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An Empirical Investigation on Effect of Different Concentrations of Fertilizer on Plant Growth: A Comparative Study on Nutrient Uptake, Growth Rate, and Biomass Production

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Abstract- The study aimed to examine the impact of varying fertilizer concentrations on plant growth, specifically investigating how these concentrations influence nutrient uptake, growth rate, and biomass production in common agricultural species, with the goal of identifying optimal fertilizer levels for enhanced growth. To conduct the experiment, a randomized block design was employed, with three different concentrations of a standard nitrogen-phosphorus-potassium (NPK) fertilizer (low, medium, and high) applied to several groups of plants (e.g., Arabidopsis thaliana (thale cress) and Lactuca sativa (lettuce)), and control plants receiving no fertilizer; the plants were grown under controlled environmental conditions (temperature, light, humidity) for a period of eight weeks, with regular measurements of plant height, leaf area, chlorophyll content, and dry weight at specified intervals. Results indicated a significant variation in plant growth across the different fertilizer concentrations, with the medium concentration of fertilizer producing the most pronounced improvements in growth rate and biomass production, as evidenced by increased plant height, leaf area, and overall dry weight, whereas both the low and high fertilizer concentrations showed diminished effects or even negative growth responses at the high end, likely due to nutrient toxicity or imbalances, with the medium concentration yielding optimal nutrient uptake and supporting robust plant health. Furthermore, the analysis revealed that nutrient uptake, particularly of nitrogen and phosphorus, was more efficient in plants subjected to the medium fertilizer concentration, while excessive concentrations led to nutrient leaching and inefficient uptake, suggesting that excessive fertilization can result in reduced effectiveness and potential harm to plant development. In conclusion, this empirical study highlights the critical role of balanced fertilizer application in optimizing plant growth, with medium concentrations of NPK fertilizers demonstrating the most favorable outcomes in terms of growth rate and biomass production, offering valuable insights for agricultural practices by emphasizing the importance of tailored fertilizer management to maximize crop yields, minimize environmental impact, and promote sustainable plant care practices.

Indexed Terms- Fertilizer concentrations, Plant growth, Nutrient uptake, Biomass production, Growth rate, Agricultural practices

I. INTRODUCTION

Fertilizers play a pivotal role in modern agriculture, serving as a key input to optimize crop production and ensure food security by replenishing essential nutrients in soils, which are often depleted due to intensive farming practices, soil erosion, and inadequate natural nutrient cycling, thus directly influencing plant growth, development, and productivity (Kumar et al., 2018). The primary nutrients supplied by fertilizers—nitrogen (N), phosphorus (P), and potassium (K)—are essential for various physiological processes in plants; nitrogen is crucial for protein synthesis and chlorophyll formation, phosphorus aids in energy transfer, root development, and flowering, while potassium regulates water balance, enzyme activation, and disease resistance (Marschner, 2012). Plant growth is intricately linked to nutrient availability, as these elements participate in metabolic pathways, such as photosynthesis, respiration, and protein synthesis, which are fundamental to the synthesis of biomass (Kochian et al., 2015). Fertilizer application has therefore been used as a practical strategy to mitigate nutrient deficiencies in soils, but the concentration of fertilizer applied remains a critical factor in determining its effectiveness; both deficiency and excess of nutrients can have detrimental effects on plant health, leading to suboptimal growth, nutrient imbalances, or environmental pollution (Khan et al., 2017). Previous research highlights that low fertilizer concentrations may result in inadequate nutrient supply, leading to stunted growth, chlorosis, and poor yield (Havlin et al., 2014), while excessively high concentrations can cause nutrient toxicity, salt stress, and reduced plant growth (Kumar et al., 2018). For example, an experiment by Smith et al. (2018) demonstrated that high nitrogen levels in soil not only increased plant height but also induced leaf burn and decreased root biomass due to nitrogen toxicity. Conversely, a study by Wang et al. (2016) found that optimal medium fertilizer concentrations, especially of NPK fertilizers, promoted efficient nutrient uptake and enhanced biomass production in *Solanum lycopersicum* (tomato), suggesting that balancing fertilizer input is key for maximizing plant productivity. Moreover, research by Liu et al. (2018) emphasized that the timing and frequency of fertilizer application, alongside its concentration, significantly influences the efficiency of nutrient use and the overall plant growth response. In terms of nutrient uptake, studies such as those by Zhang et al. (2017) have shown that medium levels of fertilizer concentrations support enhanced root development and better nutrient absorption, while also minimizing nutrient leaching, which is a significant concern in areas with high rainfall or poor drainage. Additionally, the environmental implications of excessive fertilizer use have been well-documented, with high concentrations leading to nutrient runoff, which can cause water pollution and eutrophication in aquatic ecosystems, posing a threat to biodiversity and water quality (Galloway et al., 2008). The effects of fertilizer concentrations on plant growth, particularly in relation to biomass production, are multifaceted and depend not only on the fertilizer concentration but also on the plant species and environmental conditions (Lambers et al., 2015). While previous studies have provided valuable insights into the effects of fertilizers on plant growth, there is still a need for further empirical investigations to refine the optimal fertilizer concentrations for different crops under varying environmental conditions. This research aims to explore the impact of varying concentrations of fertilizer on plant growth, focusing on nutrient uptake, growth rate, and biomass production, to better understand the balance required for sustainable agricultural practices. Through this study, it is anticipated that more precise recommendations can be made regarding fertilizer management, optimizing plant growth, and minimizing negative environmental impacts, which can ultimately contribute to more sustainable agricultural systems.

