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Design and Establishment of an Integrated Multilayer Farming System for Improved Resource Use Efficiency

Marwan Reddy Chinnam*, Abhinav

M.Sc. Scholar, Department of Agronomy, Vivekananda Global University, Jaipur, Rajasthan

Assistant professor, Department of Agronomy, Vivekananda Global University, Jaipur, Rajasthan

*Corresponding Author E-mail: marwanreddy@gmail.com

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ABSTRACT

The present investigation entitled "Design and establishment of an integrated smart multilayer farming system for improved resource use efficiency" was conducted during 2025-26 at Vivekananda Global university, the study aimed to evaluate the performance of a multilayer cropping system comprising papaya, ridge gourd, tomato, spinach and turmeric arranged according to their canopy architecture and rooting characteristics. Papaya occupied the upper layer, ridge gourd the trellis layer, the tomato middle layer, spinach the ground layer and turmeric the subterranean layer. The system was designed to maximize utilization of sunlight, land, water and nutrients while enhancing overall productivity. The yields of papaya, ridge gourd, tomato, spinach and turmeric were recorded as 55,800, 25,300, 42,850, 18,050, 27,250 kg ha⁻¹, the system provided continuous harvests throughout the cropping period and improved land use efficiency. The economic analysis indicated higher profitability compared with monocropping system, the integrated multilayer farming approach proved effective for sustainable crop production, efficient resource utilization and enhanced farm income under limited land conditions.

Keywords: *Smart multilayer farming, resource use efficiency, papaya, ridge gourd, tomato, spinach, turmeric, sustainable agriculture.*

INTRODUCTION

Agriculture is facing increasing challenges due to rapid population growth, shrinking cultivable land, climate variability and the rising demand for food, nutrients and livelihood security. Conventional monocropping systems often utilize only a portion of the available resources such as sunlight, soil moisture, nutrients and growing space, resulting in lower productivity per unit area that why the development of innovative farming systems capable of maximizing resource utilization and enhancing productivity has become a major priority in sustainable agriculture.

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Multilayer farming is an advanced crop production system in which crops differing in height, canopy architecture, rooting pattern, growth duration and resource requirements are grown simultaneously on the same piece of land.

The principle of multilayer farming is based on vertical stratification where crops occupy different layers above and below the soil surface thereby reducing competition and promoting complementary use of available resource. This approach enables efficient utilization of solar radiation, soil nutrients, water and growing space while increasing total biological productivity.

The concept of multilayer farming has gained considerable attention in recent years as an effective strategy for improving land use efficiency and farm profitability particularly for small and marginal farmers. By integrating crops with different growth habits, farmers can obtain multiple products from the same land area throughout the year. Such systems not only enhance productivity but also provide diversified income source, reduce production risk, and improves resilience against climatic and market fluctuations.

Resource use efficiency is one of the most important advantages of multilayer farming cropping systems. Different crops exploit resources from different ecological niches. Deep-rooted crops absorb nutrients and moisture from lower soil layers, while shallow-rooted crops utilize resources from the upper soil profile. Smilarly crops with varying canopy heights intercept sunlight at different levels allowing maximum utilization of available solar energy. This complementary interaction among component crops improves overall systems productivity compared with conventional monoculture systems.

The success of multilayer farming system largely depends on the selection of compatible crops that differ in canopy structure, rooting depth, nutrient requirement and growth duration. In the present study papaya (Carica papaya L.), Ridge gourd (*Luffa acutangular* L.), Tomato (*Solanum lycopersicum* L.) Spinach (*Spinacia oleracea* L.) and turmeric (*Curcuma longa* L.) were selected as component crops due their complementary growth characteristics and economic importance.

Papaya served as the principle upper-layer crop owing to its erect growth habit, relatively spares canopy and year-round fruit production. Its vertical growth pattern allows sufficient penetration of sunlight to lower crops layers, making it highly suitable for multilayer systems. In addition, papaya provides long-term economic returns and acts as the structural backbone of the system.

Ridge gourd was incorporated as a climbing vegetable crop occupying the trellis layer. It vines growth habit enables efficient utilization of vertical space above the intermediate crop canopy without creating excessive competition for ground resources. The crop contributes additional yield and income while maximizing the productive use of aerial space.

