



RESEARCH ARTICLE

Effect of urea and muriate of potash on leaf petiole nutrient content and yield of papaya in Gangetic Plains of Bihar, India

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Abstract

A two-year experiment was carried out at Bihar Agricultural University, Bhagalpur, Bihar, India, to evaluate the influence of urea and muriate of potash (MoP) on the nutrient composition of leaf petioles, growth and yield of papaya. The experiment followed a factorial randomized block design with 2 factors: 3 levels of urea (0, 100 and 200 g per plant) as the first factor and 3 levels of MoP (0, 200 and 400 g per plant) as the second factor. Pooled mean data from 2 years of the experiment indicated that different levels of urea and MoP significantly influence the petiole nutrient content, growth and yield of papaya. Petiole calcium (Ca) and magnesium (Mg) content shows an inverse relation with urea application. Application of urea at 200 g per plant significantly reduced mean phosphorous (P) and potassium (K) contents of petiole, along with mean plant height, stem thickness and fruit yield, compared to 100 g per plant. The maximum fruit yield (44.65 t ha⁻¹) was obtained with the application of 100 g urea + 400 g MoP per plant, which was statistically non-significant with 100 g urea + 200 g MoP. Petiole K exhibited a strong positive correlation with fruit yield ($r=0.83$, $p=0.01$), although it remained below the critical range required for optimum papaya productivity. The findings suggest that balanced nitrogen (N) and K fertilisation, optimises nutrient assimilation and yield performance in papaya under alluvial soils of Gangetic Plains of Bihar, India.

Keywords: alluvial soil; leaf petiole; nutrient content; papaya productivity; potassic fertiliser

Introduction

Carica papaya L. is an important fruit crop grown extensively in tropical regions, with a global production of 13.82 million metric tons. India is the leading producer, contributing approximately 38.6 % of the world's papaya production (1). Papaya has a shallow root system, which requires careful management of nutrients and water to ensure efficient uptake (2). As a fast-growing, year-round fruit-bearing plant, papaya demands a continuous and balanced nutrient supply to maintain healthy growth and high productivity (3).

Nitrogen (N) is particularly important in the early phases of root and foliage development (4) and is essential for the synthesis of nucleic acids, proteins and chlorophyll (5). About one fourth of the total N absorbed by the roots of papaya is transferred to the fruits and flowers (6). Consequently, high N application is generally associated with improved yields and better fruit quality. Its management is complex due to leaching losses, various soil biochemical reactions and its dependence on climate variables (7). Higher doses of N fertiliser reduce the quality and yield of fruit in apple tree (8). It also causes higher N deposition in plant parts, soil acidification and eutrophication in water bodies (9).

Potassium (K) is the most abundant cation and essential for the growth of plants by activating enzymes and supporting protein synthesis (10). Potassium is vital for cell growth and highly mobile in plants and helps regulate osmotic pressure as well as cations and anions in cytoplasm (11, 12). However, due to the plant's quick

redistribution of K, symptoms of a K deficiency might not be apparent in the field (13). Nutrient assessment in papaya is typically conducted through petiole and leaf blade analysis, a practice commonly used in commercial crops to prevent yield loss due to nutrient deficiencies.

Fruit yield and quality of papaya are significantly affected by N and K fertilisation (14, 15). Plant growth is restricted when there is an excess of N and a corresponding lack of K, which disrupts canopy growth (16). Increased N application frequently results in soft, lush plant growth, which can increase a plant's susceptibility to disease and pest attacks. By fortifying cell walls and controlling physiological processes, adequate K application increases plant vigour and increases resistance to pest and disease attacks. Potassium nutrition can effectively counteract the high use of N fertilisers, which makes plants more susceptible to pests and diseases.

The recommended dose of urea and muriate of potash (MoP) for papaya in the Gangetic plains of Bihar is 200 g and 150 g per plant respectively. However, a significant yield gap exists between the potential and actual productivity in this region. The effects of fertilising with N and K on papaya growth and productivity have been the subject of numerous studies. On the other hand, recent alluvial soils, which have received little attention, which has problems with N-leaching and K-fixation. Therefore, this study aims to provide further insight into the rate of N and K fertiliser requirements of papaya and their effect on petioles' nutrient contents, with the goal of maximising fruit yield.

