# Lemon cv. Assam lemon (*Citrus limon* Burm.) quality and soil-leaf nutrient availability affected by different pruning intensities and nutrient management

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**A field experiment was laid out in two factorial randomized block design with four levels of pruning and seven levels of nutrients, consisting recommended dose of fertilizers and different combinations of organic manure (vermicompost), inorganic fertilizer, bio-fertilizer (azotobacter), mycorrhiza (VAM) and their interaction between 2013 and 2015 on 9-year-old lemon plants. Studies revealed that all physicochemical parameters, viz. fruit weight, puncture force, total soluble solid, total sugar, ascorbic acid were highest in ($P_3N_4$) combination of higher level of pruning. However, the maximum availability of leaf and soil nutrients was recorded in $N_4$.**

**Keywords:** Lemon, nutrient management, pruning, soil-leaf nutrient availability, yield and quality.

CITRUS, the most economically important fruit crop in the world, is grown in developed and developing countries and constitutes one of the main sources of vitamin C. There is also an increasing demand for 'high quality fresh citrus' driven by World Health Organization recommendations[1]. It accounts for 4% (286.4 thousand ha) of total area under fruit and 3.2% (2835 thousand MT) of total fruit production with a productivity of 9.9 MT $ha^{-1}$ in India[2]. Assam lemon is one of the important varieties of lemon, extensively grown in the north-eastern parts of India. It is a dwarf cultivar suitable for high density planting[3]. In northern parts of West Bengal, it is early bearing with three fruiting seasons, viz. April–May, August–September and November–December. The earlier vegetative flushes of the previous season growth generally are more productive[4]. It was observed that the main reason for decline in the productivity of the plant was unbalanced overcrowded orchard which also resulted in high disease-pest infestation. Therefore, pruning is essential to maximize sunlight penetration which not only influences flowering and fruit set but also enhances fruit quality and colour development. As lemon plants bear thrice a year, proper manuring and fertilization have to be resorted for obtaining quality production which depends on healthy and sturdy tree growth[5]. It has been proved that nitrogenous, phosphatic and potassic fertilizers have direct influence on many life processes such as photosynthesis, formation of sugars and starch, fruit development, synthesis of proteins, enhancement of fruit flavour, colour, size, appearance, soluble solids, acidity, vitamin content, taste as well as shelf life[6,7]. However, continuous use of chemical fertilizers has degraded soil health in terms of fertility and productivity and caused soil pollution. In such a situation, the combined application of organic, inorganic and biofertilizers need to be resorted for avoiding the deleterious effect of chemical fertilizers as well as to improve the physical properties of soil by increasing water holding capacity, total pore space, aggregate stability, erosion resistance, temperature insulation and to maintain better nutrient availability in both soil and leaf. However, information about the response of lemon against pruning and nutrient management in northern parts of West Bengal is lacking. Keeping this in view, the present study was conducted to standardize the impact of pruning intensity and nutrient management in fruit yield and quality of lemon cv. Assam lemon.

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## Materials and methods

### *Experimental site*

The present study was carried out between 2013 and 2015 on seven-year-old lemon cv. Assam lemon plants. The plant were planted at 3 m × 3 m spacing at the instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, situated at 26°19′86″N lat. and 89°23′53″E long. with an altitude of 43 m amsl.

*Treatment details and experimental design*

There were four levels of pruning, namely $P_0$ – $N_0$ pruning (control), $P_1$ – 25 cm, $P_2$ – 50 cm and $P_3$ – 75 cm pruning from the terminal portion of the shoot respectively. Seven treatments of nutrient management, viz. $N_1$ – 100% recommended dose of fertilizer (RDF) (nitrogen at 210 g $plant^{-1}$, phosphorous at 140 g $plant^{-1}$, potassium at 210 g $plant^{-1}$), $N_2$ - vermicompost (20 g $plant^{-1}$) + azotobacter (18 g $plant^{-1}$) + vesicular arbuscular mycorrhiza (150 g $plant^{-1}$), $N_3$ – vermicompost, $N_4$ – 75% RDF + vermicompost + azotobacter + vesicular arbuscular mycorrhiza, $N_5$ – 75% RDF + vermicompost, $N_6$ –50% RDF + vermicompost + azotobacter + vesicular arbuscular mycorrhiza and $N_7$ – 50% RDF + vermicompost were applied alone and in combination with different levels of pruning. The experiment was laid out in two factorial asymmetrical randomized block design (RBD) and 28 treatment combinations (four levels of pruning and seven levels of nutrients) with three replications and six plants were kept in each treatment and two plants per replication.

*Application of treatments*

All pruning levels were done on 21 November 2013, after harvesting of Mrig bahar. Nitrogenous fertilizer was applied in two split doses. First, half dose of nitrogen and full dose of phosphorus, potassium and vermicompost were applied in February 2014 and the remaining half of nitrogen was applied in April 2014. Azotobacter and vesicular arbuscular mycorrhiza were applied in December 2013, after harvesting of Mrig bahar.

*Observation and methods of estimation*

All quality parameters were recorded at three distinct seasons, viz. Ambe, Mrig and Hasth bahar respectively. After harvesting of each bahar, thirty fruits were taken for each treatment, washed in running tap water and the necessary physicochemical analysis was done.

*Fruit weight*

Fruit weight was measured using an electronic (digital) balance (Mettler Toledo PB153-L) and expressed in gram (g).

*Fruit length and breadth*

Fruit length and breadth were measured using digital slide caliper and expressed in centimeters (cm).

*Fruit colour*

Fruit colour were recorded using Royal Horticulture Society mini colour chart (fifth edition, 2007).

*Specific gravity*

Specific gravity was calculated by the formula of water displacement method (water volume/weight of the fruit).

*Juice percentage*

For calculating the juice content, fruit juice was extracted with the help of a glass squeezer, then strained and its volume measured using a measuring cylinder. The juice content was expressed in percentage (%) with respect of fruit weight.

*Puncture force of fruit*

Puncture force of fruit was measured with the help of texture analyzer (Model: TA-XT plus, Stable Micro System Limited, Surrey, UK) equipped with a 50-N load cell fitted with a cylindrical probe (2 mm and a trigger force of 5 g).

*Peel thickness*

Peel thickness of fruits was determined with a digital slide caliper (expressed in mm).

*Total soluble solids (TSS)*

TSS content of fruit was recorded with a hand refractometer (expressed in °Brix)[8].

*Total sugar and reducing sugar*

Total sugar and reducing sugar content were estimated (in %)[8].

*Titrable acidity*

The acidity of the fruit juice was estimated (in %)[9].

*Ascorbic acid*

Ascorbic acid content of fruits was measured colorimetrically by UV/VIS spectrometer (Perkin Elmer, Lambda 25) (expressed as mg per 100 g fruit pulp)[9].

*Leaf nutrient analysis*

For leaf nutrient analysis, six-month-old leaves were taken for sampling. From each tree about 40 leaves with no apparent insect or any other physical damage were collected, packed in polythene bags, labelled and carried to the laboratory. The leaves were washed carefully with detergent and distilled water to remove dust and contaminants, air-dried in the shade for a couple of days followed by oven drying at 70°C, ground to fine powder and stored in air-tight plastic bottles at room temperature before digestion for nutrient analysis[10]. Total leaf nitrogen (in percentage) was estimated using oven-dried and ground leaf sample in CHNSO Elementer (Model no. Vario EL III). Total phosphorus (in percentage) content of leaves was estimated by aminonaphtholsulphonic acid (ANSA) reagent following the method of Fiske and Row[11], using UV-VIS spectrometer (Perkin Elmer) at 660 nm. Total potassium (%) content of leaves was estimated using flame photometer (Systronics, Model 128) following Jackson[12].

### *Soil nutrient analysis*

Composite soil samples from the entire experimental field were collected from 0 to 60 cm depth, as 60–80% of root activity in citrus crops is confined to first 60 cm top soil[13]. Samples were air-dried at room temperature and passed through a 2 mm sieve and homogenized[14]. Available nitrogen (kg/ha) was determined by alkaline $KMNO_4$ method developed by Subbiah and Asija[15] using Kel plus-Distill Em. Auto Analyzer[16]; phosphorus (kg/ha) content was determined by extracting the soil with a mixture of 0.03 M $NH_4F$ and 0.025 M HCl for 5 min (ref. 17) followed by calorimetric measurement of phosphorus by UV/VIS spectrometer (Perkin Elmer, Lambda 25)[18] and potassium (kg/ha) was determined by extracting the soils with neutral normal $NH_4$ acetate extract and then the content was measured using a flame photometer following Black[18].

