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Soil and Agro-climatic Suitability for Kinnow Cultivation: A Case Study of the Agra Region

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The fertile, well-drained loamy soils and subtropical climate of the Agra region create ideal conditions for Kinnow (Santra) cultivation. This study examines soil types, pH levels, and agro-climatic conditions that optimize Kinnow yields. Key factors such as sunlight, rainfall, and altitude variations are explored, with practical guidelines provided for soil management and irrigation. The findings offer valuable insights for farmers aiming for sustainable and profitable Kinnow production, though challenges such as water management and market accessibility require further exploration. This research highlights Agra's potential for expanding citrus cultivation while addressing key agricultural constraints.

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1. INTRODUCTION

Kinnow (Santra), a citrus fruit, is a product of crossbreeding two distinct mandarin varieties: 'King' (*Citrus nobilis* Lour) and 'Willow Leaf' (*Citrus deliciosa* Tenora). This hybrid was created by H.B. Frost at the University of California, Citrus Experiment Station, Riverside, Davis (USA) in 1915 and was later made available for commercial cultivation in 1935. Over time, Kinnow (Santra) has become extremely popular due to its abundant yield, juicy and flavorful fruit, and ability to thrive in different agro-climatic conditions. The development of Kinnow (Santra) was part of a comprehensive breeding program aimed at enhancing citrus cultivars through hybridization. H.B. Frost's goal was to combine the desirable characteristics of 'King' and 'Willow Leaf' mandarins, resulting in a hybrid that possesses exceptional fruit quality, resistance to diseases, and adaptability to diverse climates. The introduction of Kinnow (Santra) brought about a revolution in the citrus industry by providing a superior cultivar that met both market demands and agricultural requirements [1].

Kinnow (Santra), also known as Mandarin, is a citrus fruit that is widely cultivated in North India, with Punjab being the leading producer of this fruit in the country. Other states such as Rajasthan, Haryana, Madhya Pradesh, Himachal Pradesh, Jammu, Kashmir, and some parts of Uttar Pradesh also contribute to the production of Kinnow (Santra). This fruit is a often mistaken for oranges due to their similar appearance, seasonal availability, and nutritional benefits. However, Kinnow (Santra) and oranges can be differentiated based on their biological origin, color, skin texture, taste, and price point. Kinnow (Santra) has a distinct sweet and sour taste with a darker and brighter skin compared to oranges. It is known for its high juice content, making it a popular choice for extracting juice and pulp [2].

Mandarin oranges are widely cultivated across various regions including China, tropical Asia, India, Japan, the Mediterranean, and Florida in the United States. In India, citrus fruits hold the third position in terms of production, following banana and mango. Among the citrus crops grown in India, mandarin oranges, also known as Nagpuri Santra locally, cover the largest area, surpassing sweet orange and acid lime in terms of cultivation [3-5]. Mandarin oranges are highly valued for their production, productivity, juice content, and fruit quality. The fruit itself is medium-sized, oblate in shape, with a flattened base and loose skin that gradually transitions from green to deep orange-yellow as it ripens. Mandarin oranges are known for being very juicy and have significant market potential due to their rich vitamin content, including Vitamins A, B, C, and phosphorus. Mandarin oranges can be consumed in various forms, such as fresh fruit, juice, squash, syrup, and jam. Additionally, they are a key source of peel oil and citric acid, which are used in cosmetics. The versatility and nutritional value of mandarin oranges make them a popular choice among consumers and a significant contributor to the citrus fruit industry globally [6].

The production of Kinnu (also known as sweet orange) in Agra region has been an important aspect of the socio-economical condition of the farmers. Kinnu is a major cash crop that is grown extensively in Agra region due to its high demand in the national and international markets [7].

2. SOIL SUITABILITY

Kinnu, also known as Kinnow (Santra) is a citrus fruit variety that thrives under specific soil conditions to achieve optimal growth. In the Agra region, certain soil types are deemed suitable for cultivating Kinnu crops, with sandy loam soil being a preferred choice. Sandy loam soil provides well-drained conditions that are essential for Kinnu plants, ensuring proper root development and water absorption while preventing waterlogging that can harm citrus trees. Adequate water retention is also crucial, striking a balance between drainage and moisture retention. The soil pH level should ideally fall between 6.0 to 7.5 to facilitate proper nutrient uptake by the Kinnu plants, which require nutrients like nitrogen, phosphorus, and potassium for healthy growth. Regular soil testing and fertilization practices are necessary to maintain optimal nutrient levels in the soil, supporting the growth and development of Kinnu crops in the Agra region [8,9].

