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Enhancing Yield and Quality of Acid Lime through Integrated Nutrient Management in Punjab: A Strategic Approach

Gurmeetpal Singh[1], Sachin Bhardwaj[2], Ravinder Singh[2], Shivangi Sood[2] and Avinash Kumar Bhatia[2]*
[1]*Research Scholar, Faculty of Agriculture and Life Sciences, Desh Bhagat University, Mandi Gobindgarh (Punjab) India.*
[2]*Assistant Professor, Faculty of Agriculture and Life Sciences, Desh Bhagat University, Mandi Gobindgar (Punjab) India.*

(Corresponding author: Sachin Bhardwaj)*
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ABSTRACT: This study, titled " Enhancing Yield and Quality of Acid Lime through Integrated Nutrient Management in Punjab: A Strategic Approach " was conducted in an organic acid lime orchard in Khadoor, Tehsil Zira, Distt Ferozepur, Punjab, during the 2023-2024 season. The experiment aimed to evaluate the effects of various organic and inorganic nutrient combinations on the growth, yield, quality, and economics of acid lime cultivation. The treatments applied followed a Randomized Complete Block Design (RCBD) with eight treatments and three replications, including combinations of organic manures and recommended dose of fertilizers (RDF). Results showed that treatment T7 (RDF 50% + Vermicompost 50%) significantly enhanced vegetative growth, resulting in a 25.37% increase in tree height, 23.87% increase in tree spread, and a 7.16% increase in trunk diameter. Additionally, T7 produced superior fruit quality, exhibiting the highest fruit length, diameter, peel thickness, total soluble solids (TSS), and ascorbic acid content. The yield parameters were optimal in T7, with the highest number of fruits per tree (741) and the highest fruit yield per tree (47.66 kg). The study concluded that T7, which combines 50% RDF with 50% Vermicompost, is the most effective treatment for improving acid lime yield, quality, and profitability, and offers a sustainable option for acid lime production.

Keywords: Integrated Nutrient Management, Acid Lime and Sustainable Agriculture.

INTRODUCTION

Citrus is one of the most significant fruit crops globally, widely cultivated in tropical and subtropical regions. It ranks third among subtropical fruits due to its diverse varieties. Acid lime (*Citrus aurantifolia* Swingle), commonly known as Kagzi lime or Neebu is a member of the Rutaceae family, is thought to originate from Malaya, Assam, and China. The word Kagzi being derived from the word Kagaj meaning paper as the rind of the fruit is very thin. Acid lime has gained popularity among the commercially important citrus fruits grown in India besides mandarin, sweet oranges and grape fruit. Presently, the citrus fruits are grown all over the world in more than 140 countries; most of the crop grows on either side of a belt around the equator covering tropical and subtropical areas of the world 35°N and 35°S latitudes with cultivation and production concentrated in major regions in the Northern Hemisphere. In India, acid lime is one of the four key citrus fruits cultivated, alongside sweet oranges, mandarins, and grapefruits. The four commercially important lime species are *Citrus aurantifolia* (acid lime), *C. latifolia* (Tahiti lime), *C. limonia* (Rangpur lime), and *C. limettioides* (sweet lime).

Citrus fruits are popular in subtropical regions of North India and tropical regions of South India mainly due to their hardy nature and good nutritional values. India produced 3742 MT of lime/lemon fruits annually from 3.22 lakh hectare areas with an annual productivity of 11.72 tonnes/hectare (Anonymous, 2020-2021). In India, it is grown in Punjab, Himachal Pradesh, uttarakhand, Rajasthan, Andhra Pradesh and Marathwada region of Maharashtra. At the moment, citrus is being grown in Punjab over 52,836 hectares with annual production of 1049 metric tonnes. Citrus fruits are very important in respect of its food value specially being very rich in vitamin C and vitamin A. The immature fruits are dark green in colour which changes to light yellow when ripe. The colour of the pulp is light yellow; taste is acid, aromatic; cells fine and shiny. The fruit can be eaten as fresh and various kind of food items can also be prepared from the juice. The production of canned juice, pulp and particularly of frozen concentrated juice has increased very rapidly. The flowers, leaf and rind of citrus contain oil of good fragrance and have good commercial value for preparation of perfume. Citric acid and pectin are made primarily from cull and unmarketable fruits. It has an important role in starch metabolism, and acts as

co-factor for many enzymes, affects photosynthesis reaction, nucleic acid metabolism, and protein biosynthesis (Alloway, 2008).

