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Economic Evaluation of Integrated Nutrient Management for Acid Lime *Citrus aurantifolia* Swingle) Cultivation in Punjab: A Cost-Benefit Approach

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ABSTRACT: A cost-benefit analysis was conducted to evaluate the economic viability of Integrated Nutrient Management (INM) in the cultivation of acid lime (*Citrus aurantifolia* Swingle) under different nutrient treatments. The study, performed during the 2023-2024 season in an organic acid lime orchard at Khadoor, Punjab, included eight nutrient management treatments, each with three replications. Among the treatments, T7 (RDF 50% + Vermicompost 50%) resulted in the highest gross income (Rs. 762,560) and net return (Rs. 643,490), along with a benefit-cost ratio (BCR) of 6.40, making it the most profitable treatment. This combination of organic and inorganic nutrients significantly improved tree growth, fruit quality, and yield. The results suggest that T7 not only enhances acid lime productivity but also offers the highest economic returns, proving it to be the most cost-effective and sustainable nutrient management option for acid lime cultivation. The findings emphasize the economic potential of integrated nutrient management as a viable practice for acid lime growers, providing high yields and profitability at an optimal cost.

Keywords: Cost-Benefit Analysis, Integrated Nutrient Management, Economic Viability and Sustainable Farming.

INTRODUCTION

Acid lime (*Citrus aurantifolia* Swingle) is a distinguished member of the Citrus genus within the Rutaceae family, exhibiting a chromosome number of 2n=18. Believed to have its origins in the Himalayas and northeastern regions of India (Asati *et al.*, 2020). Acid lime thrives in climates ranging from tropical to subtropical, with cultivation extending up to altitudes of 1200 meters above sea level (Thirugnanavel *et al.*, 2007). India produces 3,742 metric tons of lime and lemon fruits each year from an area of 322,000 hectares, achieving an annual productivity of 11.72 tons per hectare (Anonymous, 2020-2021). These fruits are cultivated in states such as Punjab, Himachal Pradesh, Uttarakhand, Rajasthan, Andhra Pradesh, and the Marathwada region of Maharashtra. Currently, citrus is cultivated in Punjab across 52,836 hectares, resulting in an annual production of 1,049 metric tons.

Acid lime is not merely a fruit; it is a highly esteemed culinary treasure, integral to a multitude of applications, ranging from refreshing beverages to tangy pickles, delectable jams, and gourmet culinary creations. Additionally, the peel oil derived from acid lime plays a pivotal role in the cosmetics and perfume industries, enhancing countless products with its invigorating aroma. This extraordinary fruit is rich in citric, malic, and succinic acids, offering a bounty of essential vitamins, including vitamin C and B (Fernando *et al.*, 2010). The peel is adorned with beneficial pigments, while the albedo boasts commendable fiber content. Furthermore, essential oils such as limonene and citronellol contribute not only to its enticing fragrance but also to its myriad health benefits. Acid lime is renowned for its impressive medicinal properties, which include bolstering the immune system, supporting digestive health, and alleviating conditions such as scurvy, respiratory distress, and skin irritations (Ganguly, 2013; Kumari *et al.*, 2022; Patel *et al*., 2023). Its potential extends to the management of weight, rheumatoid arthritis, cancer, diabetes, and cardiovascular health (Mohanapriya *et al.*, 2013). Furthermore, lime peel oil and peel powder have extensive applications in soap and cosmetic industries (Debaje *et al.*, 2011). This research endeavors to explore the highlighting its substantial economic importance for farmers, policymakers, and the agribusiness community.

Acid lime occupies a prominent position in the realm of commercial fruit crops, thriving with vigor in tropical and subtropical climates. Its significance within the horticultural economy is driven by an ever-increasing demand for fresh produce, enticing processed goods, and invaluable medicinal applications. This remarkable crop showcases exceptional adaptability to a diverse range of agro-climatic conditions, frequently yielding higher returns than other citrus varieties. The economic viability of acid lime cultivation is affected by a myriad of factors, including initial establishment costs, input relationships, yield potential, market dynamics, and the effectiveness of post-harvest management. Conducting a thorough cost-benefit analysis is essential for capturing the nuances of profitability and guiding farmers toward sustainable practices in citrus farming. This study embarks on an enlightening journey to unveil the financial feasibility of acid lime cultivation by meticulously analyzing investment requirements, operational costs, revenue generation, and overall returns. Moreover, it delves into the complexities of cost structures and potential earnings, providing invaluable insights for optimizing production practices, enhancing economic efficiency, and ensuring the long-term sustainability of acid lime growers. In employing a sophisticated cost-benefit approach, this study aspires to assess the economic advantages of adopting Integrated Nutrient Management (INM) practices, emphasizing the enduring benefits for both soil health and market competitiveness. In light of the mounting pressures to meet global citrus quality standards and address the challenges presented by climate variability, this research makes a timely and significant contribution to the future of acid lime cultivation in Punjab. The insights gleaned from this study aim to illuminate the path for farmers, policymakers, and agribusiness stakeholders, empowering them to make informed and strategic decisions within the dynamic and flourishing citrus industry.

