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RESEARCH ARTICLE

Site-specific nutrient management using QUEFTS model for growth, yield and yield attributes of potato under Middle Gangetic Plains, India

Dharmendra Kumar[1,2], Neeraj Kumar[1], Mahendru Kumar Gautam[3,4*], Ravindra Sachan[5], Sushil Kumar Yadav[1], Robin Kumar[1], Alok Kumar Pandey[1] & Anand Singh[1]

[1]Department of Soil Science and Agricultural Chemistry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya 224 229, Uttar Pradesh, India
[2]School of Advanced Agriculture Sciences and Technology, Chhatrapati Shahu Ji Maharaj University, Kanpur 208 024, Uttar Pradesh, India
[3]School of Agriculture and Environmental Sciences, Shobhit University, Gangoh, Saharanpur 247 341, Uttar Pradesh, India
[4]School of Agricultural Sciences, Babu Banarasi Das University, Lucknow 226 028, Uttar Pradesh, India
[5]Department of Soil Science and Agricultural Chemistry, C.S.A. University of Agriculture and Technology, Kanpur 208 002, Uttar Pradesh, India

*Correspondence email - gautambhu15317@gmail.com

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Abstract

During the winter (*Rabi*) season of 2022-2023 and 2023-2024, a field experiment on potatoes was carried out at the vegetable research farm ANDUA&T, Kumarganj, Ayodhya (U.P.), AICRP on potato in Middle Gangetic Plains. Ten treatment combinations with three replications were used in the Randomized Block Design trial. The clay-loam soil used in the experiment had an EC of 0.27 (dS m^{-1}) and a pH of 7.81. According to the soil's nutrient study, it has available potassium (275.12 kg ha^{-1}), available phosphorus (18.01 kg ha^{-1}) and available nitrogen (175.51 kg ha^{-1}). Maximum plant emergence (96.22 %), number of haulm (7.48 $hill^{-1}$), plant height at 30 days after planting (DAP) (28.83 cm), 60 DAP (56.20 cm) and harvest stage (60.54 cm), number of leaves per plant at 30 DAP (32.42), 60 DAP (48.72) and harvesting stage (56.25) were noted in T_6, while the lowest plant emergence (90.96 %), number of haulm (4.16 $hill^{-1}$), plant height at 30 DAP (22.04 cm), 60 DAP (45.99 cm), harvesting stage (48.99 cm), number of leaves per plant at 30 DAP (24.18), 60 DAP (40.18) and harvesting stage (45.20) was noted in T_{10}. Compared to the control, the grade-wise tuber was significant in T_6.

Keywords: QUEFTS; growth and yield; site-specific nutrient management

Introduction

The nutrient requirements of potatoes are determined by yield goals, environmental conditions and management practices. Being a nutrient-intensive crop, potatoes often suffer yield and quality losses when soils fail to meet these demands due to nutrient deficiencies. The primary constraint to achieving high productivity is the unbalanced and insufficient supply of essential nutrients. While farmers generally focus on nitrogen (N), phosphorus (P) and potassium (K), the neglect of secondary and micronutrients-such as sulfur (S), iron (Fe), manganese (Mn), zinc (Zn) and boron (B)-has led to widespread deficiencies (1). Potatoes are highly efficient in producing quality output within a short growing period of less than 120 days, making them valuable for food security. They are rich in nutrients and consumed worldwide in diverse forms (2). Originating from Peru in South America, the crop spread globally via exploration, trade and migration. Of the 5000 known varieties, most still exist in South America (3).

Globally, potatoes rank fourth among staple crops after rice, wheat and maize, with production around 376 million tonnes on 19 million hectares. China leads production at 94 million tonnes, followed by the US, Russia, Ukraine and India (4). India ranks second, producing about 54 million tonnes annually on 2.16 million hectares. Uttar Pradesh, with its favorable soils and climate, is the top potato-producing state, contributing over 30 % of the national output at approximately 26 million tonnes per year. The crop thrives in *Rabi* season under subtropical conditions, with optimal night temperatures of 4–15 °C and daytime temperatures of 25–30 °C, while 18–20 °C is ideal for tuber formation. Excessive heat above 30 °C suppresses tuber initiation, though moderate warmth can enhance vegetative growth. Economically, the potato industry sustains livelihoods by generating employment in farming, labor, processing and supply chains (5).