### *Statistical analysis*

Analysis of variance (one-way classified data) for each parameter was performed using ProcGlm of statistical analysis system (SAS) software (version 9.3). Mean separation for different treatments and parameters was performed using least significant different (LSD) test ($P \leq 0.05$). Normality of residuals assuming analysis of variance (ANOVA) was tested using Kolmogrov-Smirnov, Shapiro-Wilk, Cramer-Von Mises and Anderson Darling procedures using Proc-Univariate procedure of SAS (version 9.3).

## Results and discussion

### *Fruit weight*

Observations recorded on fruit weight under different treatments and their combinations (Tables 1 and 2) show significant difference under different pruning and nutrient levels in all three respective seasons (Ambe, Mrig and Hasth bahar). Highest fruit weight was recorded in $P_3$ (75 cm pruning) followed by $P_2$ (50 cm pruning) at Ambe, Mrig and Hasth bahar. In case of nutrients, highest fruit weight was observed in $N_4$ followed by $N_6$. Lowest fruit weight was observed in $N_3$. Increase in weight might be due to availability of more nutrients both in leaf and soil in this particular treatment. The interaction effect between pruning and nutrients revealed that the fruit weight was statistically significant under all treatment combinations in three seasons. Thus maximum fruit weight was found in $T_{25}$ ($P_3N_4$) combination followed by $T_{27}$ ($P_3N_6$).

These results might be due to better sunlight penetration in plant canopy, which caused higher fruit weight and better colour development in heavily pruned citrus plants than unpruned plants[19]. Similar findings were reported by Ahmad *et al.*[20] in kinnow and Singh *et al.*[19] in citrus. Improvement in the quality of fruits might be due to proper supply of nutrients and induction of hormones, which stimulates cell division, cell elongation, increase in number and weight of fruits, better root development and better translocation of water uptake and deposition of nutrients. This might be attributed to improved fertilizer use efficiency with the application of organic source of nutrients[21]. These results agree with Kumar *et al.*[22] in lemon cv. Pant Lemon.

### *Fruit length*

The data pertaining to fruit length (Tables 1 and 2) were significantly different at different levels of pruning and nutrients and at combined effect of both. However, the data were statistically at par under $N_5$ and $N_6$ in Ambe bahar and $N_2$ and $N_3$ in Mrig bahar. Maximum fruit length was recorded in $P_3$ at Ambe, Mrig and Hasth bahar followed by $P_2$. The maximum fruit length was recorded in $N_4$ followed by $N_6$ and the minimum fruit length was observed in $N_3$ at Ambe, Mrig and Hasth bahar respectively. The fruit length was influenced by different interaction effects between pruning and nutrients. It was revealed that $T_{25}$ ($P_3N_4$) gave the highest fruit length followed by $T_{27}$ ($P_3N_6$).

### *Fruit breadth*

Observations on fruit breadth were statistically significant under different treatments except under nutrient treatments in Ambe bahar (Tables 1 and 2). The highest fruit breadth was recorded in $P_3$ followed by $P_2$ and in $N_4$, whereas the lowest fruit breadth was observed in $N_3$ at all three seasons respectively. Thus the larger fruit size (length and breadth) in heavily pruned plants might be attributed to lower fruit density and increased leaf : fruit ratio that supplied higher photosynthates to plants under this treatment; whereas lower fruit size in unpruned

**Table 1.** Effect of pruning and nutrient management on fruit weight, length, breadth and specific gravity of lemon cv. Assam lemon

| Treatments | Weight (g) | | | Length (cm) | | | Breadth (cm) | | | Specific gravity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth |
| $P_0$ | 112.00d | 119.33d | 115.00d | 12.53d | 13.72d | 13.25d | 4.27c | 5.54d | 4.78d | 0.61d | 0.67d | 0.64d |
| $P_1$ | 122.00c | 130.67c | 127.00c | 13.46c | 14.42c | 14.08c | 4.40b | 5.80c | 4.89c | 0.72c | 0.77c | 0.74c |
| $P_2$ | 124.00b | 134.00b | 128.00b | 13.64b | 15.23b | 14.75b | 4.45ab | 5.89b | 4.99b | 0.76b | 0.82b | 0.79b |
| $P_3$ | 141.00a | 154.67a | 147.00a | 14.44a | 15.70a | 15.05a | 4.48a | 6.20a | 5.21a | 0.82a | 0.87a | 0.85a |
| SEm (±) | 0.86 | 0.85 | 0.66 | 0.04 | 0.03 | 0.01 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD ($P \leq 0.05$) | 2.45 | 2.41 | 1.88 | 0.11 | 0.08 | 0.04 | 0.08 | 0.07 | 0.03 | 0.02 | 0.02 | 0.02 |
| $N_1$ | 112.00de | 119.33de | 115.00cd | 12.53c | 13.72de | 13.25c | 4.27a | 5.54bc | 4.78cd | 0.61bc | 0.67bc | 0.64cd |
| $N_2$ | 111.67de | 119.00e | 115.00d | 12.46c | 13.69ef | 13.25d | 4.26a | 5.51cd | 4.78de | 0.61cd | 0.64c | 0.62d |
| $N_3$ | 110.67e | 118.00e | 114.00d | 12.37d | 13.67f | 13.12e | 4.22a | 5.30d | 4.71e | 0.56d | 0.62c | 0.59d |
| $N_4$ | 121.33a | 128.00a | 126.00a | 12.63a | 13.98a | 13.45a | 4.37a | 5.71a | 4.83a | 0.67a | 0.73a | 0.71a |
| $N_5$ | 120.67bc | 127.67bc | 125.00b | 12.58ab | 13.80bc | 13.34b | 4.32a | 5.61abc | 4.79bc | 0.65ab | 0.72ab | 0.69ab |
| $N_6$ | 121.33ab | 128.00ab | 125.00ab | 12.63ab | 13.95ab | 13.45a | 4.34a | 5.68ab | 4.81ab | 0.66ab | 0.73a | 0.71ab |
| $N_7$ | 113.33cd | 120.33cd | 116.33c | 12.57bc | 13.74cd | 13.29b | 4.27a | 5.60abc | 4.79bcd | 0.64ab | 0.69ab | 0.67bc |
| SEm (±) | 1.14 | 1.12 | 0.88 | 0.05 | 0.04 | 0.02 | 0.03 | 0.03 | 0.02 | 0.01 | 0.01 | 0.01 |
| LSD ($P \leq 0.05$) | 3.24 | 3.19 | 2.48 | 0.15 | 0.10 | 0.05 | NS | 0.10 | 0.04 | 0.03 | 0.03 | 0.03 |

Means with the same letter are not significantly different.

