

**NUTRIENT USE EFFICIENCY, PRODUCTIVITY AND QUALITY OF
TOMATO AS INFLUENCED BY SPLIT APPLICATION OF NPK
NUTRIENTS**

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**KELADI SHIVAPPA NAYAKA UNIVERSITY OF AGRICULTURAL AND
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KELADI SHIVAPPA NAYAKA UNIVERSITY OF AGRICULTURAL AND
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CERTIFICATE

This is to certify that the thesis entitled 'NUTRIENT USE EFFICIENCY, PRODUCTIVITY AND QUALITY OF TOMATO AS INFLUENCED BY SPLIT APPLICATION OF NPK NUTRIENTS' submitted in partial fulfillment of the requirements for the award of the degree of MASTER OF SCIENCE (AGRICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY to the College of Agriculture, Shivamogga, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga is a bonafide record of research work carried out by **PRIYA MARIA JACOB, ID No. MA1TAI0362** (priyamarial964@gmail.com) during the period of study in this university under my guidance and supervision and no part of this thesis has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

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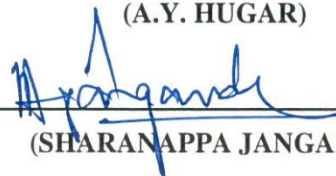
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With ever regardful memories.....

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Shivamogga

November, 2021

(Priya Maria Jacob)

**NUTRIENT USE EFFICIENCY, PRODUCTIVITY AND QUALITY OF TOMATO AS
INFLUENCED BY SPLIT APPLICATION OF NPK NUTRIENTS**

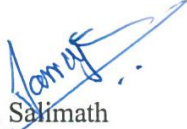
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ABSTRACT

An experiment was conducted in ICAR-KVK, COA, KSNUAHS, Shivamogga during *rabi* 2020-21, to determine the nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients. The experiment was laid out in Randomized Complete Block Design with nine treatments and three replications. The results showed that the available soil nutrient status recorded was higher in treatments provided with split application compared to recommended practice of fertilizer application. Split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) significantly improved the NPK content and uptake in tomato plant and fruit along with the growth parameters such as plant height, number of branches per plant and leaf area at flowering, fruiting and harvesting stages. The yield attributes *viz.*, number of flower clusters per plant (16.05), number of fruits per plant (50.63), girth of fruit (18.27 cm), individual fruit weight (76.73 g) and fruit yield per hectare (107.88 t ha⁻¹) and quality parameters *viz.*, total soluble solids (5.90°Brix), lycopene (6.50 mg 100g⁻¹), ascorbic acid (15.19 mg 100g⁻¹) and shelf life (15.30 days) were registered highest under the same treatment. The percentage yield increase in the split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) over the recommended dose of fertilizer application is 39 per cent. Split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) significantly improved the nutrient use efficiency and economics *viz.*, nitrogen use efficiency (29.23 kg yield kg N⁻¹), phosphorus use efficiency (29.23 kg yield kg P⁻¹), potassium use efficiency (23.38 kg yield kg K⁻¹), gross returns (Rs. 828943 ha⁻¹), cost of cultivation (Rs. 189849 ha⁻¹), net returns (Rs. 639094 ha⁻¹) and B: C (4.37). From this study, it can be concluded that the split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O is ideal for getting higher yield with better quality fruits throughout the year.

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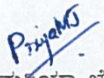

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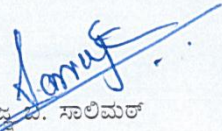
ಸಾರಜನಕ-ರಂಜಕ-ಪೋಷ್ಯಾಷಿಯಂ ಪೋಷಕಾಂಶಗಳ ವಿಭಜಿತ ಬಳಕೆಯಿಂದ ಪ್ರಭಾವಿತವಾದ
ಟೋಮ್ಯಾಟೋದ ಪೌಷ್ಟಿಕಾಂಶದ ಬಳಕೆಯ ದಕ್ಷತೆ, ಉತ್ಪಾದಕತೆ ಮತ್ತು ಗುಣಮಟ್ಟ.
(ಪ್ರಿಯಾ ಮರಿಯಾ ಜೇಕಬ್)

ಸಾರಾಂಶ

ಸಾರಜನಕ-ರಂಜಕ-ಪೋಷ್ಯಾಷಿಯಂ ಪೋಷಕಾಂಶಗಳ ವಿಭಜಿತ ಪೂರೈಕೆಯಿಂದ ಪ್ರಭಾವಿತರಾಗಿರುವ ಟೋಮ್ಯಾಟೋದ ಪೌಷ್ಟಿಕಾಂಶದ ಬಳಕೆಯ ದಕ್ಷತೆ, ಉತ್ಪಾದಕತೆ ಮತ್ತು ಗುಣಮಟ್ಟವನ್ನು ನಿರ್ಧರಿಸಲು 2020-21ರ ಹಿಂಗಾರು ಹಂಗಾಮಿನಲ್ಲಿ ಐ.ಸಿ.ಎ.ಆರ್.-ಕೃಷಿ ವಿಜ್ಞಾನ ಕೇಂದ್ರ, ಕೆಳದಿ ಶಿವಪ್ಪ ನಾಯಕ ಕೃಷಿ ಮತ್ತು ತೋಟಗಾರಿಕೆ ವಿಜ್ಞಾನಗಳ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಶಿವಮೊಗ್ಗದ ಭಾಗದಲ್ಲಿ ಪ್ರಯೋಗವನ್ನು ಹಮ್ಮಿಕೊಳ್ಳಲಾಯಿತು. ಈ ಪ್ರಯೋಗವು 9 ಉಪಚಾರಗಳೊಂದಿಗೆ ಯಾದೃಚ್ಛಿಕ ಸಂಪೂರ್ಣ ಬ್ಲಾಕ್ ವಿನ್ಯಾಸದಲ್ಲಿ ಮೂರು ಬಾರಿ ಪ್ರತಿರೂಪಿಸಲಾಯಿತು. ಪ್ರಯೋಗದ ಫಲಿತಾಂಶದ ಪ್ರಕಾರ, ಲಭ್ಯವಿರುವ ಮಣ್ಣಿನ ಪೋಷಕಾಂಶಗಳ ಸ್ಥಿತಿಯು ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಗೊಬ್ಬರ ಬಳಕೆಗೆ ಹೋಲಿಸಿದರೆ, ವಿಭಜಿತ ಪದ್ಧತಿಯಲ್ಲಿ ಹೆಚ್ಚಾಗಿ ಕಂಡುಬಂದಿದೆ. ಒಟ್ಟು 100 ಪ್ರತಿಶತ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ಮಾಡಿದ ಸಾರಜನಕ + 100 ಪ್ರತಿಶತ ರಂಜಕ + 125 ಪ್ರತಿಶತ ಪೋಷ್ಯಾಷಿಯಂ (ಚಿಕಿತ್ಸೆ-7)ನ ವಿಭಜಿತ ಬಳಕೆಯಿಂದ ಟೋಮ್ಯಾಟೋ ಸಸ್ಯ ಮತ್ತು ಹಣ್ಣುಗಳಲ್ಲಿ ಸಾರಜನಕ-ರಂಜಕ-ಪೋಷ್ಯಾಷ್ ಪ್ರಮಾಣ ಮತ್ತು ಹಿರಿಕೊಳ್ಳುವಿಕೆಯನ್ನು ಗಮನಾರ್ಹವಾಗಿ ಹೆಚ್ಚಿತು. ಇದರ ಜೊತೆ ವಿಭಜಿತ ಪೋಷಕಾಂಶಗಳ ಬಳಕೆಯು ಬೆಳವಣಿಗೆಯ ನಿಯತಾಂಕಗಳಾದ ಸಸ್ಯದ ಎತ್ತರ ಪ್ರತಿ ಶಾಖೆಗಳ ಸಂಖ್ಯೆ ಮತ್ತು ಎಲೆಗಳ ಪ್ರದೇಶವು ಹೂವು ಬಿಡುವ, ಹಣ್ಣು ಬಿಡುವ ಹಾಗೂ ಕೊಯ್ಲು ಹಂತಗಳಲ್ಲಿ ಹೆಚ್ಚಿದವು. ಪ್ರತಿ ಸಸ್ಯಕ್ಕೆ ಹೂವಿನ ಗೊಂಚಲುಗಳ ಸಂಖ್ಯೆ (16.05), ಪ್ರತಿ ಗಿಡಕ್ಕೆ ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆ (50.63), ಹಣ್ಣಿನ ಸುತ್ತಳತೆ (18.27 ಸೆಂ.) ಪ್ರತ್ಯೇಕ ಹಣ್ಣಿನ ತೂಕ (76.73 ಗ್ರಾಂ.) ಮತ್ತು ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ಹಣ್ಣಿನ ಇಳುವರಿ (107.88 ಟನ್) ಮತ್ತು ಗುಣಮಟ್ಟದ ನಿಯತಾಂಕಗಳು ಅಂದರೆ ಒಟ್ಟು ಕರಗುವ ಘನ ವಸ್ತುಗಳು (5.90⁰ಬ್ರಿಕ್ಸ್), ಲೈಕೋಪೀನ್ (6.50 ಮಿ.ಗ್ರಾಂ./100ಗ್ರಾಂ.), ಆಸ್ಕೋರ್ಬಿಕ್ ಆಮ್ಲ (15.19 ಮಿ.ಗ್ರಾಂ./100ಗ್ರಾಂ.) ಮತ್ತು ಜೀವಿತಾವಧಿ (15.30 ದಿನಗಳು) ಅದೇ ಚಿಕಿತ್ಸೆಯ ಅಡಿಯಲ್ಲಿ ದಾಖಲಾಗಿವೆ. ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ಗೊಬ್ಬರದ ಪ್ರಮಾಣಕ್ಕಿಂತ 100 ಪ್ರತಿಶತ ಸಾರಜನಕ + 100 ಪ್ರತಿಶತ ರಂಜಕ + 125 ಪ್ರತಿಶತ ಪೋಷ್ಯಾಷಿಯಂ (ಚಿಕಿತ್ಸೆ-7)ನ ವಿಭಜಿತ ಅನ್ವಯದಲ್ಲಿ ಶೇಕಡಾವಾರು ಇಳುವರಿ ಹೆಚ್ಚಳವು ಶೇಕಡಾ 39 ಆಗಿದೆ. ಒಟ್ಟು 100 ಪ್ರತಿಶತ ಸಾರಜನಕ + 100 ಪ್ರತಿಶತ ರಂಜಕ + 125 ಪ್ರತಿಶತ ಪೋಷ್ಯಾಷಿಯಂ (ಚಿಕಿತ್ಸೆ-7)ನ ವಿಭಜಿತ ಪೌಷ್ಟಿಕಾಂಶದ ಬಳಕೆಯ ದಕ್ಷತೆ ಮತ್ತು ಅರ್ಥಿಕಾಂಶವನ್ನು ಗಣನೀಯವಾಗಿ ಸುದಾರಿಸಿದೆ, ಅಂದರೆ ಸಾರಜನಕದ ಬಳಕೆಯ ದಕ್ಷತೆ (29.23 ಕಿ.ಗ್ರಾಂ. ಇಳುವರಿ/ಕಿ.ಗ್ರಾಂ. ಸಾರಜನಕ), ರಂಜಕ ಬಳಕೆಯ ದಕ್ಷತೆ (29.23 ಕಿ.ಗ್ರಾಂ. ಇಳುವರಿ/ಕಿ.ಗ್ರಾಂ. ರಂಜಕ), ಪೋಷ್ಯಾಷಿಯಂ ಬಳಕೆಯ ದಕ್ಷತೆ (23.38 ಕಿ.ಗ್ರಾಂ. ಇಳುವರಿ/ಕಿ.ಗ್ರಾಂ. ಪೋಷ್ಯಾಷಿಯಂ) ಒಟ್ಟು ಆದಾಯ (ರೂ. 828943 ಹೆ⁻¹), ಉತ್ಪಾದಕತೆಯ ವೆಚ್ಚ (ರೂ. 189849 ಹೆ⁻¹), ನಿವ್ವಳ ಆದಾಯ (ರೂ. 639094 ಹೆ⁻¹) ಮತ್ತು ಲಾಭ:ಖರ್ಚು ಅನುಪಾತ (4.37) ಆಗಿರುತ್ತದೆ. ಈ ಅಧ್ಯಯನದಿಂದ ಕೊನೆಯದಾಗಿ 100 ಪ್ರತಿಶತ ಸಾರಜನಕ +100 ಪ್ರತಿಶತ ರಂಜಕ + 125 ಪ್ರತಿಶತ ಪೋಷ್ಯಾಷಿಯಂ (ಚಿಕಿತ್ಸೆ-7)ನ ವಿಭಜಿತ ಬಳಕೆಯು ವರ್ಷಕ್ಕೆ ಹೆಚ್ಚಿನ ಪ್ರಮಾಣದಲ್ಲಿ ಇಳುವರಿ ಮತ್ತು ಶ್ರೇಷ್ಠ ಗುಣಮಟ್ಟದ ಹಣ್ಣುಗಳನ್ನು ನೀಡುವುದು ಎಂದು ತೀರ್ಮಾನಿಸಲಾಗಿದೆ.

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LIST OF ABBREVIATIONS USED

Abbreviation	Full form
B: C	Benefit cost ratio
CD	Critical difference
cm	Centimetre
cm ²	Centimetre square
DAT	Days after transplanting
⁰ C	Degree Celsius
<i>et al.</i>	And others
<i>etc.</i>	(Et cetera) and so on
Fig.	Figure
FYM	Farm yard manure
g	Gram
ha	Hectare
<i>i.e.</i>	(Id est.) that is
K	Potassium
KUE	Potassium use efficiency
kg	Kilogram
mL	Millilitre
N	Nitrogen
NUE	Nitrogen use efficiency
P	Phosphorus
PUE	Phosphorus use efficiency
RDF	Recommended dose of fertilizer
S.Em ±	Standard error of mean
t	Tonne
@	At the rate
%	Per cent
Rs.	Rupees
<i>viz.</i>	Namely

INTRODUCTION

I INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a solanaceous vegetable, which ranks next to potato and sweet potato. It is rich in carbohydrates, amino acids, minerals and vitamins. It belongs to Tropical America and was introduced to India by the Portuguese in the middle of the 16th century. They are commercialized to prepare sauce, jam, chutney, juice, ketchup, puree, paste, powder and other by-products. Fresh and matured tomato fruits are used in salads, while green ones are used in pickles and preserves. It is called 'Poor man's orange' because of its attractive appearance and very high nutritive value as that of oranges. It has high medicinal value and it is used as both mild laxatives and promoters of gastric secretion.

Tomato accounts for 6.38 per cent of global vegetable production. It is grown on 4.81 million ha worldwide, with a production of 163.09 million tonnes. The largest tomato-producing countries are China, India and United States. In India, tomato production covers roughly around 0.812 million ha and yields approximately 20.57 million tonnes per ha, with productivity of 25 million tonnes per ha (Horticultural statistics at a glance, 2019-20). The most prominent tomato-growing states are Andhra Pradesh, Karnataka and Madhya Pradesh. It is grown on 0.64 lakh ha in Karnataka, with a production of 20.81 lakh tonnes and productivity of 33.9 tonnes per ha (Horticultural statistics at a glance, 2017-18). Under the prevailing climatic conditions in Karnataka, tomatoes can be grown extensively through the year, thus Karnataka has a great potential for tomato production

Tomato fruit contains moisture (94.5 g), fat (0.01 g), protein (1.0 g), carbohydrates (3.9 g), phosphorus (0.02 g), iron (1.0 g), calorific value (21 calories), carotene (350 mg), vitamin-C (32 mg), thiamine (0.12 mg), niacin (0.04 mg) per 100g of edible portion. It is good source of minerals and organic acids. Fruit contains 3 to 5 per cent total sugar, 15 to 30 mg 100g⁻¹ ascorbic acid, 7.5 to 10.5 mg 100g⁻¹ acidity and 2.4 g 100g⁻¹ dry fruit weight of minerals. It is also rich in lycopene *i.e.*, 20 to 50 mg 100g⁻¹ of fruit pulp, which imparts red colour to ripened tomato and has anti-cancerous properties (Srinivasan *et al.*, 2010).

Although tomato is profitable, its succulent and perishable character renders it vulnerable to various biotic and abiotic stresses, reducing yield and profit. The hybrids have outperformed the improved varieties in disease tolerance, adaptability to adverse conditions, uniformity in yield and plant vigour. F₁ tomato hybrid, Arka Rakshak released by IIHR, Bangalore, is a blessing for farmers. It is popular among the growers because of its triple disease resistance against tomato leaf curl virus, bacterial wilt and early blight. Besides that, it has better fruit quality attributes like uniform fruit weight, shape (spherical), colour (deep red) and shelf life.

Due to numerous constraints, the average productivity of the crop is extremely low. Tomato is a heavy-feeding crop and have positive response to all the plant nutrients. If sufficient amounts of nutrients are not maintained, then the crops exhibit improper growth. Nitrogen, phosphorus and potassium are the most important macronutrients for increasing production. Nitrogen is crucial for chlorophyll synthesis and vegetative growth, phosphorus helps in the production of flowers, fruits, roots and seeds and potassium is essential for lycopene production, translocation of food materials and disease and drought tolerance.

Since tomato is a long duration and heavy nutrient mining crop, there is a need to supply the nutrients at its critical growth stages to meet the nutrient demand. At present, the recommendation of fertilizer (250: 250: 250 N, P₂O₅, K₂O kg ha⁻¹) is available for basal application with 50 per cent N, entire P₂O₅ and K₂O as basal dose and remaining 50 per cent N after 60 days of planting. Tomato is harvested three to four times in a season and it requires nutrition based on the crop growth stages and hence, the present recommendation need to be compared with split application of NPK fertilizers for better yield and quality.

The present investigation entitled "Nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients" was carried out at ICAR-Krishi Vigyan Kendra (KVK), Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, during *rabi* 2020-21, with the following objectives:

1. To study the effect of different levels of NPK nutrients and their split application on soil nutrient status and leaf tissue nutrient concentration
2. To study the effect of different levels of NPK nutrients and their split application on growth, uptake, quality and yield of tomato
3. To study the effect of different levels of NPK nutrients and their split application on nutrient use efficiency and economics

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Tomato is a heavy feeding crop and it responds readily to the application of nitrogenous and potashic fertilizers. So nutrients should be administered in small doses at frequent intervals to minimize the losses and improve yield and quality. A field study on "Nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients" was conducted at ICAR-KVK of Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, during *rabi* 2020-21. The pertinent literature is reviewed and presented in this chapter under the following headings.

- 2.1 Effect of split application of NPK nutrients on soil nutrient status and leaf tissue nutrient concentration
- 2.2 Effect of split application of NPK nutrients on growth, uptake, quality and yield parameters
- 2.3 Effect of split application of NPK nutrients on nutrient use efficiency and economics

2.1 Effect of split application of NPK nutrients on soil nutrient status and leaf tissue nutrient concentration

2.1.1 Effect of split application of NPK nutrients on soil nutrient status

Mounika *et al.* (2017) revealed an adequate and prolonged supply of essential nutrients in maize crop through the split application increased the nutrient availability in soil and it improved the soil environment and root penetration. Also, it enhanced the moisture and nutrient absorption, resulting in increased plant height, tiller production and dry matter accumulation.

Ortas (2017) studied the effect of different K and Mg fertilizers on growth parameters, grain yield and nutrient accumulation of maize under field conditions. The study showed that the addition of split K and Mg fertilizer increased the concentration of nitrogen (N), iron (Fe), zinc (Zn), manganese (Mn) in soil and K in the plant leaves and seed.

Kumar *et al.* (2018) revealed that the split application of organic fertilizer in the rice-chickpea cropping system improved the soil structure and enhanced the soil iron, manganese, zinc and nitrogen content at the heading stage.

Olagbende *et al.* (2019) determined the split application of nitrogen fertilizer on maize soil physico-chemical properties. He stated that split application resulted in significant improvements in soil physical and chemical parameters such as soil N,

organic matter content, exchangeable cations, total porosity, moisture content, bulk density, dispersion ratio and infiltration rate.