Tomato was positioned in the middle layer due to its moderate plant height and adaptability under partially filtered sunlight. As a high value vegetable crop with strong market demand, tomato contributes substantially to the economic productivity of the system. It growth pattern complements both the upper canopy crop and the lower ground-cover crops.

Spinach was selected as the ground-layer crop because of its short duration, rapid growth and shallow root system. The crop provides early economic returns and continues soil coverage thereby reducing weed growth, minimizing soil erosion and improving soil moisture conservation. Furthermore, spinach efficiently utilizes the light available at the lower canopy level.

Turmeric occupied the subterranean and lower canopy layer owing to its shade tolerance and underground rhizome development. The crop effectively utilizes partially shaded conditions created by the upper crop layers and generates an additional source of income without significantly competing for above-ground growing space. The inclusion of turmeric also contributes to diversification and long-term system, sustainability.

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The integration of these five crops creates a biological efficient production system in which different ecological niches are utilized simultaneously. Such complementary interactions among component crop enhances overall resource utilization, increase productivity per unit area and improve the economic viability of farming systems.

Efficient utilization of available resources is a fundamental requirement for achieving sustainable agricultural production. Land, water, nutrient, solar radiation and labor are becoming increasingly scare due to population pressure, climate change and the continuous fragmentation of agricultural holding. Therefore, production systems that maximize output from the limited resources are essential for ensuring future food and nutritional security.

Among various resource conservation approaches, multilayer farming has emerged as a highly effective strategy for improving resource-use efficiency. The vertical arrangement of crops enables better interception and utilization of solar radiation throughout the crop canopy. Crops occupying different layers capture light at varying intensities thereby reducing wastage of available sunlight. Similarly, differences in rooting depth facilities efficient exploitation of soil moisture and nutrient from various soil horizons, minimizing interspecific competition and enhancing overall system productivity.

Multilayer cropping systems also contribute significantly to environmental sustainability. Continuous ground cover provided by lower-layer crops helps reduce soil erosion, suppress weed growth, and improves soil moisture retention. Greater crop diversity promotes beneficial microbial activity, improves soil health, and enhances ecological stability. Furthermore, diversified cropping systems are generally more resilient to pest outbreaks, disease incidence and climatic fluctuations than monocropping systems.

In addition to agronomic and ecological benefits, multilayer farming offers substantial economic advantages. The inclusion of crops with different maturity periods ensures staggered harvesting and continuous income generated throughout the year. Short-duration crops provide immediate returns, while medium-and long-duration crops contribute sustained revenue thereby improving farm profitability and reducing economic risk. Such systems are particularly beneficial for small and marginal farmers who seek to maximize return from limited land resources.

Although multilayer farming has been recognized as a promising approach for sustainable agriculture scientific information regarding the integration of fruit, vegetables. Leafy vegetables and spices crop with in a single production system remains limited. Most existing studies have focused on conventional intercropping combinations while relatively few investigations have evaluated comprehensive multilayer systems involving crops with distinct canopy evaluate scientifically designed multilayer farming models that can optimize resource utilization while enhancing productivity and profitability.

Considering these facts, the present investigation was undertaken to design and establish and integrated multilayer farming system comprising papaya, ridge gourd, tomato, spinach, and turmeric. The study aimed to evaluate the suitability of these component crop for vertical integration and to assess their potential for improving resource-use efficiency, productivity and sustainability under filed conditions.

Objective

To design and establish an integrated multilayer farming system comprising papaya, ridge gourd, tomato, spinach, and turmeric for improved resource-use efficiency and enhanced productivity.

MATERIALS AND METHODS

Experimental site

The field experiment entitled “Design and Establishment of an Integrated Multilayer Farming System for Improved Resource Use Efficiency” was conducted at the research farm of the department of Agriculture, Vivekananda Global University, Jaipur, Rajasthan, India. During the year 2025-2026. The experimental site is situated in the semi-arid agro-climatic region of Rajasthan and is characterized by hot summers and moderate winter. The area receives most of its rainfall during the southwest monsoon season.