Materials and Methods

Experimental site

The experiment was carried out at the Student Research Farm of Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India (25° 14'5.0" N and 87° 02'43.8" E, 46 m altitude) during the May 2016 to April 2018. The plot size was 10 × 6 m (length × breadth) with a total area of 1620 m². Papaya cv. Red lady was propagated by seed. Thirty-day-old healthy, disease-free and uniformly sized tray seedlings were used for the experiment and subsequently transplanted. The spacing of plants was 2 m in row to row and 2 m in plant to plant and a total 15 plants were planted in each plot after proper seedbed preparation. All plants were fertilised with 100 g of phosphate through di-ammonium phosphate (DAP). The experiment consists of 9 treatments and replicates thrice under a factorial randomised block design with 2 factor. Treatment consists of 3 levels of urea: 0 g (U₀), 100 g (U₁₀₀), 200 g (U₂₀₀) per plant as first factor and 3 levels of MoP: 0 g (M₀), 200 g (M₂₀₀), 400 g (M₄₀₀) per plant as second factor. These treatments were applied in 4 equal splits at 90, 180, 270 and 360 days after planting.

Soil and climate

Soil sampling was carried out at a depth of 0–30 cm. After air-drying, the composite sample was lightly crushed and passed through a 2 mm sieve for subsequent laboratory analyses. Available N was estimated using the Kjeldahl method, available phosphorus (P) was determined by the Olsen method and available K, calcium (Ca) and magnesium (Mg) were measured using a flame photometer. The soil texture was sandy loam with an initial pH 6.84, available N of 183.6 kg ha⁻¹, available P of 12.3 kg ha⁻¹, available K of 190 kg ha⁻¹, available Ca of 1809 kg ha⁻¹ and available Mg of 79 kg ha⁻¹. Weather data, including monthly temperature and rainfall were recorded at a meteorological station situated at Bihar Agricultural University, Sabour, Bhagalpur. The mean maximum monthly temperature ranged from 18.6–35.3 °C, while the mean minimum monthly temperature varied between 6.4 °C and 26.1 °C. The average annual rainfall during the study period was 1111.5 mm (Fig. 1).

Nutrient analysis of papaya petioles

From each treatment, leaf petioles were randomly collected by 3 plants from under the most recently set fruit. Petioles were oven-dried for 48 hr at 65 °C; dried petioles were well ground to pass a 1 mm sieve, followed by plant samples being digested by di-acid

(HNO₃: HClO₄: 9 : 4). After digestion, N was estimated using the micro-kjeldahl method. Phosphorous was determined using the vanadomolybdate reagent method and measured with a spectrophotometer. Potassium was measured by flame photometer. The Ca and Mg were extracted with dilute hydrochloric acid and measured by flame photometer.

Growth parameter and yield

The following measurements were made 210 days after transplanting: a) the height of the plant (cm) was taken from the base to the point where the last leaf was inserted using a millimeter measuring tape (accuracy: 0.01 cm); and b) the diameter of the stem (mm) was taken at a height of 20 cm from the soil surface using a digital caliper (range: 0.01–300 mm, Digimess®). Fruits harvested from every plant in the experimental plots were used to calculate the yield (t ha⁻¹). Fruits were picked every week when they reached maturity stage 3, which is defined by 25 % to 50 % of the fruit peel being yellowish, in accordance with Marin's (2004) criteria. Following harvest, a precision balance (accuracy: 0.01 g) was used to weigh, count and select fruits to calculate the mass of fruit per plant. After that, the total yield was calculated by multiplying the plant population per hectare (2500 plants) by the sum of the fruit mass per plant during the whole harvest period.

Statistical analysis

The two-year experiment's simple pooled mean (average of 2 years) data was analysed using two-way analysis of variance (ANOVA) (17). Duncan's multiple-range test (DMRT) was used to separate the means from least significant difference analysis at $p \leq 0.05$. The correlations among petiole nutrients, as well as between petiole nutrient contents, plant growth and yield parameters, were calculated using Microsoft Excel software.