Pandey *et al.* (2019) showed that the split application of NPK nutrients minimized nutrient losses from the soil and resulted in higher net nutrient balance, increased nutrient availability and absorption by the maize crop at the optimum moisture supply.

Suresh *et al.* (2019) studied the influence of drip fertigation with the split application of NPK nutrients on the soil nutrient status of aonla. Split fertilizer application through drip fertigation, soil N, P₂O₅ and K₂O levels increased dramatically during vegetative, flowering and harvesting periods.

2.1.2 Effect of split application of NPK nutrients on leaf tissue nutrient concentration

Souri *et al.* (2017) showed that the amino chelate contains N-amino acid, Fe, Zn, Mn and Cu in its composition. The concentration of these nutrients in plant tissues of cucumber, tomato and green bean increased significantly in response to their split application in soil.

Kolawole *et al.* (2018) reported that supplying the nutrients through split application of nitrogen and phosphorus fertilizers and organic amendments will help build organic carbon and nutrient content, nutrient holding capacity and supply micronutrients to the soil and leaf tissue of the maize plant.

Mohammadipour and Souri (2019) revealed that the split application of glycine in coriander (*Coriandrum sativum*) significantly increased the leaf tissue concentrations of nitrogen (N), calcium (Ca), potassium (K), phosphorus (P), iron (Fe), zinc (Zn) and manganese (Mn). It also enhanced the titratable acidity, pH and TSS of leaf water extract.

Noroozlo *et al.* (2019) revealed that split application of reduced forms of nitrogen *viz.*, ammonium, glycine and glutamine to sweet basil (*Ocimum basilicum*) increased the uptake and leaf tissue concentrations of potassium (K), magnesium (Mg), calcium (Ca), iron (Fe) and zinc (Zn).

Seetseng *et al.* (2020) studied the influence of NPK applications and their interactions on the nutritional values of mustard and spinach. The result showed that split application increased the content of N and K on the leaf tissues of mustard spinach and improved fertilizer use efficiency of nitrogen, phosphorus and potassium.

Shoostari *et al.* (2020) reported that the split application of glycine in cucumber improved the nitrogen status in soil and mineral elements like N, K, Ca, Mg and Fe in plant tissues.

Thingujam *et al.* (2020) reported that the organic carbon, total and available N and available K in the post-harvest soils, leaf, fruit, shoot N, P, K and other micronutrients of the eggplant increased significantly by the split application of NPK fertilizer.

Shrestha *et al.* (2021) showed the split soil-applied boron and zinc fertilizers enhanced total B and Zn plant uptake of dry season crops with increased B and Zn content in plant tissues.

2.2 Effect of split application of NPK nutrients on growth, quality, uptake and yield parameters

2.2.1 Effect of split application of NPK nutrients on growth parameters

Sawant (2005) studied the response of cucumber to fertigation under the drip irrigation system. The results showed that drip irrigation with 100 per cent recommended dose of nitrogen through fertigation provided in 8 splits significantly increased the plant height, number of branches and leaf area index of cucumber.

Gobi *et al.* (2006) studied the effect of split application of N and K on the rice hybrid CORH 2, revealed a significant increase in growth attributes, *i.e.*, taller plants, higher dry matter production, more number of tillers per hill, higher leaf area index and crop growth rate with the split application of N and K.

Kumar *et al.* (2007) showed that the growth parameters of sweet corn *viz.*, leaf area index (100 % RDN + 100 % RD P₂O₅ + 125 % RD K₂O) and total dry matter production were influenced favourably with increasing levels of NPK application.

Asif *et al.* (2007) studied the phenology, leaf area and grain yield potential of spring maize (cv. Azam) to different rates and timings of potassium application under irrigated conditions. The results showed that potash levels and timings significantly affected phenology, flag leaf area and grain yield of spring maize.

Gonfa *et al.* (2008) studied the effect of cyclic and fertigation on off-season production of capsicum (*Capsicum annuum* L.) under protected environment conditions. The study showed that the plant height, number of primary and secondary branches, canopy perimeter, yield and yield attributes of capsicum were significantly affected by split fertigation.

Hassan *et al.* (2010) assessed the effect of broadcast, fertigation and side dressing methods combined with different N splitting strategies of maize. The treatment of three splits of N fertilizer applied through fertigation at different growth stages significantly increased number of leaves per plant, plant height, biomass production, leaf area index, leaf area duration and total dry matter of maize.

Hafiz *et al.* (2011) concluded that application of N in three splits (at the V2, V16 and R1 stage of maize) might be beneficial for achieving maximum plant growth, uptake, leaf area index and leaf area duration.

Souri *et al.* (2017) evaluated the effects of split application in soil and foliar application of a commercial amino chelate on growth, yield and quality in tomato (*Solanum lycopersicum*), cucumber (*Cucumis sativus*) and green bean (*Phaseolus vulgaris*). In comparison to the control, chlorophyll content, number of lateral shoots, shoot dry weight, number of fruits, plant yield, fruit vitamin C content, total soluble solids and leaf N concentration significantly increased in all three vegetable crops after split soil application of amino chelate fertilizer.

Jena *et al.* (2018) assessed the effect of split application in fertigation with conventional and water-soluble fertilizers in growth, uptake and yield in Bt. Andon spring wheat variety. The results showed that all the growth and physiology parameters, *viz.*, dry matter accumulation per plant, leaf area index, leaf area duration and chlorophyll content in leaf enhanced due to increased nutrient availability and absorption by the crop at the optimum moisture supply with frequent and higher nutrient supply.

Mohammadipour and Souri (2019) studied the effect of different rates of glycine amino acid on growth characteristics and nutrient uptake of coriander (*Coriandrum sativum*) under greenhouse conditions. The result stated that a significant increase was observed in plant height, leaf area, leaf SPAD value and fresh weight of shoot (fresh plant yield) and shoot and root dry weights by split application of glycine.

Bhuiya *et al.* (2020) evaluated the effect of nutrient management through split application of nutrients on the growth, productivity and economics of hybrid maize (*Zea mays* L.) cultivation. The result indicated that the split application of nutrients significantly affected the growth, productivity and nutrient uptake of hybrid maize.

2.2.2 Effect of split application of NPK nutrients on uptake of nutrients

Prabhavathi *et al.* (2008) showed that the quantities and sources of potassium significantly affect chilli yield. The treatment that received 150 per cent RDK through SOP in 2 split doses recorded the highest fruit yield (10.71 q ha⁻¹), uptake of N (67.93 kg ha⁻¹), K (106.77 kg ha⁻¹) and S (15.30 kg ha⁻¹).

Srikanth *et al.* (2009) studied the effect of plant density and fertilizer levels on yield and nutrient uptake of hybrid maize and soil nutrient status under irrigated conditions. Nitrogen was divided into three equal split doses and potassium was divided into two equal split doses. The results revealed that the split application of NPK

enhanced the effective utilization of applied nutrients, increased sink capacity, soil available NPK, nutrient uptake by the crop and grain yield.

Sharifi and Nemati (2016) indicated that the qualitative and quantitative yield of maize, agronomic characteristics and nitrogen use efficiency were significantly affected by rates, N application timing and interaction of rates of N \times its application timing.

Ortas *et al.* (2013) studied the influence of the rate of N and K nutrients on pepper (*Capsicum annuum* L.) and tomato (*Solanum lycopersicum* L.) on growth, fruit production and nutrient uptake under field conditions. The results revealed that the tomato and pepper plants had responded significantly to differences in N, P and K rates by increasing plant length, yield, nutrient content and uptake of N, P and K. Zn uptake also increased with the addition of N in splits.

Rathod *et al.* (2017) revealed that the split application of NPK had a substantial impact on the total uptake of NPK by soybean and the availability of nutrients in the soil. The application of 50: 75: 50 kg ha⁻¹ in two splits-50 percent N, P₂O₅ and K₂O at sowing and 30 DAS resulted in the highest uptake and availability of NPK in the soil at harvest.

Razavipour *et al.* (2018) investigated the effects of splitting nitrogen fertilizer on rice yield and nutrient uptake from urea. The results showed that nitrogen uptake and yield by grain and straw increased significantly by increasing urea fertilizer in two or three splits.

Sharma *et al.* (2018) studied the influence of vermicompost and split applied nitrogen in pole french bean. The performance of seed yield (10.43 q ha⁻¹), NPK uptake and yield-related traits increased significantly with the split application of vermicompost and 125 per cent of recommended nitrogen. Split applied nitrogen at 125 per cent resulted in 50 per cent increase in seed yield over basal application. Hence, vermicompost and split applied nitrogen are better for harnessing seed productivity and maintaining soil fertility. Splitting nitrogenous fertilizers can improve nitrogen use efficiency and result in better quality and quantity of harvest.

Sulochna *et al.* (2018) evaluated the nutrient uptake and nitrogen use efficiency of wheat variety under precision nitrogen management. The results revealed that the NPK uptake in grain and straw increased with better timing and splitting of NPK fertilizer. Split application of NPK was probably the primary reason to increase the uptake, resulting in enhanced biomass leading to higher nutrient accumulation in plants.

Pandey *et al.* (2019) showed that the maize NPK uptake (105.9, 30.9 and 99.7 kg ha⁻¹, respectively) was significantly higher under split application of K than its whole

basal application. Split K application at earthing up stage improved availability of K throughout the crop growth period which helped in better plant metabolic activities and hence resulted in more uptake of all three nutrients.

Pattnaik *et al.* (2019) studied the response of rice with different levels of fertility and split application of nitrogen. The study indicated that split application of nitrogen, balanced nutrient availability lead to high dry matter production, better grain filling and higher N, P and K uptake.

Gade *et al.* (2020) studied the effect of specific nutrients on yield and nutrient uptake of Bt. cotton in *Vertisols*. The optimum dose of NPK with appropriate split application of N and K with magnesium supply at proper growth stages helped increase stalk yield, seed cotton, dry matter and nutrient uptake by Bt. cotton in *Vertisols*.

2.2.3 Effect of split application of NPK nutrients on quality parameters

Tirkey *et al.* (2003) showed that in tissue-culture-raised banana cv. Dwarf Cavendish, application of 300 g N in 5 splits significantly increased the TSS (23.8 °Brix), reducing sugars (6.38 %), total sugars (17.48 %) and sugar acid ratio.

Oko-Ibom *et al.* (2007) showed that fertilizer application in two splits at two weeks after transplanting and at flowering stage gave better plant growth, fruit quality and yield characteristics of tomato.

Kumar *et al.* (2008) experimented with improving the productivity of local banana Rasthali syn. Pathkapoorra with the increase in the rate of graded doses of nitrogen and potassium nutrition. The results indicated that plant height, quality of banana fruits like TSS, sugars, acidity and fruit yield increased significantly with an increase in the application rate of nitrogen and potassium.

Prabhavathi *et al.* (2008) studied the influence of sources and levels of potassium on quality attributes and nutrient composition of red chillies. Application of potassium through sulfate of potash in split doses recorded the highest ascorbic acid content (175.16 mg 100g⁻¹) and oleoresin content (16.79 %) in chillies.

Raj *et al.* (2012) reported that a better supply of K with split application and supplementation of secondary and micronutrients significantly produced higher TSS and ascorbic acid content of tomato fruits.

Feleafel and Mirdad (2013) evaluated the impact of the NPK fertigation rates at various frequencies on the growth, yield, quality, nutrient status and nutrient uptake of an eggplant crop. The results revealed that split application of NPK with fertigation significantly increased the vegetative growth, mineral contents of leaves and fruits,

fruits yield ha⁻¹ and fruit quality of eggplants such as length, diameter and firmness of fruits.

Pawar *et al.* (2013) indicated that the continuous availability of nutrients in splits throughout the growth period of tomato resulted in superior yield and quality of tomato. The quality parameters *viz.*, pH, TSS, acidity and lycopene content in tomatoes were increased significantly with the split application of NPK nutrients.

Souri *et al.* (2017) showed that the number of fruits, plant yield, vitamin C, total soluble solids and leaf N concentration in tomato and cucumber fruits showed a significant increase with soil application of amino-chelate fertilizer.

Hadole *et al.* (2020) studied the effect of different rates of fertigation on yield, soil fertility status and nutrient uptake by brinjal. The results revealed that the growth, uptake, quality and yield increased with the increasing rate of application of fertilizers through drip fertigation due to an increase in the availability of nitrogen, phosphorus and potassium in the soil.

Vasileva *et al.* (2021) studied the split potassium application on tomato fruits' nutrient content and quality traits. The results revealed a positive correlation between potassium, lycopene and sugar content in tomato fruits. Split potassium fertilization significantly affected all tested biochemical parameters defining tomato fruit quality (except for acidity).

2.2.4 Effect of split application of NPK nutrients on yield parameters

Ananthi *et al.* (2004) noticed significantly higher number of fruits (115 per plant) and individual fruit weight (0.73 g) in chilli (cv. PKM-1) with split application of potassium on sandy clay loam soil at Coimbatore.

Ananta (2006) studied the split application of NPK through drip irrigation in chilli, bhindi and capsicum crops during *kharif* and *rabi* season. The split application of water-soluble fertilizers through fertigation revealed that the highest yield of these crops was noticed when nitrogen was applied in 8 or 10 split doses through drip irrigation. The maximum production of these crops was observed when nitrogen was supplied in 8 or 10 split doses using the water-soluble fertilizers through fertigation.

Gobi *et al.* (2006) revealed a significant increase in yield parameters *viz.*, productive tillers, panicle length, panicle weight, thousand-grain weight, number of filled grains panicle and registered higher grain and straw with the split application of N and K in hybrid rice CORH 2.

Kumar *et al.* (2007) showed that the increasing frequency of NPK application improved sweet corn yield and yield components such as cobs per plant, cob length and grains per cob.

Gonfa *et al.* (2008) studied the effect of cyclic and split fertigation on the off-season production of capsicum (*Capsicum annuum* L.) under a protected environment. The results revealed that the number of primary and secondary branches, plant height, yield and yield attributes of capsicum was higher under split fertigation. The nutrient use efficiency and water use efficiency were observed higher under split fertigation.

Jaliya *et al.* (2008) determined the effect of three dates of planting and four NPK levels on the yield and yield components of maize. The results showed that the split application of NPK ha⁻¹ gave a significantly higher 100-grain weight and grain yield ha⁻¹.

Bhalerao *et al.* (2009) observed that the application of fertilizers at weekly intervals with 75 % RDF of N and K (44 splits up to 300 days) through fertigation and P by soil placement recorded higher yield in cultivar Grand Naine besides effecting a saving in N and K fertilizers of up to 25 % over the conventional methods.

Reddy *et al.* (2009) showed that the effect of split NPK application had a significant impact on growth, grain yield (7.02 t ha⁻¹) and net returns Rs. 33593 per ha in transplanted rice.

Saleem *et al.* (2009) evaluated the split dose of N application at different growth stages of maize (total N at sowing, half N at sowing + half N 25 DAS and 1/3 N at sowing + 1/3 N 25 DAS + 1/3 N at 55 DAS). The maximum number of grains per cob, 100-grain weight and grain yield were observed when nitrogen is provided in splits *i.e.*, 1/3 N at sowing + 1/3 N at 25 DAS and 1/3 N 55 DAS.

Deol *et al.* (2010) studied the effect of nitrogen application at different growth stages and potassium application on the yield and growth of soybean. The result showed that nitrogen application in two splits, *i.e.*, at pre-flowering and pod filling stage had a beneficial effect on growth, N uptake and yield compared with single-dose applied at either of the stages.

Fabunmi *et al.* (2010) investigated the effect of different split applications of NPK fertilizer on the growth and yield of maize. This study indicated that various split applications of NPK fertilizer significantly impacted maize growth and yield.

Ashiq *et al.* (2011) investigated the effect of split doses of potash fertilizer on maize and sorghum. Grain quality, plant density and yield in maize and sorghum

showed a positive relationship with increased potash levels and its number of split applications.

Hafiz *et al.* (2011) concluded that the application of N in three splits (at three critical maize growth stages-V2, V16 and R1) increased the number of kernels per cob (419), grain yield (8.27 t ha⁻¹), days to maturity (103.3 days) and biological yield (16.56 t ha⁻¹).

Amanullah *et al.* (2014) investigated the effects of foliar NPK application in various combinations (N, P, K, N+P, N+K, P+K and N+P+K) and application times (one split at 30 and 60 DAP and two equal splits at 30+60 DAP) (*Zea mays* L.). The result revealed that the combined foliar application of the three major nutrients (N+P+K) in two equal splits increased maize productivity and yield.

Khan *et al.* (2014) studied the effect of different levels of nitrogen and phosphorus on the yield of maize varieties. When fertilized with NPK fertilizers in splits, maximum number of cob plant⁻¹, thousand grains weight, plant height, grains cob⁻¹ and grain yield (5356 kg·ha⁻¹) were reported.

Farneselli *et al.* (2015) showed that high fertigation with increased irrigation frequency is a strategy to increase N uptake efficiency, plant yield (marketable fruits per plant-64, mean marketable fruit weight-55.9 g) and yield attributes in tomatoes.

Ughade *et al.* (2015) reported that fertigation schedules of 12 equal splits of NPK at every nine days interval registered significantly higher growth attributes, yield attributes *viz.*, number of fruits per plant (72.54), fruit weight per plant (4.80 kg) and fruit yield of tomato per unit (15.56 t).

Ullah *et al.* (2015) studied the growth and yield of tomato as influenced by different levels of zinc and boron as foliar application. Four levels of zinc (0, 0.2, 0.4 and 0.6 %) and four levels of boron (0, 0.05, 0.10 and 0.15 %) were applied as foliar spray. Among different levels of Zn @ 0.4 per cent showed a significant increase in the number of flowers per cluster (27.45), number of fruits per cluster (4.57) and yield (23.40 t ha⁻¹). Among different levels of boron, 0.15 per cent showed a significant increase in the number of flower cluster per plant (27.55), number of fruit cluster per plant (4.40) and yield (23.33 t ha⁻¹). The results showed that Zn @ 0.4 per cent and B @ 0.15 per cent should be applied to tomato for better yield and productivity.

El-Sayed *et al.* (2016) studied the effect of a new irrigation method with NPK rates and frequencies on yield and yield component of Egyptian cotton variety. The obtained results revealed that splitting fertilizers led to increased boll weight, the number of sympodia plant⁻¹ and seed cotton yield per feed.

Sharifi and Nemati (2016) showed that using the highest N fertilizer rate in three equal splits could be advised for profitable corn production *i.e.*, number of grain per ear, the number of grains per ear row and grain yield were recorded high in the increased nitrogen fertilizer rates with N split application as 1/3 in planting+1/3 in 8 to 10 leaf stages+1/3 in tasseling initiation.

Mounika *et al.* (2017) revealed that due to the adequate and prolonged supply of essential nutrients through the split application, growth parameters, yield attributes, grain yield, straw yield, harvest index and nutrient uptake (NPK) of rice has significantly enhanced.

Rathod *et al.* (2017) revealed that the application of 50: 75: 50 kg ha⁻¹ N, P₂O₅ and K₂O in two splits-50 per cent at sowing and 30 DAS recorded the highest number of pods per plant (51.73), grain yield (34.53 q ha⁻¹) and stover yield (44.04 q ha⁻¹) in soybean.

Vasanthi *et al.* (2017) indicated that fertigation of 100 per cent RD of NPK in 40 equal splits at every three days interval up to 120 days after transplanting was found significantly superior in case of growth (plant height 138.83 cm), yield attributes like the number of fruits plant⁻¹ (100.83) and fruit yield (71.89 t ha⁻¹) of tomato.

Jena *et al.* (2018) showed that all the yield attributes *viz.*, sympodial branches, bolls plant⁻¹ and seed cotton yield plant⁻¹ enhanced due to increased nutrient availability and absorption by cotton at the optimum moisture with regular and higher nutrient supply.

Kumar *et al.* (2018) revealed that the split application of organic fertilizer in the rice-chickpea cropping system increased the leaf area index, above-ground biomass at the heading stage and yield attributing parameters like panicles m⁻², straw yield and filled grain number.