Soil and Climatic Conditions

The experimental field was characterized by sandy loam soil with good drainage and moderate fertility status. The climatic conditions of the region are suitable for the cultivation of fruit, vegetable, leafy vegetable and spice crops. During the experimental period, environmental parameters such as temperature, relative humidity and soil conditions were continuously monitored to assess crop performance under the multilayer production system.

Design and Establishment of the Multilayer Farming System

A multilayer cropping system was established by integrating crops of varying canopy architecture, rooting depth, growth habit and crop duration. The system was designed to maximize vertical and horizontal utilization of available resources including sunlight, soil moisture, nutrients and growing space.

The cropping arrangement consisted of five component crop occupying distinct ecological layers:

1. Papaya (*Carica papaya* L.) – Upper canopy layer
2. Ridge gourd (*Luffa acutangular* L.) – Trellis layer
3. Tomato (*Solanum lycopersicum* L.) – Intermediate canopy layer
4. Spinach (*Spinacia oleracea* L.) – Ground cover layer
5. Turmeric (*Curcuma longa* L.) – Underground rhizosphere layer

   This vertical stratification minimized interspecific competition while promoting complementary resource utilization among component crops.

Crop Establishment and Management

Papaya was established as the principal crop and formed the uppermost layer of the system. Ridge gourd was trained on overhead support structure to effectively utilize vertical space. Tomato plant was maintained within the intermediate canopy zone, while spinach was grown as a low-growing leafy vegetable covering the soil surface. Turmeric was cultivated beneath the crop canopy utilizing the lower soil profile and partially shaded microenvironment.

All agronomic operations including land preparation, sowing/transplanting, irrigation, nutrient management, intercultural operations and plant protection measures were carried out according to recommended crop production practices. Crop management was performed uniformly throughout the experimental period to ensure optimum crop growth and development.

Resource Utilization Approach

The multilayer farming system was designed based on the principle of complementary resource use. Crop with different canopy height intercepted sunlight at various levels, while varying rooting depths enabled efficient extraction of nutrient and moisture from different soil horizons. This arrangement improved overall land use efficiency and enhanced biological productivity per unit area.

Observations Recorded

Growth, yield and productivity parameters of all component crops were recorded at appropriate crop growth stages and at harvest. Yield data were collected separately for papaya, ridge gourd, tomato, spinach, turmeric. The overall performance of the multilayer farming system was evaluated on the basis of productivity, resource utilization efficiency and system sustainability.

Statistical Analysis

The recorded observations were compiled, tabulated and subjected to appropriate statistical analysis. Descriptive statistical techniques were employed to evaluate crop performance and productivity under the multilayer farming system. Results were interpreted to assess the effectiveness of crop integration for improving resource use efficiency and overall agricultural productivity.

RESULTS AND DISCUSSION

3.1 Establishment of Smart Multilayer Farming System

The multilayer farming system comprising papaya, ridge gourd, tomato, spinach and turmeric was successfully established through strategic vertical arrangement of crops according to their growth habit, canopy structure, rooting pattern and duration. The system was designed to maximize utilization of available resources including sunlight, nutrients, moisture and growing space.

Papaya served as the upper canopy crop and formed the primary structural component of the system. Ridge gourd was trained vertically on support structures, enabling efficient utilization of aerial space. Tomato occupied the middle layer beneath the ridge gourd canopy, while spinach was cultivated as ground-layer crop. Turmeric occupied the underground layer and utilized subsurface soil resources.

The arrangement enabled simultaneous cultivation of fruit, vegetables, leafy vegetables, and spice crops with in the same production unit. Such vertical stratification minimized direct competition among components crops and facilitated efficient utilization of ecological resources. The system also provided opportunities for diversified production and staggered harvesting throughout the cropping period.

The successful establishment of the multilayer farming system demonstrated the compatibility of papaya, ridge gourd, tomato, spinach and turmeric under integrated organic nutrient management conditions.

