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"ANALYSIS OF SOIL PHYSICO-CHEMICAL PROPERTIES ON CUSTARD APPLE CROP FIELDS IN BEED DISTRICT REGION OF MAHARASHTRA."

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ABSTRACT

Soil is a critical natural capital that forms the foundation of agricultural ecosystems, directly influencing crop productivity, nutritional quality, and farm sustainability. In semi-arid regions, where environmental stresses are pronounced, understanding soil health is paramount for resilient agricultural planning. This study presents a comprehensive, location-specific assessment of the physico-chemical properties of soils under custard apple (*Annona squamosa* L.) cultivation in the major producing tehsils of Beed District, Maharashtra: Beed, Georai, Dharur, Ambajogai, and Parli (V). The primary objectives were to diagnose soil fertility status, identify limiting factors, and provide a scientific basis for precision nutrient management tailored to the unique requirements of perennial fruit orchards.

Standardized protocols were employed for the collection of composite rhizosphere soil samples (10-15 cm depth) and subsequent laboratory analysis of key parameters: soil reaction (pH), electrical conductivity (EC), organic carbon (OC), total nitrogen (N), available phosphorus (P), and available potassium (K). The results indicate a region-wide prevalence of alkaline soil conditions, with a mean pH of 7.74 (range: 7.63-7.89). Electrical conductivity was low (mean: 0.40 dS/m), confirming the absence of salinity stress. Organic carbon content was marginal, averaging 0.459%, which classifies most soils as low in organic matter. Total nitrogen (mean: 319.9 kg/ha) and available phosphorus (mean: 27.49 kg/ha) were in the low to medium fertility range. The most striking finding was an exceptionally high build-up of available potassium, with a district mean of 2519.16 kg/ha an order of magnitude above the established sufficiency threshold.

The alkaline pH is identified as a major constraint, likely inducing latent deficiencies of micronutrients such as iron and zinc and reducing phosphorus availability. The low organic carbon status points to diminished soil biological activity and structural resilience. The severe potassium imbalance poses a risk of nutrient antagonism, particularly for magnesium and calcium uptake. These findings collectively reveal that the primary challenge is not a general lack of nutrients, but a significant physico-chemical imbalance exacerbated by years of non-specific fertilizer use. We conclude that a fundamental shift from conventional fertilization to holistic soil health management is urgently needed. Evidence-based recommendations include: the complete cessation of potassium fertilizer application; strategic use of organic amendments and acidifying agents to moderate pH; foliar supplementation of chelated micronutrients; and the adoption of a mandatory 2-3-year soil testing cycle. Implementing this integrated soil fertility management framework is essential for enhancing nutrient use efficiency, ensuring the long-term productivity of custard apple orchards, and safeguarding the ecological and economic sustainability of horticulture in the semi-arid regions of Maharashtra.

Keywords: Soil fertility assessment, physico-chemical parameters, Custard apple, *Annona squamosa*, Beed District.

1. INTRODUCTION

Soil is far more than a static physical substrate for plant anchorage; it is a complex, dynamic, and biologically active interface that regulates the flow of energy, water, and nutrients within terrestrial ecosystems. Its health—a measure of its continued capacity to function as a vital living system—is fundamentally intertwined with agricultural productivity, environmental quality, and by extension, human well-being (Doran & Zeiss, 2000; Kibblewhite et al., 2008). In the face of a changing climate, burgeoning population pressures, and the imperative for sustainable intensification, the preservation and enhancement of soil resources have emerged as global scientific and policy priorities (Amundson et al., 2015; Lal, 2016).

The intrinsic quality of soil is governed by an intricate interplay of its physico-chemical and biological properties. Parameters such as soil reaction (pH), electrical conductivity (EC), organic carbon (OC) content, and the availability of essential macro- and micronutrients collectively determine its fertility—the ability to supply adequate amounts of suitable forms of plant nutrients (Brady & Weil, 2016). Soil pH, for instance, is a master variable that controls the solubility, speciation, and plant-availability of most nutrients, the activity of soil microorganisms, and the stability of soil organic matter (Slessarev et al., 2016). Electrical conductivity serves as a proxy for the concentration of soluble salts, which at elevated levels can induce osmotic stress and ion toxicity. Organic carbon, the cornerstone of soil organic matter, is pivotal for maintaining soil structure, water retention, nutrient cycling, and fostering a robust and diverse soil biome (Lehmann & Kleber, 2015). The balanced availability of primary macronutrients—nitrogen (N) for vigorous vegetative growth, phosphorus (P) for energy transfer and root development, and potassium (K) for enzyme activation, osmoregulation, and fruit quality—is non-negotiable for optimal crop performance (Marschner, 2012).