Muleta (2019) conducted an experiment to study the role of nitrogen on potato production. The effective management of nutrients is critical for potato production as the tuber yield and quality are directly impacted by quantity and timing of nutrient applications. Split application of N helped to avoid losses through leaching, volatilization, denitrification, utilization by weeds and erosion by running-off water and enhanced the potato tuber size, shape and number.

Sharma *et al.* (2019) studied the effect of split application of potassium on yield and yield attributes of soybean. The study revealed that the split application of potassium enhanced the number of pods, oil content, grain yield (22.6 q ha⁻¹) and pod weight plant⁻¹, indicating improvement in crop growth, quality and yield of soybean.

Split application of potassium significantly increased soybean grain yield over the basal application with the highest benefit-cost ratio (7.1).

2.3 Effect of split application of NPK nutrients on nutrient use efficiency and economics

2.3.1 Effect of split application of NPK nutrients on nutrient use efficiency

Badr *et al.* (2010) evaluated the effect of sources and fertilizer application methods on nutrient distribution, uptake, recovery and fruit yield of tomato. The results revealed that the use of drip fertigation with the split application of NPK satisfies the nutrient demand of tomatoes. The split application of nutrients improved the tomato nutrient uptake pattern, nutrient use efficiency (95 kg yield kg⁻¹ NPK) and soil N, P and K marginal availability.

Marouelli *et al.* (2014) evaluated the combination of three soil pre-plant fertilization fractions with two splitting schemes of N *via* fertigation. The result revealed that physical and economic yields of tomato crop were maximized with the split application of N and provided sufficient N for the initial development of the plants, especially in soils with low N availability where leaching losses of N are prominent.

Sapkota *et al.* (2014) revealed that the K application combined with the split application of N in wheat improved nutrient use efficiency. The application should be subdivided into numerous splits to ensure better crop fertilizer utilization and reduce NPK nutrient loss.

Du *et al.* (2019) studied the effect of split N application on sweet potato N uptake and nitrogen use efficiency under reduced N rate. The results indicated that splitting nitrogen is beneficial for enhancing growth and promoting sweet potato yields under reduced N rates. It improves storage root yield, nitrogen use efficiency and agronomic use efficiency.

Tesfay *et al.* (2019) determined the rate of optimum irrigation water and nitrogen fertilizer levels for higher tomato yield. The results indicated that irrigation water and nitrogen fertilizer levels markedly influenced the growth and yield performance and agronomic efficiency of tomato.

Zohaib *et al.* (2021) showed better nitrogen use efficiency by NPK split application in relay intercropped wheat + cotton as compared with control. The highest nitrogen use efficiency demonstrated that maximum nutrient uptake occurs when N is applied at the correct time and split due to reduced losses through leaching, denitrification, immobilization and volatilization.

2.3.2 Effect of split application of NPK nutrients on economics

Rathod *et al.* (2012) discovered that increasing the N dose with splitting nitrogen boosted both seed and straw production of soybean. However, NPK uptake by soybean increased significantly with splitting half of N at 50 days after sowing and recorded significantly higher net monitoring returns and B: C in soybean.

Pawar *et al.* (2013) studied the effects on growth, yield and quality of hybrid tomato (*Solanum lycopersicum* L.) cv. Vaibhav. Application of water-soluble fertilizer through drip irrigation in fourteen equal splits at eight-day intervals increased availability of nutrients, leading to increased yield, quality net seasonal income, total net income and net extra income of tomato.

Raj *et al.* (2015) experimented with studying the effect of surface fertigation on nutrient removal, nutrient use efficiency and economics of hybrid Bt. cotton. The study discovered that using a 100 per cent recommended dose of fertilizer with fertigation in five splits resulted in better N, P and K uptake (160.99, 28.57 and 134.87 kg ha⁻¹, respectively). The same treatment recorded higher net returns (79231 Rs. ha⁻¹) and B: C (3.41).

Archana *et al.* (2016) studied the effect of different phosphorus levels and their time of application to improve soil phosphorus availability on the yield and economics of rice. The benefit-cost ratio obtained with phosphorus application in two equal splits was higher when compared to complete phosphorus application as basal at puddling before transplanting of rice grown in phosphorus accumulated soil.

Shah *et al.* (2017) assessed whether N and NK split applications synchronize with crop demand. The study indicated that the split application of N and NK in cotton significantly affected plant height, monopodia per plant, sympodia per plant, boll per plant, boll weight and ginning percentage. The application of N in splits resulted in a considerable increase in the number of bolls per plant. This study reported that the split application of fertilizers resulted in significant changes in this productivity parameter, especially more net income from N split application.

Vasanthi *et al.* (2017) indicated that fertigation of 100 per cent RD of NPK in 40 equal splits at every three-day interval increased the economic benefits in tomato viz., maximum gross returns (Rs. 359450 ha⁻¹) and B: C ratio of 2.84.

Zemichael *et al.* (2017) studied the effect of different rates and timing of nitrogen fertilizer application-four rates of nitrogen (23, 46, 69 and 92 kg N ha⁻¹), three timing of N application (½ at sowing + ½ at tillering, ¼ at sowing + ½ at tillering + ¼ at anthesis and 1/3 at sowing + 1/3 at tillering + 1/3 at anthesis) on the yield, quality and nitrogen use efficiency of bread wheat varieties during the main cropping season.

This study revealed that applying N in three splits at planting, tillering and anthesis stages *i.e.*, $\frac{1}{4}$ at planting, $\frac{1}{2}$ at tillering and $\frac{1}{4}$ at anthesis resulted in optimum grain yield (2775 kg ha⁻¹), protein concentration and marginal rate of return (1618 %) of the crop.

Kumar *et al.* (2018) revealed that the split application of organic fertilizer in the rice-chickpea cropping system increased the seed yield, productivity, net returns (29 %) and benefit-cost ratio.

Pandagale *et al.* (2018) studied the effect of split application of fertilizers on growth, yield and economics of Bt. cotton under rain-fed conditions. The results indicated that the split application of K₂O was significantly superior. It improved boll weight (2004 kg ha⁻¹), the number of bolls per plant (37.29), gross returns (Rs. 72078/ha⁻¹), net monetary returns (Rs. 39448/ha⁻¹) and B: C (2.22).

Danawale *et al.* (2019) studied the effect of different irrigation regimes and fertigation schedules on the growth and yield of tomato. Application of fertilizers through drip fertigation in splits recorded significantly higher fruit weight plant⁻¹ of tomato (3.865, 3.369 and 3.617 kg), fruit yield (138.24, 117.42 and 127.83 t ha⁻¹), gross monetary returns (Rs. 737641 per ha), net monetary returns and B: C (4.31).

Liang *et al.* (2019) indicated that the split fertilization treatments in a winter wheat–summer maize multiple-cropping system increased the annual N-agronomic efficiency (increased by 6.75–27.59 % and 2.53–39.87 % in 2016 and 2017, respectively), N-uptake efficiency, N-fertilizer productivity and the net annual income (increased by 12.2–18.7 % and 10.7–46.5 % in 2016 and 2017, respectively), decreasing input costs and enhancing economic benefits.

Bhuiya *et al.* (2020) showed that the split application of nutrients in hybrid maize (*Zea mays* L.) significantly enhanced the gross returns (Rs. 66021 per ha), net returns (Rs. 37976 per ha) and B: C (1.35).

Jeyabaskaran *et al.* (2021) reported that the application of N in splits through the drip-fertigation practices in horticultural crops like tomato, potato, banana, citrus *etc.* showed a high response to productivity, yield, quality and economics of horticultural crops.

MATERIAL AND METHODS

III MATERIAL AND METHODS

A field experiment entitled ‘Nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients’ was conducted during *rabi* 2020-21, at ICAR- Krishi Vigyan Kendra (KVK), Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, to study the effect of different levels of NPK nutrients and their split application on soil nutrient status, leaf tissue nutrient concentration, growth, uptake, quality, yield, nutrient use efficiency and economics of tomato. This chapter goes through the details of the materials used and the methodology followed during the research.

3.1 Geographical location of the experimental field

The experiment was conducted in ICAR- KVK, College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, which is situated in the Southern Transition Zone of Karnataka (Zone-7). The experimental field is located at an altitude of 640 meters above mean sea level between 14° to 14°1' N latitude and 75°45' to 75°42' E longitude.

3.2 Soil characteristics of experimental field

The soil of the experimental plot was *Alfisol*. Composite samples were collected from the area at a depth of 0-15 cm for the determination of physical characteristics (textural composition, water holding capacity and bulk density) and chemical properties (pH, EC, organic carbon, available N, P and K). These parameters were determined using the standard procedures. Table 3.1 shows the results of the soil analysis. The soil is red sandy loam in texture, slightly acidic (6.42), low organic carbon content (4.05 g kg⁻¹), low electrical conductivity (0.43 dSm⁻¹), low available N (153.89 kg ha⁻¹), medium P₂O₅ (41.71 kg ha⁻¹) and medium K₂O (253.62 kg ha⁻¹).

3.3 Climatic conditions

The monthly meteorological data was collected from the Agro meteorological observatory of Gramin Krushi Mausam Seva (GKMS) of Zonal Agricultural and Horticultural Research Station, Navile, 2020-21 is provided in the Appendix I.

Table 3.1 Physicochemical properties of soil of the experimental site

Sl. No.	Parameters	Values	Remarks	Methodology followed
I	Physical composition			
	Coarse sand (%)	42.6	Red sandy loam	International pipette method (Piper, 1966)
	Fine sand (%)	31.32		
	Silt (%)	8.35		
Clay (%)	17.73			
II	Physical constants			
	Water holding capacity (%)	27.45		Keen's cup method (Piper, 1966)
	Bulk density (Mg m ⁻³)	1.43		Core sampler method (Black, 1965)
III	Soil chemical properties			
	pH (1: 2.5)	6.42	Acidic	Potentiometric method (Jackson, 1973)
	EC (1: 2) (dSm ⁻¹)	0.43	Normal	Conductometric method (Jackson, 1973)
	Organic carbon (g kg ⁻¹)	4.05	Low	Walkley and Black's wet oxidation (Jackson, 1973)
	Available nitrogen (kg ha ⁻¹)	153.89	Low	Alkaline Permanganate method (Subbiah and Asija, 1956)
	Available phosphorus (kg ha ⁻¹)	41.71	Medium	Bray's method (Jackson, 1973)
	Available potassium (kg ha ⁻¹)	253.62	Medium	Flame photometry (Jackson, 1973)

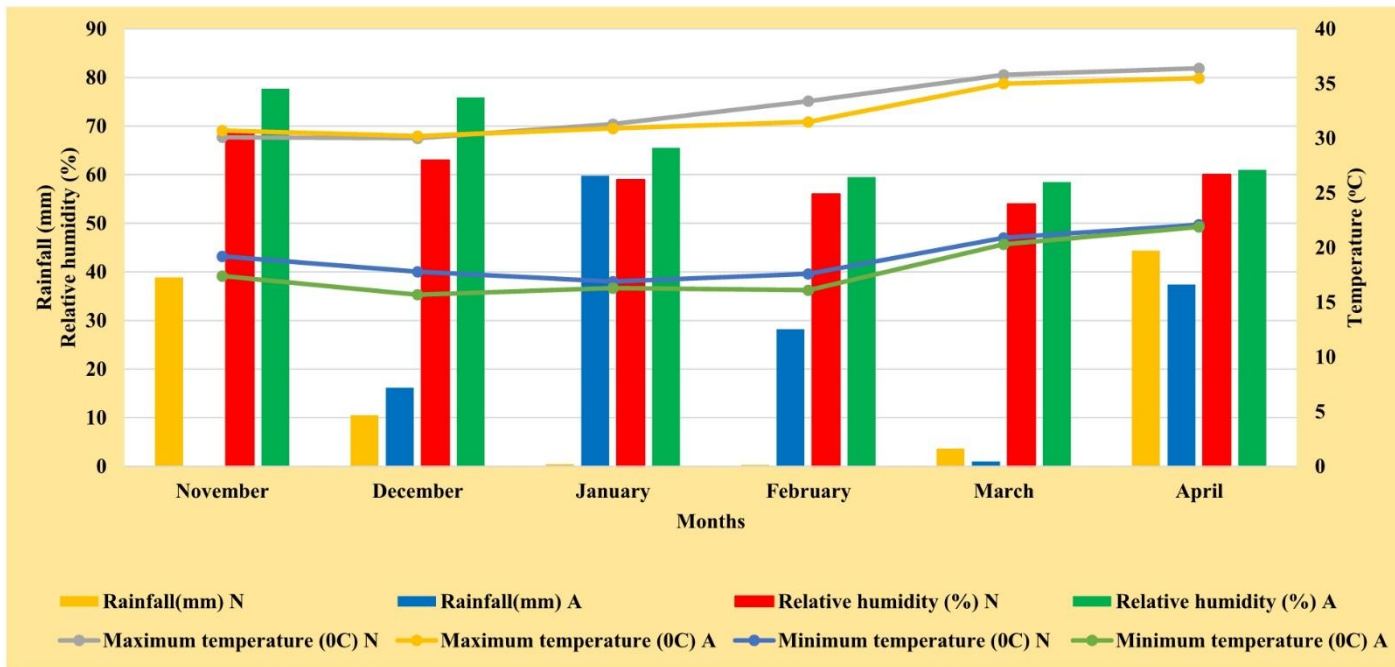


Fig. 3.1 Meteorological data indicating monthly normal and actual rainfall, relative humidity, minimum and maximum temperature during the experimental period at ZAHRS, Navile, KSNUAHS, Shivamogga, 2020-21

3.3.1 Normal climatic condition

In November, the normal rainfall was at its maximum (38.9 mm). The average monthly maximum and minimum temperature ranged from 30 °C to 36.4 °C and 17.6 °C to 22.1 °C, respectively. The highest mean relative humidity was observed in November (60 %), while the lowest was recorded in March (54 %). Mean monthly sunshine hours ranged from 6.7 to 8.5 hours.

3.3.2 Actual weather conditions prevailed during the experimental period

The experiment period was from November to April during *rabi* 2020-21. The actual rainfall obtained during the cropping season was around 142.6 mm (Table 3.2), which was higher than the normal rainfall (98.10 mm). January received the maximum rainfall (59.8 mm) and November received the least (nil). April received the highest monthly maximum temperature (35.5 °C), while December received the lowest monthly maximum temperature (30.2 °C). The lowest monthly minimum temperature was recorded in February (16.1 °C), while April recorded the highest monthly minimum temperature (21.9 °C). The mean relative humidity was lowest in March (58.5 %) and was highest in November (77.7 %).

3.4 Crop history of the experimental site

The previous crop grown at the experimental site was groundnut which was sown during June 2019 and harvested in September 2019.

3.5 Experimental details

3.5.1 Design and layout

The experiment comprises of nine treatments with three replications and is laid out in Randomised Complete Block Design (RCBD). The layout plan is shown in Fig. 3.2.

3.5.2 Treatment details

The experiment consisted of nine treatments as given below:

3.5.3 Description of the cultivar used in the study

The first triple disease resistance tomato F₁ hybrid, Arka Rakshak, is resistant to tomato leaf curl virus, bacterial wilt and early blight. It is square round, large, deep red with very firm fruits, suitable for both fresh distance marketing and processing and has excellent keeping quality (10-18 days) and long transportability.

Table 3.2. Details of the layout

Crop	Tomato (<i>Solanum lycopersicum</i> L.)
Cultivar	Arka Rakshak
Location	ICAR-KVK, KSNUAHS, Shivamogga
Season	Rabi, 2020-21
Design	RCBD
Replication	3
Treatments	9
Total number of plots	27
Gross plot size	3.6 m × 4.8 m
Net plot size	1.8 m × 3.6 m
Spacing	90 cm × 60 cm
RDF	250: 250: 250 N, P ₂ O ₅ , K ₂ O kg ha ⁻¹
FYM	25 t ha ⁻¹

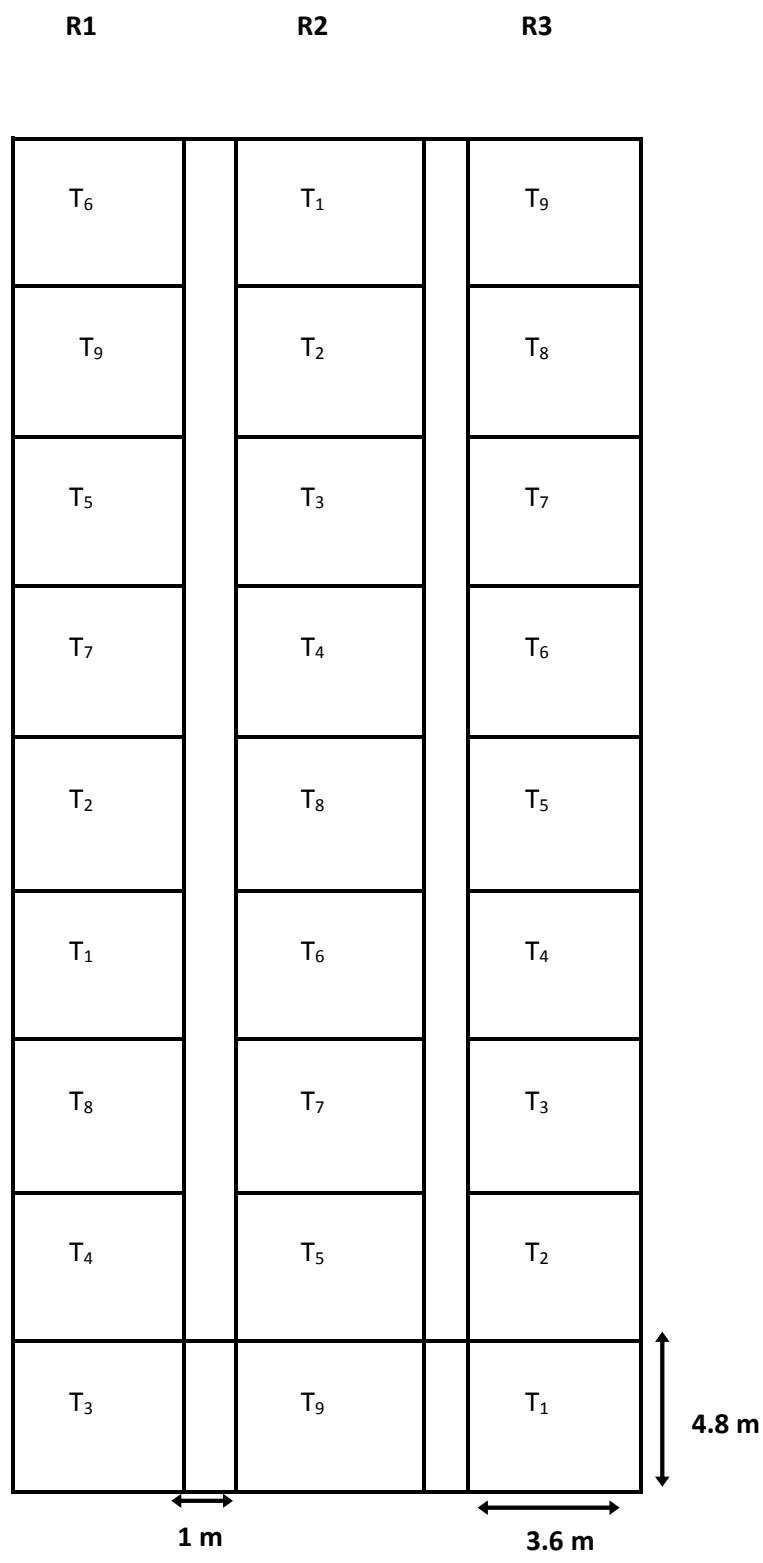
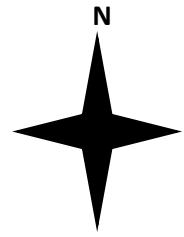


Fig. 3.2. Plan of the layout of the experiment

Table 3.3. Details of the treatments

Treatments	
T ₁	Absolute control
T ₂	100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O
T ₃	100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O
T ₄	75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O
T ₅	75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O
T ₆	Split application of T ₂
T ₇	Split application of T ₃
T ₈	Split application of T ₄
T ₉	Split application of T ₅

{N – 50 per cent as basal + 50 per cent in 3 splits

(Flowering – 15 %, fruiting – 15 %, after first harvest – 20 %)

P₂O₅ – 50 per cent as basal + 50 per cent in 2 splits

(Flowering – 25 %, fruiting – 25 %)

K₂O – 50 per cent as basal + 50 per cent in 3 splits

(Flowering – 10 %, fruiting – 20 %, after first harvest – 20 %)}

Note: Recommended fertilizer dose for tomato hybrid Arka Rakshak is 250: 250: 250 N, P₂O₅, K₂O kg ha⁻¹ respectively.