Results

Effect on nutrient content in leaf petioles

Nutrient content in papaya petioles was significantly influenced by the application of urea and MoP. The mean nutrient content is represented in Fig. 2 and Fig. 3 respectively. In the U₂₀₀ treatment, the mean N content was 4.59 % higher than in the U₁₀₀ treatment, whereas the P and K contents were decreased by a mean of 7.72 % and 5.13 % respectively. However, the mean Ca and Mg contents

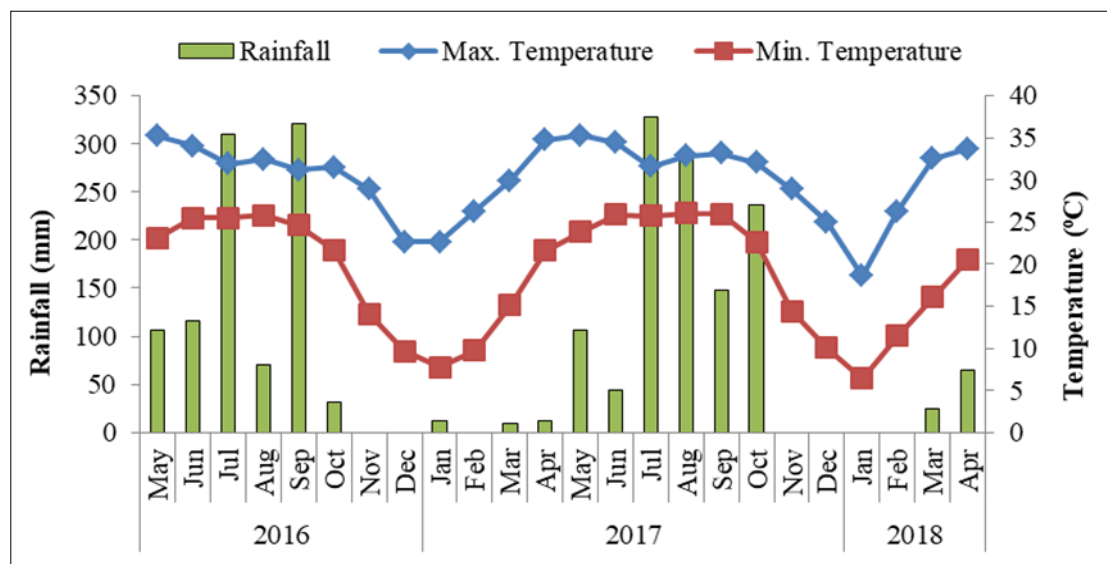


Fig. 1. Monthly rainfall, minimum and maximum temperature of the study area.

exhibited an inverse relationship with increasing levels of urea application, indicating a possible antagonistic effect of higher N on the uptake or accumulation of these secondary nutrients. In the M_{200} treatment, the mean contents of N, P, K, Ca and Mg were higher by 5.45 %, 5.20 %, 23.38 %, 8.26 % and 6.89 % respectively, compared to the M_0 treatment, suggesting a balanced and efficient nutrient uptake at this level of K application. This improvement may be attributed to enhanced nutrient availability and synergistic interactions among essential elements at moderate K levels. Furthermore, the non-significant difference in mean nutrient content between M_{200} and M_{400} treatments indicates that increasing K beyond 200 g per plant did not result in additional nutrient accumulation. This suggests the existence of an optimum K level,

beyond which nutrient uptake either plateaus or is regulated due to physiological or soil related constraints.

The interaction effect of urea and MoP showed a positive influence on petiole N content at higher dose combinations (Table 1). The highest N content was recorded in the U_{200} and M_{400} treatment combination, representing a 24.83 % increase compared to the control (U_0 and M_0). However, P and K contents showed variability across different treatment combinations. The maximum levels of both P and K were observed in the U_{100} and M_{400} treatment combination. The Ca (1.41 %) and Mg (0.72 %) were highest in the treatment having application of only MoP at the rate of 400 g per plant.

