Growth and Performance of Baby Spinach grown under different Organic Fertilizer

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Abstract: This study investigates the effects of several organic fertilizers on baby spinach (*Spinacia oleracea* L.) cultivation's growth, productivity, and sustainability. A randomized complete block design was employed to assess six organic fertilizer treatments, including vermicompost, farm yard manure (FYM), poultry waste, Azotobacter + poultry waste + FYM, Azotobacter + vermicompost, and a control (no fertilizer application). Plant growthparameters, nutrient content, pest resistance, soil health indicators, and environmental implications were evaluated to understand the effectiveness of organic fertilizers in promoting sustainable spinach production. Results indicate that treatments incorporating Azotobacter inoculants, particularly those combined with poultry waste or vermicompost, demonstrated superior performance in terms of production, biomass accumulation, plant height, leaf area, and nutrient content. These findings underscore the potential of bioinoculants in organic farming to increase soil fertility and ecological resilience, decreasedependency on synthetic inputs, and increase crop output. Moreover, organic fertilizers significantly influenced soil health parameters, with treatments exhibiting higher soil pH, organic matter content, and microbial activity contributing to improved soil fertility. Environmental implications of organic fertilizer use were also assessed, revealing varyinglevels of nutrient runoff and greenhouse gas emissions across different treatments. While Azotobacter-inoculated treatments showed higher greenhouse gas emissions, they also exhibited greater nutrient retention, indicating complex trade-offs between nutrient cyclingand environmental impact

Keywords: Organic farming, Spinach, Organic fertilizers, Azotobacter, Vermicompost, Soil health, Crop productivity, Sustainable agriculture

Introduction

Spinacia oleracea, or spinach in scientific parlance, is a tough, leafy annual plant of the amaranth family (Amaranthaceous). In many regions of the world, especially in northern Europe and the US, it is extensively grown and eaten as a vegetable. Spinach is valued for its versatility, being marketed fresh, canned, and frozen, and its young leaves are often sold as "baby spinach." The global shift towards sustainable agriculture has prompted considerable interest in organic farming practices as viable alternatives to conventional methods. Among these practices, the application of organic fertilizers stands out as a cornerstone for promoting soil health, enhancing crop productivity, and reducing environmental impacts. In this context. The cultivation of baby spinach (Spinacia oleracea L.) presents an ideal opportunity for exploring the impacts of different organic fertilizers on crop development and productivity. Recent studies have underscored the importance of organic fertilizers in fostering soil fertility and improving plant nutrient uptake, thereby contributing to the overall sustainability of agricultural systems [1,2]

The careful selection and proper application of organic fertilizers are crucial factors in determining the growth, yield, and quality of crops like baby spinach. Hence, it's essential to understand how various organic fertilizers compare to optimize spinach production while reducing environmental impact. Additionally, the increasing consumer preference for organic vegetables, including baby spinach, due to concerns about food safety and sustainability, has led to higher demand [3]. Therefore, studying how organic fertilizers affect the growth and nutritional value of baby spinach is important for both farming practices and market trends. Despite numerous studies exploring organic fertilizers' effects on different crops, there's still a lack of comprehensive research specifically focused on baby spinach. Moreover, existing literature often lacks consensus on the most effective organic fertilizers for spinach cultivation, indicating the need for further investigation and validation [4]. This research aims to fill these knowledge gaps by assessing how different organic fertilizers influence the growth and performance of baby spinach.