ZnSO₄ (10 kg ha⁻¹) and FYM (25 t ha⁻¹) were applied to all treatments except absolute control (T₁).

3.6 Details of cultivation practices

3.6.1 Sowing and raising of seedlings in the pro trays

The Indian Institute of Horticulture Research, Bangalore provided the seeds for tomato hybrid Arka Rakshak. The seeds were sown in pro trays during the first week of November, 2020 and were watered with a rose can regularly. The pro-tray was filled with Coco-peat, vermiculite and perlite @ 3:1:1.

3.6.2 Preparation of the main field

The land was brought to fine tilth by ploughing and harrowing. The plots were prepared according to the specifications, with the recommended dose of FYM (25 t ha⁻¹) applied to all treatments except absolute control during land preparation.

3.6.3 Transplanting

Twenty-five days old healthy and uniform seedlings of tomato were transplanted in the prepared field at a spacing of 90 cm × 60 cm with one seedling per hill. Gap filling was done on the seventh day of transplanting to ensure the optimum plant population.

3.6.4 Irrigation management

At the time of planting, light irrigation was given. Subsequent irrigations were provided whenever it was required. Irrigation was given initially at intervals of two to three days and later at a break of six to eight days from transplanting to harvest.

3.6.5 Nutrient management

As per the treatment details, half dose of the nitrogen and full dose of phosphorus and potash at the rate of 250: 250: 250 kg N, P₂O₅, K₂O kg ha⁻¹ was applied at the time of planting. The remaining dose of nitrogen was given at 60 DAT (T₂, T₃, T₄ and T₅) and in splits (T₆, T₇, T₈ and T₉) at the flowering, fruiting and harvesting stages. T₁ is absolute control where there is no application of nutrients.

3.6.6 Weeding and staking

Regular weeding was carried out and staking was provided eight weeks after transplanting. The plants were staked with the help of jute thread and tied to a barbed wire to prevent the lodging of plants.

3.6.7 Harvesting

The fruits were harvested when they started showing signs of maturity, *i.e.*, a progress from completely green in the first stage of maturity to more than 90 % of the tomato surface being red in the final stage of maturity. Harvesting of fruits was done at an interval of five to six days based on ripening habit.

3.7 Soil analysis

Representative soil samples (0-15 cm) from the experimental sites were collected before and after the experiment and used for determining the fundamental physicochemical properties. The collected soil samples were air-dried under shade, powdered using wooden pestle and mortar, passed through 2 mm sieve and stored in the polythene bags for further analysis (Jackson, 1973).

3.7.1 Particle size distribution

The relative proportion of silt, sand and clay particles in the soil sample was determined by the international pipette method using sodium hexametaphosphate as the dispersing agent (Piper, 1966).

3.7.2 Soil reaction (pH)

The pH of the soil was determined in a 1: 2.5 ratio of soil: water extract by the potentiometric method using a pH meter (Jackson, 1973).

3.7.3 Electrical conductivity (EC) (dSm^{-1})

The electrical conductivity of soil was determined in the supernatant solution of 1: 2.5 ratio of soil: water extract using conductivity meter and expressed as dSm^{-1} (Jackson, 1973).

3.7.4 Organic carbon (OC) ($g\ kg^{-1}$)

The organic carbon content of a finely grounded soil sample (< 0.2 mm sieve) was determined by Walkley and Black's wet oxidation method as described by Jackson (1973) and expressed in $g\ kg^{-1}$.

3.7.5 Available nitrogen ($kg\ ha^{-1}$)

The alkaline permanganate method was adopted to assess the available nitrogen content in soils (Subbiah and Asija, 1956). The easily oxidizable portion of the soil organic matter was oxidized using hot alkaline potassium permanganate solution and

the liberated ammonia was distilled to boric acid. Later, the ammonia trapped in boric acid was titrated against standard acid.

3.7.6 Available phosphorus ($kg\ ha^{-1}$)

Available phosphorus was extracted from soil using Bray's reagent. The phosphorus in the extract was determined by the ascorbic acid-molybdate complex method and the blue colour intensity was recorded at 660 nm using a spectrophotometer (Systronics Visiscan 167) (Jackson, 1973).

3.7.7 Available potassium ($kg\ ha^{-1}$)

Available potassium was extracted from the soils using neutral N ammonium acetate in 1: 5 soil to extractant ratio. The concentration of potassium present in the extract was determined by a flame photometer (Jackson, 1973).

3.8 Plant analysis

The plant samples were collected at different growth stages, *i.e.*, at vegetative, flowering and fruiting stages after fertilizer application and then the samples are analyzed for different nutrients. The plant samples were washed with tap and distilled water. The samples were first air-dried and then oven-dried at 65 °C. The dried plant samples were powdered and used for the analysis of different nutrients.

3.8.1 Total nitrogen (%)

Total nitrogen in plant samples was determined by Kjeldhal's method of nitrogen determination as described by Jackson (1973). The powdered sample of 0.5 g was digested with concentrated H_2SO_4 in the presence of a digestion mixture (K_2SO_4 : $CuSO_4 \cdot 5H_2O$: Se in the proportion of 100: 20: 1) and distilled under an alkaline medium. The liberated NH_3 was trapped in four per cent boric acid containing mixed indicator and titrated against standard H_2SO_4 .

3.8.2 Digestion of plant sample with a di-acid mixture

One gram of powdered plant sample was pre-digested with HNO_3 and then digested with a di-acid mixture containing HNO_3 and $HClO_4$ in the proportion of 10: 4, as Jackson (1967) described. The volume of the digest was made up to 100 mL with distilled water and filtered through Whatman No. 41 filter paper and collected the filtrate in a 100 mL volumetric flask and used it for total elemental analysis.

3.8.3 Total phosphorus (%)

A known volume of the di-acid digested sample (3 mL) was taken for total phosphorus determination using by vanadomolybdophosphoric yellow colour method in the nitric acid system as described by Jackson (1973).

3.8.4 Total potassium (%)

Total potassium content in the plant sample was determined by the flame photometric method after diluting 1 mL of the di-acid digest to 25 mL with distilled water. The flame photometer readings of the sample were compared with the calibration curve of potassium and per cent potassium in the plant sample was calculated (Jackson, 1973).

3.9 Nutrient uptake by plant

The nutrient uptake by the tomato plant was calculated by multiplying the nutrient content in plants with the total dry matter production and expressed in kg ha⁻¹ (Robinson *et al.*, 1986).

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Drymatter production (kg ha}^{-1}\text{)}}{100}$$

3.10 Fruit nutrient content

The representative fruits were collected from ten plants in each replication, dried under shade and then oven-dried at 60 °C. The dried fruits were powdered and used to analyze different nutrient contents *viz.*, N, P and K by following the standard procedure as followed in plant analysis (above).

Collection of experimental data

Sampling technique: Observations on various characters were recorded by selecting randomly five competitive plants of each treatment in a replication which were tagged properly. The border plants were excluded while selecting the sample plants.

3.11 Growth parameters

3.11.1 Plant height (cm)

The plant height of five randomly selected plants were recorded and averaged at flowering, fruiting and harvesting stages with the help of a meter scale from the base of the plant up to the tip. It is expressed in cm.

3.11.2 Number of branches per plant

The total number of primary branches of five randomly selected plants were counted and averaged at flowering, fruiting and harvesting stages. It is expressed in numbers.

3.11.3 Leaf area (cm²)

The average leaf area of the tagged plants were measured from five randomly selected leaves at flowering, fruiting and harvesting stages by plotting the graph paper. It is expressed in cm².

3.12 Biochemical parameters

3.12.1 Chlorophyll content (Chl-a, b and total chlorophyll) (mg g⁻¹ fresh weight)

Chlorophyll was estimated using the third fresh leaves from the top of the plants. A known weight of leaf sample was cut into small pieces and suspended in test tubes containing 7 mL of dimethyl sulphoxide (DMSO). Test tubes were incubated in a warm water bath at 60 °C for 20 min. The supernatant was decanted. Another 3 mL of DMSO was added to the residue and incubated at 60 °C for 20 min. The supernatants were grouped and the volume was made up to 10 mL by adding DMSO. Extracted chlorophyll was transferred to a cuvette, and the absorbance was read in a systronic spectrophotometer-169 at 645 and 663 nm against DMSO blank. Chlorophyll a, b and total chlorophyll were calculated. The data was recorded in mg g⁻¹ fresh weight.

$$\text{Chl. a (mg g}^{-1}\text{)} = [12.7(\text{OD}_{663}) - 2.69(\text{OD}_{645})] \times V/1000 \times W \times a$$

$$\text{Chl. b (mg g}^{-1}\text{)} = [22.9(\text{OD}_{645}) - 4.68(\text{OD}_{663})] \times V/1000 \times W \times a$$

$$\text{Total Chl. (mg g}^{-1}\text{)} = [20.2(\text{OD}_{645}) + 8.02 (\text{OD}_{663})] \times V/1000 \times W \times a$$

Where, V = Volume of the acetone used in extract (mL)

W = Weight of fresh leaf tissue (g)

A = Light path length (cm)

A₆₄₅ = Absorbance of the extract at 645 nm

A₆₆₃ = Absorbance of the extract at 663 nm

3.13 Yield parameters

3.13.1 Number of flower clusters per plant

The number of flower clusters per plant was recorded as average of full bloom clusters on five randomly tagged plants at the flowering stage and the average was taken.

3.13.2 Number of fruits per plant

The numbers of fruits from the five tagged plants harvested in all the pickings were added and the average was worked out.

3.13.3 Individual fruit weight (g)

The weight of five fruits was recorded in grams from five randomly selected plants in each replication and then averaged.

3.13.4 Girth of the fruit (cm)

The girth of the fruit was measured using vernier callipers and the average width of the fruit was computed and expressed in centimetres.

3.13.5 Yield per hectare ($t\ ha^{-1}$)

The weight of red ripe fruits harvested from each net plot was recorded. Based on the yield of the net plot, the fruit yield per hectare was calculated and expressed in tonnes per ha.

3.14 Quality parameters

3.14.1 Total soluble solids (TSS) ($^{\circ}$ Brix)

Total soluble solids were measured as stated by Dong *et al.* (2001) and Dongare *et al.* (2014). One to two drops of the tomato juice extract were prepared and placed on the prism of the digital refractometer and TSS was measured in $^{\circ}$ Brix.

3.14.2 Ascorbic acid ($mg\ 100g^{-1}$ fresh sample)

Five mL of ascorbic acid standard solution ($100\ mg\ L^{-1}$) was pipetted out into a 100 mL conical flask. Then 5 mL of oxalic acid (4 %) was added to the conical flask. It was titrated against 2, 6-dichlorophenol indophenol dye solution until the appearance of pink colour. The dye factor was determined as the amount of dye consumed, which

is equivalent to the ascorbic acid. The ascorbic acid content was estimated by taking two grams of pulp in oxalic acid, filtered through a muslin cloth. The final volume was made up to 25 mL using 4 per cent oxalic acid. From this, 5 mL of aliquot was taken. Then 5 mL of 4 per cent oxalic acid was added and titrated against 2, 6-dichlorophenol indophenol dye to a pink endpoint. The amount of ascorbic acid was calculated by the following formula and expressed as mg 100g⁻¹ fresh weight.

$$\text{Ascorbic acid content} = \frac{\text{Titre value} \times \text{dry factor} \times \text{volume made up}}{\text{Aliquot taken} \times \text{Weight of sample (g)}}$$

3.14.3 Lycopene content (mg 100g⁻¹ fresh sample)

One gram of blended fruit sample was taken into a mortar and pulp was extracted repeatedly with acetone until the residue turned colourless. The acetone extract was transferred to separating funnel containing 10 to 15 mL of hexane layer by diluting the acetone with water. Hexane containing pigments were transferred to 25 mL volumetric flask and diluted to the mark with hexane. Then one mL of aliquot was further diluted to 4 mL with hexane and the absorbance or OD was read in a spectrophotometer at 503 nm. The lycopene content was calculated by using the formula.

$$\text{Lycopene content} = \frac{\text{OD of sample} \times \text{Volume} \times \text{Dilution (mL)}}{\text{Weight of sample} \times 1000\text{g}} \times 100$$

A₅₀₃ = Absorbance of hexane layer measured at 503 nm

3.14.4 Shelf life (days)

Five matured fruits from each treatment per replication was selected and were kept at 25 to 30 °C. The number of days after which 50 per cent of the fruits showed slight symptoms of shrinkage or spoilage were considered as the end of their shelf life.

3.15 Nutrient Use Efficiency (NUE)

$$\text{NUE} = \frac{\text{Fruit yield (kg ha}^{-1}\text{)}_f - \text{Fruit yield (kg ha}^{-1}\text{)}_c}{\text{Nutrient applied (kg ha}^{-1}\text{)}}$$

Fruit yield (kg ha⁻¹)_f – Fruit yield of fertilized crop in kg

Fruit yield (kg ha⁻¹)_c – Fruit yield of unfertilized crop in kg

3.16 Statistical Analysis

The recorded data on different parameters were statistically analyzed based on the procedure given by Gomez and Gomez (1984) to find out the treatment differences. Critical differences were worked out at a 5 per cent probability level where the treatments differed significantly.

3.17 Economics of the crop

3.17.1 Total cost of cultivation (Rs. ha⁻¹)

Cost of cultivation refers to the total expenses incurred in cultivating one hectare. It includes factor costs up to the stage of gathering the harvest.

The cost of cultivation of each treatment was calculated as per hectare on the basis of prevailing rates of labour, fertilizer, organic manures, irrigation and other expenditure. The labour wages, cost of inputs and outputs are furnished in Appendix-II.

Total cost of cultivation = Total variable Cost + Total fixed cost

3.17.2 Gross returns (Rs. ha⁻¹)

Gross returns were calculated by taking the price of the product into consideration that was prevailing in the market after harvest as per the treatment and is expressed in Rs. ha⁻¹.

3.17.3 Net returns (Rs. ha⁻¹)

Net profit is gross farm income less all costs associated with production and running the business.

It encompasses cash receipts from farming as well as farm related income, including government payments minus cash expenses.

Net returns (Rs. ha⁻¹) = Gross returns (Rs. ha⁻¹) – total cost of cultivation (Rs. ha⁻¹)

3.17.4 Benefit-cost ratio

The cost benefit ratio (BCR) is the amount of money earned per amount of money spent on fertilizer. It is an indicator showing the relationship between the relative costs and benefits of a proposed project, expressed in monetary or qualitative terms.

If a project has a cost benefit ratio greater than 1.0, the project is expected to deliver a positive net present value to a firm and its investors and is acceptable.

$$\text{Benefit-cost ratio} = \frac{\text{Gross returns (Rs. ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs. ha}^{-1}\text{)}}$$



Plate 1. Field overview



Plate 2. Field overview at peak flowering stage of tomato



Plate 3. Field overview at peak fruiting stage of tomato



Plate 4. Ripening stage in tomato



Plate 5. Fruiting stage of tomato in best treatment (T₇)



Plate 6. Fruiting stage of tomato in RDF (T₂)



Plate 7. Taking observations



Plate 8. Harvesting fruits



Plate 8. Inspection of field by Dr. Sarvajna B. Salimath (Advisor)



Plate 9. Weighing harvested tomatoes



Plate 10. Inspection of field by Dr. Sarvajna B. Salimath, Dr. G. N. Thippeshappa and Dr. B. C. Dhananjaya

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

This chapter presents the findings of the field experiment conducted at ICAR-KVK, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, during *rabi* 2020-21, to investigate the “Nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients.”

4.1 Fertility status of soil

4.1.1 Chemical properties of soil

The data in table 4.1 showed the influence of split application of NPK on various chemical properties of soil.

The data on soil chemical properties *viz.*, pH, EC and OC content after the harvest of tomato due to the split application of NPK nutrients did not show any significant variations among the treatments.

4.1.2 Available nitrogen (kg ha^{-1})

The available soil nitrogen following different stages of the crop is furnished in Table 4.2.

The results of the investigation indicated that there was a significant difference among the treatments in available nitrogen content of soil due to split application of fertilizers. The treatment supplied with 100 per cent RDF (T_2) recorded the maximum soil available nitrogen ($272.58 \text{ kg ha}^{-1}$), followed by T_6 that received split application of 100 per cent RDF ($268.30 \text{ kg ha}^{-1}$) at the vegetative stage of the crop. However, T_3 that received 100 per cent RD N+100 per cent RD P_2O_5 +125 per cent RD K_2O recorded $265.09 \text{ kg ha}^{-1}$ available nitrogen.

At flowering stage, maximum soil available nitrogen of $264.32 \text{ kg ha}^{-1}$ was recorded in treatment that received split application of 100 per cent RDF (T_6), followed by T_7 ($257.99 \text{ kg ha}^{-1}$) that received split application of 100 per cent RD N + 100 per cent RD P_2O_5 +125 per cent RD K_2O . However, the available nitrogen recorded by T_2 that received 100 per cent RDF was $231.50 \text{ kg ha}^{-1}$ and T_3 that received 100 per cent RD N+100 per cent RD P_2O_5 +125 per cent RD K_2O was $228.96 \text{ kg ha}^{-1}$.

At fruiting stage, the higher soil available nitrogen content of $304.61 \text{ kg ha}^{-1}$ was registered in T_2 that received application of 100 per cent RDF, followed by T_3 ($296.39 \text{ kg ha}^{-1}$) that received 100 per cent RD N+100 per cent RD P_2O_5 +125 per cent

Table 4.1. Effect of split application of NPK nutrients on soil chemical properties after the harvest of tomato

Treatment	pH	EC (dSm ⁻¹)	OC (g kg ⁻¹)
Initial	6.42	0.43	4.05
T ₁ : Absolute control	6.3	0.44	4.04
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	6.15	0.47	4.13
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	6.16	0.48	4.26
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	6.19	0.46	4.05
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	6.18	0.47	4.24
T ₆ : Split application of T ₂	6.19	0.43	4.38
T ₇ : Split application of T ₃	6.22	0.46	4.42
T ₈ : Split application of T ₄	6.25	0.45	4.22
T ₉ : Split application of T ₅	6.20	0.45	4.45
	S.E.m±	0.01	0.01
	CD @ 5%	NS	NS

* = Significant at 5% level, NS=Non-Significant

Table 4.2. Available nitrogen status (kg ha⁻¹) of soil as influenced by split application of NPK nutrients at different growth stages of tomato

Treatments	Available nitrogen (kg ha ⁻¹)			
	Vegetative	Flowering (30 DAT)	Fruiting (60 DAT)	Harvesting (90 DAT)
Initial-153.89 kg ha ⁻¹				
T ₁ : Absolute control	149.74	130.83	81.39	45.48
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	272.58	231.50	304.61	239.58
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	265.09	228.96	296.39	228.10
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	240.67	207.17	259.57	187.32
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	239.78	197.64	250.42	172.71
T ₆ : Split application of T ₂	268.30	264.32	232.34	245.77
T ₇ : Split application of T ₃	264.92	257.99	220.23	231.57
T ₈ : Split application of T ₄	240.17	243.17	204.42	195.52
T ₉ : Split application of T ₅	237.77	237.77	192.13	178.82
	1.13	1.23	2.57	2.26
	3.29	3.54	7.38	6.37

RD K₂O and T₄ (259.57 kg ha⁻¹) that received 75 per cent RD N+100 per cent RD P₂O₅+100 per cent RD K₂O.

At harvest, the maximum available nitrogen of 245.77 kg ha⁻¹ was recorded in treatment that received split application of 100 per cent RDF (T₆), followed by T₂ (239.58 kg ha⁻¹) that received 100 per cent RDF and T₇ (231.57 kg ha⁻¹) that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O. However, T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded 228.10 kg ha⁻¹ available nitrogen in soil.