The integrated nutrient management infuses long term sustainability in the productivity level because of availability of nutrients in soil for next season crop. Incorporation of organic fertilizers is a common practice to improve the yield of many fruit crops. It is the important alternative source, which is not only beneficial to maintain the soil health but also to sustain the fruit production. Improper application of inorganic fertilizers, devoid of organic supplements, has adversely impacted soil properties across physical, chemical, and biological dimensions, leading to environmental pollution (Albiach *et al.*, 2000). Application of organic manures in conjunction with chemical fertilizers is associated with augmentation of soil fertility and improved soil physical and chemical properties, which accentuates crop production. In contrast, organic manures are gaining prominence as essential components of environmentally sustainable agriculture, with the goal of optimizing crop productivity (Sheikh and Dwivedi 2017). The integrated nutrient management (INM) is considered to be viable module with regard to efficient use of manure and fertilizers. Hence keeping in view the importance of study and above facts, the present study was carried out in order to investigate the effect of integrated nutrient management on growth, yield and qualitative characters of acid lime plants along with bio-economics.

MATERIAL AND METHOD

The present study was carried out in a ten years healthy organic orchard of acid lime located in the village of Khadoor, Tehsil Zira, Distt Ferozepur, Punjab, during the 2023-2024 season. The acid lime trees were trained as open centre system of training. Twenty four plants having uniform vigour and size, planted at spacing of 5 × 5 m were selected for the study. All the plants were maintained under uniform culture practices during the course of investigations. The experiment was laid out with 8 treatments and 3 replications in randomized block design (RBD), 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

The required quantity of these manure and fertilizers were applied based on the treatment combination to the twenty four fruit trees of Acid lime. Application of single super phosphate (SSP) and muriate of potash (MOP) along with full dose of farm yard manure was done during mid-January. Nitrogen was applied through urea and calcium nitrate in two split doses as per the details of the treatments. First half dose was applied before flowering in the spring and remaining half dose was applied after one month of first application. Plant growth promoting rhizobacteria (PGPR) was applied by drenching in two splits doses *i.e.* in mid-February and mid-March.

Observation recorded. All the growth, yield and qualitative parameters of fruits were recorded by taking four fruits randomly from each tree then average and tagged for recording various parameters. For determination of fruit quality, four healthy fruits were selected randomly from each tree at full maturity stage. The fruits were washed thoroughly before analysis for the following contents.

Statistical Analysis. The data obtained from the present investigations were appropriately computed, tabulated and further analyzed in accordance with the method described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

A comprehensive analysis of variance was performed to assess the effects of different nutrient management treatments on the vegetative growth, yield and quality parameters of acid lime. The results indicate significant differences among the treatments concerning most of the parameters under study.

Vegetative Growth Parameters. The implementation of integrated nutrient management strategies significantly impacted the vegetative growth of acid lime, as detailed in Table 2. Among the treatments, T7 (RDF 50% + Vermicompost 50%) recorded the highest overall growth, achieving maximum increases in tree height (25.37%), tree spread (23.87%), and trunk diameter (7.16%). T8 (RDF 50% + Poultry Manure 100%) closely followed, demonstrating comparable increases in tree height (24.48%) and trunk diameter (6.45%), along with a notable tree spread increase of 18.5%. T6 (RDF 50% + FYM 50%) also exhibited substantial growth, ranking third in tree height (22.15%), tree spread (20.91%), and trunk diameter (5.19%). Conversely, T1 (Absolute Control) displayed the lowest growth across all parameters, with minimal increases in tree height (10.11%), tree spread (11.67%), and trunk diameter (3.43%). This performance was statistically similar to T2 (FYM 100%), which showed

increases of 15.15% in height, 11.82% in spread, and 4.37% in trunk diameter. T3 (Vermicompost 100%) yielded moderate growth, with a tree height increase of 16.18%, tree spread of 16.18%, and trunk diameter of 4.32%. This study demonstrates that integrated nutrient management significantly enhances vegetative growth in acid lime. Combining slow-releasing organic materials with fast-acting inorganic fertilizers improves tree height, spread, and trunk diameter. Treatments with vermicompost and poultry manure outperformed the control, which lacked nutritional support. These findings advocate for the adoption of integrated nutrient management strategies to optimize yield and productivity in acid lime orchards and aligns with the students conducted by Kumar *et al*. (2020) who, demonstrated that combining 50% of the recommended dose of fertilizers (RDF) with 75% farmyard manure, 75% vermicompost, and biofertilizers (Azotobacter, phosphate-solubilizing bacteria, and vesicular-arbuscular mycorrhizae) resulted in improved vegetative parameters such as increased plant height, canopy spread, and a greater number of leaves. Similarly, Ventakalakshmi *et al*. (2023) observed that a nutrient regimen of 60% RDF and 40% vermicompost significantly enhanced key vegetative traits, including plant height, canopy development, and the number of leaves and flowers. These findings underscore the importance of integrating organic and inorganic inputs to support vigorous vegetative growth, which ultimately contributes to better nutrient uptake and sustained plant health.