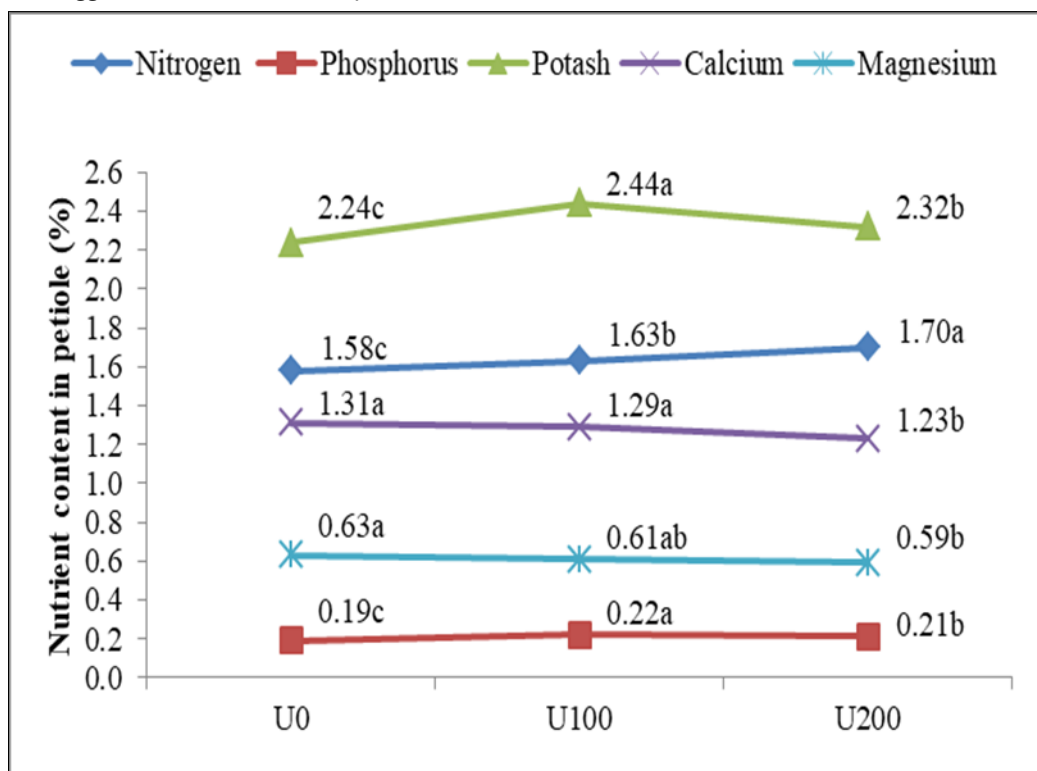


Fig. 2. Petiole nutrient contents (mean) affected by different urea rate in papaya,

*Values with different letters are significantly different at $p \leq 0.05$.