**Table 2.** Interaction effect of pruning and nutrient management on fruit weight, length, breadth and specific gravity of lemon cv. Assam lemon

| | Weight (g) | | | Length (cm) | | | Breadth (cm) | | | Specific gravity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth |
| $T_1$ ($P_0N_1$) | 112.00 | 119.33 | 115.00 | 12.53 | 13.72 | 13.25 | 4.27 | 5.54 | 4.78 | 0.61 | 0.67 | 0.64 |
| $T_2$ ($P_0N_2$) | 111.67 | 119.00 | 115.00 | 12.46 | 13.69 | 13.25 | 4.26 | 5.51 | 4.78 | 0.61 | 0.64 | 0.62 |
| $T_3$ ($P_0N_3$) | 110.67 | 118.00 | 114.00 | 12.37 | 13.67 | 13.12 | 4.22 | 5.30 | 4.71 | 0.56 | 0.62 | 0.59 |
| $T_4$ ($P_0N_4$) | 121.33 | 128.00 | 126.00 | 12.63 | 13.98 | 13.45 | 4.37 | 5.71 | 4.83 | 0.67 | 0.73 | 0.71 |
| $T_5$ ($P_0N_5$) | 120.67 | 127.67 | 125.00 | 12.58 | 13.80 | 13.34 | 4.32 | 5.61 | 4.79 | 0.65 | 0.72 | 0.69 |
| $T_6$ ($P_0N_6$) | 121.33 | 128.00 | 125.00 | 12.63 | 13.95 | 13.45 | 4.34 | 5.68 | 4.81 | 0.66 | 0.73 | 0.71 |
| $T_7$ ($P_0N_7$) | 113.33 | 120.33 | 116.33 | 12.57 | 13.74 | 13.29 | 4.27 | 5.60 | 4.79 | 0.64 | 0.69 | 0.67 |
| $T_8$ ($P_1N_1$) | 122.00 | 130.67 | 127.00 | 13.46 | 14.42 | 14.08 | 4.40 | 5.80 | 4.89 | 0.72 | 0.77 | 0.74 |
| $T_9$ ($P_1N_2$) | 121.67 | 130.33 | 126.67 | 13.44 | 14.42 | 14.08 | 4.38 | 5.75 | 4.87 | 0.69 | 0.77 | 0.74 |
| $T_{10}$ ($P_1N_3$) | 121.33 | 130.00 | 126.33 | 13.23 | 14.34 | 14.07 | 4.37 | 5.72 | 4.84 | 0.69 | 0.77 | 0.74 |
| $T_{11}$ ($P_1N_4$) | 123.33 | 132.00 | 128.00 | 13.56 | 14.65 | 14.21 | 4.43 | 5.84 | 4.93 | 0.75 | 0.81 | 0.78 |
| $T_{12}$ ($P_1N_5$) | 122.00 | 131.33 | 127.33 | 13.53 | 14.59 | 14.14 | 4.42 | 5.83 | 4.91 | 0.74 | 0.79 | 0.75 |
| $T_{13}$ ($P_1N_6$) | 122.67 | 132.00 | 127.67 | 13.55 | 14.60 | 14.17 | 4.43 | 5.83 | 4.92 | 0.74 | 0.80 | 0.77 |
| $T_{14}$ ($P_1N_7$) | 122.00 | 131.00 | 127.33 | 13.48 | 14.53 | 14.12 | 4.41 | 5.81 | 4.90 | 0.73 | 0.79 | 0.75 |
| $T_{15}$ ($P_2N_1$) | 124.00 | 134.00 | 128.00 | 13.64 | 15.23 | 14.75 | 4.45 | 5.89 | 4.99 | 0.76 | 0.82 | 0.79 |
| $T_{16}$ ($P_2N_2$) | 124.00 | 133.33 | 128.00 | 13.60 | 14.99 | 14.65 | 4.45 | 5.87 | 4.95 | 0.75 | 0.82 | 0.79 |
| $T_{17}$ ($P_2N_3$) | 123.67 | 132.67 | 128.00 | 13.60 | 14.83 | 14.43 | 4.45 | 5.85 | 4.95 | 0.75 | 0.81 | 0.78 |
| $T_{18}$ ($P_2N_4$) | 130.67 | 140.00 | 135.00 | 13.82 | 15.61 | 14.89 | 4.47 | 6.03 | 5.11 | 0.78 | 0.85 | 0.83 |
| $T_{19}$ ($P_2N_5$) | 126.67 | 134.33 | 130.33 | 13.70 | 15.56 | 14.82 | 4.46 | 5.90 | 5.07 | 0.76 | 0.84 | 0.82 |
| $T_{20}$ ($P_2N_6$) | 128.00 | 135.00 | 130.67 | 13.72 | 15.56 | 14.88 | 4.47 | 6.01 | 5.08 | 0.77 | 0.84 | 0.82 |
| $T_{21}$ ($P_2N_7$) | 124.33 | 134.33 | 130.00 | 13.68 | 15.38 | 14.81 | 4.46 | 5.90 | 5.04 | 0.76 | 0.83 | 0.81 |
| $T_{22}$ ($P_3N_1$) | 141.00 | 154.67 | 147.00 | 14.44 | 15.70 | 15.05 | 4.48 | 6.20 | 5.21 | 0.82 | 0.87 | 0.85 |
| $T_{23}$ ($P_3N_2$) | 136.33 | 148.67 | 145.00 | 14.35 | 15.68 | 14.95 | 4.48 | 6.14 | 5.19 | 0.79 | 0.87 | 0.85 |
| $T_{24}$ ($P_3N_3$) | 132.00 | 148.00 | 142.67 | 14.04 | 15.62 | 14.89 | 4.48 | 6.07 | 5.18 | 0.79 | 0.87 | 0.85 |
| $T_{25}$ ($P_3N_4$) | 154.67 | 169.33 | 158.67 | 14.97 | 15.90 | 15.45 | 4.62 | 6.28 | 5.35 | 0.84 | 0.93 | 0.92 |
| $T_{26}$ ($P_3N_5$) | 144.00 | 162.00 | 155.00 | 14.94 | 15.71 | 15.34 | 4.50 | 6.23 | 5.25 | 0.83 | 0.89 | 0.88 |
| $T_{27}$ ($P_3N_6$) | 151.67 | 165.00 | 158.00 | 14.95 | 15.78 | 15.4 | 4.51 | 6.26 | 5.31 | 0.84 | 0.91 | 0.89 |
| $T_{28}$ ($P_3N_7$) | 143.67 | 161.00 | 152.00 | 14.63 | 15.70 | 15.26 | 4.48 | 6.23 | 5.23 | 0.83 | 0.87 | 0.85 |
| SEm (±) | 2.28 | 2.25 | 1.75 | 0.10 | 0.07 | 0.03 | 0.07 | 0.07 | 0.03 | 0.02 | 0.02 | 0.02 |
| LSD ($P \leq 0.05$) | 6.47 | 6.37 | 4.97 | 0.29 | 0.21 | 0.10 | NS | NS | NS | NS | NS | NS |

plants may be due to higher competition of photoassimilates among the developing fruits[7]. Similar results were found in guava[23] and in kinnow fruit[20]. Increase in fruit length and breadth might also be due to cell division in the beginning and enlargement in later stages. Increase in fruit size with potassium application could be due to the fact that potassium increases photophosphorylation and dark reaction of photosynthesis which leads to the accumulation of more carbohydrates and also enhancing the translocation of photosynthates, which mobilize the stored material from leaves and stem towards the fruit[24].

### *Specific gravity*

Data on fruit specific gravity of lemon fruits under different treatments have been presented in Tables 1 and 2 for the three seasons. Maximum specific gravity was recorded in $P_3$ followed by $P_2$ at Ambe, Mrig and Hasth bahar. Minimum specific gravity was observed in unpruned ($P_0$) plants at all three seasons respectively. Similarly maximum specific gravity was recorded in $N_4$ followed by $N_6$ and minimum specific gravity was observed in $N_3$. The interactions between pruning and nutrients have no effect on fruit specific gravity. Higher nutrient availability and greater production of photosynthates through pruning enhanced higher fruit weight increasing the specific gravity.

### *Fruit colour*

Observations on fruit colour under different treatments and their combination are presented in Tables 3 and 4. Light green fruit colour was recorded in $P_3$ (YGG144C), dark green colour fruit was observed in ($P_0$) unpruned plants (GG143A); and light green fruit colour (YGG144B) was recorded in $N_4$ followed by $N_6$ (YGG144A). Dark green colour fruit (GG143B) was observed in $N_3$ and the interaction effect between pruning and nutrient revealed that $T_{25}$ ($P_3N_4$) maintained light green fruit colour (YGG144C), whereas dark green colour fruit was recorded (GG143C) in $T_3$ ($P_0N_3$) at Ambe, Mrig and Hasth bahar respectively. It might be due to better sunlight penetration in plant canopy, which caused better colour development in heavily pruned plants than unpruned plants[19]. Similar results were recorded by Ahmad *et al.*[20] in kinnow fruits. Changing fruit colour from dark green to light green might be enhanced by increasing potassium through integrated use of fertilizers[7].