MATERIAL AND METHOD

The present study was conducted in a healthy organic acid lime orchard located in Khadoor, Punjab, during the 2023-2024 growing season. The experimental site, situated at an altitude of 234 meters above sea level with coordinates 30°51' N and 75°22' E, receives an annual rainfall of approximately 700 mm, with a temperature range of 10°C to 40°C and relative humidity fluctuating between 50% and 75%. Soil analysis revealed a fertile medium with rich organic matter, neutral pH (7.0) and normal electrical conductivity. A Randomized Block Design (RBD) was employed with 8 treatments replicated three times, involving a total of 48 acid lime plants spaced 5 m × 5 m apart. The experimental treatments included T1 (absolute control), T2 (Farm Yard Manure at 80 kg/plant), T3 (Vermicompost at 32 kg/plant), T4 (Poultry Manure at 16 kg/plant), T5 (Recommended Dose of Fertilizers: Urea, SSP, MOP), T6 (RDF 50% + FYM 50%), T7 (RDF 50% + Vermicompost 50%), and T8 (RDF 50% + Poultry Manure 50%). Organic amendments were applied in mid-January, with nitrogen fertilizers split into two doses: before and after flowering. Data were collected on growth parameters (tree height, canopy spread, trunk diameter), yield parameters (number of fruits, total fruit weight), and fruit quality (fruit weight, juice content, total soluble solids, and acidity). The economic analysis of treatments included calculating the cost of inputs, gross income from yield, net income per hectare, and the cost-benefit ratio (CBR), as detailed in Table 1.

Table 1: Treatments detail.

Treatment code	Treatment Details
T_1	Absolute Control
T_2	Farm Yard Manure(FYM 100%) @ 80kg/plant
T_3	Vermicompost (VC 100%) @ 32kg/plant
T_4	Poultry manure (100%) @ 16kg/plant
T_5	RDF (100%)- Urea @ 0.4kg/plant, SSP @ 2kg/plant & MOP @1.2 kg/plant
T_6	RDF (50%) + FYM (50%)- Urea @ 0.2kg/plant, SSP @ 1kg/plant, MOP @0.6 kg/plant & Farm Yard Manure (FYM) @ 40kg/plant
T_7	RDF (50%) + Vermicompost (50%)- Urea @ 0.2kg/plant, SSP @ 1kg/plant, MOP @0.6 kg/plant & Vermicompost (VC) @ 16kg/plant
T_8	RDF (50%) + Vermicompost (50%)- Urea @ 0.2kg/plant, SSP @ 1kg/plant, MOP @0.6 kg/plant & Poultry manure (100%) @ 8kg/plant

Analytical Tools Utilized

Cost of Cultivation Analysis. The total cost of cultivation per hectare was determined by aggregating both fixed and variable costs. Fixed costs included labor, irrigation, and land rental value, while variable costs were contingent upon the application of fertilizers and other treatments.

Gross Income Calculation. Gross income was calculated using the following formula:

Gross Income = Yield per hectare × Selling Price per kg

Net Return Calculation. Net return per hectare was assessed with the formula:

Net Return = Gross Income - Total Cost of Cultivation

Benefit-Cost Ratio (BCR). The Benefit-Cost Ratio (BCR) was computed to evaluate the profitability of each treatment:

BCR = Gross Income / Total Cost of Cultivation. A BCR exceeding 1 signifies a profitable investment, with higher values representing more favorable returns.

Yield Analysis. Yield data were gathered from field trials and converted into kilograms per hectare. Statistical analysis was conducted to examine yield variations across different treatments.

Statistical Analysis. Descriptive statistics, mean comparison tests (ANOVA), and regression analysis were employed to assess the significance of yield differences among treatments. Data analysis was performed using established statistical tools such as SPSS and Microsoft Excel.

