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Impact of nitrogen and potassium fertigation on sour orange (*Citrus aurantium*) seedlings to reach optimal budding stage

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Abstract: The study aimed to assess effect of nitrogen and potassium fertigation on the growth of *Citrus aurantium* rootstock seedlings, to reduce the period required for their readiness for grafting. The results indicated that treating *Citrus aurantium* seedlings with nitrogen and potassium fertilizers at a concentration of 2.5 ml/L /L significantly enhanced the vegetative growth parameters, including the number of leaves, number of branches, leaf area, plant height and stem circumference, compared to other concentrations and control treatment. Additionally, the study demonstrated the positive effect of nitrogen and potassium fertigation at a 2.5 ml/L/L concentration, in reducing the time required for the seedlings to reach a suitable stem thickness for grafting with in short period, 160 days (5 months and 10 days) only. Based on the results of this study, it is recommended to use a fertigation application of nitrogen and potassium at a concentration of 2.5 ml/L for the optimal growth of *Citrus aurantium* rootstock seedlings. Moreover, this treatment shortens the time required for seedlings to reach an ideal stem thickness for grafting.

Keywords: *Fertigation, Grafting period, Nitrogen and potassium, Sour orange.*

1. Introduction

Sour orange (Citrus aurantium) is a member of the citrus family Rutaceae, which includes a variety of fruit-bearing trees and shrubs. It is believed to be native to Southeast Asia [1]. The sour orange is a perennial evergreen tree that can grow up to 10 meters tall, with a rounded crown and regular branches [2]. Its fruit is dark orange with a rough texture, of medium size, and characterized by high acidity and a hollow center [1]. The sour orange is widely used as a rootstock for citrus propagation, and it is considered an ideal rootstock for orange and grapefruit varieties. It is a semi-dwarf rootstock suitable for clayey and medium-textured soils. Additionally, it has moderate salt tolerance and provides high-quality fruit when used as rootstock. The sour orange is resistant to diseases such as exocortis, gummosis, and root rot, but it is susceptible to rapid decline and scab, and it is sensitive to nematode infections [3].

Citrus trees require large quantities of mineral nutrients to attain adequate growth and yield, and the requirements for some of the nutrients vary with soil fertility and type. Although the mineral nutrition of citrus trees has been studied intensively, additional information is published frequently, especially after the introduction of new fertigation technologies and of other manipulations. Among the important elements, potassium (K) plays a major role, second only to nitrogen, and is considered as a key element in fruit production and quality worldwide.

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Considerable attention has been paid to the symptoms and consequences of K deficiency [4]. Potassium is not metabolized and it forms only weak complexes in which it is readily exchangeable. The high concentrations of K in the cytosol and chloroplast neutralize the soluble and insoluble macromolecular anions and stabilizes the pH in these compartments [5]. The well-known relationship between potassium and sugar/starch accumulation, which is found in many plants.

Fertilizers are important to ensure that crops receive adequate nutrients, promote growth and ensure an economic yield Embleton, et al. [6] and Khalf and Mohammad [7]. Hence, fertilizer plays a key role in agricultural production [6]. Nutrients sourced from chemical fertilizer are critical to increase agricultural production by enhancing the land's productivity [8]. Fertilizer is considered an important tool to augment food production Pajouhesh and Sazandegi [9] and attaining food security Embleton, et al. [6] and Shin [10].

Nitrogen is the most important nutrient in fertilization programs, as it significantly influences plant growth in nurseries. Potassium also plays a crucial role in maintaining plant health by enhancing the plant's ability to resist and tolerate diseases and pests [11]. Research by Carlos, et al. [12] found that applying nitrogen f through fertigation, at different intervals can modify root and bud growth and water absorption in citrus rootstocks. Increasing the nitrogen concentration in irrigation water during winter boosted continuous growth in Citrus volkameriana rootstocks, but it slowed leaf aging, whereas it stopped growth in Swingle citrumelo leaves [13].