Balanced fertilization and adequate soil fertility are essential for high yields and quality tubers (6). Mismanagement of fertilizers not only reduces productivity and degrades quality but also increases environmental risks (7). The Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model offers a precise, site-specific nutrient management approach by integrating nutrient interactions and yield targets, outperforming conventional recommendation methods. It has been effectively used for crops like rice, wheat, cassava, elephant foot yam and sweet potatoes (8). Nitrogen, phosphorus and potassium are the key macronutrients for potato cultivation. Nitrogen drives vegetative growth and leaf development, directly impacting yield; however, excess application delays tuberization and increases environmental hazards, while deficiency stunts growth and lowers yield (10). Phosphorus, the second most limiting nutrient, is crucial for the synthesis of compounds like phospholipids that support cell membrane integrity and plant health (11). Potassium enhances photosynthesis, improves nitrogen use efficiency, regulates water balance, activates enzymes, supports carbohydrate metabolism and facilitates sugar translocation, thereby improving growth and yield (12).

This study aims to optimize nutrient management through balanced fertilizer application tailored to soil conditions and crop needs. The goal is to maximize yield and quality while minimizing costs and environmental impact. Based on QUEFTS-derived recommendations, applying fertilizers at 125% of the standard dose can substantially increase potato growth and yield, offering greater economic returns than both untreated plots and conventional fertilization practices.

Materials and Methods

In the winter (*Rabi*) season of 2022–2023 and 2023–2024, a two-year field experiment was carried out on the vegetable research farm (AICRP on Potato), ANDUA&T, Kumarganj, Ayodhya, U.P. (260 47′ N latitude, 820 12′ E longitude and at an elevation of 113 m above the mean sea level). T_1: 100 % NPK as recommended (150:100:120 kg ha^{-1}), T_2: 75 % NPK as recommended, T_3: 125 % NPK as recommended, T_4: 100 % NPK as per QUEFTS model (220:60:80 kg ha^{-1}), T_5: 75 % NPK as per QUEFTS model, T_6: 125 % NPK as per QUEFTS model, T_7: Without N fertilizer (PK), T_8: Without P fertilizer (NK), T_9: Without K fertilizer (NP) and T_{10}: Without NPK (Control) were the ten treatment combinations planted under Randomized Block Design with 10 treatments and 3 replications. The clay-loam soil used in the experiment had an EC of 0.27 and a pH of 7.81 (13). According to the soil's nutrient study, it has 175.51 kg ha^{-1} of available nitrogen (14), 18.01 kg ha^{-1} of available phosphorus (15) and 275.12 kg ha^{-1} of available potassium (16). The plot size of each treatment is 4.8 m × 3.6 m and 5 plants are tagged in each plot for data collection. The number of leaves on the tagged plant from the base is manually counted, the number of haulms per hill is counted and the height of the plant is measured using a scale from base to tip while maintaining its straightness. According to their size, potato tubers are divided into four groups: small (0-25 g), medium (25-50 g), large (50-75 g) and extra-large (more than 75 g). The market value, quality and suitability for many applications, including seed, processing and fresh consumption, are evaluated with the use of this size-based grading system. Multiply by 100, divide the number of emerging plants by the total number of tubers sown. The data recorded during the course of experiment were subjected to analysis using the analysis of variance technique in randomized block design. The critical differences at 5 % of probability were calculated for testing the significance of the difference between any two means where the 'F' test was significant (17).