### *Juice percentage*

Tables 3 and 4 show juice percentage under different pruning and nutrient treatments in all the three respective seasons. Maximum juice percentage was recorded in $P_3$ followed by $P_2$. Similarly maximum juice percentage was recorded in $N_4$ followed by $N_6$ at Ambe, Mrig and Hasth bahar. Minimum juice percentage was observed in $N_3$. The interaction effect between pruning and nutrients revealed significant variation with respect to juice (%) under Mrig and Hasth bahar. Results showed that $T_{25}$ ($P_3N_4$) gave the highest juice percentage followed by $T_{27}$ ($P_3N_6$) , whereas lowest juice percentage was recorded in $T_3$ ($P_0N_3$) in the three seasons respectively. These results agree with the findings of Ahmad *et al.*[20] in kinnow and in Valencia orange[25], which showed higher juice percentage in heavily pruned plants. Increase in juice percentage could be due to the fact that humic acid and fulvic acid fraction of the soil organic matter contributed by the organic sources (vermicompost) would have probably formed water soluble micronutrient, thereby increasing their availability and uptake resulting in better quality[26].

### *Peel thickness*

Observations on peel thickness under different pruning and nutrients level have been presented in Tables 3 and 4 for the three seasons. Highest peel thickness was recorded in $P_3$ (4.95, 5.08 and 5.04 mm) and the lowest peel thickness was observed in unpruned plants (4.81, 4.93 and 4.89 mm) at Ambe, Mrig and Hasth bahar respectively. Similarly highest peel thickness (44.84, 4.97 and 4.91 mm) was recorded in $N_4$ followed by $N_6$ (4.84, 4.96 and 4.91 mm) and lowest peel thickness (4.78, 4.92 and 4.85 mm) was observed in $N_3$ in the three seasons respectively. The interaction effect was statistically at par under three cropping seasons except in Ambe bahar.

### *Puncture force of fruit*

Data pertaining to puncture force of fruit under different pruning and nutrient treatments was significantly different in three seasons (Tables 3 and 4). Maximum fruit firmness was recorded in $P_3$ (0.52, 0.59 and 0.54 N) followed by $P_2$ (0.48, 0.55 and 0.51 N) and similarly in $N_4$ (0.46, 0.53 and 0.48 N) followed by $N_6$ (0.45, 0.52 and 0.48 N) in all the three seasons. Minimum puncture force of fruit (0.38, 0.45 and 0.41 N) was observed in $N_3$.

### *Total soluble solids*

Data on total soluble solids of lemon fruits under different pruning and nutrient treatments were significantly different (Tables 5 and 6) in three seasons, although it was statistically at par under different nutrient treatments in Mrig bahar. The highest total soluble solids was recorded in $P_3$ (6.03, 6.73 and 6.53°Brix) followed by $P_2$ (5.93, 6.67 and 6.33°Brix); maximum total soluble solids (5.53,

**Table 3.** Effect of pruning and nutrient management on fruit colour, juice percentage, peel thickness and puncture force of lemon cv. Assam lemon

| | Colour | | | Juice (%) | | | Peel thickness (mm) | | | Puncture force (N) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth |
| $P_0$ | YGG146B | YGG146B | YGG146B | 29.35d | 30.55d | 30.13d | 4.81d | 4.93d | 4.89d | 0.44c | 0.51b | 0.47c |
| $P_1$ | YGG144B | YGG144B | YGG144B | 37.17c | 37.87c | 37.39c | 4.87c | 5.00c | 4.95c | 0.46b | 0.53b | 0.49b |
| $P_2$ | YGG144A | YGG144A | YGG144A | 42.07b | 45.84b | 45.38b | 4.92b | 5.05b | 4.99b | 0.48b | 0.55b | 0.51b |
| $P_3$ | YGG144B | YGG144B | YGG144B | 50.32a | 51.80a | 51.34a | 4.95a | 5.08a | 5.04a | 0.52a | 0.59a | 0.54a |
| SEm (±) | – | – | – | 1.19 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD ($P \leq 0.05$) | – | – | – | 3.38 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| $N_1$ | YGG146B | YGG146B | YGG146B | 29.35e | 30.55e | 30.13e | 4.81cde | 4.93cde | 4.89bc | 0.44abc | 0.51b | 0.47abc |
| $N_2$ | YGG144A | YGG144A | YGG144A | 29.24f | 29.87f | 29.51f | 4.81de | 4.92de | 4.89cd | 0.41bc | 0.48ab | 0.44bc |
| $N_3$ | YGG144B | YGG144B | YGG144B | 29.12g | 29.72g | 29.45g | 4.78e | 4.92e | 4.85d | 0.38c | 0.45ab | 0.41c |
| $N_4$ | GG143B | GG143B | GG143B | 30.40b | 31.17a | 30.65a | 4.84a | 4.97a | 4.91a | 0.46a | 0.53a | 0.48a |
| $N_5$ | YGG144A | YGG144A | YGG144A | 30.21c | 30.85c | 30.45c | 4.83bc | 4.96bc | 4.91bc | 0.45abc | 0.52a | 0.48ab |
| $N_6$ | YGG144B | YGG144B | YGG144B | 30.26a | 31.00b | 30.59b | 4.84ab | 4.96ab | 4.91ab | 0.45ab | 0.52a | 0.48abc |
| $N_7$ | YGGN144A | YGGN144A | YGGN144A | 29.76d | 30.78d | 29.33d | 4.83bcd | 4.94bcd | 4.91bc | 0.45abc | 0.51ab | 0.47abc |
| SEm (±) | – | – | – | 1.57 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD ($P \leq 0.05$) | – | – | – | 4.47 | 0.06 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 |

Means with the same letter are not significantly different. (YGG, Yellow green group, GG, green group).

**Table 4.** Interaction effect of pruning and nutrient management on fruit colour, juice percentage, peel thickness and puncture force of lemon cv. Assam lemon