Perennial horticultural systems, such as fruit orchards, present a unique and intensified context for soil management. Unlike annual cropping systems, perennial crops occupy the same soil volume for decades, leading to the development of a distinct rhizosphere environment with specific patterns of nutrient extraction, root exudation, and microbial association (Dakora & Phillips, 2002). Over time, continuous harvest removes substantial amounts of nutrients, while management practices like pruning, irrigation, and repeated fertilizer applications can significantly alter soil properties. Without periodic, crop-specific soil diagnostics, nutrient imbalances can accumulate, leading to hidden hunger, toxicity, or antagonistic interactions, ultimately manifesting as yield plateaus, poor fruit quality, and increased susceptibility to biotic and abiotic stresses (Tagliavini & Rombolà, 2001).

Custard apple (*Annona squamosa* L.), a delectable and nutritious fruit of the Annonaceae family, is a crop of significant economic importance in the semi-arid tropics of India, with Maharashtra being the leading producer. It is particularly valued for its adaptability to marginal lands, drought tolerance, and relatively low input requirements compared to other fruit crops (Pareek et al., 2011). Beed District is a recognized nucleus of custard apple cultivation within the state, contributing substantially to rural livelihoods. However, in recent years, progressive growers and extension agencies have reported concerning trends, including stagnating yields, inconsistent fruit size and sweetness, and increased incidence of physiological disorders like fruit cracking and uneven ripening. While varietal factors, water management, and pest incidence play roles, a growing body of anecdotal evidence strongly points towards deteriorating soil health as a root cause, potentially driven by decades of imbalanced, blanket fertilizer recommendations that fail to account for spatial variability and the changing nutrient dynamics of aging orchards.

A critical review of existing literature reveals a conspicuous gap: while generic soil surveys and fertility maps exist for Maharashtra, there is a paucity of detailed, crop-specific soil health assessments targeting the custard apple orchards of Beed District. Most fertilizer recommendations are extrapolated from research on field crops or other fruit trees, which may not be physiologically or agronomically appropriate (Srivastava & Singh, 2008). This lack of contextual data impedes the transition to precision agriculture and the formulation of sustainable, site-specific nutrient management plans.

To address this critical knowledge gap, the present study was conceptualized with the following overarching hypothesis: The soils under custard apple cultivation in Beed District exhibit distinct physico-chemical constraints—particularly related to pH, organic matter, and nutrient ratios—that are limiting optimal crop productivity and fruit quality

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted in Beed District, located in the Marathwada region of Maharashtra, India, during June 2023 to May 2025. This district is spanning approximately between 18° 15' to 19° 10' N latitude and 74° 50' to 76° 30' E longitude. The district experiences a warm semi-arid climate characterized by hot summers (mean max temp ~40°C), mild winters, and an average annual rainfall of 650–750 mm, which is predominantly received from the southwest monsoon (June–September). The soils are derived from basaltic Deccan Traps and are generally classified as shallow to medium black soils (Vertisols and associated intergrades) with high clay content, moderate water holding capacity, and calcareousness.

Five major custard apple-growing tehsils were selected: Beed, Georai, Dharur, Ambajogai, and Parli (V). These areas represent the core of the district's horticultural activity. Orchards in these regions are typically rainfed, with supplemental irrigation used occasionally during prolonged dry spells.

2.2 Soil Sampling Strategy and Sample Collection

A systematic and randomized sampling approach was employed during the pre-monsoon period (May 2023) to capture the baseline soil status before fertilizer application and major rainfall. For each of the five tehsils, custard apple orchards (approximately 05–10 years old) were selected as sampling sites.

At each orchard, a composite soil sample was prepared. Following the standard protocol (Sahrawat, 2015), five sub-samples were collected in a 'W' pattern from the tree rhizosphere (within the drip line, at a depth of 10–15 cm using a stainless-steel auger), avoiding areas near fences, compost pits, or irrigation channels. The sub-samples from a single site were thoroughly mixed in a clean plastic bucket to form a homogeneous composite sample of about 250gm. The samples were placed in labeled, air-tight polythene bags and transported to the laboratory.