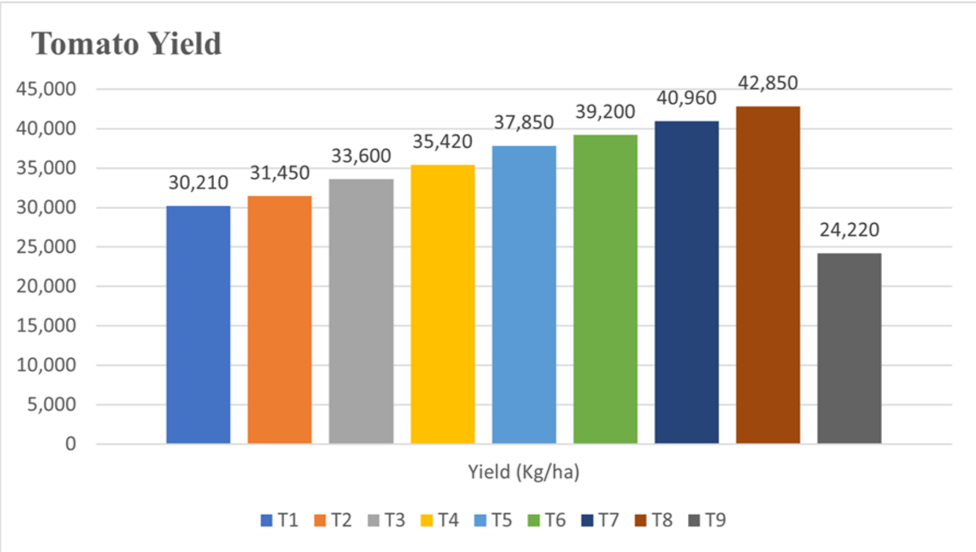

Fig. 1: Effect of Organic Nutrient Management on Tomato Yield

Table1. Effect of Different Organic Nutrient Management Treatments on Tomato Yield

Treatment	Yield (kg ha^{-1})
T1	30,210
T2	31,450
T3	33,600
T4	35,420
T5	37,850
T6	39,200
T7	40,960
T8	42,850
T9	24,220

The results revealed considerable variations in tomato yield among different nutrients management treatments. The highest yield of 42,850 kg ha⁻¹ was recorded under treatment T8, followed by T7 (40,960 kg ha⁻¹) and T6 (39,200 kg ha⁻¹). The lowest yield was observed in the control treatment (T9) with 24,220 kg ha⁻¹.

The superior performance of T8 may be attributed to the combined application of poultry manure, vermicompost, farmyard manure, azotobacter and phosphate solubilizing bacteria, which improved nutrient availability, microbial activity and soil fertility. Organic nutrient sources supplied essential nutrients gradually throughout the crop growth period, resulting in improved vegetative growth, flowering and fruit development.

Treatments receiving combinations of organic manures and biofertilizers consistently outer performed treatments receiving individual nutrient sources. The results indicate the importance of integrated organic nutrient management in improving tomato productivity with in the multilayer farming systems.

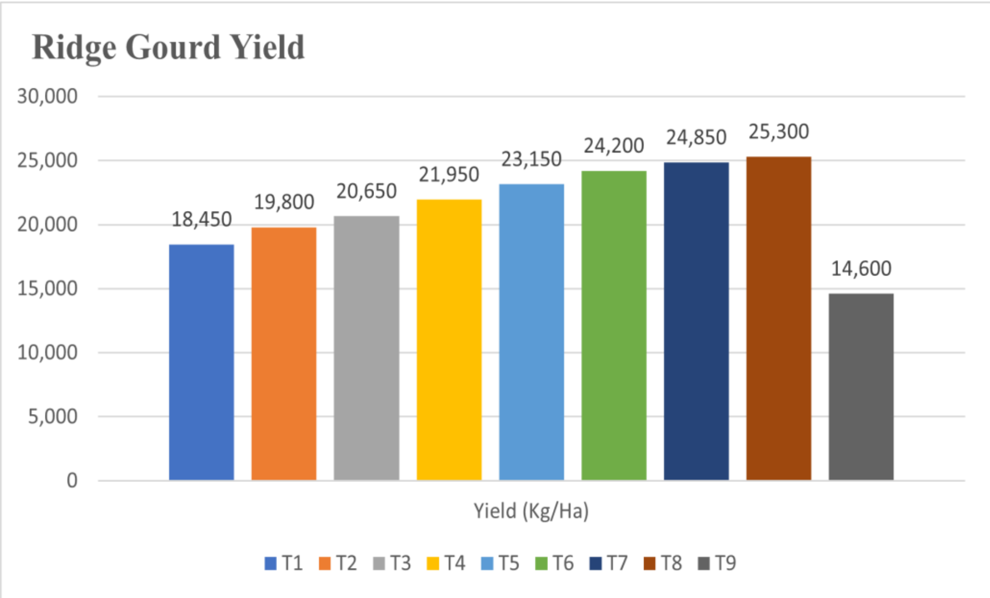

Fig. 2: Effect of Organic Nutrient Management on Ridge Gourd Yield

Table 2. Effect of Different Organic Nutrient Management Treatments on Ridge Gourd Yield