| | Colour | | | Juice (%) | | | Peel thickness (mm) | | | Puncture force (N) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth |
| $T_1$ ($P_0N_1$) | YGG146B | YGG146B | YGG146B | 29.35 | 30.55 | 30.13 | 4.81 | 4.93 | 4.89 | 0.44 | 0.51 | 0.47 |
| $T_2$ ($P_0N_2$) | YGG144A | YGG144A | YGG144A | 29.24 | 29.87 | 29.51 | 4.81 | 4.92 | 4.89 | 0.41 | 0.48 | 0.44 |
| $T_3$ ($P_0N_3$) | YGG144B | YGG144B | YGG144B | 29.12 | 29.72 | 29.45 | 4.78 | 4.92 | 4.85 | 0.38 | 0.45 | 0.41 |
| $T_4$ ($P_0N_4$) | GG143B | GG143B | GG143B | 30.40 | 31.17 | 30.65 | 4.84 | 4.97 | 4.91 | 0.46 | 0.53 | 0.48 |
| $T_5$ ($P_0N_5$) | YGG144A | YGG144A | YGG144A | 30.21 | 30.85 | 30.45 | 4.83 | 4.96 | 4.91 | 0.45 | 0.52 | 0.48 |
| $T_6$ ($P_0N_6$) | YGG144B | YGG144B | YGG144B | 30.26 | 31.00 | 30.59 | 4.84 | 4.96 | 4.91 | 0.45 | 0.52 | 0.48 |
| $T_7$ ($P_0N_7$) | YGGN144A | YGGN144A | YGGN144A | 29.76 | 30.78 | 29.33 | 4.83 | 4.94 | 4.91 | 0.45 | 0.51 | 0.47 |
| $T_8$ ($P_1N_1$) | YGG144B | YGG144B | YGG144B | 37.17 | 37.87 | 37.39 | 4.87 | 5.00 | 4.95 | 0.46 | 0.53 | 0.49 |
| $T_9$ ($P_1N_2$) | YGG144B | YGG144B | YGG144B | 36.75 | 37.83 | 37.05 | 4.87 | 4.99 | 4.94 | 0.46 | 0.53 | 0.49 |
| $T_{10}$ ($P_1N_3$) | YGG144A | YGG144A | YGG144A | 30.54 | 37.62 | 30.89 | 4.85 | 4.98 | 4.92 | 0.46 | 0.53 | 0.48 |
| $T_{11}$ ($P_1N_4$) | GG143A | GG143A | GG143A | 40.58 | 41.95 | 41.45 | 4.90 | 5.03 | 4.97 | 0.48 | 0.54 | 0.50 |
| $T_{12}$ ($P_1N_5$) | YGG144B | YGG144B | YGG144B | 37.23 | 41.33 | 37.58 | 4.88 | 5.02 | 4.95 | 0.47 | 0.54 | 0.49 |
| $T_{13}$ ($P_1N_6$) | YGG144A | YGG144A | YGG144A | 38.44 | 41.89 | 41.01 | 4.90 | 5.02 | 4.97 | 0.47 | 0.54 | 0.49 |
| $T_{14}$ ($P_1N_7$) | YGGN144A | YGGN144A | YGGN144A | 37.21 | 37.88 | 37.45 | 4.88 | 5.01 | 4.95 | 0.47 | 0.53 | 0.49 |
| $T_{15}$ ($P_2N_1$) | YGG144A | YGG144A | YGG144A | 42.07 | 45.84 | 45.38 | 4.92 | 5.05 | 4.99 | 0.48 | 0.55 | 0.51 |
| $T_{16}$ ($P_2N_2$) | YGG144B | YGG144B | YGG144B | 41.24 | 45.84 | 42.35 | 4.91 | 5.05 | 4.99 | 0.48 | 0.55 | 0.51 |
| $T_{17}$ ($P_2N_3$) | YGG144B | YGG144B | YGG144B | 41.18 | 42.73 | 41.55 | 4.90 | 5.04 | 4.98 | 0.48 | 0.55 | 0.51 |
| $T_{18}$ ($P_2N_4$) | GG143B | GG143B | GG143B | 45.42 | 50.86 | 50.49 | 4.92 | 5.06 | 5.00 | 0.49 | 0.56 | 0.52 |
| $T_{19}$ ($P_2N_5$) | YGG144A | YGG144A | YGG144A | 45.34 | 46.03 | 45.65 | 4.92 | 5.05 | 5.00 | 0.48 | 0.56 | 0.51 |
| $T_{20}$ ($P_2N_6$) | YGG144A | YGG144A | YGG144A | 45.34 | 46.12 | 45.79 | 4.92 | 5.05 | 5.00 | 0.49 | 0.56 | 0.51 |
| $T_{21}$ ($P_2N_7$) | YGGN144B | YGGN144B | YGGN144B | 45.13 | 45.93 | 45.61 | 4.92 | 5.05 | 4.99 | 0.48 | 0.55 | 0.51 |
| $T_{22}$ ($P_3N_1$) | YGG144B | YGG144B | YGG144B | 50.32 | 51.80 | 51.34 | 4.95 | 5.08 | 5.04 | 0.52 | 0.59 | 0.54 |
| $T_{23}$ ($P_3N_2$) | YGG144A | YGG144A | YGG144A | 50.28 | 50.99 | 50.64 | 4.93 | 5.06 | 5.01 | 0.50 | 0.57 | 0.53 |
| $T_{24}$ ($P_3N_3$) | YGG144A | YGG144A | YGG144A | 50.25 | 50.87 | 50.56 | 4.93 | 5.06 | 5.00 | 0.50 | 0.57 | 0.52 |
| $T_{25}$ ($P_3N_4$) | GG143A | GG143A | GG143A | 55.18 | 55.83 | 55.41 | 5.11 | 5.22 | 5.18 | 0.56 | 0.64 | 0.59 |
| $T_{26}$ ($P_3N_5$) | YGG144A | YGG144A | YGG144A | 54.83 | 55.80 | 55.30 | 5.00 | 5.12 | 5.07 | 0.52 | 0.59 | 0.55 |
| $T_{27}$ ($P_3N_6$) | YGG144B | YGG144B | YGG144B | 54.96 | 55.82 | 55.39 | 5.01 | 5.13 | 5.08 | 0.53 | 0.60 | 0.55 |
| $T_{28}$ ($P_3N_7$) | YGG144A | YGG144A | YGG144A | 51.14 | 55.69 | 55.22 | 4.97 | 5.09 | 5.04 | 0.52 | 0.59 | 0.54 |
| SEm (±) | – | – | – | 3.15 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| LSD ($P \leq 0.05$) | – | – | – | NS | 0.11 | 0.09 | 0.06 | NS | NS | NS | NS | NS |

6.27 and 5.80°Brix) was recorded in $N_4$ followed by $N_6$ (5.47, 6.20 and 5.73°Brix). Least total soluble solids (5.07, 6.07 and 5.33°Brix) were observed in $N_3$ at Ambe, Mrig and Hasth bahar respectively. The increase in total soluble solids might be due to more nutrients both in leaf and soil under this particular treatment. Prakash *et al.*[23] reported increased total soluble solids in pruned guava plants. Improvement in the total soluble solids content in fruits might be due to proper supply of nutrients and induction of hormones, which stimulates cell division, cell elongation, increase in number and weight of fruits, better root development, and better water uptake and deposition of nutrients. This might be attributed to improved fertilizer use efficiency with the application of organic source of nutrients[21].

### *Titrable acidity*

Observations on titrable acidity under different treatments have been presented in Tables 5 and 6 under three cropping seasons. Highest titrable acidity was recorded in $P_3$ and lowest titrable acidity was observed in unpruned plants. $N_4$ showed highest titrable acidity followed by $N_6$ and lowest titrable acidity was observed in $N_3$ at Ambe, Mrig and Hasth bahar respectively. The interaction effect between pruning and nutrients revealed that titrable acidity was statistically at par under three seasons. The increased in titrable acidity could be due to the fact that humic acid and fulvic acid fraction of the soil organic matter contributed by the organic sources (vermicompost) would have probably formed water soluble micronutrient, thereby increasing their availability as well as uptake which resulted in better quality[26]. Similar findings were reported by Goldwebber *et al.*[27] in Persian lime and Ahmad *et al.*[20] in pruned kinnow plants.

### *Total sugar*

Data pertaining to total sugar content in lemon fruits under different pruning treatments showed significant variations under three seasons, although it was statistically at par in pruning levels under Ambe bahar (Tables 5 and 6). Maximum total sugar content was recorded in $P_3$ followed by $P_2$ at Ambe, Mrig and Hasth bahar. The maximum content was significantly different under different nutrient levels in Ambe and Hasth bahar, whereas it was statistically at par in Mrig bahar. It was recorded maximum in $N_4$ followed by $N_6$ in all the three respective seasons. Minimum total sugar content was observed in $N_3$. The interaction effect between pruning and nutrients was statistically at par with respect to total sugar content except in Hasth bahar. It might be due to proper supply of nutrients and induction of growth hormones which stimulated cell division, cell elongation, and better translocation of water uptake and deposition of nutrients as a result of fertilizer use efficiency[28]. Similar results were reported by Dutta *et al.*[29] in guava cv. L-49 and Shukla *et al.*[30] in guava cv. Sweta.

### *Reducing sugar*

Observations on reducing sugar under different pruning and nutrient treatments (Tables 5 and 6) showed statistical significance under three cropping seasons. Highest reducing sugar was recorded in $P_3$ and the lowest in $P_0$; highest content was recorded in $N_4$ at all three seasons followed by $N_6$, whereas lowest reducing sugar was observed in $N_3$. Increased fruit quality could be due to the fact that the different sources of organic and inorganic nutrients (farm yard manures, vermicompost, azotobacter, phosphate solubilizing bacteria, nitrogenous, phosphatic and potassium fertilizers) enhanced the nutrient availability by enhancing the capability of plants for better uptake of nutrients from rhizosphere resulting in the conversion of acid to sugar and their derivatives by the reversal glycolytic pathway[31].