4.1.3 Available phosphorus (kg ha⁻¹)

The data on available phosphorus content in soil following different stages of the crop is presented in Table 4.3.

The results indicated that there was a significant difference in the available phosphorus content of soil due to the split application of NPK nutrients. The treatment supplied with 100 per cent RDF (T₂) recorded the maximum available phosphorus of 67.93 kg ha⁻¹ at the vegetative stage, which was on par with T₄ that received 75 per cent RD N+100 per cent RD P₂O₅+100 per cent RD K₂O with soil available phosphorus of 67.45 kg ha⁻¹. However, T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded 65.53 kg ha⁻¹ available phosphorus.

At flowering stage, maximum available phosphorus (61.79 kg ha⁻¹) was recorded in the treatment that received 75 per cent RD N + 100 per cent RD P₂O₅+100 per cent RD K₂O (T₄), which was on par with treatment that received 100 per cent RDF (T₂) with available soil phosphorus of 61.31 kg ha⁻¹, followed by T₅ (60.36 kg ha⁻¹) that received 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O. However, T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded 59.10 kg ha⁻¹ available phosphorus.

The higher soil available phosphorus at fruiting stage was registered in T₈ (57.84 kg ha⁻¹) that received split application of 75 per cent RD N+100 per cent RD P₂O₅+100 per cent RD K₂O, which was on par with T₆ that received split application of 100 per cent RDF (56.72 kg ha⁻¹). However, T₂ that received 100 per cent RDF recorded 48.10 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 43.75 kg ha⁻¹.

At harvest, the treatment that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 100 per cent RD K₂O (T₈) recorded the maximum available phosphorus of 37.19 kg ha⁻¹, which was on par with T₄ that received 75 per cent RD N + 100 per cent RD P₂O₅ + 100 per cent RD K₂O recorded 35.78 kg ha⁻¹. However, T₂ that received 100 per cent RDF recorded 32.38 kg ha⁻¹ and T₃ that received 100 per

Table 4.3. Available phosphorus status (kg ha⁻¹) of soil as influenced by split application of NPK nutrients at different growth stages of tomato

Treatments	Available phosphorus (P ₂ O ₅ kg ha ⁻¹)			
	Vegetative	Flowering (30 DAT)	Fruiting (60 DAT)	Harvest (90 DAT)
Initial - 41.71 kg ha ⁻¹				
T ₁ : Absolute control	39.48	34.51	24.89	14.54
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	67.93	61.31	48.10	32.38
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	65.53	59.10	43.75	26.34
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	67.45	61.79	50.89	35.78
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	65.68	60.36	45.25	28.11
T ₆ : Split application of T ₂	48.11	53.10	56.72	34.27
T ₇ : Split application of T ₃	46.20	49.79	54.74	30.43
T ₈ : Split application of T ₄	48.40	52.51	57.84	37.19
T ₉ : Split application of T ₅	46.42	51.66	55.46	31.62
	0.64	0.87	1.03	1.16
	1.84	2.44	3.05	3.38

cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 26.34 kg ha⁻¹ available phosphorus.

4.1.4 Available potassium (kg ha⁻¹)

The data on available potassium content in soil following different stages of the crop is presented in Table 4.4.

There was a significant difference in the available potassium content of soil due to the split application of NPK nutrients among the treatments. Maximum available potassium of 469.91 kg ha⁻¹ at the vegetative stage was recorded in the treatment that received 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₅), which was on par with T₃ (465.45 kg ha⁻¹) that received 100 per cent RD N +100 per cent RD P₂O₅ +100 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 427.57 kg ha⁻¹ available potassium.

At flowering, the treatment that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O (T₉) registered the maximum available potassium (415.40 kg ha⁻¹), which is on par with T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O (411.77 kg ha⁻¹). However, T₂ that received 100 per cent RDF recorded 354.45 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 406.55 kg ha⁻¹ available potassium.

The higher soil available potassium of 366.43 kg ha⁻¹ was registered in T₉ that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O at fruiting stage, which was on par with T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O, with 359.76 kg ha⁻¹. However, T₂ that received 100 per cent RDF recorded 265.06 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 306.95 kg ha⁻¹ available potassium.

At harvest, the treatment that received split application of 100 per cent RDF (T₆) recorded the maximum available potassium of 263.70 kg ha⁻¹, which was on par with treatment that received 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (T₅) with soil available potassium of 257.69 kg ha⁻¹. However, T₂ that received 100 per cent RDF recorded 202.72 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 240.82 kg ha⁻¹.

Table 4.4. Available potassium status (kg ha⁻¹) of soil as influenced by split application of NPK nutrients at different growth stages of tomato

Treatments	Available potassium (K ₂ O kg ha ⁻¹)			
	Vegetative	Flowering (30 DAT)	Fruiting (60 DAT)	Harvest (90 DAT)
Initial – 253.62 kg ha ⁻¹				
T ₁ : Absolute control	244.34	212.97	124.32	86.11
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	427.57	354.45	265.06	202.72
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	465.45	406.55	306.95	240.82
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	424.10	361.33	276.91	229.73
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	469.91	408.49	315.20	257.69
T ₆ : Split application of T ₂	341.89	380.39	320.84	225.41
T ₇ : Split application of T ₃	357.87	411.77	359.76	256.13
T ₈ : Split application of T ₄	344.17	388.54	338.64	241.40
T ₉ : Split application of T ₅	358.88	415.40	366.43	263.70
S.E.m±	2.67	2.93	3.28	2.69
CD @ 5%	7.72	8.55	9.71	8.01

4.2 Leaf tissue analysis

4.2.1 Total nitrogen (%)

Results with respect to nitrogen content of tomato leaves recorded at vegetative, flowering and fruiting stages differed considerably among the treatments and is furnished in Table 4.5.

The treatment that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O (T₇) recorded the highest N content (1.62 %) in the plant, which was on par with T₃ (1.60 %) that received 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O at the vegetative stage. However, T₂ that received 100 per cent RDF recorded 1.54 per cent N.

At the flowering stage, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded significantly higher nitrogen content of 1.93 per cent in plant, which was on par with T₉ (1.88 %) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 1.72 per cent N and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 1.80 per cent N.

The maximum N content (2.10 %) at the fruiting stage was recorded in T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O in the plant, which was on par with T₉ (2.04 %) that received the split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 1.77 per cent N and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 1.94 per cent N in plant.

4.2.2 Total phosphorus (%)

Results with respect to phosphorus content of tomato leaves recorded at vegetative, flowering and fruiting stages differed considerably among the treatments and is furnished in Table 4.5.

The treatment that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (T₃) recorded the highest P content (0.47 %), which was on par with T₂ (0.45 %) that received 100 per cent RDF at the vegetative stage.

The maximum P content of 0.50 per cent at flowering stage was recorded in treatment that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (T₇), which was on par with T₉ (0.48 %) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O.

Table 4.5. Effect of split application of NPK nutrients on the nutrient content (%) of tomato leaf at different growth stages

Treatments	Vegetative (%)			Flowering (%)			Fruiting (%)		
	N	P	K	N	P	K	N	P	K
T ₁ : Absolute control	1.09	0.26	3.06	1.40	0.32	3.48	1.54	0.37	3.87
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.54	0.45	4.04	1.72	0.45	4.40	1.77	0.48	4.61
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.60	0.47	4.43	1.80	0.45	4.50	1.94	0.51	4.68
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.39	0.39	3.82	1.61	0.38	4.13	1.77	0.42	4.31
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.45	0.41	4.01	1.70	0.42	4.16	1.81	0.48	4.33
T ₆ : Split application of T ₂	1.49	0.35	3.51	1.85	0.46	4.59	1.99	0.52	4.86
T ₇ : Split application of T ₃	1.62	0.37	3.63	1.93	0.50	4.76	2.10	0.57	5.03
T ₈ : Split application of T ₄	1.41	0.34	3.45	1.77	0.38	4.41	1.96	0.42	4.69
T ₉ : Split application of T ₅	1.58	0.36	3.59	1.88	0.48	4.69	2.04	0.54	4.97
	0.05	0.01	0.07	0.02	0.01	0.03	0.03	0.01	0.03
	0.13	0.03	0.20	0.04	0.03	0.09	0.09	0.02	0.09

However, T₂ that received 100 per cent RDF and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 0.45 per cent.

At the fruiting stage, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded a significantly higher P content (0.57 %) in plant, which was on par with T₉ (0.54 %) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 0.48 per cent P and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 0.51 per cent P.

4.2.3 Total potassium (%)

Total potassium (%)

The K content of tomato leaves recorded at vegetative, flowering and fruiting stages differed considerably among the treatments and is furnished in Table 4.5.

The treatment that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (T₃) recorded a significantly higher K content of 4.43 per cent in the plant, followed by T₂ (4.04 %) that received 100 per cent RD N+100 per cent RD P₂O₅+100 per cent RD K₂O at the vegetative stage.

The maximum K content of 4.76 per cent in the plant was recorded in T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, which was on par with T₉ (4.69 %) that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 4.40 per cent and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 4.50 per cent.

At the fruiting stage, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded a significantly higher K content of 5.03 per cent in the plant, which was on par with T₉ (4.97 %) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 4.61 per cent and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 4.68 per cent.

4.3 Effect of split application of NPK nutrients on the nutrient uptake (kg ha⁻¹) by tomato plant

The data on nutrient uptake by tomato plant is significantly influenced by split application of NPK nutrients and is given in Table 4.6.

Table 4.6. Effect of split application of NPK nutrients on the nutrient uptake (kg ha⁻¹) of tomato plant at different growth stages

Treatments	Vegetative (kg ha ⁻¹)			Flowering (kg ha ⁻¹)			Fruiting (kg ha ⁻¹)		
	N	P	K	N	P	K	N	P	K
T1: Absolute control	3.67	0.88	10.32	10.67	2.41	26.57	24.07	5.72	60.67
T2: 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	6.87	1.98	18.02	15.01	3.88	38.39	35.06	9.51	91.20
T3: 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	7.44	2.20	20.74	16.30	4.03	40.76	40.14	10.55	96.73
T4: 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	5.70	1.60	15.64	12.94	3.06	33.29	32.90	7.71	80.11
T5: 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	6.19	1.75	17.11	14.55	3.55	35.61	35.55	9.43	85.04
T6: Split application of T ₂	6.31	1.48	14.85	18.40	4.57	45.64	41.73	10.83	102.07
T7: Split application of T ₃	7.47	1.71	16.79	21.70	5.42	53.61	46.83	12.63	112.33
T8: Split application of T ₄	5.84	1.41	14.33	16.57	3.57	41.41	40.12	8.60	96.01
T9: Split application of T ₅	6.96	1.59	15.81	19.76	5.27	47.50	44.18	11.96	105.45
	0.06	0.04	0.39	0.69	0.06	1.15	0.90	0.25	1.43
	0.17	0.12	1.06	2.02	0.16	3.26	2.54	0.62	4.16

4.3.1 Uptake of nitrogen

The treatment that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (T₇) recorded the maximum N uptake (7.47 kg ha⁻¹) at the vegetative stage, followed by T₃ (7.44 kg ha⁻¹) that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 6.87 kg ha⁻¹.

During flowering, the N uptake was recorded highest in T₇ (21.70 kg ha⁻¹), that received the split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, followed by T₉ (19.76 kg ha⁻¹) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 15.01 kg ha⁻¹ N and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 16.30 kg ha⁻¹ N.

The treatment that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded the highest N uptake (46.83 kg ha⁻¹) at fruiting stage, followed by T₉ (44.18 kg ha⁻¹) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 35.06 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 40.14 kg ha⁻¹.

4.3.2 Uptake of phosphorus

During the vegetative stage, the P uptake was recorded highest in T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O (2.20 kg ha⁻¹), followed by T₂ (1.98 kg ha⁻¹) that received 100 per cent RDF. However, T₇, that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded 1.71 kg ha⁻¹ P uptake.

The treatment that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (T₇) recorded 5.42 kg ha⁻¹, followed by T₉ (5.27 kg ha⁻¹) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O at the flowering stage. However, the treatment T₂ that received 100 per cent RDF recorded 3.88 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded 4.03 kg ha⁻¹ P uptake.

During fruiting, the P uptake was significantly highest in T₇ (12.63 kg ha⁻¹) that received the split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, followed by T₉ (11.96 kg ha⁻¹) that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 9.51 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 10.55 kg ha⁻¹ P uptake.

4.3.3 Uptake of potassium

The treatment that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, T₃ (20.74 kg ha⁻¹) recorded the highest K uptake, followed by T₂ (18.02 kg ha⁻¹) that received 100 per cent RDF at vegetative stage. However, the treatment T₇, that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 16.79 kg ha⁻¹ K uptake.

During flowering, the K uptake was significantly highest in T₇ (53.61 kg ha⁻¹), that received the split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, followed by T₉ (47.50 kg ha⁻¹) that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O). However, the treatment T₂ that received 100 per cent RDF recorded 38.39 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 40.76 kg ha⁻¹ K uptake.

The maximum K uptake was recorded in T₇ (112.33 kg ha⁻¹), that received the split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, followed by T₉ (105.45 kg ha⁻¹), that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O at the fruiting stage. However, the treatment T₂ that received 100 per cent RDF recorded 91.20 kg ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 96.73 kg ha⁻¹ K uptake.

4.4 Effect of split application of NPK nutrients on the nutrient content (%) of tomato fruit

Table 4.7 shows the N, P and K content of tomato fruits.

4.4.1 Total nitrogen (%)

The nitrogen content of tomato fruit was measured after harvest and found to vary considerably among the treatments.

In the first two harvests, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O registered the highest N content (1.45 and 1.47 %, respectively) and was on par with T₉ that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (1.42 and 1.44 %, respectively). However, the treatment T₂ that received 100 per cent RDF recorded 1.26 and 1.24 per cent and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 1.35 and 1.34 per cent.

Table 4.7. Effect of split application of NPK nutrients on the nutrient content (%) of tomato fruit at different harvest

Treatments	First harvest			Second harvest		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
T ₁ : Absolute control	1.13	0.19	3.65	1.10	0.17	3.57
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.26	0.28	4.38	1.24	0.26	4.32
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.35	0.29	4.48	1.34	0.28	4.45
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.21	0.24	4.05	1.18	0.21	3.97
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.23	0.26	4.37	1.19	0.25	4.35
T ₆ : Split application of T ₂	1.39	0.33	4.64	1.42	0.31	4.67
T ₇ : Split application of T ₃	1.45	0.35	4.79	1.47	0.37	4.84
T ₈ : Split application of T ₄	1.36	0.27	4.55	1.39	0.29	4.58
T ₉ : Split application of T ₅	1.42	0.34	4.74	1.44	0.35	4.8
	S.E.m±	0.01	0.02	0.01	0.01	0.02
	CD @ 5%	0.03	0.05	0.03	0.03	0.05

4.4.2 Total phosphorus (%)

The content of P in tomato fruit was measured after harvest and showed considerable differences between the treatments.

In the first two harvests, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O registered the highest P content (0.35 and 0.37 %, respectively) and was on par with T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (0.34 and 0.35 %, respectively). However, T₂ that received 100 per cent RDF recorded 0.28 and 0.26 per cent and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 0.29 and 0.28 per cent.

4.4.3 Total potassium (%)

After harvest, the content of K in tomato fruit was measured and there were significant changes among the treatments.

The treatment T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded significantly higher K content (4.79 and 4.84 %, respectively) in the initial harvests and was found to be on par with T₉ that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (4.74 and 4.80 %, respectively). However, T₂ that received 100 per cent RDF recorded 4.38 and 4.32 per cent and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 4.48 and 4.45 per cent K in fruit at first and second harvest respectively.

4.5 Effect of split application of NPK nutrients on growth parameters of tomato

4.5.1 Plant height (cm)

The data recorded with respect to plant height of tomato at different growth stages as influenced by split application of NPK fertilizers is presented in Table 4.8.

It was noticed from the results that, plant height significantly increased with the split application of NPK nutrients over RDF. The height of plants at flowering, fruiting and harvesting stages varied from 53.01 to 69.16 cm, 95.05 to 114.60 cm and 113.45 to 128.05 cm, respectively. From flowering to harvest, the plant height of tomato crops gradually increased. Among the different treatments studied, the plant height was constantly higher in treatment that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) at flowering, fruiting and harvesting stages (69.16, 114.60 and 128.05 cm, respectively), which was on par with T₉: Split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (67.25, 111.55 and 126.15 cm, respectively). However, T₂ that received 100

Table 4.8. Plant height (cm) of tomato at different growth stages as influenced by the split application of NPK nutrients

Treatments	Plant height (cm)		
	Flowering (30 DAT)	Fruiting (60 DAT)	At harvest (90 DAT)
T ₁ : Absolute control	53.01	95.05	113.45
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	61.36	104.20	120.37
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	62.87	106.15	121.85
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	57.42	100.85	117.95
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	60.83	102.90	119.64
T ₆ : Split application of T ₂	64.02	109.60	124.60
T ₇ : Split application of T ₃	69.16	114.60	128.05
T ₈ : Split application of T ₄	63.47	107.35	122.29
T ₉ : Split application of T ₅	67.25	111.55	126.15
	0.84	1.53	1.60
	2.25	4.38	4.23

per cent RDF recorded 61.36, 104.20 and 120.37 cm and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 62.87, 106.15 and 121.85 cm plant height at flowering, fruiting and harvest stages.

4.5.2 Number of branches per plant

The data pertaining to number of branches per plant of tomato at flowering, fruiting and harvesting stages as significantly influenced by split application of NPK fertilizers are presented in Table 4.9.

The findings showed that the split application of NPK nutrients significantly influenced the number of branches per plant of tomato. The number of branches per plant at flowering, fruiting and harvesting stages varied from 6.10 to 8.26, 10.02 to 13.03 and 12.73 to 15.59, respectively. This depicted that the number of branches per tomato plant progressively increased from flowering to harvest. Significantly higher number of branches per plant was recorded in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O at flowering, fruiting and harvesting stages (8.26, 13.03 and 15.59, respectively), which was on par with T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (8.15, 12.83 and 15.26, respectively). However, T₂ that received 100 per cent RDF recorded 7.52, 12.34 and 14.67 branches and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 7.71, 12.46 and 14.92 branches at flowering, fruiting and harvest stages, respectively.

4.5.3 Leaf area (cm²)

The data pertaining to leaf area of tomato at flowering, fruiting and harvesting stages as influenced by split application of NPK fertilizers are presented in Table 4.10.

The data indicated that the leaf area increased significantly by split application of NPK nutrients. The leaf area of tomato ranged from 32.47 to 36.78 cm² at flowering, 62.15 to 75.17 cm² at fruiting and 51.45 to 64.95 cm² at harvest, respectively. The leaf area gradually expanded from flowering to fruiting, then gradually dropped at harvesting. Significantly higher leaf area was recorded in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O at flowering, fruiting and harvesting stages (36.78, 75.17 and 64.95 cm², respectively), which was on par with T₉: Split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (36.52, 74.91 and 62.3 cm², respectively). However, T₂ that received 100 per cent RDF recorded 35.03, 71.85, 60.91 cm² and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 35.87, 72.97 and 61.07 cm², respectively.