Treatment	Yield (Kg/Ha)
T1	18,450
T2	19,800
T3	20,650
T4	21,950
T5	23,150
T6	24,200
T7	24,850
T8	25,300
T9	14,600

The yield of ridge gourd increased progressively with improvement in nutrient management. Treatment T8 recorded the maximum yield of 25,300 kg ha⁻¹, followed by T7 (24,850 kg ha⁻¹) and T6 (24,200 kg ha⁻¹). The minimum yield was recorded under the control treatment T9 (14,600 kg ha⁻¹).

The increase in yield under integrated nutrient management treatments may be attributed to improve nutrient supply, enhanced microbial activity and better soil physical properties. Organic manures improved moisture retention and nutrient availability, while biofertilizers enhanced nutrient mobilization and uptake. These factors collectively promoted vigorous vegetation growth and higher fruit production.

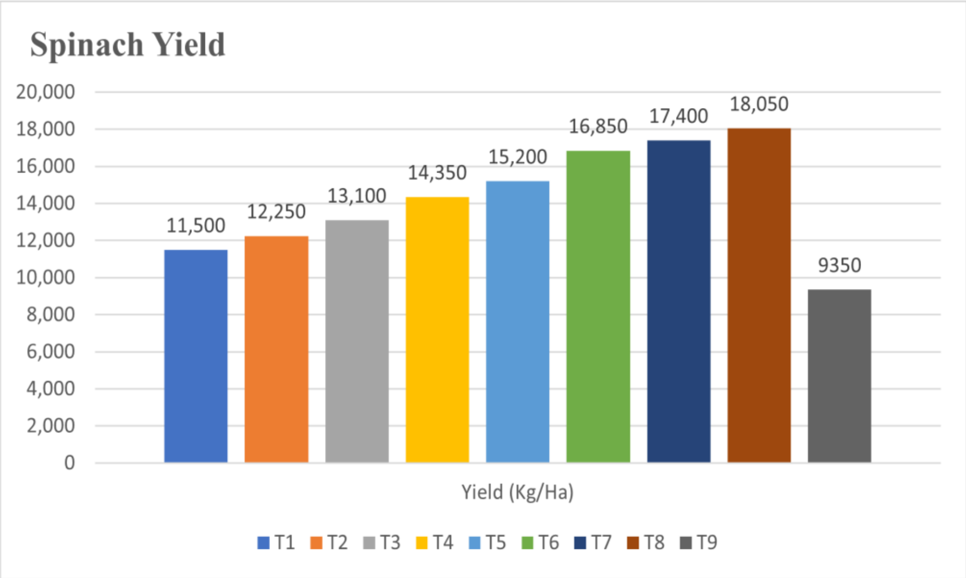

Fig. 3: Effect of organic nutrient management on spinach yield

Table4. Effect of Different Organic Nutrient Management Treatments on Spinach Yield

Treatment	Yield (Kg/Ha)
T1	11,500
T2	12,250
T3	13,100
T4	14,350
T5	15,200
T6	16,850
T7	17,400
T8	18,050
T9	9350

Significant differences in spinach yield were observed among treatments. Treatment T8 produced the highest yield of 18,050 kg ha^{-1}, followed by T7 (17,400 kg ha^{-1}) and T6 (16,850 kg ha^{-1}). The lowest yield was recorded under the control treatment (9,350 kg ha^{-1})

The superior performance of integrated nutrient management treatments may be attributed to increase nutrient availability and improved soil biological activity. Leafy vegetables respond rapidly to nutrient supply, and the combined application of organic manures and biofertilizers provided a balanced nutrient environment for continuous leaf production. The results indicated the integrated nutrient management is highly beneficial for spinach cultivation within multilayer systems.