### *Ascorbic acid*

Data on ascorbic acid content in lemon fruits under different treatments and their combination were significantly different under Ambe, Mrig and Hasth bahar (Tables 5 and 6) although it was statistically at par under pruning and nutrient treatments in Ambe bahar. Maximum ascorbic acid content was recorded in $P_3$ followed by $P_2$ at the three seasons. Maximum content was recorded in $N_4$ followed by $N_6$ and minimum amount was observed in $N_3$ at the three seasons respectively. Increase in ascorbic acid might be due to more availability of nutrients both in leaf and soil under this particular treatment. The interaction effect between pruning and nutrient revealed that $T_{25}$ ($P_3N_4$) gave the highest ascorbic acid content, whereas lowest was recorded in $T_3$ ($P_0N_3$). These results agree with Prakash *et al.*[23] in pruned guava plants. High ascorbic acid content in fruits might be due to proper supply of nutrients and induction of growth hormones, which stimulate cell division, cell elongation, increase in number and weight of fruits, better root development, and better translocation of water and deposition of nutrients. This might be attributed to improved fertilizer use efficiency with the application of organic source of nutrients[21]. These results agree with the findings of Kumar *et al.*[26] in lemon cv. Pant Lemon-1.

### *Leaf nutrient status*

Data pertaining to leaf nutrient (N and K) availability was statistically significant under all the treatments (Tables 7 and 8), whereas the data on leaf phosphorus was statistically at par under all the treatments except after Ambe

**Table 5.** Effect of pruning and nutrient management on quality of lemon cv. Assam lemon

| | TSS (°brix) | | | Acidity (%) | | | Total sugar (%) | | | Reducing sugar (%) | | | Ascorbic acid (mg/100 g pulp) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth |
| $P_0$ | 5.13d | 6.07c | 5.53d | 0.51d | 0.6d | 0.57d | 4.18a | 4.97d | 4.56d | 3.88d | 4.18c | 4.09d | 42.53a | 42.82d | 42.78d |
| $P_1$ | 5.60c | 6.40b | 5.93c | 0.62c | 0.85c | 0.69c | 4.59a | 5.18c | 4.85c | 4.14c | 5.01b | 4.40c | 44.44a | 44.92c | 44.79c |
| $P_2$ | 5.93b | 6.67a | 6.33b | 0.72b | 0.81b | 0.77b | 4.80a | 5.39b | 5.17b | 4.32b | 5.05b | 4.83b | 45.11a | 45.44b | 45.32b |
| $P_3$ | 6.07a | 6.73a | 6.53a | 0.75a | 0.76a | 0.8a | 4.97a | 5.57a | 5.28a | 4.58a | 5.12a | 5.00a | 47.91a | 48.25a | 48.12a |
| SEm (±) | 0.06 | 0.07 | 0.06 | 0.01 | 0.01 | 0.01 | 0.05 | 0.06 | 0.05 | 0.06 | 0.02 | 0.05 | 0.08 | 0.03 | 0.01 |
| LSD ($P \leq 0.05$) | 0.17 | 0.18 | 0.16 | 0.03 | 0.02 | 0.02 | NS | 0.16 | 0.13 | 0.16 | 0.07 | 0.16 | NS | 0.08 | 0.03 |
| $N_1$ | 5.13abc | 6.07a | 5.53ab | 0.51bc | 0.60bc | 0.57cd | 4.18a | 4.97a | 4.56abc | 3.88abc | 4.18bc | 4.09ab | 42.53a | 42.82d | 42.78e |
| $N_2$ | 5.13bc | 6.07a | 5.47ab | 0.46cd | 0.56cd | 0.51de | 4.17a | 4.94a | 4.43bc | 3.88bc | 4.17bc | 4.06ab | 42.42a | 42.75e | 42.61f |
| $N_3$ | 5.07c | 6.07a | 5.33b | 0.41d | 0.52d | 0.49e | 4.14a | 4.89a | 4.34c | 3.67c | 4.15c | 4.03b | 42.13a | 42.70e | 42.57g |
| $N_4$ | 5.53a | 6.27a | 5.80a | 0.55a | 0.70a | 0.63a | 4.52a | 5.12a | 4.78a | 4.05a | 4.38a | 4.23a | 44.09a | 44.57a | 44.44a |
| $N_5$ | 5.20abc | 6.13a | 5.67ab | 0.53ab | 0.63ab | 0.61ab | 4.27a | 5.08a | 4.61abc | 3.97abc | 4.20abc | 4.13ab | 43.89a | 44.25b | 44.12c |
| $N_6$ | 5.47ab | 6.20a | 5.73ab | 0.53ab | 0.69a | 0.63a | 4.44a | 5.11a | 4.72ab | 3.99ab | 4.33ab | 4.21ab | 44.02a | 44.41b | 44.28b |
| $N_7$ | 5.20abc | 6.13a | 5.67ab | 0.53ab | 0.63ab | 0.58bc | 4.21a | 5.07a | 4.57abc | 3.95abc | 4.19abc | 4.12ab | 42.79a | 42.90c | 42.86d |
| SEm (±) | 0.08 | 0.09 | 0.08 | 0.01 | 0.01 | 0.01 | 0.07 | 0.08 | 0.06 | 0.08 | 0.03 | 0.07 | 0.10 | 0.04 | 0.01 |
| LSD ($P \leq 0.05$) | 0.22 | NS | 0.22 | 0.04 | 0.03 | 0.03 | NS | NS | 0.17 | 0.22 | 0.09 | 0.21 | NS | 0.10 | 0.04 |

Means with the same letter are not significantly different.