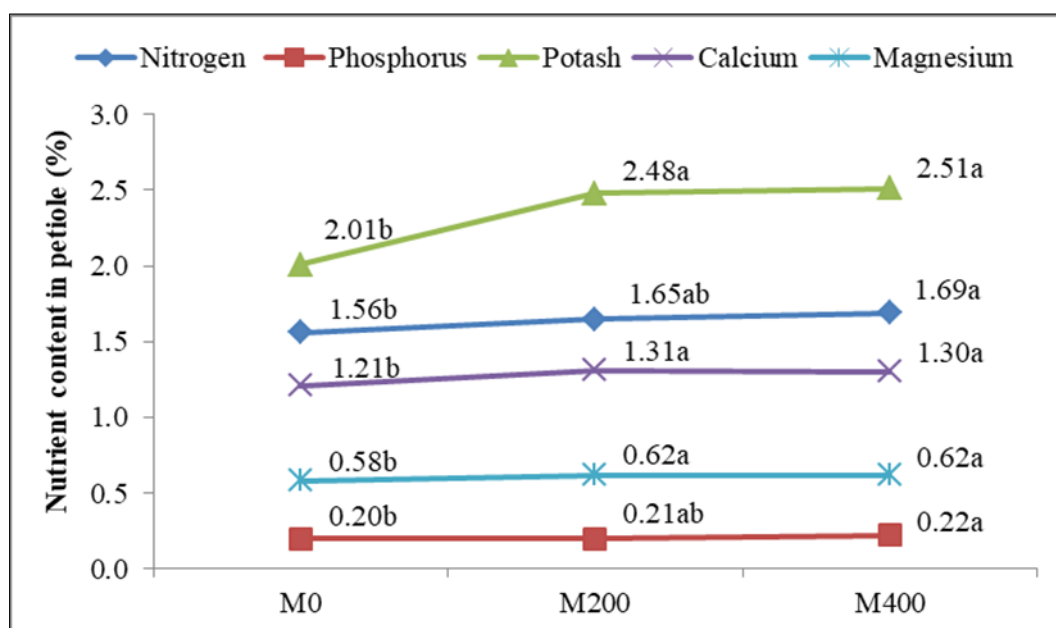


Fig. 3. Petiole nutrient contents (mean) affected by different MoP rate in papaya,

*Values with a different letters are significantly different at $p \leq 0.05$.

Table 1. Interaction effects of urea and MoP fertiliser on nutrient content of leaf petiole of papaya

Treatment	Nitrogen (%)	Phosphorus (%)	Potash (%)	Calcium (%)	Magnesium (%)
U ₀ M ₀	1.41d	0.191d	1.92e	1.15d	0.543d
U ₀ M ₂₀₀	1.69ab	0.201cd	2.46b	1.35b	0.641b
U ₀ M ₄₀₀	1.64b	0.192d	2.36c	1.41a	0.726a
U ₁₀₀ M ₀	1.66b	0.207c	1.95e	1.26c	0.631bc
U ₁₀₀ M ₂₀₀	1.54c	0.199cd	2.63a	1.36ab	0.644b
U ₁₀₀ M ₄₀₀	1.67b	0.255a	2.74a	1.24c	0.566d
U ₂₀₀ M ₀	1.62b	0.210bc	2.17d	1.21c	0.552d
U ₂₀₀ M ₂₀₀	1.72a	0.210bc	2.35c	1.23c	0.603c
U ₂₀₀ M ₄₀₀	1.76a	0.221b	2.44bc	1.24c	0.621bc
SEM (±)	0.0236	0.0038	0.0328	0.0184	0.0120
LSD _{0.05}	0.067	0.011	0.093	0.057	0.034

*Values with a different letters in a column are significantly different at $p \leq 0.05$.

Effect on growth and yield

Mean data on the effect of urea and MoP on growth and yield of papaya are presented in Table 2. The highest level of urea application (U₂₀₀) significantly reduced plant height, stem thickness and fruit yield compared to U₁₀₀. However, the number of flowers significantly improved in U₂₀₀ as compared to U₁₀₀. The MoP application did not affect the plant height significantly. The highest stem thickness was observed in the mean of treatment M₂₀₀. The mean number of flowers significantly increased with increasing levels of MoP. The fruit yield was maximum in M₂₀₀, which was 13.17 % higher than M₀.

The interaction of both urea and MoP application did not significantly affect plant height or stem thickness. Interaction effect on number of flowers and fruit yield was presented in Fig. 4 and 5 respectively. The highest number of flowers (22.21) was recorded in

the U₂₀₀M₂₀₀ treatment, followed by the U₂₀₀M₄₀₀. The maximum fruit yield (44.65 t ha⁻¹) was achieved with 100 g urea combined with 400 g MoP, showing a 22.32 % increase over the control. However, further increase in MoP under higher N (U₂₀₀M₄₀₀) did not significantly enhance yield, likely due to nutrient imbalance or diminishing response at higher urea application.