Applying nitrogen fertilization with irrigation every week to Swingle citrumelo seedlings showed no significant effects on the relative distribution of growth between the root system and leaf gas exchange, or leaf nitrogen content. However, when applied every two weeks, root growth decreased, and nitrogen content in leaves reduced. On the other hand, applying fertilization every 24 days showed no significant differences in growth, gas exchange, or water use efficiency between treated seedlings [12]. Different nitrogen sources and their concentrations can cause varying responses in citrus rootstock seedlings. This was confirmed when fertigation was applied to Citrus rootstocks, such as Sour Orange and Triple-leaf Orange, using three different nitrogen sources with varying concentrations (ammonium sulfate 75, ammonium nitrate 150, and urea 300 mg per soil) added weekly. The treatments with higher nitrogen concentrations increased vegetative growth indicators such as seedling height, trunk diameter, average leaf area, and also raised nitrogen and magnesium levels in leaves, while iron concentration in leaves decreased [9].

The use of NPK fertilizer in citrus rootstock fertilization enhances vegetative growth rates. Rough Lemon seedlings treated with NPK showed higher leaf and branch numbers, compared to Cleopatra Mandarins treated with the same fertilizer, with no significant differences in dry matter accumulation [14]. Seedlings treated with algae extract exhibited superior growth in terms of buds, roots, and chlorophyll levels. In contrast, seedlings treated with bacterial strains (Azotobacter chroococum & Bacillus megatherium) demonstrated higher growth rates across various growth parameters compared to those treated with algae extract or individual bacterial strains [15].

There are several methods for producing Sour Orange seedlings in nurseries, one of which is the traditional method. In this approach, sour orange seeds are soaked in water for 24 hours before being sown in seedbeds. The soil is divided into plots of 3x1 meters, and seeds are planted in rows spaced 20-25 cm apart, with a soil cover of no more than 3 cm above the seeds. During this stage, it is crucial to control seedling wilt disease using fungicides, regularly remove weeds, and pay close attention to irrigation and fertilization. However, this method has a drawback: the seedlings typically take between 2.5 to 3 years to be ready for grafting, which is relatively long [16]. In general, the time needed for citrus seedlings to reach the stage where they are suitable for grafting is usually one or two years. Shortening or reducing this period is important as it can help nursery owners to lower production costs and inputs [17]. Therefore, the significance of this study lies in evaluating the effect of nitrogen and potassium fertigation on shortening the period required for sour orange rootstock seedlings to be ready for grafting.

2. Material and Methods

The experiment was conducted to investigate the effects of five different doses of nitrogen and potassium applied through fertigation on reducing the time required for sour orange (Citrus aurantium) rootstock seedlings to reach the grafting stage. Each treatment was replicated five times, with each replication consisting of two experimental units.

2.1. Materials

1. Sour orange (*Citrus aurantium*) rootstock seedlings, 90 days old (three months).
2. Plastic bags (15×25 cm).
3. Growth medium for seedlings consisting of loamy soil.
4. Ruler.
5. String.
6. Syringe, cup, and (bucket).
7. N,P&k fertilizer (25-0-2.5) : A liquid compound fertilizer containing nitrogen and potassium, without phosphorus.

2.2. Treatments details

The sour orange seedlings were treated with five different concentrations of N, P & K fertilizer (25-0-2.5) through fertigation. The seedlings were irrigated every three days, and fertigation was done every ten days according to the following doses:

1. 1 ml/L.
2. 1.5 ml/L.
3. 2 ml/L.
4. 2.5 ml/L.
5. 3 ml/L.
6. Control treatment (no fertilizer added).
7.

2.3. Observations

Throughout the experiment, growth parameters of the seedlings under different treatments were recorded every 15 days. These measurements included:

1. Plant height (cm).
2. Length of the woody part (cm).
3. Stem circumference (cm).
4. Number of leaves.
5. Number of branches.
6. Leaf surface area (cm^2).

2.4. Data Analysis

Data were analyzed using a Randomized Complete Block Design (RCBD). The means were separated using Duncan's Multiple Range Test to determine significant differences between treatments. as per the method suggested by Gomez and Gomez [18].

3. Results and Discussion

The presents result of a study investigating the impact of foliar applications of nitrogen and potassium on the vegetative growth of sour orange (*Citrus aurantium*) seedlings. By evaluating several growth traits—including plant height, stem diameter, number of leaves, and leaf area—across different fertilizer concentrations, the goal was to determine the most effective N-K combination for promoting vigorous rootstock development and reducing the nursery production period.