Table 2: Effect of Different Treatments on Vegetative Growth Attributes.

Treatment Code	Trunk Diameter Increase (%)	Tree Height Increase (%)	Tree Spread Increase (%)
T1	3.43 (1.98)	10.11 (3.26)	11.82 (3.51)
T2	4.37 (2.21)	15.15 (3.96)	11.67 (3.49)
T3	4.32 (2.20)	16.34 (4.10)	16.18 (4.08)
T4	4.77 (2.30)	17.58 (4.25)	18.10 (4.31)
T5	4.67 (2.27)	17.83 (4.28)	19.63 (4.49)
T6	5.19 (2.39)	22.15 (4.76)	20.91 (4.63)
T7	7.16 (2.77)	25.37 (5.09)	23.87 (4.94)
T8	6.45 (2.64)	24.48 (5.00)	18.50 (4.36)
CD (0.05)	2.49 (1.73)	5.23 (2.39)	6.03 (2.56)
SE(m)	0.81 (1.14)	1.72 (1.49)	1.98 (1.57)
SE(d)	1.15 (1.28)	2.43 (1.71)	2.81 (1.82)
C.V.	28.13 (5.35)	16.01 (4.06)	19.54 (4.48)

Yield Attributes. Integrated nutrient management (INM) has demonstrated a significant influence on various yield attributes in the cultivation of acid lime, as detailed in Table 3. The treatment combining 50% of the recommended dose of fertilizer (RDF) with 50% vermicompost (designated as T7) consistently produced superior results in comparison to the absolute control treatment (T1). Specifically, T7 achieved the longest fruit length of 4.667 cm and the largest fruit diameter of 4.533 cm, both of which were statistically comparable to treatments incorporating additional organic amendments such as farmyard manure (FYM) or poultry manure. Additionally, T7 recorded the highest average fruit weight at 46.333 g, which notably exceeded the control value of 33.667 g. The number of fruits per tree under T7 was also significantly enhanced, yielding an average of 741 fruits per tree compared to 576 fruits in the control treatment. This increase in fruit quantity contributed to a substantial improvement in overall productivity, as T7 recorded the highest fruit yield of 47.66 kg per tree, while the control only achieved 14.60 kg per tree. Optimizing nutrient management has been shown to positively impact fruit yield in acid lime. Kumar *et al*. (2020) reported that a balanced combination of 50% RDF, 75% farmyard manure, 75% vermicompost, and biofertilizers led to higher fruit set and overall yield. This supports earlier findings from Solanki *et al*. (2020), who observed that peach trees receiving 75% RDF along with 15 kg of vermicompost per tree exhibited significant improvements in fruit set (87.70%) and yield (20.16 kg per tree). Similarly, Ventakalakshmi *et al*. (2023) highlighted that integrating 60% RDF with 40% vermicompost enhanced both vegetative and reproductive growth, ultimately leading to an increased number of flowers and improved fruit yield. These results validate the effectiveness of INM strategies in improving crop productivity through enhanced nutrient availability and uptake. These findings clearly indicate that the integration of organic nutrient sources with chemical fertilizers not only enhances fruit morphological characteristics but also improves yield attributes in acid lime. The synergistic effect of combining diverse nutrient inputs promotes both vegetative growth and fruit development, thereby ensuring enhanced productivity per unit area. This approach supports the economic viability and sustainability of acid lime cultivation.

Table 3: Effect of Different Treatments on Yield Attributes.

Treatment Code	Fruit Length (cm)	Fruit Diameter (cm)	Average Fruit Weight (g)	Number of Fruits per Plant	Fruit Yield per Tree (kg)
T1	3.833	3.933	33.667	576.333	14.60
T2	4.033	4.133	36.333	664.333	21.11
T3	4.167	4.033	38.333	679.667	26.08
T4	4.333	4.233	39.333	692.000	24.80
T5	4.367	4.333	40.333	703.333	19.35
T6	4.467	4.367	42.333	731.333	31.94
T7	4.667	4.533	46.333	741.000	47.66
T8	4.567	4.433	41.333	712.667	36.13
CD (0.05)	0.321	0.292	2.718	37.228	5.30
SE(m)	0.105	0.095	0.888	12.156	1.7445
SE(d)	0.148	0.135	1.255	17.191	2.4671
C.V.	4.223	3.881	3.867	3.062	10.9055