3. AGRO-CLIMATIC CONDITIONS

The Agra region in India experiences a subtropical climate characterized by distinct seasons. In this region, the agro-climatic conditions are favorable for cultivating Kinnu

crops. Kinnu plants thrive in warm subtropical climates, where the temperature ranges between 20°C to 35°C. It is important to note that extreme temperatures can have a negative impact on the quality and yield of the fruit. Adequate rainfall is crucial for the initial growth and development of Kinnu plants. However, excessive rainfall can lead to waterlogging and root rot, making well-drained soil a necessity. Citrus plants, including Kinnu, prefer moderate to high humidity levels for optimal growth. Maintaining the right humidity levels can help prevent diseases and pests that commonly affect citrus crops. Sunlight is essential for Kinnu plants as it facilitates photosynthesis and fruit development. Therefore, planting them in a location with full sun exposure is ideal for maximizing the quality and yield of the fruit [10,11].

4. CLIMATE SPECIFIC RECOMMENDA-TIONS

4.1 Sub-tropical Regions

- Regions**:** Areas like Punjab, Haryana, Himachal Pradesh, and parts of Uttar Pradesh in India are well-suited.
- Conditions: These regions offer the right combination of temperature, sunlight, and soil types.

4.2 Semi-arid Tropics

- **Regions:** Areas with semi-arid tropical climates can also be suitable if irrigation is available.
- **Conditions:** Proper water management and soil conservation techniques are crucial in these regions.

5. NUTRIENT REQUIREMENT FOR PLANTS

Kinnow trees have varying fertilizer needs depending on their age. Young, non-bearing trees require a moderate dose of 30 kg farmyard manure, along with 75-100g nitrogen (N), 50g phosphorus (P), 75-100g potassium (K), and 35g zinc sulfate (ZnSO4). Mature trees benefit from a higher dose: 80 kg farmyard manure, 600g N, 400g P, 600g K, and 250g ZnSO4. Natural variations and outside factors, such as variations in solar radiation, volcanic eruptions, and natural variability within the climate system, have influenced the Earth's climate throughout its history and contribute to the overall natural variability of the climate system. These changes persist over long periods, frequently spanning decades or even longer. But over the past few centuries, human activity particularly since the industrial revolution has significantly altered the makeup of the atmosphere. In spite of a changing climate, climate-resilient agronomy aims to maintain sustainable food production and stable livelihoods for farmers [12]. By fixing atmospheric nitrogen, both in conjunction with plant roots and independently, biofertilizers solubilize insoluble soil phosphates and generate plant growth components in the soil, so contributing significantly to improved soil fertility [13]. Nano-technology offers great potential to tailor fertilizer production with the desired chemical composition, higher nutrient use efficiency that may reduce environmental impact and boost the plant productivity. The nano-fertilizers deal with the elements in nano- meter dimensions [14].

5.1 Application Timing

Farmyard manure (FYM) should be applied annually in July-August. Inorganic fertilizers can be divided into three applications: apply one-third of the total N, P, and K in February, April, and August each. Similarly, split the ZnSO4 dose in half and apply it during February and April. Phosphorus regulates protein synthesis in plants, because it is a component of the complex nucleic acid structure. Phosphorus is also important in cell division and development of new tissues [15]. Presently, development of new varieties for higher yields has reached a plateau and no further increase is achieved unless biotechnological interventions are made. Lodging is the state of permanent displacement of the stems from their upright position [16].

5.2 Soil Specificity

Remember, these are general recommendations. Arid regions often have specific soil characteristics. Their soils tend to be low in organic matter and nitrogen, but may have medium levels of phosphorus and potassium. Always adjust fertilizer application based on regional soil testing results for optimal plant health. Ghosh and Barman [17].

Table 1. Manure and fertilizers requirement of kinnow

Age of tree	FYM (kg/tree)	N (kg/tree)	P (kg/tree)	K (kg/tree)
1-3	10-40	60-200	20-50	20-40
4-6	50-75	200-300	50-100	50-150
7-10	75-100	350-600	150-300	175-250
>10	75-100	700-1200	300-500	250-500

5.3 Incorporation

Spread the farmyard manure and fertilizer mixture evenly under the tree canopy and incorporate it into the topsoil for best results. This revised version improves readability by:

- Using a clear heading "Nutrient Requirements."
- Breaking down the information for young and mature trees.
- Explaining the application timing for different fertilizers.
- Highlighting the importance of adjusting fertilizer based on soil tests.
- Adding a section on fertilizer incorporation.

6. IRRIGATION

The frequency of irrigation is determined by various factors such as the type of soil, climate conditions, amount of rainfall, and the age of the plant. It is generally beneficial to provide light irrigation with a high frequency. However, it is important to avoid flooding as it can lead to diseases like root rot and collar rot. Instead, it is recommended to use a drip system for irrigation during crucial stages of crop growth. For Kinnow (Santra) plants, the water requirement is highest between April and June. To meet this requirement, a three-year-old plant should be given 23.0, 30, and 32.0 liters of water every alternate day through drip irrigation in the months of April, May, and June. Similarly, a seven-year-old plant may require 100, 120, and 142 liters of water every alternate day during the same months [18,19,20,21,22].