RESULTS

This study provides a comprehensive evaluation of the economic performance of acid lime production across eight distinct treatments (T1 to T8). It focuses on critical economic indicators such as yield, gross income, total cost, net return, and the benefit-cost ratio (BCR), as detailed in Table 2. The insights derived from this analysis significantly enhance the understanding of the profitability and operational efficiency associated with various nutrient management strategies, affirming the findings of prior research.

Yield and Gross Income. The yield of acid lime exhibited considerable variation among the treatments (Table 2), with T7 achieving the highest yield of 190.64 quintals per hectare (q/ha), which is nearly three times that of T1, recorded at 58.4 q/ha. Other notable treatments, namely T8 and T6, yielded 144.52 q/ha and 127.76 q/ha, respectively, indicating substantial improvements in production capacity. This variability in yield directly influenced gross income, as higher yields corresponded to increased revenues. Specifically, T7 generated the highest gross income of Rs. 7, 62,560, followed by T8 at Rs. 5, 78,080 and T6 at Rs. 5, 11,040. In contrast, T1, with the lowest yield, recorded a gross income of Rs. 2, 33,600.

Total Cost and Net Return. An analysis of production costs revealed significant disparities among the treatments (Table 2), with T7 incurring the highest production cost at Rs. 1,19,070, followed closely by T8 at Rs. 1,10,445 and T6 at Rs. 1,01,820. Notably, despite these higher production costs, the corresponding net returns for these treatments were remarkably favorable, demonstrating the economic viability of yield-focused approaches. T7 recorded the highest net return of Rs. 6, 43,490, while T8 and T6 achieved net returns of Rs. 4, 67,635 and Rs. 4, 09,220, respectively. Conversely, T1, despite its lowest production cost of Rs. 77,815, yielded a modest net return of Rs. 1, 55,785, indicating that cost reduction alone does not guarantee enhanced profitability.

Benefit-Cost Ratio (BCR). The Benefit-Cost Ratio (BCR) serves as a vital indicator of financial efficiency within agricultural systems. The results presented in Table 2 and Fig. 1, clearly indicate that T7 is the most economically efficient treatment, achieving a BCR of 6.40, which signifies that every rupee invested yields Rs. 6.40 in return. Treatments T8 and T6 also demonstrated commendable financial performance, with BCRs of 5.23 and 5.02, respectively. In stark contrast, T1, while recording lower total costs, achieved the lowest BCR at 3.00, reflecting inadequate profitability in relation to the investment made.

Economic Viability and Profitability. Treatments with lower production costs, such as T1, are misleadingly appealing. The data presented in Table 2, clearly shows that reduced costs do not lead to higher profitability. T1, with a yield of just 58.4 q/ha and a net return of Rs. 1, 55,785, reveals that cost minimization is not a viable strategy. In contrast, treatments T7, T8, and T6, which required higher investments, yielded significantly better results, with T7 achieving a remarkable yield of 190.64 q/ha and a net return of Rs. 6,43,490. This confirms that optimizing yield is crucial for economic sustainability in acid lime production.

Table 2: Economics of the Acid lime production as affected by different treatments.

Treatments	Yield (q/ha)	Yield (kg/ha)	Selling Price (Rs/kg)	Gross Income (Rs/ha)	Total Cost (Rs/ha)	Net Return (Rs/ha)	Benefit- Cost Ratio
T1	58.4	5,840	40	2,33,600	77,815	1,55,785	3.00
T2	84.44	8,444	40	3,37,760	98,315	2,39,445	3.43
T3	104.32	10,432	40	4,17,280	1,15,565	3,01,715	3.61
T4	99.2	9,920	40	3,96,800	1,06,940	2,89,860	3.71
T5	77.4	7,740	40	3,09,600	81,320	2,28,280	3.80
T6	127.76	12,776	40	5,11,040	1,01,820	4,09,220	5.02
T7	190.64	19,064	40	7,62,560	1,19,070	6,43,490	6.40
T8	144.52	14,452	40	5,78,080	1,10,445	4,67,635	5.23