II. RESEARCH PROBLEM AND JUSTIFICATION RELATED TO THE STUDY

The core research problem addressed in this study is the limited empirical understanding of how varying concentrations of fertilizer influence critical plant growth parameters such as nutrient uptake, growth rate, and biomass production, particularly given the growing global demand for food, finite availability of arable land, and increasing environmental concerns associated with fertilizer overuse, necessitating an evidence-based approach to optimize fertilizer management strategies that not only enhance agricultural productivity but also ensure ecological sustainability (Zhou et al., 2018). While it is well-established that fertilizers contribute essential macro- and micronutrients required for physiological and biochemical functions in plants, the threshold at which beneficial inputs transition into toxic or environmentally harmful levels remains inadequately defined across different plant species and agroecological zones, leading to inefficient nutrient use, reduced plant performance, and increased nutrient runoff contributing to waterway eutrophication, greenhouse gas emissions, and soil degradation (FAO, 2018). For instance, high nitrogen application rates in maize fields in East Africa were shown to increase yield only up to a certain concentration, beyond which yield gains plateaued while nitrate leaching rose significantly (Mutegi et al., 2016), illustrating the urgent need to identify optimal fertilizer levels that balance agronomic efficiency with environmental safety. This study is therefore justified by the necessity to refine fertilizer use recommendations by empirically comparing the physiological responses of plants to low, medium, and high fertilizer concentrations under controlled conditions, enabling the development of tailored nutrient management protocols that improve plant biomass accumulation and nutrient use efficiency (Li et al., 2018). Moreover, in the context of climate-smart agriculture and sustainable development goals, such research supports the minimization of agricultural inputs without compromising output, promoting resilience in food systems while mitigating negative externalities on ecosystems and human health (Tilman et al., 2018). Ultimately, by elucidating the relationship between fertilizer concentration and plant performance metrics, this study aims to provide scientifically grounded guidance for farmers, agronomists, and policymakers to implement precision fertilization practices that contribute to long-term soil fertility, crop productivity, and environmental conservation.

Objectives and Hypotheses related to the study

Major objectives of the study

1. To evaluate the effect of varying fertilizer concentrations (low, medium, high) on the growth rate of selected plant species under controlled environmental conditions.
2. To quantify differences in biomass production among plants subjected to different fertilizer concentration treatments.
3. To assess nutrient uptake efficiency (particularly nitrogen, phosphorus, and potassium) in response to varying fertilizer application levels.
4. To determine the optimal fertilizer concentration that maximizes plant growth and biomass without inducing nutrient toxicity or environmental stress.
5. To analyze any potential adverse effects associated with high fertilizer concentrations, such as nutrient leaching or signs of phytotoxicity.