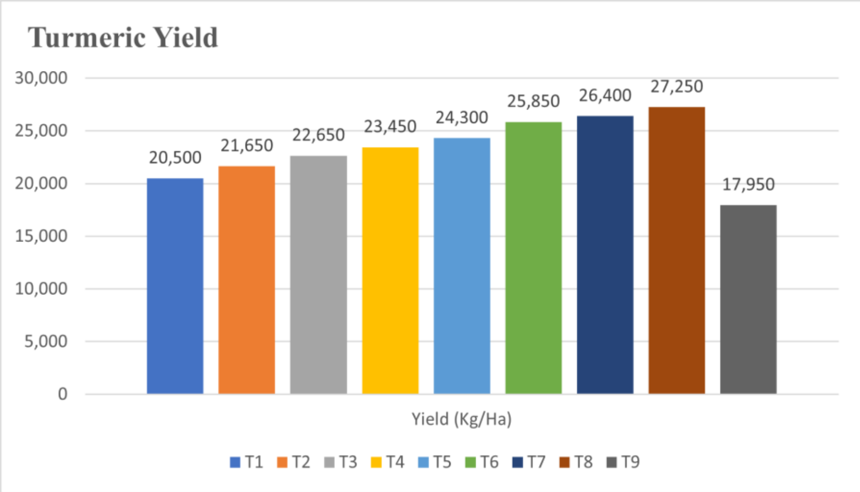

Fig. 4: Effect of Organic Nutrient Management on Turmeric Yield

Table 3: Effect of Different Organic Nutrient Management Treatments on Turmeric Yield

Treatment	Yield (Kg/Ha)
T1	20,500
T2	21,650
T3	22,650
T4	23,450
T5	24,300
T6	25,850
T7	26,400
T8	27,250
T9	17,950

The yield of turmeric was significantly influenced by nutrient management treatments. The highest yield (27,250 kg ha^{-1}) was recorded under treatment T8 followed by T7 (26,400 kg ha^{-1}) and T6 (25,850 kg ha^{-1}). The control treatment recorded the lowest yield (17,950 kg ha^{-1}).

Turmeric responds favourably to organic nutrient sources because of its long growth duration and high nutrient requirement. Organic manures improved soil structure and nutrient availability, while biofertilizers enhanced nutrient mobilization. Consequently, integrated nutrient management treatments produced higher rhizome yields compared with individual nutrient applications.

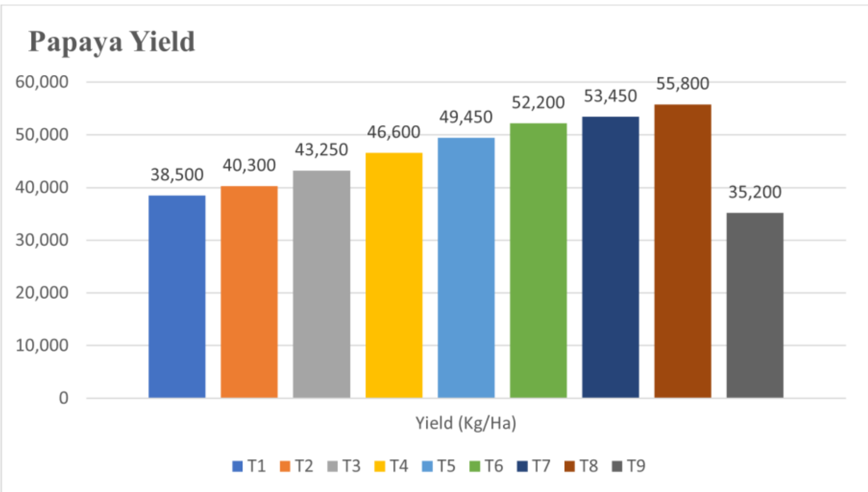

Fig. 5: Effect of Organic Nutrient Management on Papaya Yield

Table 4: Effect of Different Organic Nutrient Management Treatments on Papaya Yield

Treatment	Yield (Kg/Ha)
T1	38,500
T2	40,300
T3	43,250
T4	46,600
T5	49,450
T6	52,200
T7	53,450
T8	55,800
T9	35,200

Papaya exhibited a positive response to integrated nutrient management. Treatment T8 recorded the maximum yield of 55,800 kg ha^{-}, followed by T7 (53,450 kg ha^{-1}) and T6 (52,200 kg ha^{-1}). The lowest yield was observed under the control treatment (35,200 kg ha^{-1})

The higher yield recorded under T8 may be attributed to sustained nutrient release from organic manures and enhanced nutrient availability through biofertilizers activity. Improved soil health and nutrient uptake likely contributed to greater fruit development and overall productivity.