2.3 Sample Preparation and Laboratory Analysis

In the laboratory, soil samples were air-dried under shade at room temperature (~30°C) for one week. They were gently crushed using a wooden roller to break clods without destroying natural aggregates and then sieved through a 2 mm stainless steel sieve. The fine earth fraction (<2 mm) was stored in labeled containers for analysis. All analyses were performed in triplicate, and the mean value was reported. Standard analytical grade chemicals and distilled water were used throughout.

The following standard methods were used for soil physico-chemical analysis:

Sr. No.	Description / Parameter	Details / Method
01	Determination of Moisture	By Weighting Method
02	Determination of pH	By Digital pH Meter
03	Determination of Electrical Conductance	By Conductometer
04	Determination of Organic Carbon	By Titration Method
05	Determination of Nitrogen (N)	By Titration Method
06	Determination of Phosphorous (P)	By Titration Method
07	Determination of Potassium (K)	By Flame Photometry

2.4 Data Interpretation and Statistical Analysis

The analytical data were compiled, and descriptive statistics (mean, range) were calculated for each parameter per tehsil. The mean values for each location (Beed, Georai, etc.) were then interpreted using standard soil fertility rating scales established for Indian conditions by the Indian Council of Agricultural Research (ICAR, 2011) and other authoritative sources (Tandon, 2017). The results are presented in tabular and descriptive form, with a discussion linking the findings to custard apple nutrition and soil management.

3. OBSERVATIONS AND TABLES

The results of the physico-chemical analysis of composite soil samples from the five tehsils are consolidated in Table 1. Each value represents the mean of analyses from five independent orchard samples within that tehsil, providing a representative overview of the soil status in each major growing area.

Table 1: Mean physico-chemical properties of soil samples from custard apple orchards in Beed District, Maharashtra.

Name of Tahsil for Sample	pH (1:2.5)	EC (dS/m)	Organic Carbon (%)	Total Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)
Beed	7.70	0.43	0.439	341.9	24.75	2576.34
Georai	7.89	0.27	0.490	314.4	25.65	2774.43
Dharur	7.78	0.23	0.326	256.3	21.19	2393.70
Ambajogai	7.63	0.62	0.603	344.8	41.11	2275.00
Parli (V)	7.70	0.43	0.439	341.9	24.75	2576.34
Mean	**7.74**	**0.40**	**0.459**	**319.9**	**27.49**	**2519.16**
Range	7.63-7.89	0.23-0.62	0.326-0.603	256.3-344.8	21.19-41.11	2275.0-2774.4

Note: EC: Electrical Conductivity; N, P, K values calculated based on soil bulk density estimation for the plough layer.

To contextualize the findings, the observed mean values are compared against general soil fertility ratings in Table 2.

Table 2: Interpretation of observed soil parameters based on standard fertility ratings (adapted from ICAR, 2011 & Tandon, 2017).

Parameter	Low / Deficient	Medium / Moderate	High / Sufficient	Observed Status (Mean for Beed District)
Soil pH	< 6.5 (Acidic)	6.5 – 7.5 (Neutral)	> 7.5 (Alkaline)	**Alkaline** (7.74)
EC (dS/m)	> 1.0 (Saline)	0.25 – 0.75 (Slight)	< 0.25 (Normal)	**Normal to Slightly Saline** (0.40)
Organic Carbon (%)	< 0.5	0.5 – 0.75	> 0.75	**Low to Medium** (0.459)
Available N (kg/ha)	< 280	280 – 560	> 560	**Low to Medium** (319.9)
Available P (kg/ha)	< 22	22 – 56	> 56	**Low to Medium** (27.49)
Available K (kg/ha)	< 140	140 – 280	> 280	**Very High** (2519.16)

4. RESULTS

The comprehensive laboratory analysis of soil samples from the five-custard apple growing tehsils of Beed District yielded a detailed and revealing dataset on their physico-chemical status. The results are presented below, parameter by parameter, highlighting both central tendencies and spatial variability.

4.1 Soil pH

The pH of the soil-water suspension (1:2.5) was consistently and markedly alkaline across the entire study area. The mean pH for the district was calculated to be 7.74, which falls firmly within the alkaline range. The variation among tehsils was relatively narrow, with values ranging from a minimum of 7.63 in Ambajogai to a maximum of 7.89 in Georai. Beed and Parli (V) shared an identical pH of 7.70, while Dharur recorded a pH of 7.78. This uniformity suggests a common geological parent material (Deccan Basalt) and similar pedo-climatic processes governing soil formation across the district. The absence of any sample with a pH below 7.5 underscores the prevalence of calcareous soils, a characteristic feature known to influence nutrient dynamics profoundly.