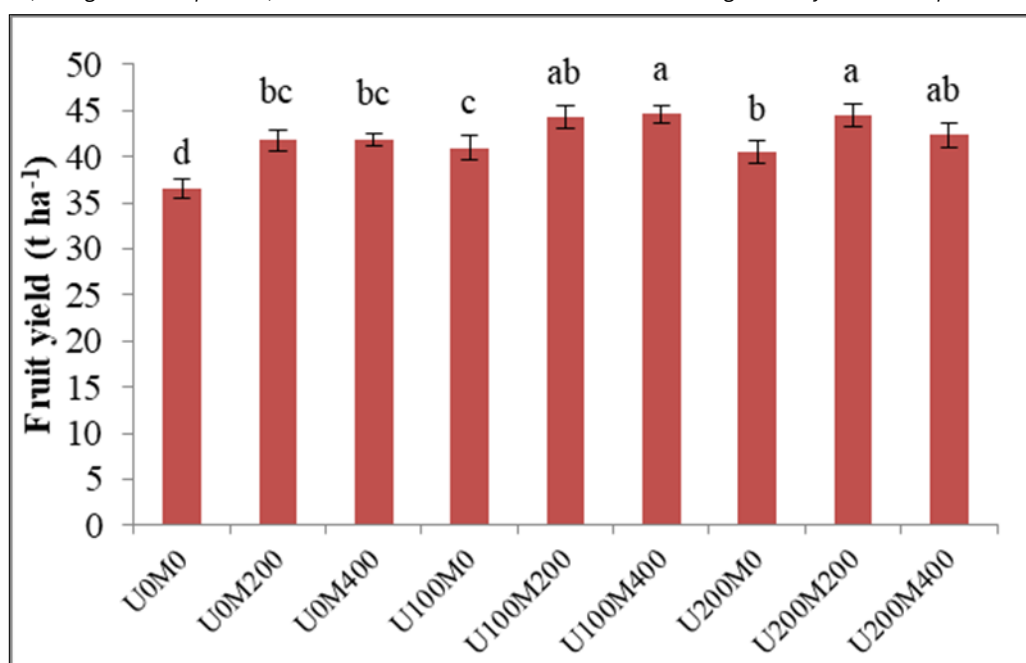
Correlation among the petiole nutrient content and growth and yield

Correlation among nutrient contents in papaya petiole presented in Table 3. The Ca content in plant was highly positively correlated with Mg ($r = 0.90, p = 0.01$). The correlations between N and P ($r = 0.50$) and P and potash ($r = 0.50$) were found to be moderately positive. Magnesium (Mg) and P ($r = -0.43$) and Ca and P ($r = -0.33$) were two other nutrient pairs that showed negative but non-significant correlations.

Table 2. Effects of urea and muriate of potash on growth and yield of papaya

Treatment	Plant height (cm)	Stem thickness (cm)	No. of flowers per plant	Fruit yield (t ha ⁻¹)
U ₀	102.82a	76.90a	19.97b	41.70b
U ₁₀₀	103.05a	75.11a	20.15b	43.27a
U ₂₀₀	99.34b	67.91b	21.44a	42.45ab
M ₀	102.21a	71.29b	19.33c	39.32b
M ₂₀₀	102.09a	76.13a	20.71b	44.50a
M ₄₀₀	100.91a	72.50b	21.53a	43.60a
SEM (±)	0.776	0.728	0.243	0.435
LSD _{0.05}	2.15	2.11	0.69	1.225
U×M	NS	NS	S	S

NS= Non significant, S= significant at $p \leq 0.05$, *Values with a different letter in a column are significantly different at $p \leq 0.05$.

**Fig. 4.** Interaction effect of urea and muriate of potash on number of flowers in papaya.

*Values with a different letters are significantly different at $p \leq 0.05$.