**Table 6.** Interaction effect of pruning and nutrient management on quality of lemon cv. Assam lemon

| Treatments | TSS (°brix) | | | Acidity (%) | | | Total sugar (%) | | | Reducing sugar (%) | | | Ascorbic acid (mg/100g pulp) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth | Ambe | Mrig | Hasth |
| $T_1$ ($P_0N_1$) | 5.13 | 6.07 | 5.53 | 0.51 | 0.60 | 0.57 | 4.18 | 4.97 | 4.56 | 3.88 | 4.18 | 4.09 | 42.53 | 42.82 | 42.78 |
| $T_2$ ($P_0N_2$) | 5.13 | 6.07 | 5.47 | 0.46 | 0.56 | 0.51 | 4.17 | 4.94 | 4.43 | 3.88 | 4.17 | 4.06 | 42.42 | 42.75 | 42.61 |
| $T_3$ ($P_0N_3$) | 5.07 | 6.07 | 5.33 | 0.41 | 0.52 | 0.49 | 4.14 | 4.89 | 4.34 | 3.67 | 4.15 | 4.03 | 42.13 | 42.70 | 42.57 |
| $T_4$ ($P_0N_4$) | 5.53 | 6.27 | 5.80 | 0.55 | 0.70 | 0.63 | 4.52 | 5.12 | 4.78 | 4.05 | 4.38 | 4.23 | 44.09 | 44.57 | 44.44 |
| $T_5$ ($P_0N_5$) | 5.20 | 6.13 | 5.67 | 0.53 | 0.63 | 0.61 | 4.27 | 5.08 | 4.61 | 3.97 | 4.20 | 4.13 | 43.89 | 44.25 | 44.12 |
| $T_6$ ($P_0N_6$) | 5.47 | 6.20 | 5.73 | 0.53 | 0.69 | 0.63 | 4.44 | 5.11 | 4.72 | 3.99 | 4.33 | 4.21 | 44.02 | 44.41 | 44.28 |
| $T_7$ ($P_0N_7$) | 5.20 | 6.13 | 5.67 | 0.53 | 0.63 | 0.58 | 4.21 | 5.07 | 4.57 | 3.95 | 4.19 | 4.12 | 42.79 | 42.90 | 42.86 |
| $T_8$ ($P_1N_1$) | 5.60 | 6.40 | 5.93 | 0.62 | 0.85 | 0.69 | 4.59 | 5.18 | 4.85 | 4.14 | 5.01 | 4.40 | 44.44 | 44.92 | 44.79 |
| $T_9$ ($P_1N_2$) | 5.60 | 6.33 | 5.87 | 0.60 | 0.83 | 0.68 | 4.57 | 5.14 | 4.83 | 4.14 | 4.96 | 4.39 | 44.28 | 44.76 | 44.63 |
| $T_{10}$ ($P_1N_3$) | 5.60 | 6.27 | 5.87 | 0.60 | 0.83 | 0.65 | 4.55 | 5.14 | 4.81 | 4.10 | 4.95 | 4.31 | 44.24 | 44.62 | 44.48 |
| $T_{11}$ ($P_1N_4$) | 5.73 | 6.47 | 6.13 | 0.68 | 0.88 | 0.75 | 4.66 | 5.36 | 5.03 | 4.21 | 5.05 | 4.76 | 44.81 | 45.18 | 44.98 |
| $T_{12}$ ($P_1N_5$) | 5.67 | 6.40 | 6.07 | 0.67 | 0.87 | 0.74 | 4.63 | 5.29 | 4.97 | 4.18 | 5.03 | 4.67 | 44.68 | 45.03 | 44.87 |
| $T_{13}$ ($P_1N_6$) | 5.73 | 6.40 | 6.07 | 0.67 | 0.87 | 0.75 | 4.64 | 5.31 | 4.96 | 4.18 | 5.04 | 4.69 | 44.76 | 45.15 | 44.97 |
| $T_{14}$ ($P_1N_7$) | 5.67 | 6.40 | 5.93 | 0.65 | 0.86 | 0.71 | 4.61 | 5.18 | 4.86 | 4.18 | 5.03 | 4.66 | 44.59 | 45.01 | 44.83 |
| $T_{15}$ ($P_2N_1$) | 5.93 | 6.67 | 6.33 | 0.72 | 0.81 | 0.77 | 4.80 | 5.39 | 5.17 | 4.32 | 5.05 | 4.83 | 45.11 | 45.44 | 45.32 |
| $T_{16}$ ($P_2N_2$) | 5.87 | 6.6 | 6.27 | 0.7 | 0.81 | 0.77 | 4.71 | 5.38 | 5.10 | 4.29 | 5.05 | 4.79 | 44.95 | 45.30 | 45.17 |
| $T_{17}$ ($P_2N_3$) | 5.80 | 6.53 | 6.2 | 0.69 | 0.81 | 0.77 | 4.68 | 5.38 | 5.09 | 4.26 | 5.04 | 4.77 | 44.86 | 45.27 | 45.16 |
| $T_{18}$ ($P_2N_4$) | 6.00 | 6.67 | 6.33 | 0.74 | 0.83 | 0.79 | 4.89 | 5.49 | 5.25 | 4.55 | 5.08 | 4.92 | 47.60 | 47.94 | 47.80 |
| $T_{19}$ ($P_2N_5$) | 6.00 | 6.67 | 6.33 | 0.73 | 0.82 | 0.78 | 4.86 | 5.43 | 5.21 | 4.49 | 5.07 | 4.9 | 45.41 | 45.75 | 45.62 |
| $T_{20}$ ($P_2N_6$) | 6.00 | 6.67 | 6.33 | 0.73 | 0.82 | 0.78 | 4.88 | 5.45 | 5.23 | 4.54 | 5.07 | 4.923 | 45.47 | 45.81 | 45.69 |
| $T_{21}$ ($P_2N_7$) | 5.93 | 6.67 | 6.33 | 0.72 | 0.82 | 0.78 | 4.82 | 5.40 | 5.19 | 4.39 | 5.06 | 4.86 | 45.32 | 45.68 | 45.56 |
| $T_{22}$ ($P_3N_1$) | 6.07 | 6.73 | 6.53 | 0.75 | 0.76 | 0.8 | 4.97 | 5.57 | 5.28 | 4.58 | 5.12 | 5.00 | 47.91 | 48.25 | 48.12 |
| $T_{23}$ ($P_3N_2$) | 6.00 | 6.73 | 6.47 | 0.75 | 0.72 | 0.79 | 4.94 | 5.52 | 5.27 | 4.57 | 5.10 | 4.99 | 47.86 | 48.2 | 48.07 |
| $T_{24}$ ($P_3N_3$) | 6.00 | 6.73 | 6.40 | 0.74 | 0.71 | 0.79 | 4.90 | 5.51 | 5.26 | 4.56 | 5.10 | 4.97 | 47.84 | 48.15 | 48.01 |
| $T_{25}$ ($P_3N_4$) | 6.33 | 6.93 | 6.60 | 0.79 | 0.8 | 0.84 | 5.14 | 5.68 | 5.38 | 4.95 | 5.23 | 5.09 | 52.45 | 52.78 | 52.65 |
| $T_{26}$ ($P_3N_5$) | 6.13 | 6.87 | 6.53 | 0.79 | 0.79 | 0.82 | 4.99 | 5.61 | 5.37 | 4.61 | 5.17 | 5.01 | 52.29 | 52.60 | 52.49 |
| $T_{27}$ ($P_3N_6$) | 6.27 | 6.87 | 6.53 | 0.79 | 0.79 | 0.84 | 5.13 | 5.63 | 5.37 | 4.88 | 5.19 | 5.03 | 52.3 | 52.64 | 52.51 |
| $T_{28}$ ($P_3N_7$) | 6.13 | 6.87 | 6.53 | 0.77 | 0.77 | 0.81 | 4.97 | 5.59 | 5.33 | 4.60 | 5.14 | 5.01 | 52.24 | 52.58 | 52.45 |
| SEm (±) | 0.16 | 0.17 | 0.15 | 0.03 | 0.02 | 0.02 | 0.14 | 0.15 | 0.12 | 0.15 | 0.06 | 0.14 | 0.21 | 0.07 | 0.03 |
| LSD ($P \leq 0.05$) | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.58 | 0.20 | 0.08 |

**Table 7.** Effect of nutrient management on leaf nutrient status of lemon cv. Assam lemon

| | Leaf nitrogen content (%) | | | | | | Leaf phosphorus content (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Initial | 30 days after nutrition | 60 days after nutrition | After harvesting (Ambe bahar) | After harvesting (Mrig bahar) | After harvesting (Hasth bahar) | Initial | 30 days after nutrition | 60 days after nutrition | After harvesting (Ambe bahar) | After harvesting (Mrig bahar) | After harvesting (Hasth bahar) | After harvesting (Hasth bahar) |
| $P_0N_1$ | 1.42bcd | 2.12d | 2.25cd | 1.76de | 1.38bcd | 1.12cd | 0.08a | 0.16a | 0.17a | 0.12ab | 0.11 | 0.09a | 1.27e |
| $P_0N_2$ | 1.40cd | 2.11d | 2.22de | 1.72ef | 1.33cd | 1.04d | 0.07a | 0.16a | 0.17a | 0.11b | 0.10 | 0.09a | 1.14d |
| $P_0N_3$ | 1.37d | 2.10d | 2.19e | 1.68f | 1.30d | 1.00d | 0.07a | 0.16a | 0.17a | 0.11b | 0.10 | 0.07a | 1.09d |
| $P_0N_4$ | 1.49a | 2.28a | 2.39a | 2.06a | 1.74a | 1.55a | 0.09a | 0.17a | 0.18a | 0.15b | 0.14 | 0.10a | 1.59a |
| $P_0N_5$ | 1.46abc | 2.20bc | 2.29bc | 1.84c | 1.54abc | 1.31bc | 0.08a | 0.17a | 0.18a | 0.14ab | 0.13 | 0.10a | 1.47b |
| $P_0N_6$ | 1.47ab | 2.25ab | 2.33b | 1.95b | 1.58ab | 1.38ab | 0.09a | 0.17a | 0.18a | 0.14ab | 0.13 | 0.10a | 1.53ab |
| $P_0N_7$ | 1.44abc | 2.17cd | 2.28bc | 1.80dc | 1.44bcd | 1.2bcd | 0.08a | 0.17a | 0.18a | 0.13ab | 0.12 | 0.10a | 1.35c |
| SEm (±) | 0.03 | 0.03 | 0.02 | 0.03 | 0.10 | 0.10 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.04 |
| LSD ($P \leq 0.05$) | 0.06 | 0.07 | 0.05 | 0.06 | 0.21 | 0.21 | NS | NS | NS | 0.03 | NS | NS | 0.09 |

Means with the same letter are not significantly different.