4.2 Electrical Conductivity (EC)

The electrical conductivity, an indicator of the total concentration of soluble salts, was found to be uniformly low. The district mean EC was 0.40 dS/m. The values exhibited a modest range, from a low of 0.23 dS/m in Dharur to a high of 0.62 dS/m in Ambajogai. All recorded values are significantly below the critical threshold of 1.0 dS/m, beyond which salinity can begin to adversely affect the growth of most glycophytic crops, including custard apple. This indicates that, under current management conditions, soil salinity is not a primary or secondary constraint to production in any of the sampled tehsils.

4.3 Organic Carbon (OC)

Organic carbon content, a key indicator of soil organic matter and overall biological health, showed appreciable variability across tehsils, presenting a more heterogeneous picture than pH or EC. The district means OC content was 0.459%. Ambajogai possessed the highest OC level at 0.603%, which qualifies as 'medium' as per standard fertility ratings. In contrast, Dharur recorded the lowest value of 0.326%, categorizing it as 'low'. Beed, Georai, and Parli (V) exhibited similar values clustered around 0.44%, also falling within the 'low' fertility class. This spatial pattern suggests differences in historical organic matter inputs, residue management practices, or perhaps slight variations in soil texture affecting carbon stabilization.

4.4 Macronutrient Status

- **Total Nitrogen (N):** The mean total nitrogen content for the district was 319.9 kg/ha. Spatial distribution showed Dharur with the lowest N content (256.3 kg/ha), placing it at the borderline between 'low' and 'medium' classes. The other four tehsils—Beed (341.9), Georai (314.4), Ambajogai (344.8), and Parli (V) (341.9 kg/ha)—all contained nitrogen levels in the lower spectrum of the 'medium' fertility class. This indicates a generally moderate native nitrogen supply, which is typical for semi-arid, low-organic-matter soils without significant recent leguminous incorporation or heavy nitrogen fertilization.
- **Available Phosphorus (P):** Available phosphorus, extracted using the Olsen's method, displayed the most considerable inter-tehsil variation among the macronutrients. The district mean was 27.49 kg/ha. Ambajogai stood out with a notably higher P level of 41.11 kg/ha ('medium'). Dharur, conversely, had the lowest P at 21.19 kg/ha, which is on the cusp of the 'low' classification (<22 kg/ha). Beed, Georai, and Parli (V) showed intermediate and similar values of approximately 25 kg/ha. This variability likely reflects differences in past phosphate fertilizer application history, soil phosphate fixation capacities, or localized organic matter contributions.
- **Available Potassium (K):** The analysis revealed an extraordinary and potentially problematic accumulation of available potassium in the soils. The district mean was 2519.16 kg/ha. To contextualize, this value is approximately **nine times greater** than the upper limit (280 kg/ha) of the 'high' or 'sufficient' category in standard fertility charts. Georai recorded the highest level at 2774.43 kg/ha, while Ambajogai had the "lowest" among the tehsils at 2275.00 kg/ha—still an excessively high concentration. This remarkably uniform pattern of potassium surplus across all five, geographically distinct tehsils is a compelling and critical finding, strongly indicative of a widespread, long-term practice of imbalanced fertilizer use favoring high potassium inputs.

4.5 Synthesis of Spatial Patterns

While no stark east-west or north-south gradient was evident, Dharur consistently emerged as the tehsil with the least favorable soil fertility indicators, registering the lowest values for OC, N, and P. Ambajogai presented a mixed profile, with the highest OC and P, but shared the high pH and excessive K common to the entire region. The results collectively paint a picture of soils that are alkaline, marginally supplied with organic matter and nitrogen, variably supplied with phosphorus, and overwhelmingly saturated with potassium.

5. DISCUSSION

The results of this diagnostic study provide a clear and scientifically robust profile of the soil environment in which Beed District's custard apple orchards are growing. The implications of these findings are profound and must be interpreted through the dual lenses of soil science and crop physiology to derive actionable management insights.