Plant emergence percentage = (Number of emerged plants/ Total tuber planted) × 100

Results and Discussion

Plant emergence (%)

Table 1 show the results of a statistical analysis of the plant emergence, which was expressed as a percentage and reported 30 days after planting. It was discovered that different nutrient dosages caused a considerable difference in the percentage of plant emergence at 30 days. Nevertheless, the mean performance of plant emergence showed that T_6 had the highest percentage of plant emergence (96.22 %), outperforming all other treatments. In contrast, T_{10} had the lowest percentage of emergence (90.96 %). At 30 DAP, observations regarding the quantity of haulm per hill were made and the results are shown in Table 1. The recorded data showed that, as a result of varying nutrition dosages, the quantity of haulm per hill varied considerably. The quantity of haulm per hill at 30 DAP ranged from 4.16 to 7.48. The results shows that the T_6 had the considerably greatest number of haulm per hill (7.48), followed by the T_4 and T_3. Out of all the treatment combinations, treatment T_6 was shown to be statistically significant. In absolute control T_{10}, the haulm per hill was the lowest, at 4.16. Applying SSNM may have increased plant height because the crop was properly nourished, which supports maximum development and enhances a number of metabolic processes. The timely delivery of nutrients that are good for crop growth promoted cell elongation and meristematic cell activity, which increased plant height and leaf size (18).

Plant height

The plant height under different treatments was recorded thrice as 30 DAP, 60 DAP and at harvest presented in Table 2. It was revealed from the data recorded that there was significantly

Table 1. Effect of site-specific nutrient management by QUEFTS model on plant emergence at 30 DAP (%) and Number of haulm hill^{-1} on pooled basis

Treatments	Plant Emergence (%) at 30 DAP	Number of haulm hill^{-1}
T_1-100 % NPK as per recommendation	94.66	6.25
T_2-75 % NPK as per recommendation	94.58	5.71
T_3-125 % NPK as per recommendation	95.89	7.12
T_4-100 % NPK as per QUEFTS Model	96.08	7.27
T_5-75 % NPK as per QUEFTS Model	95.77	6.97
T_6-125 % NPK as per QUEFTS Model	96.22	7.48
T_7-Without N fertilizer (PK)	94.38	4.23
T_8-Without P fertilizer (NK)	94.91	5.23
T_9-Without K fertilizer (NP)	94.78	5.01
T_{10}-Absolute control	90.96	4.16
SEm (±)	0.79	0.11
CD (P = 0.05)	2.35	0.34

Table 2. Effect of site-specific nutrient management by QUEFTS model on plant height at 30 DAP, 60 DAP and harvesting stage (cm) on pooled basis

Treatments	Plant Height at 30 DAP (cm)	Plant Height at 60 DAP (cm)	Plant Height at harvesting stage (cm)
T_1-100 % NPK as per recommendation	26.04	53.79	56.32
T_2-75 % NPK as per recommendation	25.47	52.94	53.94
T_3-125 % NPK as per recommendation	27.93	55.47	58.99
T_4-100 % NPK as per QUEFTS Model	28.14	55.80	58.48
T_5-75 % NPK as per QUEFTS Model	27.01	54.87	58.40
T_6-125 % NPK as per QUEFTS Model	28.83	56.20	60.54
T_7-Without N fertilizer (PK)	23.97	51.39	55.08
T_8-Without P fertilizer (NK)	24.94	52.82	56.47
T_9-Without K fertilizer (NP)	24.40	51.82	54.92
T_{10}-Absolute control	22.04	45.99	48.99
SEm (±)	0.67	0.86	0.96
CD (P = 0.05)	1.40	2.59	2.89

difference due to different doses of nutrients applied in the experiment. At 30 DAP, the significantly highest plant height of 28.83 cm was recorded in T_6, followed byT_4 and T_3. The lowest plant height was recorded in T_{10}; absolute control (22.03 cm) which is significantly inferior over all the treatments. At 60 DAP, the significantly highest plant height of 56.20 cm was recorded in T_6. The lowest plant height was recorded in T_{10}; absolute control (45.99 cm) which is significantly inferior over all the treatments. At harvest stage, the significantly highest plant height of 60.54 cm was recorded in T_6. The lowest plant height was recorded in T_{10}; absolute control (48.99 cm) which is significantly inferior over all the treatments. Increasing nitrogen levels can significantly enhance plant growth by stimulating carbohydrate and protein assimilation. This process boosts cell division and tissue formation, resulting in greater plant height, an increased number of leaves and more vigorous shoot development. Additionally, higher nitrogen levels encourage the formation of stems and axillary branches, promoting overall vegetative growth (19).