Table 4.9. Number of branches per plant of tomato at different growth stages as influenced by the split application of NPK nutrients

Treatments	Number of branches per plant		
	Flowering (30 DAT)	Fruiting (60 DAT)	At harvest (90 DAT)
T ₁ : Absolute control	6.10	10.02	12.73
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	7.52	12.34	14.67
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	7.71	12.46	14.92
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	6.72	11.75	14.40
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	7.45	12.26	14.55
T ₆ : Split application of T ₂	7.94	12.71	15.17
T ₇ : Split application of T ₃	8.26	13.03	15.59
T ₈ : Split application of T ₄	7.82	12.55	15.02
T ₉ : Split application of T ₅	8.15	12.83	15.26
	0.07	0.21	0.10
S.Em±			
	0.19	0.60	0.28
CD @ 5%			

Table 4.10. Leaf area (cm²) of tomato at different growth stages as influenced by the split application of NPK nutrients

Treatments	Leaf area (cm ²)		
	Flowering (30 DAT)	Fruiting (60 DAT)	At harvest (90 DAT)
T ₁ : Absolute control	32.47	62.15	51.45
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	35.03	71.85	60.91
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	35.87	72.97	61.07
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	34.30	68.35	55.75
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	34.73	71.32	60.25
T ₆ : Split application of T ₂	36.30	73.95	61.55
T ₇ : Split application of T ₃	36.78	75.17	64.95
T ₈ : Split application of T ₄	35.91	73.16	61.29
T ₉ : Split application of T ₅	36.52	74.91	62.30
	0.22	0.94	1.11
	0.52	2.65	3.20

4.6 Effect of split application of NPK nutrients on biochemical parameters of tomato

4.6.1 Chlorophyll-a content (mg g^{-1} fresh weight)

The data on chlorophyll-a content of tomato leaf at flowering, fruiting and harvesting stages as influenced by split application of NPK fertilizers is presented in Table 4.11.

Results indicated that the split application of NPK nutrients had a significant influence on the chlorophyll-a content. It varied from 0.90 to 1.37, 1.18 to 1.48 and 0.79 to 1.11 mg g^{-1} fresh weight at flowering, fruiting and harvesting phases, respectively. The maximum chlorophyll-a (1.37, 1.48 and 1.11 mg g^{-1} fresh weight at flowering, fruiting and harvesting phases, respectively) was recorded in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉: Split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (1.33, 1.45, 1.08 mg g^{-1} fresh weight, respectively). However, T₂ that received 100 per cent RDF recorded 1.14, 1.37, 0.95 mg g^{-1} fresh weight and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 1.17, 1.39 and 1.01 mg g^{-1} fresh weight, respectively.

4.6.2 Chlorophyll-b content (mg g^{-1} fresh weight)

The data on chlorophyll-b content at different stages of tomato as influenced by the split application of NPK nutrients is presented in Table 4.12.

Results indicated that the chlorophyll-b content varied from 0.43 to 0.65, 0.49 to 0.76 and 0.31 to 0.46 mg g^{-1} fresh weight at flowering, fruiting and harvesting stages, respectively. The treatment that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) produced the maximum chlorophyll-b (0.65, 0.76 and 0.46 mg g^{-1} fresh weight at flowering, fruiting and harvesting stages, respectively), which was on par with T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (0.62, 0.72, 0.44 mg g^{-1} fresh weight, respectively). However, T₂ that received 100 per cent RDF recorded 0.55, 0.62, 0.37 mg g^{-1} fresh weight and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 0.56, 0.63 and 0.38 mg g^{-1} fresh weight, respectively.

4.6.3 Total chlorophyll content (mg g^{-1} fresh weight)

The data on total chlorophyll at different stages of tomato as influenced by the split application of NPK nutrients is presented in Table 4.13.

Table 4.11: Chlorophyll-a content (mg g⁻¹ fresh weight) of tomato at different growth stages as influenced by the split application of NPK nutrients

Treatments	Chlorophyll-a (mg g ⁻¹ fresh weight)		
	Flowering (30 DAT)	Fruiting (60 DAT)	At harvest (90 DAT)
T ₁ : Absolute control	0.90	1.18	0.79
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.14	1.37	0.95
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.17	1.39	1.01
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.06	1.30	0.84
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.12	1.34	0.93
T ₆ : Split application of T ₂	1.25	1.43	1.05
T ₇ : Split application of T ₃	1.37	1.48	1.11
T ₈ : Split application of T ₄	1.20	1.41	1.02
T ₉ : Split application of T ₅	1.33	1.45	1.08
	0.01	0.03	0.03
	0.02	0.07	0.08

Table 4.12. Chlorophyll-b content (mg g⁻¹ fresh weight) of tomato at different growth stages as influenced by split application of NPK nutrients

Treatments	Chlorophyll-b (mg g ⁻¹ fresh weight)		
	Flowering (30 DAT)	Fruiting (60 DAT)	At harvest (90 DAT)
T ₁ : Absolute control	0.43	0.49	0.31
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	0.55	0.62	0.37
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	0.56	0.63	0.38
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	0.47	0.55	0.34
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	0.52	0.60	0.37
T ₆ : Split application of T ₂	0.60	0.69	0.43
T ₇ : Split application of T ₃	0.65	0.76	0.46
T ₈ : Split application of T ₄	0.57	0.66	0.40
T ₉ : Split application of T ₅	0.62	0.72	0.44
	S.E.m±	0.02	0.01
	CD @ 5%	0.05	0.03

Table 4.13. Total chlorophyll content (mg g⁻¹ fresh weight) of tomato at different growth stages as influenced by the split application of NPK nutrients

Treatments	Total chlorophyll (mg g ⁻¹ fresh weight)		
	Flowering (30 DAT)	Fruiting (60 DAT)	At harvest (90 DAT)
T ₁ : Absolute control	1.33	1.67	0.90
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.68	1.99	1.13
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.75	2.03	1.17
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	1.53	1.86	0.99
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	1.67	1.94	1.09
T ₆ : Split application of T ₂	1.84	2.12	1.27
T ₇ : Split application of T ₃	2.01	2.23	1.36
T ₈ : Split application of T ₄	1.78	2.08	1.22
T ₉ : Split application of T ₅	1.95	2.15	1.31
	0.02	0.04	0.03
	0.05	0.10	0.08

Results indicated that the total chlorophyll content varied from 1.33 to 2.01, 1.67 to 2.23 and 0.90 to 1.36 mg g⁻¹ fresh weight at flowering, fruiting and harvesting stages, respectively. Among the different treatments, T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O recorded the maximum total chlorophyll content (2.01, 2.23 and 1.36 mg g⁻¹ fresh weight) at flowering, fruiting and harvesting stages, respectively, which was on par with T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (1.95, 2.15 and 1.31 mg g⁻¹ fresh weight, respectively). However, T₂ that received 100 per cent RDF recorded 1.68, 1.99, 1.13 mg g⁻¹ fresh weight and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 1.75, 2.03 and 1.17 mg g⁻¹ fresh weight, respectively.

4.7 Effect of split application of NPK nutrients on yield parameters of tomato

The data on yield attributes of tomato *viz.*, number of flower clusters per plant, individual fruit weight, girth of fruit, number of fruits per plant, fruit yield per plot and fruit yield per hectare were all recorded after harvest and the results are presented in Table 4.14.

4.7.1 Number of flower clusters per plant

Results indicated that there was significant increase in number of flower clusters per plant over RDF as influenced by the split application of NPK nutrients. The number of flower clusters per plant from the treatments ranged from 11.85 to 16.05.

Among the treatments, T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O recorded the highest number of flower clusters per plant, followed by T₉ (15.64) that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 14.45 and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 14.61 flower clusters per plant.

4.7.2 Individual fruit weight (g)

The results on tomato fruit weight showed significant variations among the treatments over RDF due to split application of NPK nutrients. The fruit weight from the treatments ranged from 53.30 to 76.73 g.

The most significant fruit weight (76.73 g) was noticed in T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O, followed by T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (74.60 g). However, T₂ that received 100 per cent RDF

Table 4.14. Effect of split application of NPK nutrients on yield attributes of tomato

Treatments	Yield attributes				
	Number of flower clusters per plant	Individual fruit weight (g)	Girth of fruit (cm)	Number of fruits per plant	Fruit yield per ha (tonnes ha ⁻¹)
T ₁ : Absolute control	11.85	53.30	14.61	23.51	34.80
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	14.45	66.94	16.48	33.39	65.79
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	14.61	68.87	17.32	35.23	68.50
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	13.90	57.84	15.67	28.51	49.01
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	14.34	63.75	15.96	32.07	60.32
T ₆ : Split application of T ₂	15.21	73.71	17.74	36.96	73.61
T ₇ : Split application of T ₃	16.05	76.73	18.27	50.63	107.88
T ₈ : Split application of T ₄	14.90	70.02	17.41	35.43	69.68
T ₉ : Split application of T ₅	15.64	74.60	18.05	45.47	94.19
	0.20	2.55	0.46	2.41	3.36
	0.65	8.33	1.49	7.87	10.06

recorded 66.94 g and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 68.87 g fruit weight.

4.7.3 Girth of fruit (cm)

The results on fruit girth showed significant variations among the treatments over RDF due to split application of NPK nutrients. The tomato fruit girth varied from 14.61 to 18.27 cm.

The highest fruit girth was recorded in T₇ (18.27 cm) that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ (18.05 cm) that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O. Whereas, T₂ that received 100 per cent RDF recorded 16.48 cm and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 17.32 cm fruit girth.

4.7.4 Number of fruits per plant (kg)

It was noticed from the results that the number of fruits per plant was registered maximum in T₇ (50.63) that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ (45.47) that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. However, T₂ that received 100 per cent RDF recorded 33.39 fruits and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 35.23 fruits.

4.7.5 Fruit yield per hectare (t ha⁻¹)

The data on fruit yield per ha showed significant differences among the treatments due to split application of NPK nutrients. Maximum fruit yield of 107.88 t ha⁻¹ was registered in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, followed by T₉ (94.19 t ha⁻¹) that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. Whereas, T₂ that received 100 per cent RDF recorded 65.79 t ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 68.50 t ha⁻¹ fruit yield.

4.8 Effect of split application of NPK nutrients on quality parameters of tomato

The data on quality parameters in tomato fruits as influenced by the split application of NPK nutrients are presented in Table 4.15.

Table 4.15. Effect of split application of NPK nutrients on quality attributes of tomato

Treatments	Quality attributes			
	TSS (^o Brix)	Lycopene content (mg 100g ⁻¹)	Ascorbic acid (mg 100g ⁻¹)	Shelf life (days)
T ₁ : Absolute control	3.85	4.95	12.28	8.51
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	5.15	5.93	14.21	12.93
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	5.30	6.13	14.57	13.29
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	4.45	5.49	13.14	10.40
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	4.60	5.57	14.03	12.64
T ₆ : Split application of T ₂	5.55	6.28	14.84	14.16
T ₇ : Split application of T ₃	5.90	6.50	15.19	15.30
T ₈ : Split application of T ₄	5.35	6.20	14.63	13.53
T ₉ : Split application of T ₅	5.65	6.35	15.06	14.65
	0.12	0.05	0.11	0.23
	0.31	0.12	0.30	0.54

TSS= Total Soluble Solids

4.8.1 Total soluble solids (°Brix)

The TSS levels in Arka Rakshak tomato hybrid varied substantially between treatments from 3.85 to 5.90 °Brix.

The highest TSS content in tomato fruits (5.90 °Brix) were recorded in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (5.65 °Brix). Whereas in T₂ that received 100 per cent RDF recorded TSS of 5.15 °Brix and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 5.30 °Brix in fruits.

4.8.2 Ascorbic acid content (mg 100g⁻¹)

The amount of ascorbic acid in the Arka Rakshak tomato varied significantly between treatments from 12.28 to 15.19 mg 100g⁻¹.

The highest ascorbic acid content (15.19 mg 100g⁻¹) in tomato fruits were recorded in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (15.06 mg 100g⁻¹). However, T₂ that received 100 per cent RDF recorded an ascorbic acid content of 14.21 mg 100g⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 14.57 mg 100g⁻¹ ascorbic acid content.

4.8.3 Lycopene content (mg 100g⁻¹)

The amount of lycopene in the Arka Rakshak tomato differed significantly between treatments from 4.95 to 6.50 mg 100g⁻¹.

Among the treatments, T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O recorded the highest lycopene content (6.50 mg 100g⁻¹) in tomato fruits, which was on par with T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (6.35 mg 100g⁻¹). However, T₂ that received 100 per cent RDF recorded a lycopene content of 5.93 mg 100g⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 6.13 mg 100g⁻¹ lycopene content.

4.8.4 Shelf life (days)

The shelf life of the Arka Rakshak tomato hybrid varied significantly among the treatments from 8.51 to 15.30 days.

The most extended shelf life of 15.30 days was registered in T₇ that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ that received split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (14.65 days). Whereas, T₂ that received 100 per cent RDF recorded a shelf life of 12.93 days and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 13.29 days of shelf life.

4.9 Effect of split application of NPK nutrients on nutrient use efficiency of tomato

The data on nitrogen use efficiency (NUE), phosphorus use efficiency (PUE) and potassium use efficiency (KUE) of tomato as influenced by the split application of NPK nutrients are presented in Table 4.16.

Among the treatments, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O, registered the highest NUE (29.23 kg yield kg N⁻¹), PUE (29.23 kg yield kg P⁻¹) and KUE (23.38 kg yield kg K⁻¹) followed by T₉ that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O [NUE (31.68 kg yield kg N⁻¹), PUE (23.76 kg yield kg P⁻¹) and KUE (19.01 kg yield kg K⁻¹)]. This was followed by T₆ that received split application of 100 per cent RD N+100 per cent RD P₂O₅+100 per cent RD K₂O [NUE (15.52 kg yield kg N⁻¹), PUE (15.52 kg yield kg P⁻¹) and KUE (15.52 kg yield kg K⁻¹)] which was on par with T₈ that received split application of 75 per cent RD N+100 per cent RD P₂O₅+100 per cent RD K₂O [NUE (18.60 kg yield kg N⁻¹), PUE (13.95 kg yield kg P⁻¹) and KUE (13.95 kg yield kg K⁻¹)]. Lowest [NUE (7.58 kg yield kg N⁻¹), PUE (5.68 kg yield kg P⁻¹) and KUE (5.68 kg yield kg K⁻¹)] was recorded in T₄ that received 75 per cent RD N+100 per cent RD P₂O₅ +100 per cent RD K₂O.

4.10 Effect of split application of NPK nutrients on economics of tomato

Farmers are primarily concerned about the profitability and returns obtained from their produce; hence, studies on the economics of different treatments are essential to determine the most cost-effective treatment. The data on cost of cultivation, gross returns, net returns and benefit-cost ratio of tomato as influenced by the split application of NPK nutrients are presented in Table 4.17.

4.10.1 Cost of cultivation (Rs. ha⁻¹)

The total cost of cultivation includes common expenditures (field preparation, seed, sowing expenses, weeding, irrigation, harvesting, general expenses *etc.*) and treatment-specific costs. Among the treatments, T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O registered the highest cost of cultivation (Rs. 189849 ha⁻¹), followed by T₉ that received split

Table 4.16. Effect of split application of NPK nutrients on nutrient use efficiency of tomato

Treatments	NUE (kg yield kg N ⁻¹)	PUE (kg yield kg P ⁻¹)	KUE (kg yield kg K ⁻¹)
T ₁ : Absolute control	-	-	-
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	12.39	12.39	12.39
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	13.48	13.48	10.78
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	7.58	5.68	5.68
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	13.61	10.20	8.16
T ₆ : Split application of T ₂	15.52	15.52	15.52
T ₇ : Split application of T ₃	29.23	29.23	23.38
T ₈ : Split application of T ₄	18.60	13.95	13.95
T ₉ : Split application of T ₅	31.68	23.76	19.01
	S.E.m±	0.34	0.32
	CD @ 5%	1.13	1.05

Table 4.17. Effect of split application of NPK nutrients on the economics of tomato

Treatments	Gross Income (Rs. ha ⁻¹)	Total cost of cultivation (Rs. ha ⁻¹)	Net Returns (Rs. ha ⁻¹)	B:C
T ₁ : Absolute control	278425	159900	118525	1.74
T ₂ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	526300	183997	342303	2.86
T ₃ : 100 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	548026	185749	362277	2.95
T ₄ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 100 per cent RD K ₂ O	392102	183269	208833	2.14
T ₅ : 75 per cent RD N + 100 per cent RD P ₂ O ₅ + 125 per cent RD K ₂ O	482522	185021	297501	2.61
T ₆ : Split application of T ₂	588905	188097	400808	3.13
T ₇ : Split application of T ₃	828943	189849	639094	4.37
T ₈ : Split application of T ₄	557465	187369	370096	2.98
T ₉ : Split application of T ₅	753556	189121	564435	3.98

B: C = Benefit-Cost Ratio, Rs. ha⁻¹ = Rupees per hectare

application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O, incurred Rs. 189121 ha⁻¹. However, T₂ that received 100 per cent RDF recorded a cost of cultivation of Rs. 183997 ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded Rs. 185749 ha⁻¹.

4.10.2 Gross returns (Rs. ha⁻¹)

The highest gross returns was obtained in T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O (Rs. 828943 ha⁻¹), followed by T₉ that received split application of 75 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O (Rs. 753556 ha⁻¹). However, T₂ that received 100 per cent RDF recorded gross returns of Rs. 526300 ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded Rs. 548026 ha⁻¹.

4.10.3 Net returns (Rs. ha⁻¹)

According to the data in Table 4.17, the highest net returns was obtained in T₇ that received split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O of Rs. 639094 ha⁻¹, followed by T₉ that received split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O with Rs. 564435 ha⁻¹. The treatment receiving 100 per cent RDF (T₂) recorded a net returns of Rs. 342303 ha⁻¹ and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅+125 per cent RD K₂O recorded Rs. 362277 ha⁻¹.

4.10.4 Benefit-cost ratio (B: C)

Split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) registered the highest BC ratio (4.37), followed by split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₉) with a BC ratio of 3.98. Among the treatments, the lowest BC ratio was obtained under absolute control (1.74). The treatment receiving 100 per cent RDF (T₂) recorded a BC ratio of 2.86 and T₃ that received 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O recorded 2.95.

DISCUSSION

V DISCUSSION

Tomato (*Solanum lycopersicum* L.) is a protective fruit with heavy yield potential. It is susceptible to varying environmental factors and improper fertilizer application, ultimately determining yield and quality. Nutrient depletion reduces the plant growth and productivity resulting in stunted growth, chlorophyll degradation, flower and fruit drop and ultimately reduces fruit output. This study entitled "Nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients" was conducted to determine the effect of split application of NPK nutrients in improving the growth, uptake, yield and quality of tomato. In this chapter, the findings of the experiment are given, interpreted and discussed.

5.1 Weather and crop growth

Crop growth and its performance are influenced by weather conditions and other biotic factors that prevailed during the cropping period, ultimately affecting the yield. Rainfall and sunshine hours are the most important weather parameters in obtaining better tomato growth and productivity. The meteorological conditions that prevailed during *rabi* 2020-21 *i.e.*, deviation from the normal with respect to rainfall, maximum and minimum temperature, mean relative humidity and sunshine hours are presented in Appendix I and depicted in Fig. 3.1.

In the present study, it was observed that the total amount of rainfall received during the cropping period was 142.60 mm, which is 45.36 per cent more than the normal rainfall (98.1 mm). The mean maximum temperature was less than the normal during the crop growth period and it ranged between 30.2 °C in December and 35.5 °C in April. The mean minimum temperature ranged between 15.7 °C to 21.9 °C in the month of December and April respectively. Humidity plays an important role in crop productivity and the highest mean relative humidity during the crop growth period was observed during November (77.70 %). Temperature along with photoperiod is the key component for crop development and the highest sunshine hour was obtained during February (8.5 hours).

5.2 Effect of split application of NPK nutrients on available nutrient status of the soil

Soil chemical parameters such as pH, EC, organic carbon (after the harvest) and available soil nutrients at different stages have been studied. The pH, EC, and organic carbon of soil after the harvest of tomato was found to be non-significant among the treatments.

The fertility status of soils of the experimental field was investigated for primary nutrient availability. The initial soil nutrient status showed low available nitrogen,

medium P_2O_5 and medium K_2O status in soil after harvest of the previous crop (groundnut). During the cropping period, available N was found low in the field due to the continual uptake by tomato as it is a long duration and a heavy nutrient mining crop.

During the vegetative stage, the N status of soil increased in all treatments due to the application of urea fertilizer (50 % of N for all treatments except the absolute control). However, there was a reduction in the N status of soil in treatments T₂, T₃, T₄ and T₅ at the flowering stage as there was no application of N at this stage, whereas in T₆, T₇, T₈ and T₉, there was an increase in N status due to the split application of N (*i.e.* 15 % N in T₆, T₇, T₈ and T₉). The N status of soil in treatments T₂, T₃, T₄ and T₅ increased in fruiting stage as there was the application of remaining 50 per cent N, whereas, in T₆, T₇, T₈ and T₉, there was comparatively a moderate increase in N status due to the split application of N (15 % N). At harvest, higher available nitrogen was observed in treatments receiving split application compared to other treatments without split application. This showed that the split application of nutrients improved the available nitrogen status of the soil.