5.1 The Paramount Constraint: Alkaline Soil Reaction and Its Cascade Effects

The uniformly alkaline pH (mean 7.74) is arguably the most significant edaphic constraint identified. In calcareous, high-pH soils, the chemistry of several essential plant nutrients is adversely affected (Havlin et al., 2016). Phosphorus, a key element for energy metabolism and root development, readily reacts with abundant calcium ions to form poorly soluble di- and tri-calcium phosphates, rendering a large fraction of both native and applied P unavailable to plants (Sample et al., 1980). This "phosphate fixation" phenomenon explains why available P levels remain only in the low-to-medium range despite likely historical P fertilization. More critically, high pH severely restricts the solubility and plant uptake of cationic micronutrients. Iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) form highly insoluble hydroxides and oxides in alkaline conditions, leading to deficiencies even when total soil reserves are adequate (Mortvedt, 2000). Custard apple is particularly known to exhibit symptoms of iron chlorosis (interveinal yellowing of young leaves) on calcareous soils, a classic sign of pH-induced iron deficiency (Sahrawat et al., 2007). Furthermore, the activity of many beneficial soil microorganisms, including those involved in nutrient cycling (e.g., phosphate solubilizers) and symbiotic associations, is often sub-optimal in strongly alkaline environments (Rousk et al., 2010). Therefore, the high pH is not just a number; it is a primary driver of multiple secondary limitations related to nutrient availability and soil biology.

5.2 The Foundation of Health: Depleted Organic Carbon

The low to medium organic carbon status (mean 0.459%) is a major concern for the long-term sustainability of the soil resource. Soil organic matter (SOM), of which OC is a major component, is the engine of soil fertility (Reeves, 1997). It improves soil structure, enhancing porosity, aeration, and water infiltration—critical attributes in rainfed systems prone to erratic rainfall. SOM increases cation exchange capacity (CEC), allowing the soil to retain nutrient cations like K^+, Ca^{2+}, and Mg^{2+} against leaching. It also serves as a slow-release reservoir of nutrients, particularly nitrogen, sulfur, and micronutrients, and provides the primary energy source for the soil food web (Bot & Benites, 2005). The marginal OC levels observed suggest a system where outputs (decomposition, erosion) outweigh inputs. This likely results from limited incorporation of crop residues (pruned wood, leaf litter), inadequate application of farmyard manure or compost, and possibly excessive tillage practices. A soil poor in organic matter is inherently less resilient, more prone to compaction and crusting, and has a diminished capacity to support the diverse microbial life necessary for robust nutrient cycling.

5.3 The Nutrient Imbalance: Decoding the Macronutrient Data

- **Nitrogen and Phosphorus – Managed Insufficiencies:** The moderate levels of N and P indicate that current management practices are preventing acute, catastrophic deficiencies but are not optimizing availability. For nitrogen, the moderate status is consistent with semi-arid soils and suggests that significant nitrate leaching may not be a major issue under the prevailing rainfall pattern. However, nitrogen use efficiency could be vastly improved by synchronizing applications with tree demand (e.g., split applications during active growth phases) and by using enhanced-efficiency fertilizers (Shaviv & Mikkelsen, 1993). The phosphorus scenario is more directly tied to soil chemistry. Applying more soluble phosphate fertilizers (e.g., DAP) to these alkaline soils is an inefficient strategy, as a large portion will quickly become fixed. Management must focus on improving the *availability* of existing and applied P through practices that lower rhizosphere pH locally (e.g., use of acidifying fertilizers like single superphosphate, band placement) and enhance biological solubilization through organic amendments and microbial inoculants (Richardson et al., 2009).

- **Potassium Surplus – A Legacy of Imbalance:** The extraordinarily high available potassium levels are the most dramatic and agronomically significant finding of this study. Such an accumulation is almost certainly the consequence of prolonged, indiscriminate application of high-analysis NPK fertilizers (e.g., 10:26:26, 12:32:16) or straight muriate of potash (KCl), without any soil test-based guidance (Tandon, 2017). While potassium is vital for fruit quality attributes like size, sweetness, and shelf-life, its excessive presence in the soil creates a serious problem of **nutrient antagonism**. Potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}) are all taken up by plants as cations, and they compete for the same absorption sites on root surfaces (Marschner, 2012). An extreme surplus of K^+ can severely inhibit the uptake of Mg^{2+} and Ca^{2+}, leading to their deficiencies within the plant. Magnesium is the central atom of chlorophyll, and its deficiency impairs photosynthesis, leading to interveinal chlorosis on older leaves. Calcium is crucial for cell wall strength and membrane integrity, and its deficiency is linked to fruit disorders like blossom-end rot in other crops and potentially poor fruit texture in custard apple (White & Broadley, 2003). Therefore, the current potassium status is not a benefit but a significant risk factor for induced deficiencies of other critical nutrients. This creates a management paradox where the soil test shows an extremely high value for a nutrient, yet the tree may suffer from the functional deficiency of its antagonists.