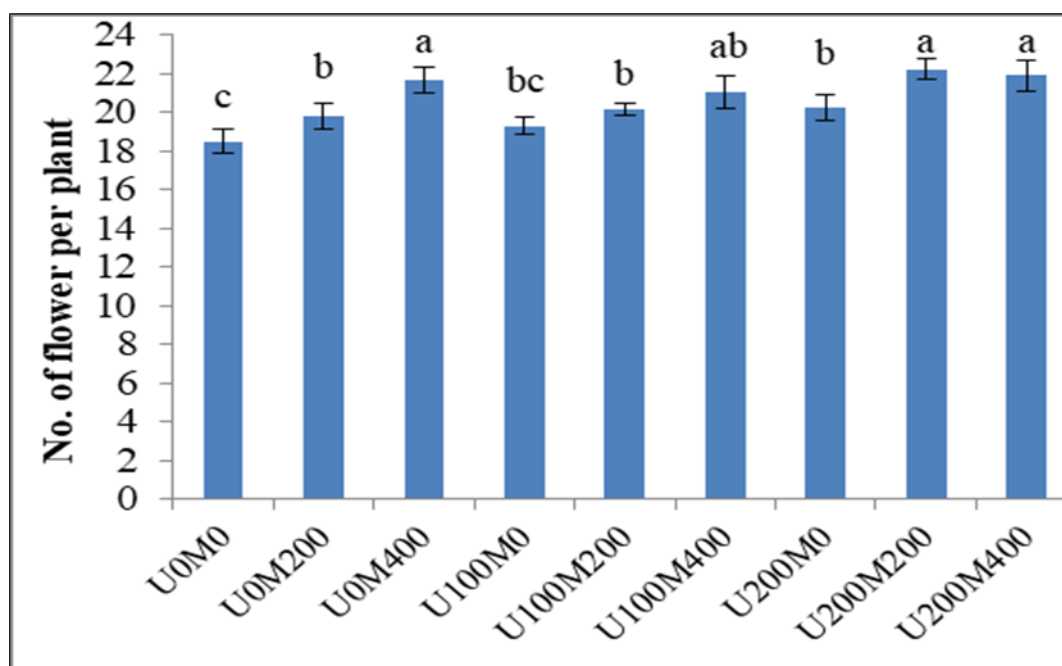


Fig. 5. Interaction effect of urea and muriate of potash on number of fruit yield of papaya.

*Values with different letters are significantly different at $p \leq 0.05$.

Table 3. Correlation among the petiole nutrient contents in papaya

	Nitrogen (%)	Phosphorus (%)	Potash (%)	Calcium (%)	Magnesium (%)
Nitrogen (%)	1				
Phosphorus (%)	0.50	1			
Potash (%)	0.40	0.50	1		
Calcium (%)	0.23	-0.33	0.47	1	
Magnesium (%)	0.32	-0.43	0.21	0.90**	1

*Significant at $p=0.05$; **Significant at $p=0.01$.

The correlation between petiole nutrient contents and growth and yield of papaya is presented in Table 4. Nitrogen was significantly and positively correlated with the number of flowers per plant ($r=0.72$, $p=0.05$) and fruit yield ($r=0.66$, $p=0.05$). Potash was highly positively correlated with fruit yield ($r=0.83$, $p=0.01$) and moderately correlated with flower count ($r=0.55$). There was a significant correlation between calcium with fruit yield ($r=0.67$, $p=0.05$) and stem thickness ($r=0.69$, $p=0.05$). Phosphorus and Mg did not significantly correlate with yield or related attributes.

Discussion

Nitrogen content in the petiole increased with increasing urea level due to more uptake of N available in the soil (18). In contrast, previous results found no significant effect of N fertilisation on leaf N content of apple (19). Besides fertilization several other factors like climate, moisture stress, high temperature, may influence the nutrient content in plant parts (20). Urea application at a higher dose significantly decreases the petiole P content. N fertiliser promotes plant growth; due to the dilution effect, the nutrient content may decrease in the plant (21). The Ca and Mg content fall with increasing urea level; this could be because N

inhibits oxalate degradation and encourages oxalate synthesis, which eventually causes oxalate accumulation. Oxalate readily forms insoluble crystals with Ca and Mg, thereby reducing their availability in plant tissues (22). The mean data of MoP application at 200 g improves the nutrient content in papaya petioles. The absorbed N tends to accumulate as free amino acids rather than being incorporated into proteins when the K levels are low. On the other hand, adequate K availability enhances the biological utilisation of N and enables optimal protein synthesis (23). With K fertilisation, the P content in pepper plants increases significantly (24); a similar result has been found in previous researches (25).

