects of varying magnesium levels on tomato plants to improve tomato culture on calcareous soil by identifying the ideal magnesium-dose rates for improved plant development. As a result, it provides useful information on the minimal mineral requirements for improved tomato production under such soil circumstances by evaluating plant height and including data on fruit yield and chlorophyll content at different magnesium concentrations in soil science.

Groups on Plant Height

The heights of tomato plants in five groups that received unusual magnesium concentration treatments were measured and examined. With a plant height of 15 cm, Group 1 with the lowest content indicated little growth as a result of magnesium deficiency. With a height of 25 cm, Group 2 showed increased growth, while Group 3 reached 35 cm, demonstrating a highly significant response to rising magnesium levels. Group 4 reached the highest height of 45 cm, indicating that the concentration needed for growth was ideal. However, Group 5 saw a 40 cm drop in height as a result of an overabundance of magnesium that could have disrupted the nutritional balance. These results make it abundantly evident that maintaining the ideal magnesium content is necessary to optimize plant development and yield. Tables 1 illustrate the values of plant height lower in Group 1 of 15cm and higher in 40cm.

Table 1. Quantitative values of plant height

Groups	**Plant Height (cm)**
Group 1	15
Group 2	25
Group 3	35
Group 4	45
Group 5	40

The impact of different Mg concentrations on tomato productivity was assessed by comparing the fruit production of five groups of plant science. With the lowest fruit yield of 45 g/plant, Group 1 showed a nutritional deficit at this Mg level. Group 2 demonstrated enhanced plant performance with a moderate improvement at 60 g/plant. A good response to the ideal magnesium concentration was shown by Group 3, which reported 85 g/plant. The highest yield of 100 g/plant was demonstrated by Group 4, indicating that this magnesium level is optimally balanced in terms of nutrients for fruit development and growth. Group 5 experienced a modest decline to 90 g/plant, suggesting that excessive magnesium can be starting to affect productivity in soil science. The research emphasizes that for the highest fruit output, balanced magnesium levels are necessary. Table 2 shows the values of fruit yield in Group 1 at 45g which is lower than the Group 3, Group 4, and Group 5.

Table 2. Quantitative values of Fruit Yield

Groups	**Fruit Yield (g/plant)**
Group 1	45
Group 2	60
Group 3	85
Group 4	100
Group 5	90

In correlation with variations in Mg concentration, the five groups under investigation had varying levels of chlorophyll content, as measured by the SPAD index. At SPAD 20, Group 1 had the lowest chlorophyll concentration, suggesting a low photosynthetic rate brought on by a potential nutritional shortage. In contrast, Group 4 had the maximum chlorophyll content (SPAD = 45), indicating that there was enough magnesium present to boost photosynthetic activity. Group 3's intermediate magnesium availability can support plant growth, as indicated by its SPAD reading of 35. Group 2's SPAD reading was 25, whilst Group 5's was slightly lower at 40in plant science. These findings highlight the important role magnesium plays in determining chlorophyll concentration and overall plant health. Table 3 presents the values of chlorophyll content in Group 1 attained 20 SPAD and high in Group 4 at 40 SPAD.

Table 3. Quantitative Values of Chlorophyll Content

Groups	Chlorophyll Content (SPAD Index)
Group 1	**20**
Group 2	**25**
Group 3	**35**
Group 4	**45**
Group 5	**40**

Descriptive statistics on Plant Height

The distribution and variability of important factors influencing tomato production in calcareous soils can be understood by descriptive statistics in plant science. Significant differences in plant height between the several groups were the outcome of different magnesium treatments. With plant heights ranging from 25.0 to 25.5 cm and a median of 25.0 cm, Group 1 exhibits greater diversity than Group 2, which has heights ranging from 35.0 to 36.5 cm and a median of 35.0 cm. The median size of Group 3's plant population is 45.0 cm, with a range of 45.0 to 47.5 cm. Despite the observed heights falling between 48 and 50.2 cm, Group 4's median plant height measurements from Group 5 are 48.0 cm. According to the research, magnesium levels and plant height are positively correlated until Group 4 reaches maximal growth. Table 4 and Figure 3 present the Descriptive statistics on Plant Height.