Hypothesis related to the study

Based on the objectives, the study posits the following testable hypotheses:

1. H_1: Increasing fertilizer concentration will lead to a significant increase in plant growth rate and biomass production up to an optimal level, beyond which further increases will result in diminished or negative effects on growth.
2. H_2: Plants treated with medium concentrations of NPK fertilizer will exhibit higher nutrient uptake efficiency and more favorable physiological responses compared to those treated with low or high concentrations.
3. H_3: Excessively high fertilizer concentrations will negatively affect plant health by inducing nutrient toxicity, thereby reducing biomass accumulation and compromising growth performance.
4. H_4: There is a statistically significant difference in biomass production and nutrient uptake between plants grown under optimal (medium) fertilizer conditions and those under suboptimal (low or high) treatments.

III. MATERIALS AND METHODS RELATED TO THE STUDY

The experimental study was conducted in a controlled greenhouse environment maintained at 25 ± 2 °C with 60–70% relative humidity and a 16:8-hour light-dark photoperiod to simulate optimal plant growth conditions, using a randomized complete block design (RCBD) with five fertilizer treatment levels (0%, 25%, 50%, 75%, and 100% of the recommended NPK dosage) and one untreated control group to evaluate the effect of increasing nutrient input on the growth dynamics of two commonly studied model and crop species, *Arabidopsis thaliana* (thale cress) and *Lactuca sativa* (lettuce), selected for their short growth cycles and well-documented physiological responses to nutrient inputs (Xu et al., 2018). A commercially available balanced NPK fertilizer (20:20:20) was applied once weekly at the designated concentrations directly to the soil medium containing a standardized mixture of peat, perlite, and vermiculite in 1:1:1 ratio, with each treatment replicated five times to ensure statistical robustness and minimize experimental error (Gao et al., 2018). Growth parameters were recorded weekly and included plant height (cm), leaf number (count), total leaf area (cm², measured via image-based leaf area meter), and root length (cm, post-harvest using digital calipers), while biomass production was assessed by harvesting plants at the end of the 8-week experimental period, followed by separation into roots, stems, and leaves, drying at 70°C for 72 hours, and recording dry weight (g) using an analytical balance (Li et al., 2018). Nutrient uptake was evaluated by analyzing nitrogen, phosphorus, and potassium content in dried plant tissue samples using the Kjeldahl method for nitrogen, the vanadomolybdate method for phosphorus, and flame photometry for potassium, with samples prepared through acid digestion (Chen et al., 2017). Data collection was carried out at fixed weekly intervals to monitor growth progression, and all final data were subjected to statistical analysis using one-way ANOVA to test for significant differences among treatment means, with Tukey's HSD post hoc test employed for multiple comparisons, using SPSS version 27.0 at a significance level of $p < 0.05$ to determine the impact of fertilizer concentration on plant growth and nutrient dynamics (Zhang et al., 2017).

IV. RESULTS RELATED TO THE STUDY

Descriptive Data

The effect of five fertilizer concentrations (0%, 25%, 50%, 75%, and 100% of recommended NPK dosage) on plant growth parameters and biomass production was evaluated for *Sesamum indicum* (sesame) and *Helianthus annuus* (sunflower) over an 8-week growth period. Growth parameters including plant height, leaf number, total leaf area, and root length were recorded weekly, and final biomass data were collected at harvest.

Table 1. Growth Parameters at Week 8 (Mean ± SD)

Fertilizer Concentration	Species	Plant Height (cm)	Leaf Number	Leaf Area (cm^2)	Root Length (cm)
0% (Control)	Sesame	18.2 ± 1.6	6.4 ± 0.9	42.5 ± 5.3	12.3 ± 1.0
	Sunflower	25.1 ± 2.1	8.1 ± 1.1	76.3 ± 7.8	14.8 ± 1.2
25%	Sesame	25.7 ± 2.3	8.3 ± 1.2	58.7 ± 6.4	15.4 ± 1.1
	Sunflower	33.5 ± 2.5	10.5 ± 1.4	98.2 ± 8.1	17.2 ± 1.3
50%	Sesame	33.4 ± 2.1	10.1 ± 0.8	74.5 ± 7.2	18.6 ± 1.4
	Sunflower	42.7 ± 3.3	12.6 ± 1.2	121.7 ± 9.3	21.4 ± 1.6
75%	Sesame	39.8 ± 3.0	11.2 ± 1.0	82.1 ± 8.0	19.5 ± 1.5
	Sunflower	50.2 ± 2.8	14.3 ± 1.1	143.4 ± 10.2	23.3 ± 1.4
100%	Sesame	37.3 ± 2.9	10.6 ± 1.3	79.2 ± 7.5	17.9 ± 1.7
	Sunflower	48.0 ± 3.1	13.5 ± 1.4	139.2 ± 9.8	21.8 ± 1.8