Plant height and stem thickness increased when urea was applied; however, at the highest urea application rate, these parameters decreased. Nitrogen application encourages apple tree growth, but excessive application inhibits the growth (18). An adequate supply of N promotes better plant height, whereas excessive amounts can create nutrient imbalances that ultimately restrict growth (26). Higher N levels can stimulate vascular bundle formation and increase stem thickness, but overly high N inputs may reduce lignin accumulation in plants (27). Fruit yield increased with increasing K fertilisation. The result was consistent with early findings, who reported application of K fertiliser led to a notable

Table 4. Correlation among the petiole nutrient contents in papaya

	Plant height (cm)	Stem thickness (cm)	No. of flowers per plant	Fruit yield (t ha ⁻¹)
Nitrogen (%)	-0.44	-0.29	0.72*	0.66*
Phosphorus (%)	-0.33	-0.49	0.40	0.31
Potash (%)	-0.24	0.23	0.55	0.83**
Calcium (%)	0.01	0.69*	0.25	0.67*
Magnesium (%)	0.06	0.58	0.34	0.52

*Significant at $p=0.05$; **Significant at $p=0.01$.

increase in the average fruit yield (28). Potassium's role in regulating plant water and enhancing resistance to environmental stress, such as wind, waterlogging, drought and extremely high or low temperatures, is directly linked to fruit quality and tree productivity (29).

Table 5 presents the recommended adequate range of nutrients for papaya leaf petioles to achieve optimum yield, an adaptation from previous reference (30). In the present study, K content is below the adequate range even when MoP applied at the highest rate. However, K content in plants significantly improves with K fertilisation, but when further increasing the dose, petioles K did not improve significantly. This may be due to the increasing K application significantly enhances K fixation capacity in alluvial soils (31). In our study, we also found that petiole K content was highly significantly correlated ($r=0.83$, $p=0.01$) to the papaya yield. That shows that the plant cannot uptake K from the soil system that is required to achieve optimum yield. Feeding K through foliage may improve the K content in the plant, thereby improving yield. Future research should focus on evaluating the effectiveness of foliar K application at different growth stages of papaya to enhance nutrient uptake and yield. Studies are also needed to optimise the concentration and frequency of foliar sprays in relation to soil K application. Exploring the physiological mechanisms governing K uptake and translocation within the plant can further help in developing efficient nutrient management strategies for maximising papaya productivity.

Table 5. Recommended and existing nutrient content in papaya petioles

Nutrients	Recommended nutrient content in Papaya petioles	Existing nutrient content in Papaya petioles
N (%)	1–2.5	1.38–1.79
P (%)	0.2–0.4	0.18–0.27
K (%)	3–5	1.92–2.74
Ca (%)	1–3	1.14–1.43
Mg (%)	0.4–1.2	0.54–0.72

Nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca).

Conclusion

Urea and muriate of potash (MoP) applications employed significant effects on petiole nutrient dynamics, growth and yield of papaya. Moderate nitrogen (N) fertilisation showed superior plant growth and yield, while excessive N fertilisation caused nutrient imbalance and growth suppression. The MoP application at 200 g improved nutrient uptake, particularly Potassium (K), which exhibited a strong positive correlation with yield. The findings highlight the application of 200 g of urea in combination with 200 g of MoP to improve both the number of flowers and yield of papaya in the alluvial soil of Bihar. Optimising integrated foliar and soil K application to enhance uptake efficiency, nutrient interactions and translocation, should be focused for improving papaya productivity in Gangetic Plains of Bihar, India.

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Authors' contributions

PK carried out the research programme, laboratory analysis and writing the manuscript. MFA design the research programme. AKC participated in the laboratory analysis of soil. KM participated in the design of the study and coordination. SP participated in study and coordination. AK participated in writing and drafting manuscript and performed the statistical analysis. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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