Spinach has a long history of cultivation and consumption, dating back centuries. It gained significant popularity as a crop in the 1920s when its nutritional benefits, Spinach renowned for its tender leaves and rich nutritional profile, has embarked on a remarkable historical journey spanning centuries and continents. Originating in ancient Persia, modern-day Iran and neighboring regions, baby spinach has traversed cultural boundaries, influenced cuisines, and left an indelible mark on global culinary traditions. This narrative traces the historical trajectory of baby spinach from its ancient origins to its widespread cultivation across various regions, highlighting its enduring popularity and cultural significance. Baby spinach traces its roots back to ancient Persia, where it was cultivated and cherished for its culinary and medicinal properties over 2,000 years ago. Known as "aspanakh" in Persian, spinach thrived in the fertile soils of Persia and became a staple ingredient in Persian cuisine. Its tender leaves and versatile nature made it a prized addition to various dishes, from savory stews to delicate salads. The journey of baby spinach took a significant turn with the arrival of Arab traders, who introduced the vegetable to India during their maritime expeditions. In India, spinach quickly found favor among cooks and became integrated into the rich tapestry of Indian cuisine. Its introduction to ancient China in 647 AD, referred to as the "Persian vegetable," further expanded its reach across Asia, where it became embraced for its culinary versatility and nutritional benefits. During the ninth century, spinach made its way to Sicily, where it was introduced by Arab traders or through trade routes connecting the Mediterranean region. Sicilians embraced spinach as a valuable addition to their culinary repertoire, incorporating it into traditional dishes and culinary creations. From Sicily, spinach found its way to Spain and England, where it gradually gained popularity and became integrated into local cuisines. Despite its global spread, baby spinach maintains a strong connection to its native region of Persia, with wild spinach still found growing in modern-day Iran. The enduring presence of spinach in its place of origin underscores its cultural significance and continued importance in Persian cuisine. Spinach remains a beloved ingredient in Iranian dishes, symbolizing the rich culinary heritage of the region. contributing significantly to global agricultural output. According to recent statistics, the total global production of spinach stands at approximately 32,294,452 tons. This substantial production underscores the widespread cultivation and consumption of spinach worldwide. The production of spinach is geographically distributed, with Asia and Europe being the primary regions of cultivation. Asia leads in spinach production, accounting for a significant portion of the global output with a total of 30,855,894 tons. Europe follows closely behind, contributing 775,476 tons to the global production figures. These regions' substantial contribution to spinach cultivation highlights the vegetable's popularity and importance in diverse cuisines and dietary preferences across continents. Several countries stand out as leading producers of spinach, further emphasizing its economic significance on a global scale. China emerges as the foremost producer of spinach, contributing a substantial portion to the total global production. Following China, the United States, Turkey, and Japan also play significant roles in spinach cultivation, contributing substantially to the overall production volume. These countries' agricultural sectors benefit from spinach cultivation, generating income, employment opportunities, and contributing to national food security. Spinach is renowned for its exceptional nutritional profile, making it a highly sought-after vegetable in the global market soil and plant quality [5]. The application of organic fertilizer is practiced for more than thousand years in many countries as it helps in providing the essential nutrients to plants, improves soil structure, helps in moisture retaining capacity in various types of soil and also

helps in increasing the microbial activities [6]. An ideal soil structure helps the plants roots to reach the moisture and to absorb the nutrients from the soil [7]. For the organic fertilizer, agricultural and animal waste are the major source that are produced by the process of composting. Composting is the natural process that is influence by the certain bacteria and actinomycetes [8]. The production of crop that are organically grown are rich in nutritional value and hence provide balanced nutrient supply, facilitates the growth of beneficial baby spinach due to their antioxidant nature [9]
Baby spinach is an annual, cool season crop and green leafy vegetable, rich in core nutrients and phytochemicals [10,11]. It has recently gain attention with the increasing population. It can be consumed as fresh, canned, frozen and is mostly desirable in salads It is reported that the leaves of baby spinach are rich in vitamin C and other micronutrients such as iron (Fe), zinc (Zn), magnesium (Mg), and selenium (Se). Phytochemicals such as phenols, total antioxidants activities, total carotenoids, and total flavonoids are predominantly associated with the quality of spinach [12].

The global increase in population, coupled with concerns about the indiscriminate use of agrochemicals, has highlighted the significance of organic farming [13]. Organic fertilizers, such as farmyard manure (FYM), goat manure, poultry manure, and biofertilizers, have gained attention as substitutes for chemical or inorganic fertilizers in cultivating baby spinach [14]. Reports suggest that organic fertilizers offer several benefits, including improved soil aggregation and physical properties like water retention and aeration. Additionally, the application of organic manure influences soil and crop productivity, which varies based on its quality [15]. The quality of baby spinach, when grown with organic manure, is closely related to its chemical composition and nutrient content. The quality of manure affects the rate of mineralization, thereby influencing the availability of nitrogen (N) and other nutrients essential for plant growth. Studies indicate that high-quality organic manure, such as poultry manure, tends to have a higher rate of mineralization compared to, for instance, cattle manure. Consequently, the quality of organic manure directly impacts soil nutrient levels.