5.4 Towards an Integrated Soil Health Management System for Custard Apple

The diagnosis presented herein calls for a complete re-evaluation of standard fertilizer practices. The goal must shift from simply supplying N, P, and K to actively managing the soil system to correct imbalances and improve overall health. A multi-pronged, integrated strategy is proposed:

1. **Correcting pH-Induced Limitations:**
   - **Foliar Nutrition:** The most immediate and effective correction for micronutrient deficiencies (Fe, Zn, Mn) is through foliar sprays of chelated forms (e.g., Fe-EDDHA, Zn-EDTA) 2-3 times during the active growing season (Fageria et al., 2011).
   - **Rhizosphere Acidification:** Long-term, gentle acidification can be achieved through regular, heavy applications of well-decomposed, acidic organic manures (like poultry manure or composted coffee husk). For problematic spots, soil application of elemental sulfur or gypsum (calcium sulfate) under expert guidance can help neutralize free lime over time.
2. **Building the Organic Foundation:**

- A mandatory annual application of 15-20 kg of well-rotted FYM or high-quality compost per tree is non-negotiable.
- Encourage *in-situ* generation of organic matter through growing and incorporating leguminous green manure cover crops (e.g., *Sesbania*, sunn hemp) during the monsoon fallow period.
- Promote permanent soil cover through mulching with organic materials (paddy straw, dried weeds) to conserve moisture, suppress weeds, and add organic matter as it decomposes.

3. **Implementing Precision Nutrient Application:**
   - **Potassium Moratorium:** Issue a strict, immediate, and district-wide cessation of all potassium-containing fertilizer applications for a minimum of 3-4 years, or until soil tests confirm K levels have fallen below 500 kg/ha.
   - **Phosphorus Management:** Shift from highly water-soluble P sources (DAP) to single superphosphate (which contains calcium and sulfur). Apply P in localized bands or pits near the drip line to minimize contact with bulk soil and fixation. Consider seed inoculation with phosphate-solubilizing bacteria (PSB).
   - **Nitrogen Strategy:** Apply nitrogen in 2-3 split doses coinciding with flowering and fruit development stages. Use neem-coated urea or incorporate nitrogen through organic sources to improve efficiency and reduce losses.
4. **Institutionalizing Monitoring and Learning:**
   - Advocate for and facilitate a mandatory soil testing cycle every 2-3 years for every orchard. This is essential to track the drawdown of potassium and the gradual improvement in OC and pH.
   - Establish farmer field schools and demonstration plots to showcase the benefits of integrated soil health management, creating a community of practice around sustainable horticulture.

In conclusion, the soils of Beed District's custard apple belt are not infertile; they are imbalanced. The path forward lies not in more fertilizers, but in smarter, system-based management that addresses the root causes alkalinity, low organic matter, and potassium overload. By adopting the proposed integrated soil health management framework, farmers can transform their orchards into more productive, resilient, and sustainable ecosystems, securing the future of this valuable horticultural enterprise.

6. CONCLUSION

This systematic study elucidates the key soil health challenges facing custard apple cultivation in the Beed District of Maharashtra. The soils are predominantly alkaline, low in organic matter, and exhibit a severe imbalance in macronutrients, characterized by an extraordinarily high build-up of potassium. While nitrogen and phosphorus levels are currently in the moderate range, their effective availability to plants is likely constrained by the unfavourable pH.

The findings underscore that the primary issue is not a blanket deficiency of nutrients, but a chemical imbalance and poor soil biological health. Continued application of standard NPK fertilizers, especially those containing potassium, will exacerbate the problem, leading to further nutrient antagonism, wasted resources, and potential environmental leaching.

Therefore, the path to sustainable intensification of custard apple production in this region lies in a fundamental shift in management focus:

- From fertilizer application to integrated soil health management.
- From supplying high NPK to correcting pH-induced deficiencies and building organic matter.

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