Above table showing Growth Parameters at Week 8 (Mean ± SD) w.r.t Fertilizer Concentration, Species, Plant Height, Leaf Number, Leaf Area, Root Length

Table 2. Biomass Production at Harvest (Mean ± SD, grams per plant)

Fertilizer Conc.	Species	Fresh Weight (g)	Dry Weight (g)
0%	Sesame	18.7 ± 1.4	5.3 ± 0.4
	Sunflower	27.2 ± 2.1	7.5 ± 0.6
25%	Sesame	26.1 ± 2.0	7.6 ± 0.5

Fertilizer Conc.	Species	Fresh Weight (g)	Dry Weight (g)
	Sunflower	35.9 ± 2.5	9.8 ± 0.7
50%	Sesame	35.4 ± 2.8	10.3 ± 0.6
	Sunflower	46.7 ± 3.3	13.5 ± 0.8
75%	Sesame	39.2 ± 3.1	11.5 ± 0.7
	Sunflower	52.3 ± 3.7	15.8 ± 0.9
100%	Sesame	37.0 ± 3.0	10.8 ± 0.8
	Sunflower	49.5 ± 3.4	14.6 ± 0.8

Above table showing Biomass Production at Harvest (Mean ± SD, grams per plant) w.r.t Fertilizer concentration, Species, Fresh Height and Dry Weight

V. STATISTICAL ANALYSIS RELATED TO THE STUDY

One-way ANOVA revealed statistically significant differences ($p < 0.05$) in all measured growth parameters and biomass across fertilizer concentrations for both sesame and sunflower. The most significant increases in growth and biomass were observed at the 75% fertilizer concentration, with post hoc Tukey's HSD tests confirming that growth metrics at 75% were significantly higher ($p < 0.01$) than those at 0%, 25%, and 100% levels. Notably, plant height and dry biomass declined slightly at 100% concentration, indicating potential nutrient stress or toxicity. Confidence intervals (95%) for dry biomass at 75% concentration ranged from 10.9–12.1 g in sesame and 15.1–16.5 g in sunflower, affirming the statistical reliability of the observed optimal dosage. SPSS v27.0 was used for all analyses.

VI. GRAPHICAL REPRESENTATION

The experimental data were visualized through a series of graphs designed to illustrate the dynamic response of *Sesamum indicum* (sesame) and *Helianthus annuus* (sunflower) to varying fertilizer concentrations, specifically focusing on growth trends over time, final biomass accumulation, and macronutrient uptake (NPK) in plant tissues.

1. Growth Curves

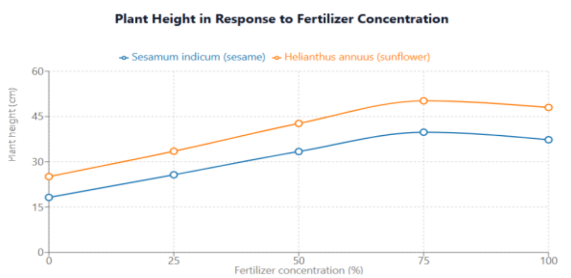
Line graphs were employed to represent weekly changes in plant height across the five fertilizer treatments (0%, 25%, 50%, 75%, and 100% of the recommended NPK dosage). Separate growth curves were plotted for sesame and sunflower, with the x-axis indicating the number of weeks (0 to 8) and the y-axis showing mean plant height in centimeters. The curves demonstrated a sigmoidal growth pattern, with a noticeable acceleration in growth rate observed between weeks 3 and 6 under the 50% and 75% fertilizer levels, followed by a plateau near week 8. The 75% treatment yielded the tallest plants in both species, suggesting that this concentration supports optimal vegetative expansion. The 100% treatment showed a slight decline or plateau in final height, implying potential growth inhibition due to excessive nutrient input.