Furthermore, the nitrogen content in organic manure plays a crucial role in determining leaf quality. Excessive nitrogen can increase leaf nitrate concentration, negatively impacting leaf quality. Conversely, inadequate nitrogen availability can result in stunted leaf growth, leading to poor physiochemical quality of baby spinach during its early growth stages [17].
Farmyard manure (FYM) holds significant importance in agriculture, particularly in livestock-based farming systems in semi-arid regions. It is a decomposition mixture of dung, urine, litter, and fodder consumed by farm animals like cattle. FYM is considered a key component of integrated nutrient management (IMN) due to its affordability and widespread availability [6,18]. Unlike inorganic fertilizers, FYM provides a comprehensive range of macro and micronutrients essential for plant growth, serving as a primary source of nitrogen, phosphorus, and potassium. It is recommended to apply FYM 3-4 weeks before crop sowing to ensure its effectiveness. The use of FYM significantly influences the growth and yield of spinach, as it contains all the necessary minerals required for crop development, particularly nitrogen. Research indicates that combining nitrogen and FYM application affects various growth parameters such as root-shoot length, leaf number, and leaf area, ultimately impacting baby spinach yield [8,19]. Similarly, studies have shown that the application of organic fertilizers like chicken manure increases the number of leaves per plant, contributing to enhanced yield [20]. Additionally, research by Jha and Jana (2009) demonstrated that applying vermicompost along with NPK fertilizer as recommended resulted in increased leaf count, fresh green yield, and seed yield. Moreover, the application of organic manure promotes soil aeration and enhances the activity of beneficial soil microorganisms, which are crucial for baby spinach growth and production. The nutritional benefits of organic manure also contribute to maintaining soil fertility. Studies have shown that combining organic manure with FYM, poultry manure, or cow dung leads to significant increases in yield parameters, highlighting the positive impact of organic fertilizers on baby

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spinach cultivation [20,21]. Spinach cultivation for commercial purposes involves specific techniques and practices to ensure optimal growth, high yield, and quality produce. This section outlines key aspects of commercial spinach cultivation, including planting methods, seed densities, harvest timing, and post-harvest handling. Spinach is typically planted relatively shallow, at depths of about ½ to ¾ inches. High seed densities are utilized, with approximately 21 to 48 seed lines per 80-inch beds. This results in a high density of approximately 3.5 million plants per acre, maximizing yield potential. In regions like the Salinas Valley, spinach can be harvested within a relatively short timeframe of 21 to 50 days after planting. This quick turnaround allows for multiple harvests throughout the growing season, maximizing productivity. Commercially cultivated spinach is primarily grown for two main market destinations: the fresh market and the processing industry [21,22,23].

MATERIALS AND METHODS

Selection of Spinach Variety

For this experiment, we chose Spinacia oleracea L., commonly known as baby spinach, due to its suitability for the local environment and availability in the market. This variety is valued for its tender leaves, rapid growth, and high nutritional content, making it ideal for studying the impact of organic fertilizers on spinach growth.

Experimental Design

The experimental design plays a vital role in ensuring the reliability and validity of research findings. In this study, a randomized complete block design (RCBD) was employed to minimize experimental error and account for variability in soil conditions and environmental factors across the experimental plot. The experimental plot, measuring 42 square meters (10.5 meters in length and 4 meters in width), was divided into six equal-sized blocks, each representing a different treatment. Each treatment was randomly assigned to a block to ensure uniform distribution and minimize potential bias.

Description of organic fertilizer used

Six organic fertilizers were chosen for their availability, nutrient content, and suitability for spinach cultivation:

Vermicompost: Nutrient-rich fertilizer from earthworm decomposition, enhancing soil fertility and plant growth.

Farm Yard Manure (FYM): Traditional organic fertilizer from composted animal waste, valued for its organic matter and slow-release nutrients.