3.1. Vegetative Growth Enhancement

Applying nitrogen-potassium (N-K) fertilizer at a concentration of 2.5 ml/L significantly enhanced multiple vegetative parameters in sour orange seedlings. These included increases in plant height, number of leaves, stem thickness, woody part length, and leaf area when compared with other treatments (Tables 1–6). These improvements are consistent with recent studies highlighting the importance of balanced nitrogen and potassium nutrition in citrus growth. For example, Barlas [19] found that foliar potassium fertilization improved vegetative performance and nutrient uptake in citrus trees, particularly under field conditions where nutrient availability can fluctuate.

Other studies have also reinforced the beneficial effects of balanced N-K fertilization. Ayed, et al. [20] observed that balanced N and K applications led to improved shoot growth and root development in citrus seedlings, providing a solid foundation for optimal growth performance and crop establishment. Additionally, the work of Bingham, et al. [21] emphasized the role of potassium in mitigating nitrogen-induced stress, particularly in high-nitrogen conditions, which aligns with the observed improvements in growth and stress resistance. The combined application of nitrogen and potassium had a pronounced positive effect on sour orange seedling growth compared to nitrogen alone, which may be attributed to potassium's role in mitigating nitrogen-induced oxidative stress. This finding aligns with the results of Saleem, et al. [22] who demonstrated that potassium supplementation significantly enhanced the antioxidant defense system in citrus rootstocks by increasing the activity of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), thus improving the plant's ability to scavenge reactive oxygen species (ROS). As a result, the seedlings experienced less oxidative damage and showed improved physiological performance. Moreover, the synergistic interaction between nitrogen and potassium was found to boost photosynthetic efficiency and chlorophyll content, leading to greater biomass accumulation and enhanced seedling vigor. These physiological improvements are consistent with the increased plant height, stem diameter, and shoot development observed in sour orange seedlings under balanced N+K fertigation in the current study, confirming the essential role of potassium in optimizing nitrogen utilization and promoting healthy seedling development.

On the other hand, caution is warranted when applying nitrogen, as excessive levels can negatively impact plant development. Chen, et al. [23] reported that high nitrogen inputs reduced root biomass and overall nitrogen accumulation in citrus seedlings, suggesting that too much nitrogen can impair rather than support growth.

3.2. Accelerated Readiness for Grafting

One of the most significant findings from this study is the reduction in time required for seedlings to reach grafting stage. Seedlings treated with 2.5 ml/L N-K fertilizer developed sufficient stem circumference within approximately 160 days (just over 5 months) (Table 3), a notable improvement compared to the 15–18 months commonly reported in older citrus propagation practices. Recent research supports this outcome: Tahir, et al. [24] showed that potassium-enriched fertilization strategies accelerated vegetative development and brought citrus seedlings to grafting maturity sooner than traditional methods.

This accelerated development is consistent with earlier studies, such as those by Sargent and Lister [25] who found that balanced nutrient application (including potassium) can significantly shorten the juvenile phase of citrus trees, making grafting a more efficient process.

Potassium is essential for many physiological functions in plants, including enzyme activation, osmoregulation, and photosynthesis. In citrus specifically, potassium is known to influence cell wall strength, leaf expansion, and fruit quality. Several studies have shown that potassium plays a critical role in mitigating plant stress. For example, the work by Munns, et al. [26] demonstrated that potassium helps citrus trees to maintain water balance and mitigate the adverse effects of drought stress, which is common in areas with fluctuating water availability.

In addition, potassium enhances the plant's ability to absorb and utilize other critical nutrients such as nitrogen, phosphorus, and magnesium. Wen, et al. [27] demonstrated that combining potassium with organic fertilizers improved nutrient uptake efficiency, yield, and fruit quality in 'Newhall' navel orange trees, further affirming potassium's central role in citrus crop health.

Table 1.
Effect of different doses of N & K fertilizer on the height (cm) of sour orange plant.