Quality Attributes. Integrated nutrient management has demonstrated a significant effect on the quality attributes of acid lime, as detailed in Table 4. Notably, treatment T7, which comprises 50% Recommended Dose of Fertilizer (RDF), 50% Vermicompost, and Poultry Manure, consistently yielded superior results across multiple quality parameters. Specifically, treatment T7 attained the highest total soluble solids (TSS) at 7.733°Brix, the greatest fruit juice content at 45.667%, and the highest ascorbic acid content at 32.233 mg/100g. These outcomes were statistically comparable to those of other integrated treatments, including T8, which achieved a TSS of 7.567°Brix and a juice content of 43.767%, as well as T4 with a TSS of 7.533°Brix; however, T7 remained the most effective overall. Additionally, the alternative treatments exhibited improvements when assessed against the Absolute Control (T1), which recorded the lowest values for TSS at 7.033°Brix and fruit juice content at 35.733%. Although the variations in ascorbic acid content were not statistically significant, the observed trends further substantiate the advantages of integrated nutrient management. Treatments T6, which yielded 41.467% juice and 31.5 mg/100g ascorbic acid, and T3, with 31.3 mg/100g ascorbic acid, closely followed T7 in performance. The influence of INM on fruit quality attributes has been well-documented in acid lime and other fruit crops. Kumar *et al*. (2020) found that acid lime fruits from trees receiving 50% RDF with 75% farmyard manure, 75% vermicompost, and biofertilizers exhibited improved biochemical characteristics, including higher total soluble solids (TSS), better sugar-acid balance, and increased ascorbic acid content. These findings align with previous research by Hasan *et al*. (2013), who reported that vermicompost application in mango (cv. Himsagar) led to improvements in fruit length, weight, pulp content, TSS, and vitamin C levels while reducing acidity. Additionally, Solanki *et al*. (2020) demonstrated that peach trees receiving 75% RDF with vermicompost showed enhanced sugar content and TSS. These studies collectively emphasize the role of INM in optimizing fruit quality parameters, making it a crucial practice for improving the nutritional and market value of acid lime. In conclusion, the integration of organic and inorganic nutrient sources, particularly as implemented in treatment T7, effectively optimizes the compositional and yield attributes of acid lime, thereby supporting its potential for sustainable and profitable production.

Table 4: Effect of Different Treatments on Quality Attributes.

Treatment Code	Fruit Juice Content (%)	Peel Thickness (mm)	TSS (°Brix)	Ascorbic Acid Content (mg/100g)
T1	38.033 (38.07)	1.133	7.033	30.543
T2	35.733 (36.71)	1.333	7.333	31.210
T3	39.567 (38.08)	1.333	7.433	31.300
T4	39.133 (38.72)	1.533	7.533	31.133
T5	40.633 (39.60)	1.333	7.333	30.600
T6	41.467 (40.09)	1.367	7.467	31.500
T7	45.667 (42.51)	1.633	7.733	32.233
T8	43.767 (41.42)	1.433	7.567	31.267
CD (0.05)	2.719 (9.49)	0.27	0.25	Non-Significant
SE(m)	0.888 (5.41)	0.088	0.082	0.441
SE(d)	1.256 (6.43)	0.125	0.115	0.624
C.V.	3.797 (11.24)	10.995	1.904	2.447

CONCLUSIONS

In summary, the results of this study provide compelling evidence that integrated nutrient management markedly improves both the vegetative growth and yield attributes of acid lime, while also enhancing key quality parameters. The application of combined organic amendments and inorganic fertilizers, particularly the regimen incorporating 50% RDF with 50% vermicompost, yielded statistically significant improvements in tree height, trunk diameter, and canopy spread, as well as in fruit dimensions, weight, and overall yield. These enhancements are

attributable to the synergistic effects of organic amendments, which improve soil structure, nutrient availability, and microbial activity, in conjunction with the rapid nutrient release afforded by inorganic fertilizers. Although certain quality parameters, such as ascorbic acid content, did not exhibit statistically significant differences, trends indicate that integrated nutrient management contributes to improved fruit juice content and total soluble solids. Collectively, these findings underscore the critical role of balanced nutrient management in optimizing crop performance and advancing sustainable production practices in acid lime cultivation, with potential implications for enhanced economic returns and long-term soil health.

FUTURE SCOPE

Future research should incorporate multi-year trials across diverse regions, explore a broader array of nutrient treatments, and include economic and long-term soil health assessments. Such investigations will be critical in developing optimized, region-specific protocols that enhance both crop productivity and environmental sustainability in acid lime cultivation.

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Conflict of Interest. None.

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