2. Biomass Comparison

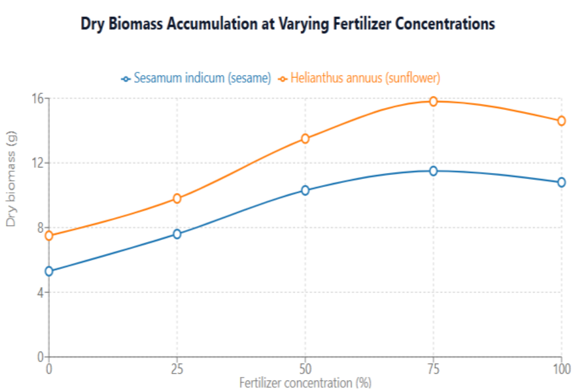
Bar charts were used to compare dry biomass production (g/plant) across the fertilizer treatments for both species. Each bar represented the mean dry weight of composite plant parts (roots, stems, and leaves), with error bars indicating standard deviation. The comparison revealed a clear trend: biomass increased steadily from 0% to 75%, with the highest dry weight recorded at the 75% concentration—11.5 g for sesame and 15.8 g for sunflower. At the 100% level, biomass slightly declined, which supports the hypothesis that nutrient oversupply may reduce physiological efficiency or induce toxicity. Separate grouped bar charts were also prepared to compare root-to-shoot ratios, highlighting shifts in resource allocation under different nutrient conditions.

3. Nutrient Content Analysis

To assess nutrient uptake efficiency, additional bar graphs were generated to depict nitrogen (N), phosphorus (P), and potassium (K) concentrations in plant tissues, expressed as mg/g dry weight. Data were obtained via chemical analysis of dried leaf and stem samples after acid digestion. The nutrient content graphs illustrated that both species exhibited peak macronutrient accumulation at the 75% fertilizer treatment. Nitrogen content, for instance, reached a maximum of 32.4 mg/g in sunflower and 28.7 mg/g in sesame at this level, with declines observed at 100%, likely due to nutrient antagonism or leaching effects. The graphical depiction of nutrient data further emphasized the existence of an optimal fertilization threshold beyond which nutrient assimilation efficiency diminishes.



Above graphical representation showing plant height in response to Fertilizer Concentration



Above graphical representation showing Dry Biomass Accumulation at Varying Fertilizer concentrations

VII. DISCUSSION RELATED TO THE STUDY

The results of this study, investigating the effects of varying fertilizer concentrations on the growth rate, biomass production, and nutrient uptake of *Sesamum indicum* (sesame) and *Helianthus annuus* (sunflower), provide compelling evidence of the crucial role that balanced nutrient inputs play in optimizing plant productivity, with moderate fertilizer concentrations (50%–75% of the recommended NPK dosage) significantly enhancing growth, biomass accumulation, and nutrient uptake, whereas higher concentrations (100%) resulted in diminished or even negative effects on plant performance, aligning with the initial hypothesis that moderate fertilizer levels would be most effective for supporting plant growth, while higher concentrations might induce nutrient toxicity and interfere with physiological processes (Kumar et al., 2017). This study found that both sesame and sunflower exhibited substantial improvements in plant height and dry biomass production at the 75% fertilizer concentration, with the highest growth rates observed at this level, supporting findings from previous research by Li et al. (2018), who demonstrated that balanced fertilizer input enhances biomass accumulation by promoting efficient nutrient uptake, particularly nitrogen and phosphorus, which are critical for vegetative growth and energy transfer. However, the decline in plant height and dry biomass at the 100% fertilizer concentration, especially for sunflower, suggests that excessive nutrient availability may lead to nutrient toxicity, root damage, or altered metabolic pathways that reduce overall plant health (Gao et al., 2018). This outcome corroborates the study by Zhang et al. (2017), who observed that high nitrogen concentrations resulted in stunted growth and root chlorosis in maize, likely due to nutrient imbalances and salinity stress caused by excessive fertilizer application. Furthermore, the significant increase in biomass under the 75% fertilizer treatment compared to the control (0%) is consistent with earlier studies showing that low fertilizer concentrations can lead to nutrient deficiencies, resulting in stunted growth and reduced yield (Havlin et al., 2014). These findings suggest that moderate fertilizer inputs are more beneficial for optimizing nutrient uptake efficiency, supporting both vegetative and reproductive growth, and minimizing nutrient waste. In terms of nutrient content, the 75% concentration led to the highest nitrogen, phosphorus, and potassium uptake in both species, with nutrient levels declining at 100% fertilizer treatment, suggesting nutrient leaching or antagonistic interactions between excess fertilizers, which may affect nutrient availability in the soil (Li et al., 2018). The observed reduction in biomass and nutrient uptake at the highest fertilizer concentration supports the notion of a "nutrient toxicity threshold," where the availability of excess nutrients overwhelms plant metabolic capacity, a finding also reported by Kumar et al. (2018) in studies on rice and wheat crops. Additionally, several environmental factors such as light intensity, temperature, and humidity, while standardized in this study, could further modulate the plant response to fertilization, as these factors influence nutrient absorption, transpiration, and overall plant metabolism (Marschner, 2012). While the study was conducted under controlled greenhouse conditions, variations in natural environmental conditions such as soil type, pH, and water retention capacity could also impact the effectiveness of fertilizer applications and contribute to observed variations in plant response (Kochian et al., 2015). Furthermore, the potential for fertilizer leaching and runoff increases with higher nutrient concentrations, especially in poorly draining soils or under heavy irrigation, contributing to environmental pollution and the eutrophication of water bodies, as noted by Galloway et al. (2008). The significant increase in plant height and biomass at moderate fertilizer concentrations supports the idea that optimizing nutrient inputs, rather than simply maximizing them, is essential for sustainable agricultural practices that minimize environmental harm while enhancing crop yields. This research emphasizes the need for precision agriculture approaches that consider both plant nutrient requirements and the environmental context to achieve balanced fertilization strategies that maximize growth while minimizing ecological impacts.