Poultry Waste: Rich in nitrogen and essential nutrients, beneficial for plant growth and soil fertility.

Azotobacter + Poultry Waste + FYM: Utilizes Azotobacter inoculant, poultry waste, and FYM to enhance soil fertility and stimulate plant growth.

Azotobacter + Vermicompost: Combines Azotobacter inoculant with vermicompost for improved nitrogen fixation and nutrient uptake, promoting spinach growth.

Control: Represents no fertilizer application, serving as a baseline for evaluating the effects of organic fertilizers on spinach growth.

Application rate and method

The organic fertilizers were applied to the spinach crop according to the following rates:

- Vermicompost (Vermicompost): Applied at a rate of 5 tons per hectare, equivalent to approximately 0.21 kg per square meter of the experimental plot.
- Farm Yard Manure (FYM): Applied at a rate of 10 tons per hectare, equivalent to approximately 0.42 kg per square meter of the experimental plot.
- Poultry Waste: Applied at a rate of 7 tons per hectare, equivalent to approximately 0.29 kg per square meter of the experimental plot.
- Azotobacter + Poultry Waste + FYM: Azotobacter inoculant was applied at a rate of 2.5 kg per hectare, along with poultry waste and FYM at the rates mentioned above.
- Azotobacter + Vermicompost: Azotobacter inoculant was applied at a rate of 2.5 kg per hectare, along with vermicompost at the rate mentioned above.
- Control: No organic fertilizers were applied in the control treatment.

Growing condition and management practices

The spinach crop was sown on 8th January 2024, and the germination process began on 28th January 2024. The experimental plot was prepared according to standard agronomic practices, including land leveling, soil preparation, and irrigation scheduling. Adequate moisture levels were maintained throughout the growing season to support seed germination, seedling establishment,

Data Collection Procedures

Throughout the experiment, we collected data on plant height, leaf area, biomass accumulation, yield, nutrient content, and soil parameters. Measurements were taken at intervals to track growth and analyze the effects of organic fertilizers on spinach and soil health.

Data Analysis and Presentation

Collected data were analyzed statistically to identify significant differences among fertilizer treatments. Interpretation and presentation of findings aimed to communicate the effectiveness of organic fertilizers in promoting sustainable spinach production

RESULTS AND DISCUSSION

Plant Growth Parameters:

- Treatments T4 (Azotobacter + Poultry Waste + FYM) and T5 (Azotobacter + Vermicompost) showed the highest mean plant height, leaf area, biomass accumulation, and yield.
- Vermicompost (T1) also resulted in favorable outcomes across all parameters.
- Control treatment (T6) consistently exhibited the lowest values
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Table – Plant growth parameters

Treatment	Mean Plant Height (cm)	Mean Leaf Area (sq cm)	Mean Biomass Accumulation (g)	Yield (kg/m²)
T1: Vermicompost	25.6	120.5	380.2	2.3
T2: Farm Yard Manure	23.8	115.2	372.5	2.2
T3: Poultry Waste	24.5	118.3	378.1	2.4
T4: Azotobacter + Poultry Waste + FYM	27.2	125.6	395.6	2.6
T5: Azotobacter + Vermicompost	26.4	122.8	387.3	2.5
T6: Control	22.1	110.9	360.8	2.0

Nutrient Content:

- Treatments T4 and T5 exhibited the highest nitrogen, phosphorus, potassium, and micronutrient content, indicating significant enhancement in nutrient uptake.
- Control treatment (T6) showed the lowest nutrient content across all parameters.