Table 4. The quantitative value of Plant Height

Groups	Plant Height Min (cm)	Plant Height Max (cm)	Plant Height Median (cm)
Group 1	25.5	25.0	25.0
Group 2	36.5	35.0	35.0
Group 3	47.5	45.0	45.0
Group 4	52.5	50.0	50.0
Group 5	50.2	48.0	48.0

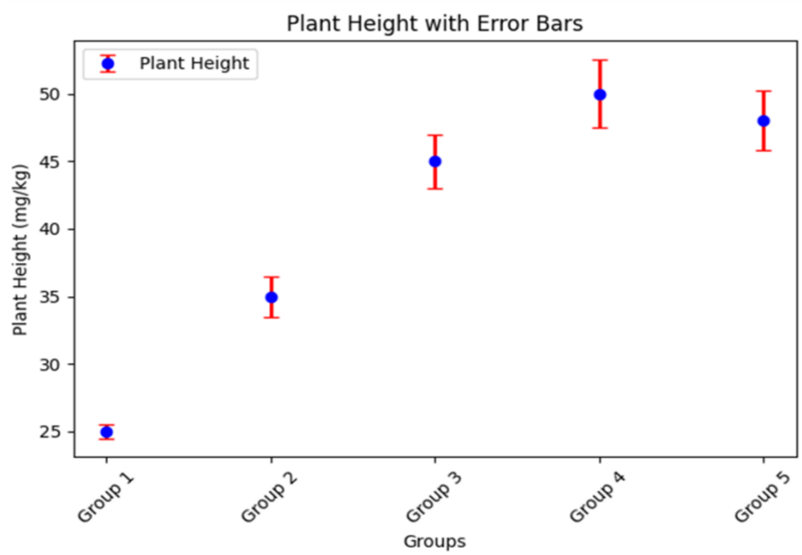

Figure 3. Presents the Descriptive statistics on Plant Height

Descriptive Statistics on Fruit Yield

Fruit yields in five groups with varying Mg levels are shown by analysis in plant science. Fruit yield values in Group 1 range from 0.45 to 0.55 mg, with 0.5 mg serving as the median. With a median of 0.8 mg and a range of 0.7 to 0.9 mg, Group 2 exhibits a greater yield. The median yield for Group 3 is 1.2 mg, with a range of 1.0 to 1.4 mg. Fruit yield in Group 4 ranges from 1.2 to 1.8 mg, with a median of 1.5 mg. The median yield for Group 5 is 1.4 mg, with a range of 1.0 to 1.8 mg. The results of the experiment show that higher fruit production rates are associated with higher mg content during the experiment. Table 5 and Figure 4 present the Descriptive statistics on Fruit yields.

Table 5. Quantitative value of Fruit yields

Groups	Fruit yields Min	Fruit yields Max	Fruit yields Median
Group 1	0.45	0.55	0.50
Group 2	0.70	0.90	0.80
Group 3	1.00	1.40	1.20
Group 4	1.20	1.80	1.50
Group 5	1.00	1.80	1.40

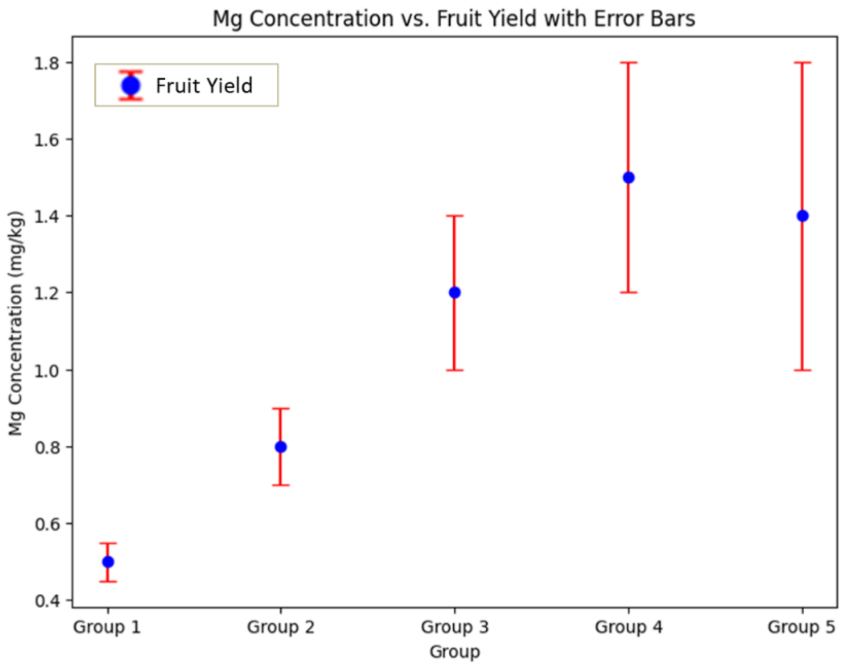

Figure 4. Presents the Descriptive statistics on Fruit yields

Descriptive Statistics on Chlorophyll Content

The chlorophyll content in five distinct groups with differing Mg concentrations is the main focus of the data in plant science. Group 1's chlorophyll concentrations ranged from 34.5 to 35.5, with an average of 35.0, whereas Group 2's concentrations ranged from 43.8 to 46.2, with a median of 45.0. Group 3 scores have a median of 60.0 and ranges from 58.2 to 61.8. Group 4 shows a median of 65.0 and a further rise in ranges from 63.0 to 67.0. The chlorophyll content of Group 5 ranges from 61.1 to 64.9, with a median of 63.0. Table 6 and Figure 5 shows the Descriptive statistics on chlorophyll content.