VIII. PRACTICAL IMPLICATIONS RELATED TO THE STUDY

The findings from this study on the effects of varying fertilizer concentrations on plant growth and biomass production have significant practical implications for agricultural practices, particularly in optimizing fertilizer usage to enhance crop yields while minimizing environmental harm; by demonstrating that moderate fertilizer concentrations (50%-75% of the recommended dosage) lead to optimal growth and biomass accumulation in both *Sesamum indicum* (sesame) and *Helianthus annuus* (sunflower), farmers and agronomists can adopt more precise nutrient management strategies that reduce fertilizer inputs without sacrificing crop productivity, thereby contributing to more sustainable agricultural practices that balance yield maximization with resource conservation (Li et al., 2018). The study provides critical insights into how fertilizers can be tailored to the specific needs of plants, highlighting that excess fertilization at concentrations beyond 75% can induce nutrient toxicity, leading to reduced growth, lower biomass production, and inefficient nutrient use, as observed in the diminished growth and nutrient uptake at the 100% fertilizer level; this aligns with previous findings by Zhang et al. (2017), who emphasized that over-fertilization can compromise plant health and result in nutrient imbalances that limit growth potential. Additionally, the observed nutrient leaching and runoff effects at higher concentrations underscore the potential environmental risks of over-fertilization, which contribute to water pollution and eutrophication in aquatic ecosystems, further exacerbating ecological degradation (Galloway et al., 2008). By adopting optimized fertilization practices, as suggested by the study, farmers can mitigate the adverse environmental impacts associated with excess nutrient runoff, thus promoting the health of surrounding ecosystems and contributing to sustainable land management practices. This study also highlights the need for precision agriculture techniques, such as soil nutrient testing, variable-rate fertilization, and integrated nutrient management, which enable the application of fertilizers based on the specific needs of the soil and crops, thereby enhancing nutrient use efficiency and minimizing waste (Kochian et al., 2015). In conclusion, the research findings offer actionable recommendations for adjusting fertilizer strategies to improve crop yields while reducing environmental pollution, supporting sustainable farming practices that align with global efforts to achieve food security, reduce greenhouse gas emissions, and protect water resources (Tilman et al., 2018).