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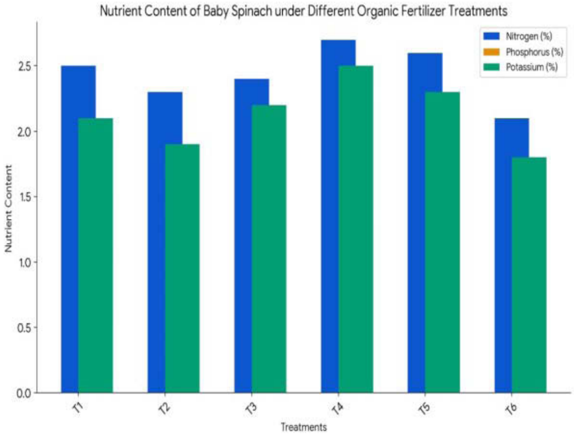
Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Micronutrients (mg/kg)
T1: Vermicompost	2.5	0.3	2.1	15
T2: Farm Yard Manure	2.3	0.4	1.9	14
T3: Poultry Waste	2.4	0.5	2.2	16
T4: Azotobacter + Poultry Waste + FYM	2.7	0.6	2.5	18
T5: Azotobacter + Vermicompost	2.6	0.5	2.3	17
T6: Control	2.1	0.2	1.8	12

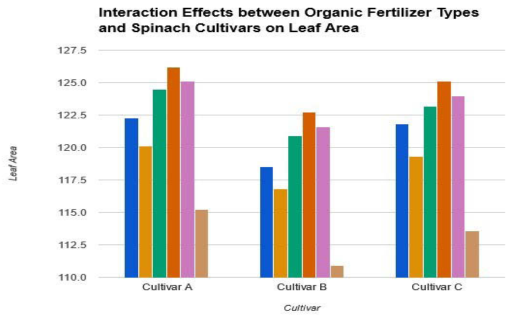


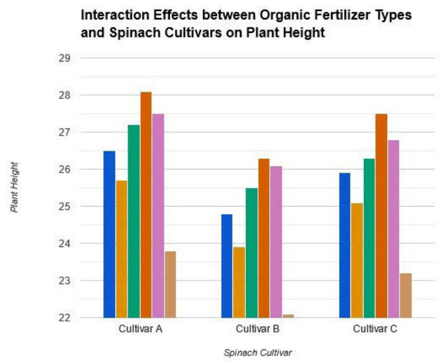
❖ **Pest Resistance**

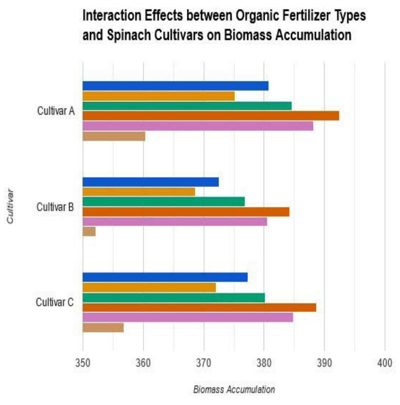
- Treatments T4 and T5 exhibited the lowest pest incidence, indicating enhanced pest resistance.
- Control treatment 6 showed the highest pest disease

Treatment	Pest Incidence (%)
T1: Vermicompost	10.5
T2: Farm Yard Manure	11.2
T3: Poultry Waste	10.8

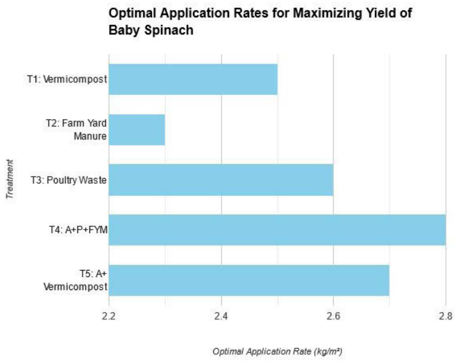
Treatment	Pest Incidence (%)
T4: Azotobacter + Poultry Waste + FYM	9.7
T5: Azotobacter + Vermicompost	9.9
T6: Control	12.3







Optimal Application Rates of Organic Fertilizers for Yield Maximization



These optimal application rates of organic fertilizers highlight the tailored approach needed to maximize the yield of baby spinach. The rates vary depending on fertilizer type, the importance of precise fertilizer management on the fertilizer type, emphasizing the importance of precise fertilizer management