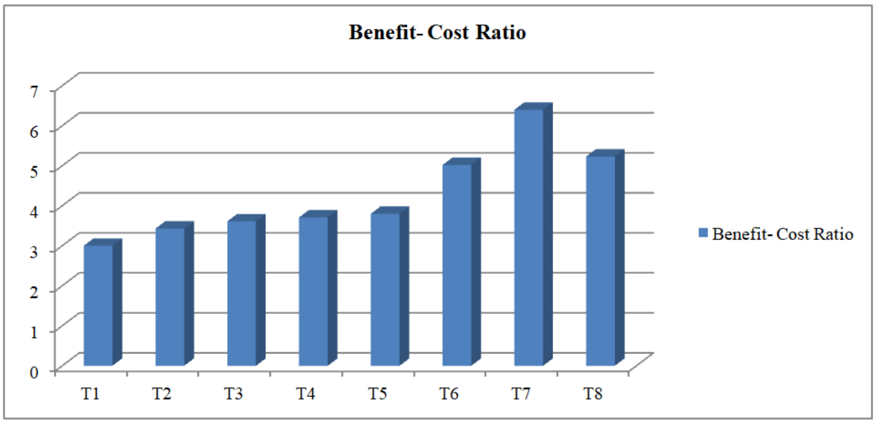

Fig. 1. Benefit-Cost Ratio Analysis of Acid Lime Under Different Treatments.

DISCUSSION

The present study reaffirms the importance of integrated nutrient management (INM) in enhancing both economic returns and soil sustainability. The combination of organic and inorganic fertilizers has been widely recognized as a sustainable strategy for improving crop productivity while maintaining soil health. The findings of this study align with those of Harimohan *et al*. (2018), who reported that the application of 50% RDF + 50% Vermicompost (T9) resulted in a Benefit-Cost Ratio (BCR) of 1:10.77. This high BCR indicates the economic feasibility of integrating organic and inorganic nutrient sources, balancing profitability with long-term soil fertility improvement. The results further underscore the potential of INM to optimize nutrient availability, leading to improved plant growth and yield stability over successive cropping cycles.

The findings underscore the significance of a well-balanced INM strategy in optimizing cowpea productivity while potentially promoting soil health through enhanced organic matter incorporation (Patel *et al*., 2023).

Furthermore, the effectiveness of nutrient integration was corroborated by Ventakalakshmi *et al.* (2023), who demonstrated that the application of 25% Vermicompost + 75% NPK (T6) yielded a BCR of 2.42 and a net return of Rs. 10,08,075 per 100 m² in strawberry cultivation. These findings reinforce the economic advantages of combining vermicompost with inorganic fertilizers, highlighting its role in enhancing yield and profitability. The increased economic returns observed in this study can be attributed to the synergistic effects of organic and inorganic inputs, which improve soil structure, microbial activity, and nutrient availability.

The integration of organic amendments such as vermicompost with chemical fertilizers offers multiple agronomic benefits, including enhanced nutrient-use efficiency, improved soil organic matter content, and long-term sustainability. This approach aligns with global efforts to promote sustainable agricultural practices by reducing dependency on synthetic fertilizers while maintaining high productivity. The results of the present study, together with previous research, suggest that INM not only ensures immediate economic benefits but also contributes to the long-term resilience of agricultural systems. Future research should focus on optimizing the ratios of organic and inorganic inputs across different agro-climatic conditions to further enhance the sustainability and profitability of strawberry production and other high-value crops.

CONCLUSIONS

The findings of this study highlight the critical role of yield in determining the economic success of acid lime production. T7 stands out as the most profitable treatment, achieving the highest yield, gross income, net return, and benefit-cost ratio. Treatments with lower yields, such as T1, despite their reduced production costs, exhibited inferior economic performance. Therefore, it is concluded that optimizing yield is essential for enhancing profitability in acid lime production. Producers are encouraged to prioritize yield-enhancing strategies to maximize net returns and benefit-cost ratios, even if such strategies necessitate increased investment in production.

FUTURE SCOPE

The study revealed significant variations in economic performance among the different treatments, with T7 exhibiting the highest yield, gross income, net return, and benefit-cost ratio, clearly demonstrating that higher investments in nutrient management can lead to superior profitability in acid lime production. However, the research also highlighted limitations such as its geographic specificity, reliance on fixed market prices, and short-term assessment, which suggest that future studies should incorporate multi-location and multi-year trials, integrate dynamic economic modeling to account for price fluctuations, and consider additional agronomic and environmental factors. Advancing research in this field by adopting precision agriculture technologies and comprehensive sustainability metrics will be essential for developing robust, economically viable, and environmentally sustainable nutrient management strategies.

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