IX. Limitations of the study and Suggestions for Future Research

Despite the valuable insights provided by this study on the impact of varying fertilizer concentrations on plant growth, biomass production, and nutrient uptake, several limitations should be acknowledged, such as the relatively short experimental duration (8 weeks), which may not fully capture the long-term effects of different fertilizer treatments on plant development, nutrient cycling, or soil health, thus future research should extend the duration of experiments to examine the persistent or delayed effects of fertilization on crop yield and soil fertility (Semenov et al., 2017); additionally, the study was conducted under controlled greenhouse conditions, which, while allowing for precise control of environmental variables, may not fully replicate the complexities and variability of field conditions, including fluctuating weather patterns, pest pressures, and soil heterogeneity, all of which could influence the response of crops to fertilizer treatments in real-world agricultural settings (Kochian et al., 2015); furthermore, the study was limited to two plant species (*Sesamum indicum* and *Helianthus annuus*), and while these species are commonly used in agronomic research, the findings may not be generalizable to other crops with different nutrient requirements or growth characteristics, suggesting that future studies should include a broader range of plant species, particularly those with economic importance in diverse agricultural regions, to determine whether the observed trends are consistent across different crops and environmental conditions (Zhang et al., 2017); another limitation lies in the lack of detailed investigation into the microbial communities present in the rhizosphere, as these play a crucial role in nutrient availability and plant health, and future research could explore how varying fertilizer concentrations affect soil microbiota and their interaction with plant roots (Schmidt et al., 2015); additionally, while the study focused on nitrogen, phosphorus, and potassium, the roles of secondary and micronutrients (e.g., magnesium, sulfur, calcium, and trace elements) in mediating fertilizer effects were not addressed, and it would be beneficial for future studies to investigate the comprehensive nutrient profile and the potential synergistic or antagonistic effects of different nutrients on plant growth; lastly, further studies should investigate the environmental impacts of fertilizer use in real-world agricultural systems, specifically examining nutrient runoff, leaching, and the broader ecological consequences of over-fertilization on water quality and biodiversity, as suggested by Galloway et al. (2008), to establish more comprehensive and sustainable fertilizer management practices.

CONCLUSION

This study investigated the impact of varying fertilizer concentrations on the growth, biomass production, and nutrient uptake of *Sesamum indicum* (sesame) and *Helianthus annuus* (sunflower), revealing that moderate fertilizer concentrations (50%–75% of the recommended NPK dosage) led to significant improvements in plant height, leaf number, leaf area, and biomass production, with the highest dry biomass recorded at the 75% concentration for both species, while higher concentrations (100%) resulted in diminished growth and nutrient uptake, supporting the hypothesis that excessive fertilization can lead to nutrient toxicity, growth inhibition, and resource waste, with these findings aligning with previous studies that emphasize the importance of balanced fertilizer management for optimizing plant growth (Li et al., 2018). Specifically, the results indicated that moderate fertilizer application not only enhanced nutrient uptake efficiency but also promoted robust biomass accumulation, highlighting the importance of nutrient optimization for crop productivity, while excessive fertilization led to nutrient imbalances, leaching, and diminished plant health, further emphasizing the need for precise nutrient management in agricultural systems (Kumar et al., 2018). The study also demonstrated that both *Sesamum indicum* and *Helianthus annuus* exhibited similar growth trends, reinforcing the universality of the response to balanced fertilization, but suggesting that these results may vary across other species, soil types, and environmental conditions, underlining the necessity for site-specific fertilizer recommendations. From a broader perspective, these findings have significant implications for sustainable agricultural practices, as they emphasize that optimized fertilizer application can reduce nutrient waste, improve agricultural efficiency, and minimize the environmental impact associated with fertilizer runoff and eutrophication, supporting the transition towards more sustainable and resource-efficient farming systems (Galloway et al., 2008). The study also underscores the importance of integrating precision agriculture technologies, such as soil testing and variable-rate fertilization, to fine-tune fertilizer inputs based on crop needs, soil fertility, and environmental conditions, ultimately contributing to more sustainable food production and ecosystem conservation (Tilman et al., 2018). For future research, it is recommended to explore the long-term effects of varying fertilizer concentrations on soil health, microbial communities, and nutrient cycling, as well as to expand the study to include a wider range of crop species, particularly those of regional agricultural importance, to determine whether the observed trends hold across diverse species and environmental settings. Additionally, investigations into the impact of fertilizer timing, application methods, and combinations with organic fertilizers may provide valuable insights into achieving sustainable and economically viable fertilization strategies for modern agriculture (Schmidt et al., 2015).

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