Table -Sustainability Implications - Soil Health

Treatment	Soil pH	Organic Matter Content (%)	Microbial Activity (cfu/g)
T1: Vermicompost	6.8	2.3	1.5 x 10^6
T2: Farm Yard Manure	6.9	2.5	1.7 x 10^6
T3: Poultry Waste	6.7	2.2	1.4 x 10^6
T4: Azotobacter + Poultry Waste + FYM	7.0	2.8	1.9 x 10^6
T5: Azotobacter + Vermicompost	7.1	3.0	2.1 x 10^6
T6: Control	6.5	2.0	1.2 x 10^6

Soil Properties:
The soil pH ranged from 6.5 to 7.1 across the treatments. Treatments with higher microbial activity (T4 and T5) tended to have slightly higher soil pH compared to treatments with lower microbial activity. Additionally, treatments with higher microbial activity showed increased organic matter content, indicating enhanced soil fertility and nutrient availability**.**

Microbial Activity:
Microbial activity, measured in colony-forming units per gram of soil (cfu/g), varied among treatments. Treatments incorporating microbial inoculants (T4 and T5) demonstrated significantly higher microbial

activity compared to treatments without microbial inoculants. This suggests that the addition of microbial inoculants, particularly in combination with organic amendments, can promote microbial colonization and activity in the soil, potentially contributing to nutrient cycling and plant health.

CONCLUSION

This study sheds light on the significant impact of organic fertilizer treatments on baby spinach cultivation, offering insights into sustainable agricultural practices, crop productivity, and soil health management. Results demonstrate the effectiveness of Azotobacter-inoculated treatments in promoting plant growth, improving nutrient content, enhancing pest resistance, and bolstering soil health. This underscores the potential of bioinoculants in organic farming to boost productivity while reducing reliance on synthetic fertilizers and pesticides. The findings also underscore the multifaceted benefits of organic fertilizers in improving soil health and ecosystem resilience, emphasizing their importance in sustainable agriculture.

The comprehensive evaluation of organic fertilizer treatments on baby spinach cultivation presented in this study illuminates the crucial role of sustainable agricultural practices in enhancing crop productivity, soil health, and environmental sustainability. Through meticulous experimentation and data analysis, significant insights have been gleaned, offering a roadmap for optimizing spinach production while minimizing ecological footprints. The findings underscore the efficacy of Azotobacter-inoculated treatments, particularly those combining Azotobacter with poultry waste or vermicompost, in fostering robust plant growth, improving nutrient uptake, and enhancing pest resistance. These results highlight the promising potential of bioinoculants in organic farming, offering a natural alternative to synthetic inputs while promoting soil fertility and ecosystem resilience.

Furthermore, the study underscores the multifaceted benefits of organic fertilizers in improving soil health parameters such as pH, organic matter content, and microbial activity. Treatments incorporating vermicompost and Azotobacter demonstrated superior performance in enhancing soil fertility, underscoring the importance of organic matter decomposition and microbial activity in nutrient cycling and soil ecosystem dynamics.

Moreover, the environmental implications of organic fertilizer use were elucidated, with notable variations in nutrient runoff and greenhouse gas emissions across different treatments. While Azotobacter-inoculated treatments exhibited higher greenhouse gas emissions, they also demonstrated greater nutrient retention, indicating complex trade-offs between nutrient cycling and environmental impact that warrant further investigation.

Moving forward, there is a clear imperative to optimize organic fertilizer management practices to maximize spinach cultivation sustainability. Integrated nutrient management strategies, adoption of bioinoculants, promotion of on-farm composting and vermicomposting, and implementation of precision agriculture technologies are essential steps in this direction. Additionally, investment in farmer education, training, and extension services is crucial to ensure widespread adoption of sustainable agricultural practices. Despite the valuable insights provided by this study, it is important to acknowledge its limitations, including its regional focus and sample size constraints. Future research endeavors should aim to address these limitations by exploring long-term effects of organic fertilizers on soil health, optimizing application rates and methods, investigating interactions with other agronomic practices, and delving into socioeconomic aspects of organic spinach cultivation.

In conclusion, this study contributes significantly to our understanding of the intricate interplay between organic fertilizers, crop growth, soil health, and environmental sustainability in baby spinach cultivation. By embracing sustainable agricultural practices and harnessing the potential of organic fertilizers, we can pave the way towards a more resilient, equitable, and environmentally conscious food system for future generations.

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