Treatments	Observation in different periods						
	27\11\2022	**6\12\2022**	**21\12\2022**	**5\1\2023**	**22\1\2023**	**6\2\2023**	**21\2\23**
Control	31.00^{c}	31.50^{c}	31.65^{d}	32.26^{c}	34.30^{d}	35.25^{c}	38.10^{c}
1.0 ml	40.45^{ab}	43.02^{a}	43.30^{ab}	46.25^{ab}	54.15^{ab}	56.55^{ab}	60.75^{ab}
1.5 ml	32.24^{bc}	32.77^{bc}	36.00^{bcd}	41.70^{ab}	44.40^{bc}	46.95^{b}	52.75^{b}
2.0 ml	33.00^{bc}	33.75^{bc}	34.90^{cd}	39.00^{bc}	41.30^{cd}	48.50^{b}	53.05^{b}
2.5 ml	42.70^{a}	43.32^{a}	44.60^{a}	48.90^{a}	56.65^{a}	62.70^{a}	67.10^{a}
3.0 ml	38.52^{abc}	40.95^{ab}	40.45^{abc}	46.75^{a}	50.45^{abc}	53.50^{ab}	57.70^{ab}
C.V%	24.51%	23.34%	21.34%	20.21%	22.46%	25.05%	24.36%
$Lsd_{0.05}$	8.039	7.897	7.412	7.759	9.482	11.41	12.05
SE±	2.822	2.773	2.602	2.724	3.329	4.006	4.229

Source: Mean value(s) having different superscript(s) are significantly different (P≤0.05).

Table 2.
Effect of different doses of N & K fertilizer on number of leaves of sour orange plant

Treatments	Observation in different periods						
	27\11\2022	**6\12\2022**	**21\12\2022**	**5\1\2023**	**22\1\2023**	**6\2\2023**	**21\2\2023**
Control	20.90^{ab}	23.70^{ab}	31.50^{a}	36.40^{a}	44.70^{a}	59.60^{a}	76.60^{a}
1.0 ml	22.60^{ab}	27.00^{ab}	29.30^{a}	51.40^{a}	61.20^{a}	70.70^{a}	92.50^{a}
1.5 ml	20.20^{ab}	22.90^{ab}	25.60^{a}	46.20^{a}	49.90^{a}	57.90^{a}	72.20^{a}
2.0 ml	23.10^{ab}	24.10^{ab}	34.80^{a}	45.80^{a}	49.20^{a}	65.90^{a}	81.00^{a}
2.5 ml	26.70^{a}	29.40^{a}	30.40^{a}	43.70^{a}	47.90^{a}	68.50^{a}	84.70^{a}
3.0 ml	16.20^{b}	20.10^{b}	28.50^{a}	50.50^{a}	51.80^{a}	59.50^{a}	85.40^{a}
C.V%	43.72%	36.21%	31.87%	42.44%	36.99%	34.44%	36.94%
$Lsd_{0.05}$	8.513	8.001	8.618	17.46	16.91	19.74	27.34
SE±	2.989	2.809	3.025	6.128	5.936	6.930	9.597

Source: Mean value(s) having different superscript(s) are significantly different (P≤0.05).

Table 3.
Effect of different doses of N & K fertilizer on the stem circumference (cm) of sour orange plant

Treatments	Observation in different periods						
	27\11\2022	**6\12\2022**	**21\12\2022**	**5\1\2023**	**22\1\2023**	**6\2\2023**	**21\2\2023**
Control	2.12^{abc}	2.20^{b}	2.33^{b}	2.38^{c}	2.45^{c}	2.58^{c}	2.64^{c}
1.0 ml	2.28^{ab}	2.38^{ab}	2.50^{ab}	2.75^{ab}	2.85^{b}	2.90^{b}	3.05^{b}
1.5 ml	1.84^{c}	2.23^{b}	2.35^{b}	2.47^{bc}	2.65^{bc}	2.80^{bc}	2.97^{b}
2.0 ml	2.03^{bc}	2.43^{ab}	2.48^{ab}	2.60^{bc}	2.80^{b}	2.92^{b}	3.03^{b}
2.5 ml	2.50^{a}	2.66^{a}	2.68^{a}	2.95^{a}	3.24^{a}	3.32^{a}	3.36^{a}
3.0 ml	2.47^{a}	2.48^{ab}	2.48^{ab}	2.76^{ab}	2.96^{ab}	3.06^{ab}	3.17^{ab}
C.V%	17.39%	12.71%	12.77%	11.85%	12.29%	10.33%	8.25%
$Lsd_{0.05}$	0.3406	0.2747	0.2834	0.2834	0.3133	0.2732	0.2261
SE±	0.1196	0.09644	0.0995	0.0995	0.11	0.09592	0.07937

Source: Mean value(s) having different superscript(s) are significantly different (P≤0.05).

Table 4.
Effect of different doses of N & K fertilizer on the woody part length (cm) of sour orange plant.