**Table 8.** Effect of nutrient management on leaf nutrient status of lemon cv. Assam lemon

| | | Leaf potassium content (%) | | | | |
|---|---|---|---|---|---|---|
| Treatments | Initial | 30 days after nutrition | 60 days after nutrition | After harvesting (Ambe bahar) | After harvesting (Mrig bahar) | After harvesting (Hasth bahar) |
| $P_0N_1$ | 0.89bcd | 1.69cd | 1.9cd | 1.39d | 1.31c | 1.27e |
| $P_0N_2$ | 0.87cd | 1.68d | 1.86de | 1.24e | 1.18d | 1.14d |
| $P_0N_3$ | 0.85d | 1.68d | 1.82e | 1.19f | 1.12d | 1.09d |
| $P_0N_4$ | 0.95a | 1.79a | 2.01a | 1.64a | 1.63a | 1.59a |
| $P_0N_5$ | 0.91abc | 1.73bc | 1.97ab | 1.58b | 1.51b | 1.47b |
| $P_0N_6$ | 0.93ab | 1.76ab | 1.98ab | 1.63a | 1.58ab | 1.53ab |
| $P_0N_7$ | 0.89bcd | 1.7cd | 1.94bc | 1.46c | 1.39c | 1.35c |
| SEm (±) | 0.02 | 0.02 | 0.03 | 0.01 | 0.04 | 0.04 |
| LSD ($P \leq 0.05$) | 0.05 | 0.05 | 0.06 | 0.03 | 0.09 | 0.09 |

Means with the same letter are not significantly different.

**Table 9.** Effect of nutrient management on soil nutrient status of lemon cv. Assam lemon

| | Available soil nitrogen (kg/ha) | | | | | | Available soil phosphorus (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Initial | 30 days after nutrition | 60 days after nutrition | After harvesting (Ambe bahar) | After harvesting (Mrig bahar) | After harvesting (Hasth bahar) | Initial | 30 days after nutrition | 60 days after nutrition | After harvesting (Ambe bahar) | After harvesting (Mrig bahar) | After harvesting (Hasth bahar) |
| $P_0N_1$ | 196.87d | 198.39e | 201.59e | 200.12e | 197.19a | 194.25c | 14.73e | 15.92e | 17.69e | 17.19e | 16.91d | 16.73d |
| $P_0N_2$ | 196.56e | 198.18f | 201.17f | 199.74f | 195.54a | 192.23d | 14.21f | 15.69f | 17.35f | 16.97f | 16.73e | 16.60e |
| $P_0N_3$ | 194.34f | 197.51g | 200.96g | 199.25g | 195.09a | 191.95d | 14.11g | 15.38g | 17.14g | 16.78g | 16.42f | 16.22f |
| $P_0N_4$ | 198.45a | 201.6a | 206.72a | 205.86a | 202.04a | 199.72a | 15.85a | 16.79a | 18.93a | 17.91a | 17.63a | 17.48a |
| $P_0N_5$ | 198.27b | 200.75c | 203.89c | 202.18c | 199.87a | 196.24b | 15.12c | 16.41c | 18.59c | 17.54c | 17.19c | 16.97c |
| $P_0N_6$ | 198.32b | 201.23b | 206.41b | 205.58b | 201.63a | 196.95b | 15.43b | 16.65b | 18.76b | 17.78b | 17.46b | 17.27b |
| $P_0N_7$ | 197.51c | 199.83d | 203.65d | 202.06d | 199.76a | 196.14b | 14.96d | 16.29d | 18.42d | 17.36d | 16.96d | 16.80d |
| SEm (±) | 0.03 | 0.02 | 0.02 | 0.03 | 0.28 | 0.64 | 0.01 | 0.01 | 0.03 | 0.01 | 0.06 | 0.06 |
| LSD ($P \leq 0.05$) | 0.07 | 0.04 | 0.03 | 0.06 | 0.86 | 1.40 | 0.02 | 0.02 | 0.06 | 0.02 | 0.13 | 0.13 |

Means with the same letter are not significantly different.

**Table 10.** Effect of nutrient management on soil nutrient status of lemon cv. Assam lemon

| | Available soil phosphorus | | | | | |
|---|---|---|---|---|---|---|
| Treatments | Initial | 30 days after nutrition | 60 days after nutrition | After harvesting (Ambe bahar) | After harvesting (Mrig bahar) | After harvesting (Hasth bahar) |
| $P_0N_1$ | 110.89e | 113.26e | 115.8e | 114.78e | 113.97d | 112.86c |
| $P_0N_2$ | 110.61f | 112.9f | 115.58f | 114.61f | 113.83e | 112.85c |
| $P_0N_3$ | 110.33g | 112.78g | 115.29g | 114.49g | 113.54f | 112.59d |
| $P_0N_4$ | 113.67a | 114.81a | 116.69a | 115.73a | 114.78a | 113.86a |
| $P_0N_5$ | 111.35c | 113.97c | 116.18c | 115.34c | 114.40c | 113.46b |
| $P_0N_6$ | 113.45b | 114.23b | 116.41b | 115.48b | 114.53b | 113.61b |
| $P_0N_7$ | 111.19d | 113.49d | 115.93d | 114.89d | 113.99d | 112.87c |
| SEm (±) | 0.02 | 0.02 | 0.01 | 0.02 | 0.06 | 0.09 |
| LSD ($P \leq 0.05$) | 0.04 | 0.04 | 0.02 | 0.05 | 0.13 | 0.19 |

Means with the same letter are not significantly different.

bahar harvest. Observations reveal that availability of nutrients, viz. nitrogen, phosphorus and potassium in lemon leaves increased gradually after application of fertilizers up to pre-harvesting of Ambe bahar and then decreased gradually after harvesting of each season. Maximum availability of these three nutrients (N, P and K) was found after 60 days after nutrient application under all the treatments. However, among the seven nutrient treatments, $N_4$ recorded highest nitrogen, phosphorus and potassium availability after 30 days and 60 days of fertilizers application and after harvesting of Ambe, Mrig and Hasth bahar which was followed by $N_6$. Lowest availability of leaf nutrients was recorded in $N_3$ after 30 days and 60 days of fertilizers application and after harvesting of the three seasons respectively. Reduction in the leaf nutrient availability after harvesting could be due to uptake of nutrients by plants during vegetative and reproductive stages. It might be due to combined effect of azotobacter, vermicompost and vesicular arbuscular mycorrhiza, where azotobacter fixes the atmospheric nitrogen and convert it into inorganic form by mineralization of nitrogen, which in turn is taken by plants and thereby increase its availability. Vermicompost and mycorrhiza assist the plant to acquire mineral nutrients from the soil, especially immobile elements like phosphorus and mobile elements such as potassium and nitrogen[32–35].

### *Soil nutrient status*

Effect of nutrient management on soil nutrient (N, P and K) availability was statistically significant under all treatments from initial stage up to harvest except in soil nitrogen after harvesting of Mrig bahar, where the data was statistically at par under all treatments (Tables 9 and 10). Data showed that the availability of nutrients, viz. nitrogen, phosphorus and potassium increased gradually after application of fertilizers up to pre-harvesting of Ambe bahar and then decreased gradually after harvesting of each season. However, the maximum availability of these three nutrients (N, P and K) was found after 60 days after nutrient application under all treatments. Among the seven nutrient treatments, $N_4$ recorded highest nitrogen, phosphorus and potassium availability after 30 days and 60 days of fertilizers application and after harvesting of the three seasons respectively which was followed by $N_6$. Reduction in the soil nutrient availability after harvesting might be due to uptake of nutrients by plants during vegetative and reproductive stages. These results are similar with the findings of Bala *et al.*[36] Application of biofertilizers along with vermicompost and vesicular arbuscular mycorrhiza and different doses of NPK was found effective to maintain the nitrogen level of the soil as the microbial population under such treatments was much higher and thereby improved fertility status of the soil.

## Conclusion

The integrated application of inorganic fertilizers, organic and biological sources of nutrients in an efficient way would not only reduce the sole dependence on inorganic fertilizers but also influence the fruit's physicochemical composition. Besides, it also improved the leaf and soil nutrient status which ultimately resulted in quality production. Pruning also has significant effect in fruit quality improvement. Among the three seasons of cropping, Mrig bahar recorded the best result in respect to quality of the fruits followed by Hasth bahar and Ambe bahar due to favourable agro-climatic conditions prevailed during fruit growth and developmental period. It could be concluded from the above results that severe pruning (75 cm pruning from the terminal portion of the shoot) along with integrated use of fertilizers, viz. 75% RDF + vermicompost + azotobacter + vesicular arbuscular mycorrhiza proved best in terms of quality lemon production for this region.


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