Available phosphorus level was higher in all the treatments except for absolute control. Comparison of treatments found that the P_2O_5 availability was much higher in treatments supplied with the split application of nutrients. According to the chemistry and behaviour of phosphorus in soil, any phosphoric fertilizer applied to the crop in acidic, alkaline or calcareous soil gets fixed and becomes unavailable to the crop. Due to fixation losses, it is often preferable to administer phosphorus in split application to crops. During the vegetative stage, the P_2O_5 status of soil increased in all treatments due to the application of DAP fertilizer (100 % P_2O_5 for T₂, T₃, T₄ and T₅ and 50 per cent P_2O_5 for T₆, T₇, T₈ and T₉ except in case of absolute control). However, there was a slight reduction in soil P_2O_5 content in treatments T₂, T₃, T₄ and T₅ at the flowering stage as there was no application at this stage, whereas in T₆, T₇, T₈ and T₉, there was an increase in P_2O_5 status due to the split application of 25 per cent P_2O_5 . In the fruiting stage, there was a decrease in soil P_2O_5 status in treatments T₂, T₃, T₄ and T₅ due to the vigorous uptake by plants and possibly there might be some fixation, whereas, in T₆, T₇, T₈ and T₉, there was comparatively a moderate increase in P_2O_5 status due to the split application of 25 per cent P_2O_5 . At harvest, higher P_2O_5 was observed in treatments provided with the split application compared to other treatments.

During the vegetative stage, the available potassium status of soil increased in all treatments due to the application of MOP fertilizer (100 % K_2O for T₂, T₃, T₄ and T₅ and 50 % of K_2O for T₆, T₇, T₈ and T₉) except in case of absolute control. However, at the flowering stage, there was a slight reduction in K_2O content in treatments T₂, T₃, T₄ and T₅ as there was no application of K_2O along with continual uptake by plants at this stage, whereas, in T₆, T₇, T₈ and T₉, there was an increase in K_2O status due to the

split application 10 per cent K_2O . In the fruiting stage, there was a significant reduction in K_2O status in treatments T_2 , T_3 , T_4 and T_5 due to more uptake by plants, whereas, in T_6 , T_7 , T_8 and T_9 , there was an increase in K_2O status due to the split application of 20 per cent K_2O . At harvest, higher K_2O status was observed in treatments provided with split application compared to other treatments. These findings are in line with those of Olagbende *et al.* (2019), Pandey *et al.* (2019) and Suresh *et al.* (2019).

This shows that with basal application of nitrogen, phosphorus and potassium in treatments T_2 , T_3 , T_4 and T_5 , there is a possibility of a loss of nitrogen due to volatilization, leaching, denitrification and phosphorus and potassium fixation in soil (Pandey *et al.*, 2019 and Zohaib *et al.*, 2021). Also, due to the continual uptake by tomato, there will be a decrease in the availability of nutrients in the root zone. Whereas, in split application treatments (T_6 , T_7 , T_8 and T_9), the losses of nutrients due to factors mentioned above were comparatively lesser and hence, uptake of nutrients were higher than recommended practice of fertilizer application.

5.3 Effect of split application of NPK nutrients on leaf tissue analysis

The treatments receiving the split application of NPK nutrients recorded higher nutrient content at vegetative, flowering and fruiting stages of tomato. The N content of tomato leaves were higher in T_7 receiving split application of 100 per cent RD N + 100 per cent RD P_2O_5 + 125 per cent RD K_2O at flowering and fruiting stages (Fig. 5.1). This might be attributed to the enhanced availability of plant nutrients at the root zone area and improved root activity due to split application, which allowed better nutrient uptake in tomato plants. At the vegetative stage, the P and K content of tomato leaves was higher in T_3 receiving 100 per cent RD N + 100 per cent RD P_2O_5 + 125 per cent RD K_2O due to the complete basal application of P and K fertilizers enhanced the soil nutrient status and plant nutrient uptake. Whereas, in flowering and fruiting stages, the N, P and K content was higher in T_7 receiving split application of 100 per cent RD N + 100 per cent RD P_2O_5 + 125 per cent RD K_2O (Fig. 5.1). This might be attributed to the increased soil nutrient availability and uptake due to the split application of nutrients at critical growth stages of tomato. The uptake increased with split application of fertilizers as it improved the absorption and utilization of nutrients for growth. The results revealed that there was an increase in the nutrient content of plants at successive growth stages, indicating that nutrient uptake increases as the plant growth progresses. Further, losses of nitrogen due to leaching, volatilization and denitrification and phosphorus and potassium fixation in the soil are minimized with the split application. These findings are in line with Srikanth *et al.* (2009), Souri *et al.* (2017), Kolawole *et al.* (2018), Pandey *et al.* (2019) and Zohaib *et al.* (2021).

5.4 Effect of split application of NPK nutrients on the nutrient uptake (kg ha⁻¹) by tomato plant

Significant difference among the treatments with respect to nitrogen, phosphorous and potassium uptake were noticed by split application of NPK fertilizers. Numerically, higher total nitrogen uptake by tomato plant was recorded in T₇ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O at vegetative, flowering and fruiting stages. This might be attributed to the increased availability of NPK nutrients at the plant root zone region which improved the root activity of tomato when compared to the nutrient uptake in recommended practice of fertilizer application. However, phosphorous and potassium uptake at the vegetative stage was higher in T₃ receiving 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O due to entire basal application of phosphorous and potassium, which increased the soil P₂O₅ and K₂O and ultimately the plant uptake. Whereas, at flowering and fruiting stages of tomato plant, the uptake of phosphorous and potassium was higher in T₇, receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. These findings are in line with those of Prabhavathi *et al.* (2008), Srikanth *et al.* (2009), Ortas *et al.* (2013), Souri *et al.* (2017) and Zohaib *et al.* (2021).

The uptake of NPK nutrients in treatments, T₂ (100 % RDF), T₃ (100 % RD N + 100 % RD P₂O₅ + 125 % RD K₂O), T₄ (75 % RD N + 100 % RD P₂O₅ + 100 % RD K₂O) and T₅ (75 % RD N + 100 % RD P₂O₅ + 125 % RD K₂O) was comparatively lower than that of treatments receiving split application T₆ (Split application of T₂), T₇ (Split application of T₃), T₈ (Split application of T₄) and T₉ (Split application of T₅). The study revealed that the treatment receiving split application of NPK nutrients exhibited the highest uptake of nutrients when compared to recommended practice of fertilizer application at vegetative, flowering and fruiting stages since the loss of nutrients due to volatilization, leaching, denitrification and fixation were comparatively low. The increased availability of nutrients in the rhizosphere promoted better root growth and allowed the plant to obtain the nutrients more efficiently.

5.5 Effect of split application of NPK nutrients on the nutrient content (%) of tomato fruit

Nutrients are essential for enhancing the growth, yield, uptake and quality of tomato. Higher the nutrient uptake, higher will be the yield. Since tomato is a long duration and heavy nutrient mining crop, there is a need to supply the nutrients at its critical growth stages, *i.e.*, at vegetative, flowering and fruiting stages, to ensure the required nutrient demand. Split application has a considerable impact on the uptake of primary nutrients *viz.*, N, P and K over the recommended practice of fertilizer application. The data analysis revealed that the maximum NPK content in tomato fruit was obtained in treatments receiving split application than the rest of the treatments.

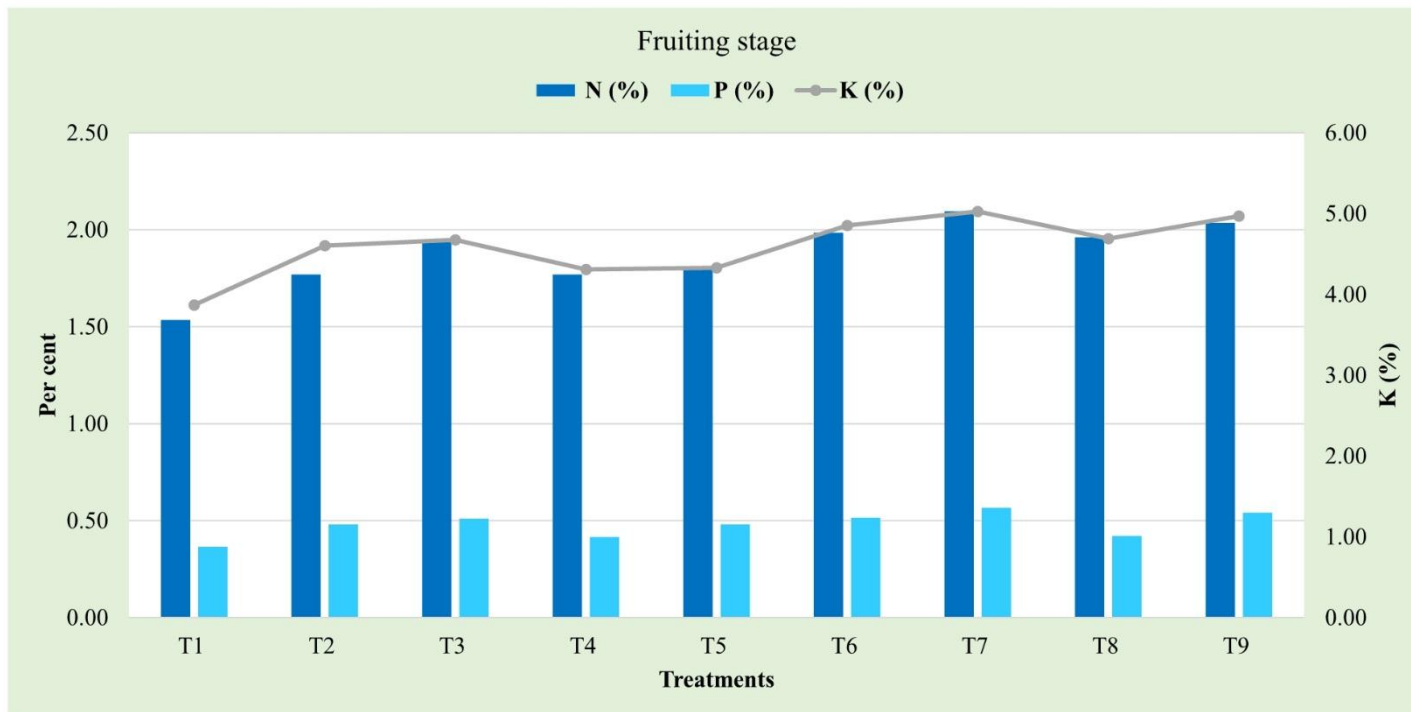


Fig. 5.1 Effect of split application of NPK nutrients on nutrient content of tomato leaf at fruiting stage

With the split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇), significantly higher nutrient content in tomato fruits were recorded and the values were on par with T₉ receiving split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. However, the treatment T₃ receiving 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (without splits) recorded comparatively lower values than T₇ (split application of 100 % RD N + 100 % RD P₂O₅ + 125 % RD K₂O). Due to improved absorption and utilization, the nutrient uptake of tomato fruit increased with the sequential addition or split application of fertilizers. The treatments receiving higher nitrogen and potassium application showed a significant increase in fruit nutrient content due to better uptake and translocation when compared to rest of the treatments.

5.6 Effect of split application of NPK nutrients on growth parameters of tomato

The eventual yield of a plant is determined by its growth parameters. They are primarily reliant on the adequate supply of plant nutrients necessary for enhanced metabolic activity. The current study found that the split application of NPK nutrients considerably influenced the growth parameters, *viz.*, plant height, number of branches, and leaf area over the recommended practice of fertilizer application. The outcomes recorded are addressed below.

Significant differences in plant height, the number of branches and leaf area were observed among the treatments. The treatment receiving split application of fertilizers recorded the highest plant height, number of branches and leaf area at flowering, fruiting and harvesting stages over the recommended practice of fertilizer application. The highest values were recorded in T₇ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ receiving split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. However, the treatment T₃ receiving 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (without splits) recorded comparatively lower values than T₇ (split application of 100 % RD N + 100 % RD P₂O₅ + 125 % RD K₂O).

Plant height is considered to be an important morphological character influencing the growth and development of tomato. Treatments receiving split application of nutrients excelled over rest of the treatments by recording higher plant height at all critical growth stages. The highest plant height was recorded in T₇ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which might be ascribed to the improved nutrient absorption, translocation and effective utilization of nutrients which boosted the cell division and cell elongation in plants.

The number of branches and leaf area are also the essential factors that affect the yield of tomato. Branches bear the leaves that fix the CO₂ through the process of photosynthesis and leaves may serve as the source of assimilates for the developing fruits. It was noticed that the number of branches and leaf area of tomato were influenced by split application of NPK nutrients. More nitrogen in soil aided the vegetative growth of plants *i.e.*, it enhanced the initiation of leaves, promoting cell division and cell expansion, which gradually increased the number of branches and leaf area. It also enhanced protein synthesis, which helped to build carbohydrates resulting in an overall increase in plant growth. These results are consistent with Imas and Magen (2004), Sawant (2005), Gonfa *et al.* (2008), Hafiz *et al.* (2011), Feleafel (2013), Pawar *et al.* (2013) and Mounika *et al.* (2017).

5.7 Effect of split application of NPK nutrients on biochemical parameters of tomato

Chlorophyll is a pigment that aids the plant in synthesizing its food through photosynthesis. The highest chlorophyll production (*i.e.*, chlorophyll-a, chlorophyll-b and total chlorophyll) was recorded in treatments receiving split application of NPK nutrients over the recommended practice of fertilizer application at different growth stages. The highest values were recorded in treatment T₇ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O, which was on par with T₉ receiving split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O. This could be attributed to the sufficient K availability due to the split application of NPK nutrients in the soil, which boosted the nutrient uptake, nutrient use efficiency and minimum wastage of nutrients in tomato. The irrigation provided throughout the crop growth period also enhanced the chlorophyll content of plants. These findings are consistent with Ullah *et al.* (2015), Souri *et al.* (2017) and Jena *et al.* (2018). In absolute control, the lowest values were recorded. The decrease in chlorophyll content at the fruiting stage is related to reduced catalase activity and increased amylase and invertase activity, indicating vigorous translocation of assimilates to the fruit.

5.8 Effect of split application of NPK nutrients on yield parameters of tomato

The yield attributing parameters *viz.*, number of flower clusters per plant, number of fruits per plant, individual fruit weight, girth of fruit and total yield per hectare differed significantly due to the split application of NPK nutrients (Fig. 5.3).

The highest yield attributing characters were recorded in treatments receiving the split application of NPK nutrients. The highest number of flower clusters per plant (16.05), number of fruits per plant (50.63), individual fruit weight (76.73 g), girth of fruit (18.27 cm) and total yield per hectare (107.88 t ha⁻¹) were recorded in treatment

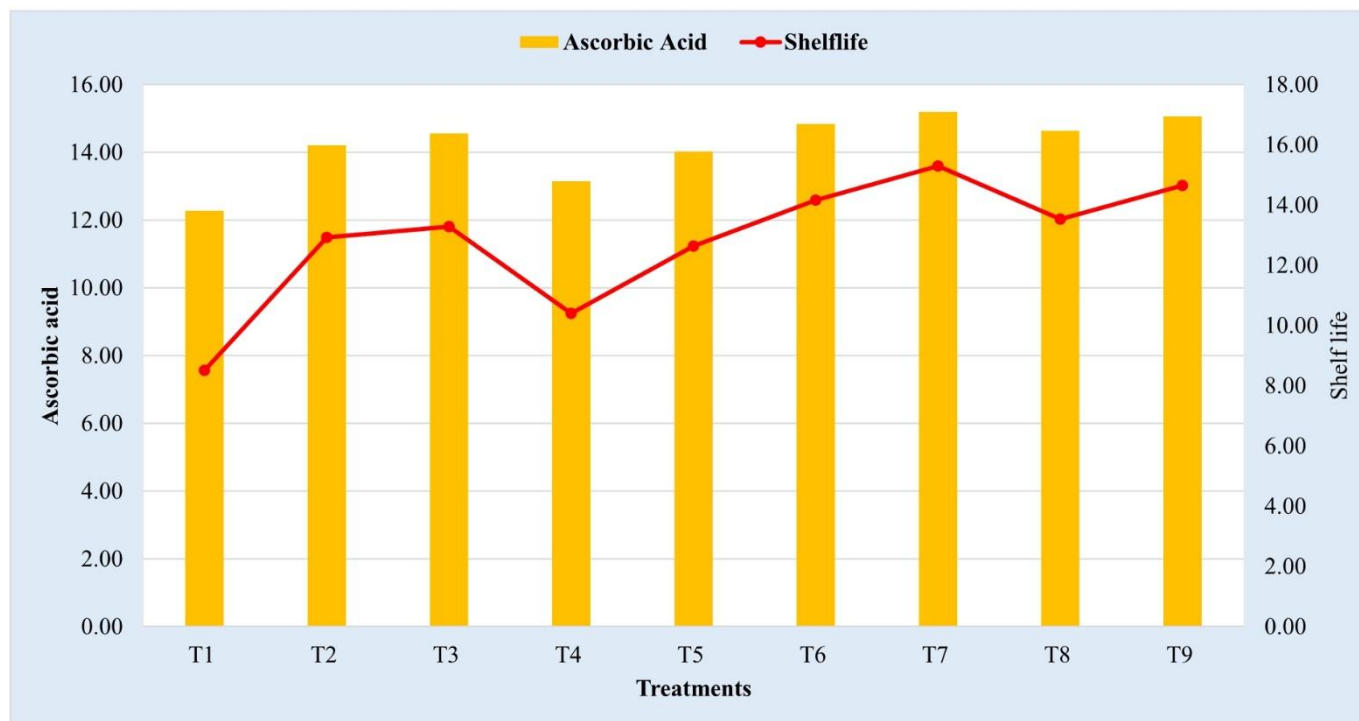


Fig. 5.2 Effect of split application of NPK nutrients on ascorbic acid and shelf life of tomato

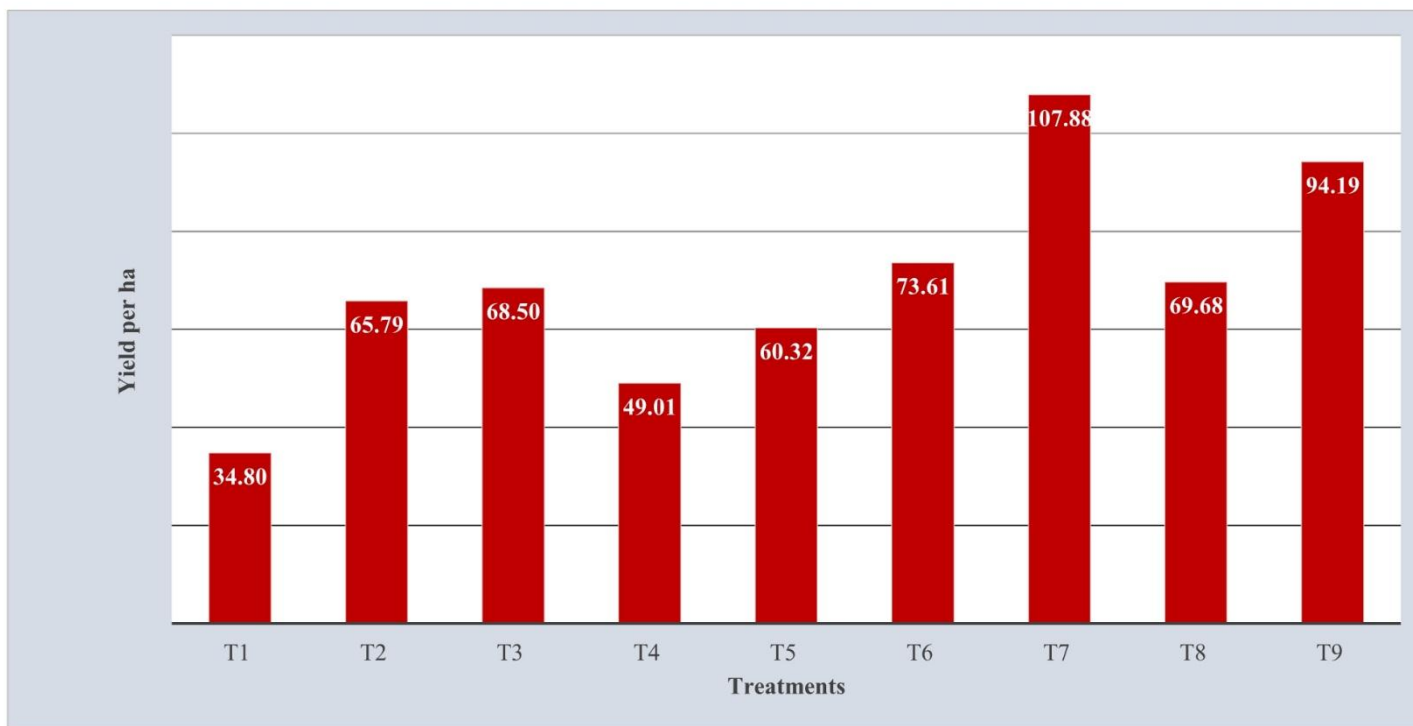


Fig. 5.3 Effect of split application of NPK nutrients on yield per hectare of tomato

T₇ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O over RDF. It was followed by T₉ receiving split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O.