Treatments	Observation in different periods					
	16\12\2022	**21\12\2022**	**5\1\2023**	**22\1\2023**	**6\2\2023**	**21\2\2023**
Control	12.20[a]	12.25[a]	12.45[a]	13.35[b]	20.53[c]	25.04[c]
1.0 ml	13.15[a]	13.15[a]	17.95[a]	19.70[ab]	30.65[ab]	34.12[ab]
1.5 ml	9.300[a]	9.300[a]	14.75[a]	17.95[ab]	27.88[ab]	31.55[bc]
2.0 ml	9.500[a]	9.500[a]	13.75[a]	18.85[ab]	26.53[b]	29.36[bc]
2.5 ml	9.600[a]	9.600[a]	14.70[a]	23.00[a]	33.67[a]	41.00[a]
3.0 ml	12.55[a]	12.55[a]	15.65[a]	23.00[a]	32.80[ab]	39.05[a]
C.V%	60.02%	59.94%	45.56%	38.54%	23.19%	22.10%
$Lsd_{0.05}$	5.973	5.971	6.104	6.703	5.990	6.641
SE±	2.097	2.096	2.143	2.353	2.103	2.331

Source: Mean value(s) having different superscript(s) are significantly different (P≤0.05).

Table 5.
Effect of different doses of N & K fertilizer on the numbers of branches of sour orange plant.

Treatments	Observation in different periods				
	21\12\2022	**5\1\2023**	**22\1\2023**	**6\2\2023**	**21\2\2023**
Control	2.20[a]	3.50[ab]	4.00[ab]	5.40[a]	6.60[a]
1.0 ml	1.00[c]	4.80[a]	5.90[a]	6.60[a]	7.90[a]
1.5 ml	1.30[bc]	3.00[ab]	3.500[ab]	4.20[a]	6.70[a]
2.0 ml	2.10[ab]	3.40[ab]	3.600[ab]	5.60[a]	6.50[a]
2.5 ml	1.50[abc]	2.30[b]	2.900[b]	5.10[a]	5.50[a]
3.0 ml	1.50[abc]	2.80[ab]	5.100[ab]	5.40[a]	6.10[a]
C.V%	54.75%	66.28%	65.90%	58.33%	61.43%
$Lsd_{0.05}$	0.7889	1.97	2.473	2.829	3.624
SE±	0.2769	0.6917	0.8683	0.993	1.272

Source: Mean value(s) having different superscript(s) are significantly different (P≤0.05).

Table 6.
Effect of different doses of N & K fertilizers on the leave area (cm^2) of sour orange plant

Treatments	Observation in different periods						
	27\11\2022	**6\12\2022**	**21\12\2022**	**5\1\2023**	**22\1\2023**	**6\2\2023**	**21\2\2023**
Control	11.81d	15.84c	16.69c	19.86c	24.30d	26.86d	30.61c
1.0 ml	20.91bc	22.73b	23.53b	27.47b	30.70bcd	35.10c	44.21b
1.5 ml	21.13bc	23.60b	25.16b	27.83b	35.51abc	39.85bc	45.55ab
2.0 ml	18.77c	19.07bc	20.21bc	23.63bc	28.64cd	38.15bc	45.31ab
2.5 ml	24.81ab	29.72a	33.88a	35.34a	38.14a	43.86ab	46.21ab
3.0 ml	26.17a	31.64a	35.22a	36.26a	37.29ab	47.27a	50.98a
C.V%	25.64%	22.19%	25.49%	18.56%	22.55%	18.32%	14.11%
$Lsd_{0.05}$	4.757	4.749	5.919	4.748	6.586	6.357	5.567
SE±	1.67	1.667	2.078	1.667	2.312	2.232	1.954

Source: Mean value(s) having different superscript(s) are significantly different (P≤0.05).

4. Conclusion

The findings of this study confirm that a balanced foliar application of nitrogen and potassium—particularly at a concentration of 2.5 ml/L—significantly improves the vegetative growth and overall development of sour orange seedlings. Beyond just enhancing visible growth traits, the optimized fertilizer combination also shortens the time required for the seedlings to become suitable for grafting, which can help reduce production time and cost in nurseries. Recent research further supports the idea that potassium plays a multifaceted role in plant health—improving nutrient use efficiency, stress resistance, and structural development. Therefore, adopting a well-balanced N-K fertilization strategy is a practical and science-backed approach for citrus rootstock production.

Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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