3.7 Comparative Productivity of Component Crops

Table5. Highest Yield Recorded by Component Crops

Crop	Highest Yield (Kg Ha^{-1})
PAPAYA	55,800
TOMATO	42,850
TURMERIC	27,250
RIDGE GOURD	25,300
SPINACH	18,050

Among all component crops, papaya recorded the highest yield under integrated nutrient management, followed by tomato, turmeric, ridge gourd and spinach. The results indicated that all crops responded positively to organic nutrient management practices.

The multilayer farming system successfully accommodated five different crops within the same production unit and demonstrated the feasibility of diversified crop production. The productivity achieved across all crop’s layers indicated effective utilization of available growing space and resources.

3.8 Effect of Integrated Organic Nutrient Management in Multilayer Farming System

A consistent trend was observed across all component crops, wherein integrated nutrient management treatments produced higher yields than individual nutrient sources and control treatment. Treatments T8 recorded the highest yield in tomato, ridge gourd, spinach, turmeric and papaya, indicating the superiority of combined organic nutrient management.

The positive response may be attributed to complementary effects of farmyard manure, vermicompost, poultry manure, Azotobacter and phosphate-solubilizing bacteria. Organic manures improved soil physical properties, enhanced nutrient availability and increased microbial activity, while biofertilizers contributed to biological nitrogen fixation and phosphorus solubilization.

The results clearly demonstrate that integrated organic nutrient management plays an important role in improving productivity within multilayer farming systems. The combined use of organic manures and biofertilizers was ore effective that the application of individual nutrient sources and offers a sustainable approach for enhancing crop production.

CONCLUSION

The present investigation successfully demonstrated the design and establishment of a multilayer cropping system comprising papaya, ridge gourd, tomato, spinach and turmeric under integrated organic nutrient management. The multilayer arrangement enabled the simultaneous cultivation of fruit, vegetable, leafy vegetable, and spice crops within the same production unit through efficient utilization of vertical and horizontal space.

The results revealed that all components crop responded positively to the application of organic manures and biofertilizers. Among the various nutrient management treatments, treatment T8 consisting of poultry manure (5 t ha^{-1}), vermicompost (5 t ha^{-1}) and farmyard manure (10 t ha^{-1}), Azotobacter and phosphate solubilizing bacteria consistently recorded the highest yield across all crops. The maximum yields obtained under T8 were 42,850 kg ha^{-1} in tomato, 25,300 kg ha^{-1} in ridge gourd, 18,050 kg ha^{-1} in spinach, 27,250 kg ha^{-1} in turmeric, and 55,800 kg ha^{-1} in papaya.

The superior performance of integrated nutrient management treatments may be attributed to improved nutrient availability, enhanced microbial activity better soil physical properties, and sustained nutrient release throughout the crop growth period. The combined application of organic manures and biofertilizers proved more effective than individual nutrient sources in improving crop productivity.

The study further demonstrated that the papaya-ridge gourd-tomato-spinach-turmeric based multilayer farming system is a practical and sustainable production model capable of increasing productivity while promoting crop diversification. The integrated of organic nutrient sources within the multilayer system provides an environmentally friendly approach to agriculture production and contributes to long-term soil fertility and sustainability.

Based on the findings of the present investigation, it may be concluded that smart multilayer farming integrated with organic nutrient management offers considerable potential for enhancing agricultural productivity and promoting sustainable farming practices, particularly under conditions of limited land availability.

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Conflict of Interest:
The authors affirm that there are no conflicts of interest.

Author Contributions:
All authors have made substantial contributions to the revision and approval of the manuscript.

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