Number of leaves per plant

Number of leaves per plant were recorded three times as 30 DAP, 60 DAP and at harvest which are presented in Table 3. It was revealed from the data that there was significant difference for number of leaves per plant by different doses of nutrients. Number of leaves per plant at 30 DAP, varied from 24.17 (absolute control) T_{10} to 32.42 in T_6. The significantly highest number of leaves per plant was found in T_6; 32.42 which was statically significant with T_4 and T_3. Whereas, the lower number of leaves per plant was recorded in absolute control T_{10}; 24.17. Similar trend was following for data recorded at 60 DAP, the highest number of leaves per plant in T_6 (48.71) and lowest T_{10} (40.17). At harvest, the highest number of leaves per plant in T_6 (56.25) and lowest T_{10} (45.19). The significantly larger leaf area results from increased nitrogen and phosphorus uptake, which enhances chlorophyll content in the leaves. This boost in chlorophyll improves the crop's photosynthetic efficiency, promoting better nutrient assimilation and overall growth, ultimately leading to broader leaves and improved vegetative development (20).

Yield

The results revealed that the pooled mean tuber yields across both years varied significantly among the different treatments (Table 4). Treatment T_6, which involved applying 125 % of the recommended NPK dose, recorded the highest tuber yield at

Table 3. Effect of site-specific nutrient management by QUEFTS model on Number of leaves per plant at 30 DAP, 60 DAP and harvesting stage on pooled basis

Treatments	Number of leaves plant^{-1} at 30 DAP	Number of leaves plant^{-1} at 60 DAP	Number of leaves plant^{-1} at harvesting stage
T_1-100 % NPK as per recommendation	29.14	45.75	52.32
T_2-75 % NPK as per recommendation	27.99	44.59	52.04
T_3-125 % NPK as per recommendation	30.03	46.42	53.48
T_4-100 % NPK as per QUEFTS Model	31.21	48.28	55.72
T_5-75 % NPK as per QUEFTS Model	30.23	47.82	54.94
T_6-125 % NPK as per QUEFTS Model	32.42	48.72	56.25
T_7-Without N fertilizer (PK)	26.13	44.44	48.43
T_8-Without P fertilizer (NK)	27.52	44.59	49.85
T_9-Without K fertilizer (NP)	25.87	43.32	48.81
T_{10}-Absolute control	24.18	40.18	45.20
SEm (±)	0.59	1.07	1.14
CD (P = 0.05)	1.76	3.18	3.40

Table 4. Effect of site-specific nutrient management by QUEFTS model on tuber and haulm yield (t ha^{-1}) on pooled basis

Treatments	Tuber yield (t ha^{-1})	Haulm yield (t ha^{-1})
T_1-100 % NPK as per recommendation	30.15	12.90
T_2-75 % NPK as per recommendation	28.18	12.08
T_3-125 % NPK as per recommendation	32.22	13.77
T_4-100 % NPK as per QUEFTS Model	34.06	14.56
T_5-75 % NPK as per QUEFTS Model	31.56	13.49
T_6-125 % NPK as per QUEFTS Model	36.14	15.41
T_7-Without N fertilizer (PK)	23.88	10.21
T_8-Without P fertilizer (NK)	25.52	10.90
T_9-Without K fertilizer (NP)	24.41	10.43
T_{10}-Absolute control	19.92	8.91
SEm (±)	0.76	0.44
CD (P = 0.05)	2.28	1.36

Table 5. Effect of site-specific nutrient management by QUEFTS model on grade wise tuber yield (t ha^{-1}) on pooled basis