Table 6. Quantitative values of chlorophyll content

Groups	chlorophyll content Min	chlorophyll content Max	chlorophyll content Median
Group 1	34.5	35.5	35.0
Group 2	43.8	46.2	45.0
Group 3	58.2	61.8	60.0
Group 4	63.0	67.0	65.0
Group 5	61.1	64.9	63.0

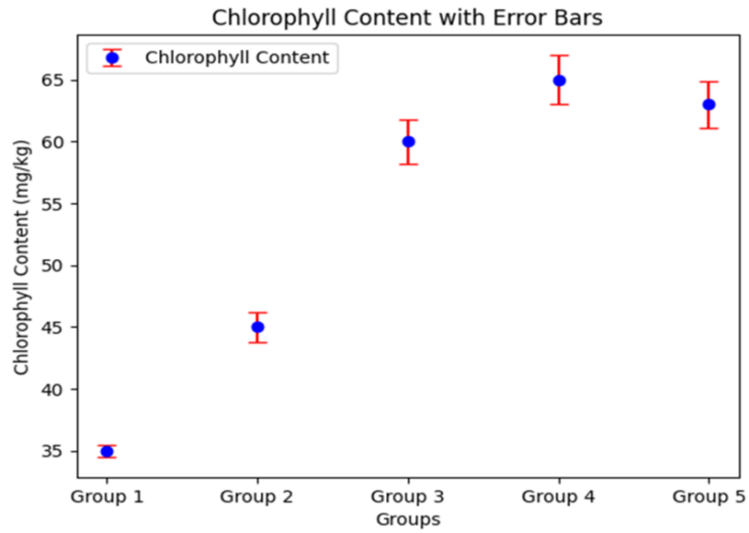

Figure 5. Presents the Descriptive statistics on chlorophyll content

Discussion

The impacts on plant growth, fruit output, and chlorophyll content varied among the treatment groups with varying soil Mg concentrations in plant science. Fruit output and chlorophyll content were extremely low in the Low (20 mg/kg) group due to reduced plant growth. The plants' poor development seems to have been hampered by the inadequate magnesium supply it was exposed to, which had a negative impact on their overall health and production. With lower chlorophyll values than ideal, the medium-low (40 mg/kg) variant displayed reduced growth and fruit output. Although magnesium levels remained, it was insufficient for optimal growth and productivity in plant science. Maximal growth, maximum fruit output, and maximum chlorophyll content were all attained by the Medium (60 mg/kg) group, confirming the notion that Mg concentration is ideal for tomato plant development. There is a threshold beyond which magnesium availability can have no further additional benefits, as seen by the Medium-High (80 mg/kg) group's robust growth but minor declines in yield and chlorophyll content. High magnesium (100 mg/kg) would likely cause some nutritional imbalances, as evidenced by the group's stunted development, low yield, and chlorophyll content.

Conclusion

The significance of varying Mg concentrations for tomato plant growth and yield when grown in calcareous soil of plant science. The findings demonstrated that magnesium promotes optimal plant growth and that the ideal concentration for maximum plant height, fruit output, and chlorophyll content was 50-70 mg/kg and lower at 50 mg/kg. The plants thrive and produce the most fruit at this concentration, demonstrating the importance of balanced magnesium availability for plant health. Additionally, plants with low magnesium levels grew poorly, while those with high levels were less productive; 20 mg/kg is low enough to prevent growth, while 100 mg/kg decreased output in plant science. The research also shows that elevated magnesium levels would likely disrupt the nutritional balance resulting in growth inhibition and lower yields well than those of the low magnesium group in plant science. Accordingly, balanced magnesium levels are a crucial requirement for maximizing plant health and crop productivity, and the research shows that magnesium management in calcareous soils is necessary for tomato production in plant science. The long-term impacts of magnesium supplementation, both alone and in combination with other soil elements for integrated agriculture should also be the main focus of follow-up research.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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