It was substantiated that applying nitrogen, phosphorus and potassium fertilizers in split augmented the yield of tomato over the recommended practice of fertilizer application. The increase in yield and yield attributing characters with the split application of nutrients through fertilizers might be due to the quick release of nutrients and their availability in required quantities in the soil. It might also be related to better growth parameters of tomato such as plant height, number of branches, leaf area and biochemical parameters like chlorophyll a, chlorophyll b and total chlorophyll. These results are consistent with Ortas *et al.* (2013), Sulochna *et al.* (2018) and Pattnaik *et al.* (2019). The split application of P and K assisted the production of auxins which enhanced fruit girth and size, whereas split application of N and P increased the number of flowers and fruits. Furthermore, providing nutrients in splits promoted the nutrient uptake in plants as the availability of nutrients in the rhizosphere enhanced. This led to better photosynthate utilization and accumulation that aided in the increased production of tomato fruits.

5.9 Effect of split application of NPK nutrients on quality parameters of tomato

Balanced nutrition promotes the quantity as well as the quality of the fruits. Qualitative attributes become more relevant when the produce is used to manufacture jam, juice, sauce and ketchup. Fruit quality parameters such as shelf life, TSS, lycopene and ascorbic acid content are discussed below (Figure 5.2).

There was significant difference among the treatments with respect to quality of tomato fruits. Numerically, the higher TSS (5.90 °Brix), lycopene content (6.50 mg 100g⁻¹), ascorbic acid content (15.19 mg 100g⁻¹) and quality of shelf life (15.30 days) was recorded with the split application of NPK nutrients. The treatment T₇ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O excelled over rest of the treatments as mentioned above, which was on par with T₉ receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O.

The TSS in tomato fruit was significantly influenced by the exogenous supply of potassium (which is the known to be the quality nutrient) through split application that boosted the flow of plant assimilates into the emerging fruits, especially when the flow of assimilates from other parts of the plant becomes limited. During ripening, it helps to convert starch to simple sugars by activating the sucrose synthetase enzyme, resulting in higher TSS. The ascorbic acid content of fruits also enhanced with the increased availability of potassium since K reduces the enzyme activity that oxidizes

ascorbic acid and neutralizes the physiologically relevant organic acids. It helps in the synthesis, breakdown and translocation of carbohydrates and protein. Also K increased the lycopene content in fruits by enhancing enzyme activity involved in carbohydrate metabolism. The tomato hybrid Arka Rakshak is a triple disease-resistant tomato variety and hence the incidence of diseases were very low and did not affect the productivity, yield and quality. The increased ascorbic acid and potassium content improved the shelf life of tomato fruits (Chaurasia *et al.*, 2006). These results are consistent with Feleafel and Mirdad (2013), Pawar *et al.* (2013) and Souri *et al.* (2017).

5.10 Effect of split application of NPK nutrients on nutrient use efficiency (agronomic efficiency) of tomato

Significantly higher nutrient use efficiency (NUE, PUE and KUE) values were observed in treatments receiving split application of NPK nutrients. This could be related to the better availability of nutrients in the root zone due to the split application. Furthermore, the reduced loss of nutrients combined with better root activity increased the uptake, resulted in higher nutrient use efficiency. Lower nutrient use efficiency among the other treatments might be due to the nutrient losses *viz.*, denitrification, leaching and volatilization losses of nitrogen and fixation losses of phosphorus and potassium. These results are consistent with Badr *et al.* (2010), Gonfa *et al.* (2008), Souri *et al.* (2017), Sharma *et al.* (2018) and Zohaib *et al.* (2021).

5.11 Effect of split application of NPK nutrients on economics of tomato

Numerically, the higher gross returns, net returns, cost of cultivation and benefit-cost ratio were obtained in treatments receiving split application of fertilizers. Among the nine treatments, T₇ receiving split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O registered the highest cost of cultivation (Rs. 189849 ha⁻¹), gross returns (Rs. 828943 ha⁻¹) and net returns (Rs. 639094 ha⁻¹), followed by T₉: Split application of 75 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O.

The labour cost for watering, fertilizer application in split doses and staking for tomato increased the cost of production when compared to recommended dose of fertilizer. However, this was balanced by higher productivity and quality of tomato obtained, which increased the gross and net returns. These results are consistent with Pawar *et al.* (2013) and Vasanthi *et al.* (2017).

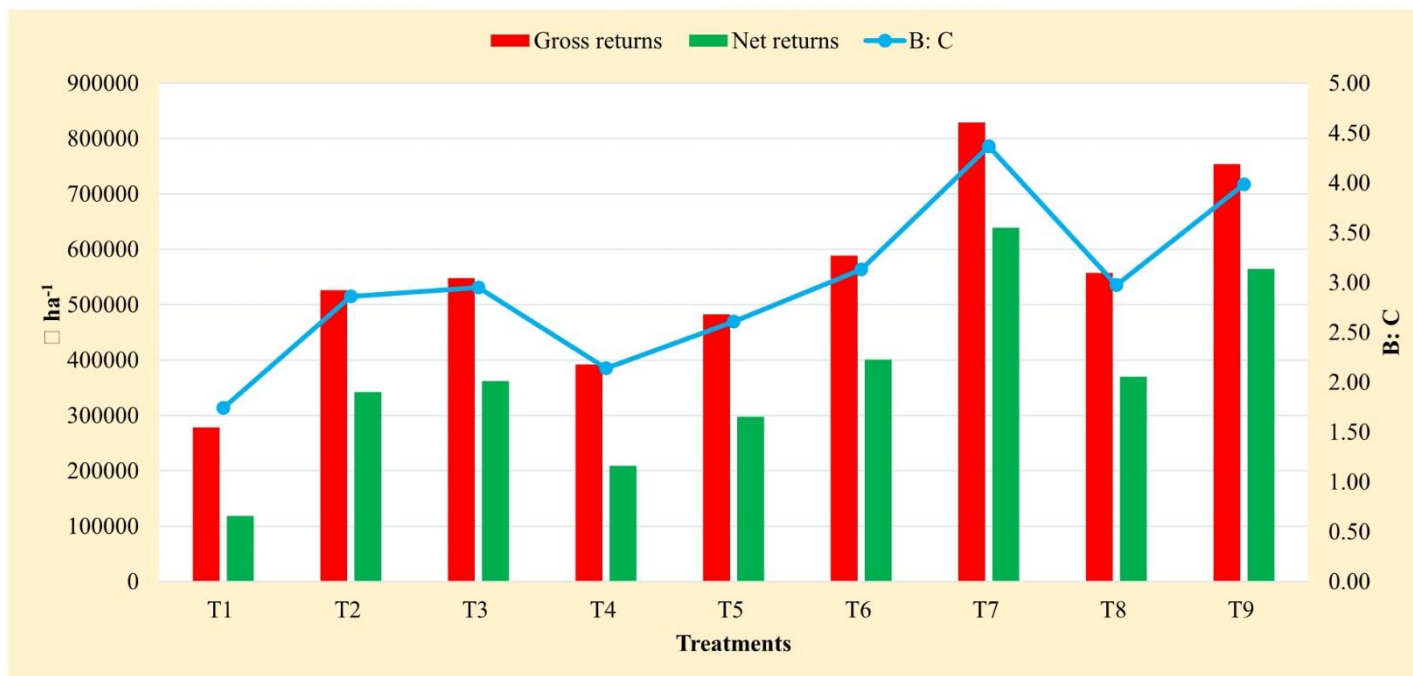


Fig. 5.4 Cost economics of split application of NPK nutrients in tomato

The benefit-cost ratio is crucial in determining the optimum levels of inputs to produce maximum output (Fig. 5.4). The highest BC ratio (4.37) was observed in T₇: Split application of 100 per cent RD N+100 per cent RD P₂O₅ +125 per cent RD K₂O. The results show that applying nitrogen, phosphorus and potassium in splits is profitable for tomato production. These results were consistent with Pawar *et al.* (2013) and Archana *et al.* (2016).

SUMMARY

VII SUMMARY

The present study entitled, “Nutrient use efficiency, productivity and quality of tomato as influenced by split application of NPK nutrients” was conducted at ICAR-KVK, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, during *rabi* 2020-21. The inferences drawn from the results are summarized below.

The experiment was laid out in RCBD with nine treatments and three replications. The treatments comprised of

T₁: Absolute control (no fertilizer)

T₂: 100 per cent RD N + 100 per cent RD P₂O₅ + 100 per cent RD K₂O

T₃: 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O

T₄: 75 per cent RD N + 100 per cent RD P₂O₅ + 100 per cent RD K₂O

T₅: 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O

T₆: Split application of T₂

T₇: Split application of T₃

T₈: Split application of T₄

T₉: Split application of T₅

{N – 50 % as basal + 50 % in 3 splits (At flowering – 15 %, at fruiting – 15 %, after first harvest – 20 %)

P₂O₅ – 50 % as basal + 50 % in 2 splits (At flowering – 25 %, at fruiting – 25 %)

K₂O – 50 % as basal + 50 % in 3 splits (At flowering – 10 %, at fruiting – 20 %, after first harvest – 20 %)}

The relevant findings from the experiment regarding soil nutrient status, nutrient content and uptake in tomato plant, nutrient content in tomato fruit, growth parameters, yield attributes, quality parameters, nutrient use efficiency and economics were recorded.

Application of nutrients through split application of fertilizer recorded significantly better performance of Arka Rakshak tomato hybrid. The available N, P₂O₅ and K₂O content in soil at flowering, fruiting and harvesting stages excelled in treatment receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ +

125 per cent RD K₂O (T₇) when compared to recommended practice of fertilizer application.

The NPK content and its uptake in tomato plant was significantly higher in the plots that received nutrients through split application. The treatment receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) recorded the highest values when compared to recommended practice of fertilizer application.

The nutrient content of tomato fruit (N, P and K) was significantly higher in the plots that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) viz., N (1.45 and 1.47 %), P (0.35 and 0.37 %) and (4.79 and 4.84 %), followed by split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₉). However, the treatment T₂ receiving 100 per cent RDF recorded comparatively lower N (1.26 and 1.24 %), P (0.28 and 0.26 %) and K (4.38 and 4.32 %) content.

Application of nutrients through split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) recorded significantly higher plant height (69.16, 114.60 and 128.05 cm), number of branches per plant (8.26, 13.03 and 15.59) and leaf area (36.78, 75.17 and 64.95 cm²) at flowering, fruiting and harvesting stages, respectively. However, the treatment T₂ receiving 100 per cent RDF recorded comparatively lower plant height (61.36, 104.20 and 120.37 cm), number of branches per plant (7.52, 12.34 and 14.67) and leaf area (35.03, 71.85 and 60.91 cm²) at flowering, fruiting and harvesting stages, respectively.

Biochemical parameters viz., chlorophyll-a (1.37, 1.48 and 1.11 mg g⁻¹ fresh weight), chlorophyll-b (0.65, 0.76 and 0.46 mg g⁻¹ fresh weight) and total chlorophyll (2.01, 2.23 and 1.36 mg g⁻¹ fresh weight) recorded higher values in the treatment that received split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) at flowering, fruiting and harvesting stages, respectively.

Application of nutrients through split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) recorded higher number of flower clusters per plant (16.05), girth of fruit (18.27 cm), individual fruit weight (74.6 g), number of fruits per plant (50.63) and yield per ha (107.88 t ha⁻¹). Whereas, the treatment receiving 100 per cent RDF (T₂) without splits recorded comparatively lower number of flower clusters per plant (14.45), girth of fruit (16.48 cm), individual fruit weight (66.94 g), number of fruits per plant (33.39) and yield per ha (65.79 t ha⁻¹).

Quality parameters viz., shelf life (15.30 days), total soluble solids (5.9 °Brix), ascorbic acid (15.19 mg 100g⁻¹) and lycopene content (6.50 mg 100g⁻¹) recorded higher

values in treatment receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇). However, treatment receiving 100 per cent RDF (T₂) recorded comparatively lower shelf life (12.93 days), total soluble solids (5.15 °Brix), ascorbic acid (14.21 mg 100g⁻¹) and lycopene content (5.93 mg 100g⁻¹).

The highest NUE (29.23 kg yield kg N⁻¹), PUE (29.23 kg yield kg P⁻¹) and KUE (23.38 kg yield kg K⁻¹) were recorded in treatment receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇), followed by T₉ receiving split application of 75 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O [NUE (31.68 kg yield kg N⁻¹), PUE (23.76 kg yield kg P⁻¹) and KUE (19.01 kg yield kg K⁻¹)].

Among the nine treatments, the higher cost of cultivation (Rs. 189849 ha⁻¹), gross returns (Rs. 828943 ha⁻¹), net returns (Rs. 639094 ha⁻¹) and B: C (4.37) were obtained in treatment receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇). However, the treatment receiving 100 per cent RDF (T₂) recorded comparatively lower cost of cultivation (Rs. 183997 ha⁻¹), gross returns (Rs. 526300 ha⁻¹), net returns (Rs. 342303 ha⁻¹) and B: C (2.86).

Conclusion

It was noticed from this study that the application of NPK nutrients in splits helped to increase the growth, uptake, yield and quality attributes in tomato. It also improved the soil nutrient status and leaf tissue nutrient concentration. The nutrient use efficiency and economics of tomato cultivation were registered highest in the treatment receiving split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O (T₇) over recommended dose of fertilizer application. Hence, application of extra 25 per cent K₂O than RDF in splits *i.e.*, T₇ (split application of 100 per cent RD N + 100 per cent RD P₂O₅ + 125 per cent RD K₂O) can be recommended to gain appropriate yield and quality of tomato with a higher BC ratio.

Future line of work

- Scheduling of intervals of fertigation for better nutrient use efficiency in tomato need to be carried out.
- Split application in tomato need to be carried in farmer's fields for wider acceptability.

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APPENDICES

VIII APPENDICES

Appendix I. Monthly meteorological data for the cropping period against normal at ZAHRS, KSNUAHS, Shivamogga, 2020-21

Months	Rainfall (mm)			Maximum temperature (°C)			Minimum temperature (°C)			Relative humidity (%)			Sunshine hours		
	N	A	D	N	A	D	N	A	D	N	A	D	N	A	D
November	38.9	0	-38.9	30.1	30.7	0.6	19.2	17.4	-1.8	69	77.7	8.7	7.3	7.1	-0.2
December	10.5	16.2	5.7	30	30.2	0.2	17.8	15.7	-2.1	63	75.9	12.9	8.4	7.8	-0.6
January	0.4	59.8	59.4	31.3	30.9	-0.4	16.9	16.3	-0.6	59	65.5	6.5	9	8	-1
February	0.3	28.2	27.9	33.4	31.5	-1.9	17.6	16.1	-1.5	56	59.5	3.5	9	8.5	-0.5
March	3.6	1	-2.6	35.8	35	-0.8	20.9	20.3	-0.6	54	58.5	4.5	7	6.7	-0.3
April	44.4	37.4	-7	36.4	35.5	-0.9	22.1	21.9	-0.2	60	61	1	8	8.2	0.2
Total	98.1	142.6	---	32.8	32.3	---	19.08	17.95	---	60.16	66.3	---	8.11	7.71	---

Note: N - Normal meteorological data (mean of 1986-2019)

A - Actual meteorological data (2020-21)

D- Deviation from the normal (A-N)

Appendix II. Details of costs incurred for various operations

Particulars	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉
Seeds	4000	4000	4000	4000	4000	4000	4000	4000	4000
FYM, ZnSO ₄ and lime	40000	40000	40000	40000	40000	40000	40000	40000	40000
Land preparation	8000	8000	8000	8000	8000	8000	8000	8000	8000
Nursery	8000	8000	8000	8000	8000	8000	8000	8000	8000
Transplanting	8000	8000	8000	8000	8000	8000	8000	8000	8000
Weeding	7500	7500	7500	7500	7500	7500	7500	7500	7500
Irrigation	20000	20000	20000	20000	20000	20000	20000	20000	20000
Pesticide	1400	1400	1400	1400	1400	1400	1400	1400	1400
Bunding	7000	7000	7000	7000	7000	7000	7000	7000	7000
Staking	20000	20000	20000	20000	20000	20000	20000	20000	20000
Harvesting	25000	25000	25000	25000	25000	25000	25000	25000	25000
Grading, packing & transportation	10000	10000	10000	10000	10000	10000	10000	10000	10000
Fertilizers	1000	25097	26849	24369	26121	29197	30949	28469	30221
Total cost	159900	183997	185749	183269	185021	188097	189849	187369	189121

Note: Price of tomato @ 8 per kg

Appendix III. Balance sheet of nitrogen, phosphorus and potassium as influenced by split application of NPK nutrients in soil

Treatment	Initial status of soil NPK (kg ha ⁻¹)			Addition of nutrients through fertilizer (kg ha ⁻¹)			Total status of soil (kg ha ⁻¹)			Crop removal (kg ha ⁻¹)			Expected balance (kg ha ⁻¹)			Actual balance (kg ha ⁻¹)			Net loss (kg ha ⁻¹)		
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
T ₁	153.89	41.71	254	-	-	-	153.89	41.71	254	24.07	5.72	60.67	129.82	35.99	192.95	45.48	14.54	86.11	84.34	21.45	106.84
T ₂	153.89	41.71	254	250	250	250	403.89	291.71	504	35.06	9.51	91.2	368.83	282.2	412.42	239.58	32.38	202.72	129.25	249.82	209.70
T ₃	153.89	41.71	254	250	250	312.5	403.89	291.71	566	40.14	10.55	96.73	363.75	281.16	469.39	228.1	26.34	240.82	135.65	254.82	228.57
T ₄	153.89	41.71	254	187.5	250	250	341.39	291.71	504	32.9	7.71	80.11	308.49	284	423.51	187.32	35.78	229.73	121.17	248.22	193.78
T ₅	153.89	41.71	254	187.5	250	312.5	341.39	291.71	566	35.55	9.43	85.04	305.84	282.28	481.08	172.71	28.11	257.69	133.13	254.17	223.39
T ₆	153.89	41.71	254	250	250	250	403.89	291.71	504	41.73	10.83	102.07	362.16	280.88	401.55	245.77	34.27	225.41	116.39	246.61	176.14
T ₇	153.89	41.71	254	250	250	312.5	403.89	291.71	566	46.83	12.63	112.33	357.06	279.08	453.79	231.57	30.43	256.13	125.49	248.65	197.66
T ₈	153.89	41.71	254	187.5	250	250	341.39	291.71	504	40.12	8.6	96.01	301.27	283.11	407.61	195.52	37.19	241.4	105.75	245.92	166.21
T ₉	153.89	41.71	254	187.5	250	250	341.39	291.71	566	44.18	11.96	105.45	297.21	279.75	460.67	178.82	31.62	263.7	118.39	248.13	196.97