Treatments	0-25 g	25-50 g	50-75 g	>75 g
T_1-100 % NPK as per recommendation	2.04	10.88	9.15	8.09
T_2-75 % NPK as per recommendation	1.95	10.54	8.99	6.70
T_3-125 % NPK as per recommendation	2.41	10.98	9.44	9.39
T_4-100 % NPK as per QUEFTS Model	2.68	11.79	10.20	9.40
T_5-75 % NPK as per QUEFTS Model	2.34	12.26	9.66	7.30
T_6-125 % NPK as per QUEFTS Model	2.69	12.88	10.34	10.23
T_7-Without N fertilizer (PK)	1.83	10.09	7.41	4.56
T_8-Without P fertilizer (NK)	1.86	9.61	8.62	5.44
T_9-Without K fertilizer (NP)	1.95	8.74	7.35	6.37
T_{10}-Absolute control	1.68	7.89	6.27	4.09
SEm±	0.03	0.18	0.14	0.10
CD (P = 0.05)	0.11	0.53	0.44	0.31

36.14 t ha^{-1}, followed by T_4 with 34.06 t ha^{-1}. In contrast, the lowest yield was observed in the control treatment (T_{10}), with an average of 19.92 t ha^{-1}. These findings highlight the positive effect of optimized fertilizer application on enhancing tuber yield. Table 4 presents data on the haulm yield under different treatments. The results showed that fertilizer application had a significant influence on haulm yield. Among all treatments, T_6 produced the highest haulm yield at 15.51 t ha^{-1}, followed by T_4 with 14.56 t ha^{-1}. The lowest haulm yield was recorded in the control treatment T_{10}, with an average of 8.91 t ha^{-1}. The improved and balanced N supply resulted in higher tuber and haulm yield (21). The higher tuber yields when fertilizer management was recommended by the QUEFTS model, attributing the improvement to increased nutrient use efficiency and better internal nutrient utilization. The enhanced yields in QUEFTS-based treatments likely result from a balanced nutrient supply and timely availability during critical stages of crop development (3). The present N and K recommendations were lower than the estimated location-specific nutrient or soil test-based nutrient rates (22). At the same time, the applied phosphorus fertilizer rates were higher than the site-specific nutrient or soil test-based nutrient rates, resulting into lower yields and also phosphorus buildup in the soil. They recommended using QUEFTS to develop location-specific fertilizer rates (22).

Grade wise yield

Table 5 presents the tuber yield across different size grades. In the smallest grade (0-25 g), the highest yield was observed in treatment T_6 (125 % NPK based on the QUEFTS model), producing 2.69 t ha^{-1}, while the lowest yield came from the absolute control (T_{10}) at 1.68 t/ha. For the next size group (25–50 g), T_6 again led with a yield of 12.88 t ha^{-1}, compared to just 8.68 t ha^{-1} in T_{10}. Similarly, in the 50-75 g category, T_6 produced the most at 11.45 t ha^{-1}, whereas T_{10} had the least at 7.09 t ha^{-1}. In the largest grade (>75 g), T_6 continued to outperform with 9.12 t ha^{-1}, while T_{10} yielded only 4.15 t ha^{-1}. Overall, treatment T_6 consistently resulted in the highest yields across all tuber size grades, while the absolute control showed the lowest performance. The application of 125 % NPK, as recommended by the QUEFTS model, led to a notable improvement in tuber yields across all size grades. This treatment consistently produced the highest yields in each category, highlighting the effectiveness of balanced and optimized nutrient management in enhancing overall tuber production (23).

Conclusion

The QUEFTS model is based on the idea that nutrient interactions affect crop growth and that either too much or too little nutrient treatment can limit potential yield. QUEFTS assists in determining the ideal nutrient supply by taking into account yield targets, soil nutrient availability and plant nutrient demand. In addition to improving important agronomic parameters like plant emergence, plant height, number of haulms, number of leaves and yield of both potato tubers and haulms, this method increases the efficiency of nutrient use and decreases fertilizer waste through site-specific nutrient management.

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Authors' contributions

DK conducted the experiment and drafted the manuscript and NK helped in providing valuable insights. MKG, RS & AKP helped edit the manuscript, SKY assisted in manuscript preparation and RK helped with AS and contributed to the lab analysis. All authors have read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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