7. TOLERANCE TO ABIOTIC STRESSES

For sustainable production under arid climatic conditions, the crop/variety should be resistant to abiotic stresses. In some parts of arid region, occurrence of frost is also a common feature during winter season, which affects vegetative growth of plants, fruits quality as well as productivity. Some of arid horticultural crops namely aonla, lasoda, ber, and mulberry are susceptible to frost but kinnow (Santra) can easily tolerate intense heat during summer and frost during winter [23].

8. SUSTAINABLE PRODUCTION

The economic productive life of kinnow orchard is 25 to 30 years under good management practices which is very high as compared to other arid horticultural and traditional crops. It starts bearing after 3-4 year of planting and this long gestation period is a constraint for early returns. But it can be easily overcome by cultivation of intercrops like cluster bean, moong, cowpea, gram, cucurbits like kachri, muskmelon, ridge gourd and water melon etc. [24].

9. PLANT PROTECTION

Citrus psylla, white fly, leaf miner, mite, mealy bug and fruit fly are some of the major pests of Kinnow. For the control of psylla, white fly and leaf miner, Confidor 17.8 SL (Imidacloprid) @ 0.5ml/L of water should be sprayed at monthly interval between February-July. For mites, Fenzaquin 10 EC @1000ml/500 litre of water should be sprayed between May-June as a preventive spray [25].

Mealy bug can be controlled by spraying Carbosulphan @1.5ml/10 litre of water. Among diseases, Phytopthora is a major problem, particularly in orchards which are subjected to flood irrigation. If appropriate care is not taken, it results into the death of trees within a very short period of time. For its control, the pit should be drenched with Ridomil MZ (27.5g) + Bavistin (10g) per 10 litre of water particularly during June-July [26,27,28].

Bio control agents such as Trichoderma have been found very effective if applied along with FYM. Control of Post-harvest Diseases Post-harvest decay of Kinnow mandarin due to infection of various pathogens (Botryodiplodia theobromme, Colletotrichum gloeosporiodes and Alternari acitri as pre harvest pathogens) can be controlled, if proper disease control packages are adopted. Three pre-harvest sprayings (45, 30

and 15 days before harvesting) with Benzimidazole covering the whole canopy control stem end rot disease.

10. HARVESTING AND POST-HARVEST MANAGEMENT

Kinnow mandarins begin to bear fruit for commercial purposes after 4 to 5 years of being planted. As a non-climacteric fruit, it is important to harvest Kinnow mandarins at their full maturity during the months of January and February, when the TSS/Acid ratio falls between 12:1 or 14:1. On average, each tree can yield around 400-450 fruits, with an average weight of 70-80 kg. After harvesting, it is crucial to wash the fruits with water and then treat them with a chlorine wash (100-150 ppm). For export purposes, proper grading and waxing should be carried out [29].

To ensure the quality of the exported fruits, precooling at a temperature of 5-6°C with a relative humidity of 90-95% and an air circulation ratio of 100:200 is recommended. The fruits should then be stored in cold storage at a temperature of 5-6°C with a relative humidity of 85-90%. Vented plastic crates (55cm×35cm×30cm) are increasingly being used as containers for bulk handling of Kinnow mandarins in both field and packing houses, replacing the traditional bamboo containers. In Punjab, mechanized harvesting and handling of the fruits are being practiced [30,31].

Due to their weight, Kinnow mandarins contain a higher amount of juice. Medium-sized fruits are preferred for juice recovery. When stored, these fruits yield approximately 46-55% juice. The TSS (Total Soluble Solids) content of the fruits also increases during storage, while the acidity decreases. This makes Kinnow mandarins suitable for juice processing over a longer period, as they can be stored at both ambient temperature and refrigerated conditions for different durations (20-55 days). However, the higher seed content in Kinnow mandarins requires further research to ensure the extraction of juice with lower limonin content, thus improving its quality [32,33,34,35,36,37].

11. CONCLUSION

Kinnow (Santra) cultivation in the Agra region demonstrates significant potential for sustainable and profitable agriculture due to its compatibility with the area's subtropical climate, fertile sandy loam soils, and manageable agro-climatic conditions. Farmers adopting recommended practices, such as appropriate soil and nutrient management, efficient irrigation methods, and integrated pest control, can optimize Kinnow production. Additionally, intercropping during the initial non-bearing years and the implementation of advanced post-harvest handling techniques can further enhance productivity and marketability. By leveraging these research-backed strategies, farmers can ensure consistent high yields, superior fruit quality, and long-term orchard sustainability. Addressing challenges such as water management, market access, and pest resistance will further strengthen the viability of Kinnow cultivation, making it an excellent option for enhancing income and livelihood security in the region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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