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AP Gedam
Ph.D. Scholar, Department of Fruit Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

SR Patil
Professor, Department of Fruit Science, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

SG Bharad
Professor, Department of Fruit Science, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

AM Sonkamble
Professor, Department of Vegetable Science, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

NM Konde
Associate Professor, Department of Soil Science and Agricultural Biochemistry, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

RD Walke
Associate Professor, College of Agriculture, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Corresponding Author:
AP Gedam
Ph.D. Scholar, Department of Fruit Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Correlation and interrelationship of soil and leaf nutrients with plant growth and fruit quality in Nagpur mandarin (*Citrus reticulata* blanco)

AP Gedam, SR Patil, SG Bharad, AM Sonkamble, NM Konde and RD Walke

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Abstract
The present investigation was conducted to study the relationships between soil and leaf nutrient status for Nagpur mandarin and attempt to understand the same in relation to plant health and soil management aspects. It is strongly positively correlated with leaf nitrogen and leaf phosphorus, mainly because nitrogen is involved in the formation of amino acids, while phosphorus is essential for energy transfer. Similarly, soil N and P were positively correlated, having common sources or fertilization practices. The study indicates synergistic effects of nutrients such that, for example, leaf P is significantly related to Cu, which can enhance copper uptake. Soil Zn was correlated with soil N and leaf N, respectively, indicating zinc importance for nitrogen metabolism and plant vigour. The study also indicated moderate correlations of the soil and leaf copper and low manganese (Mn) correlations, thus revealing complex interactions, probably under the influence of soil pH and organic matter. Sugars, leaf nutrients, and physical characteristics strongly contributed to the variation as showed by the Principal Component Analysis (PCA). The area of leaves had a strong correlation with leaf chlorophyll content, closely tied to yield parameters, clearly demonstrating that an optimum crop production system depends on the nutrient status. The study concluded that all these nutrient dynamics are important to design sustainable agronomic practices in a way that crops are grown for enhanced productivity, minimizing environmental degradation. Proper nutrient management has to be designed in such a way that the intricate interactions mainly between phosphorus and copper support plant growth and development.

Keywords: Nutrition, fruit distortion, Nagpur mandarin, quality and yield

Introduction
Nutrient management is important to sustain citrus production, and integrated nutrient management has been successful in improving the quality of crop yields and soil properties (Srivastava, 2009) [10]. However, in most of the INM studies, data generation is lacking on nutrient budgeting, yield quality, and biological properties of the soil. Thus, in-depth analysis of INM components will be necessary to meet the increased nutrient demands with varying levels of cultivation intensities it may be intensive with high-density planting and low-volume fertigation or extensive cropping, as generally prevalent in high-altitude areas. These conditions would be prime for underscoring the importance of diagnosing the fertility constraints and managing them effectively with INM strategies for Nagpur mandarin (*Citrus reticulata* Blanco). Any limitation in nutrient supply at any stage of phenological growth in crops that are highly responsive to nutrients, such as citrus, may jeopardize the advantage of balanced fertilization accruing up to that growth stage. Nutrient partitioning in a situation of differential nutrient response among critical growth stages has an enormous agronomic and physiological implication in terms of both yield as well as quality.
Citrus as an evergreen and perennial tree and to obtain high productivity and quality of fruits citrus trees require adequate amount of macronutrients along with micronutrients. (Cao *et al*., 2022) [1] Nitrogen (N), phosphorus (P) and potassium (K) prove to be an important resource for the growth and development of the plants as the trees tend green and shed branches over the year. Nitrogen being a fundamental macronutrient and is also a critical component of amino acids, proteins, nucleic acids (DNA and RNA), and chlorophyll.

It is essential for plant growth and photosynthesis, as it forms part of the chlorophyll molecule, which is vital for light absorption. Nitrogen often interacts with phosphorus and potassium. High nitrogen availability enhances the uptake of other nutrients but can also lead to an imbalance if not managed correctly. Low N content in soil may causes a gradual decline in fruit production by reducing the leaves and tree growth (Mattos *et al*., 2020) [6]. Phosphorus (P) is a crucial nutrient for energy transfer in plants, as it forms part of ATP (adenosine triphosphate). It is also a component of nucleic acids and phospholipids, making it essential for cell membrane structure and function. Phosphorus uptake is influenced by soil pH and the presence of other elements like calcium and iron, which can form insoluble compounds with phosphorus, reducing its availability. P deficiency may lead to a lower citrus yield, and an increase in soil P can reduce fruit acid concentration and increase the total soluble solids (TSS)/titratable acidity (TA) ratio (Zekri *et al*., 2015) [12]. Potassium (K) is involved in enzyme activation, osmoregulation, and the regulation of stomatal opening and closing, which affects transpiration and gas exchange. It is also vital for carbohydrate synthesis and translocation. Potassium interacts with nitrogen and phosphorus, often affecting the overall nutrient balance in plants. It can compete with magnesium and calcium for uptake. The response of fruit quality to K availability is associated with the contents of glucose, fructose and soluble sugars in the fruit (Pettigrew, 2010; Schwarz *et al*., 2013) [7, 8]. Extensively citrus yield is affected by the deficiency of micronutrients i.e., zinc (Zn), copper (Cu), boron (B) and iron (Fe) (Ilyas *et al*., 2015) [4]. Zinc is a micronutrient that acts as a cofactor for numerous enzymes involved in metabolism, DNA synthesis, and protein synthesis. It is crucial for the synthesis of auxin, a plant hormone that regulates growth and development. High levels of phosphorus can inhibit zinc uptake, while zinc deficiency can be alleviated by applying zinc-containing fertilizers. Soil fertility and leaf nutrients are important indicators of plant nutrition status, which greatly impact citrus plant growth, fruit yield and quality therefore, there is need to find the relationship between different fruit quality parameters and leaf nutrients, leaf and soil nutrient interrelationships.

Materials and Methods

The 12-year-old Nagpur mandarin trees spaced at 6 x 6 meters were selected for experimentation. By correlation, the relationship between soil and leaf nutrient interactions, plant growth parameters, and fruit quality were determined. The treatments were superimposed on seven distinct nutrient management modules included various combinations of nitrogen (N), phosphorus (P), potassium (K), organic compost, and foliar applications and to evaluate their effects using a randomized block design (RBD) with three replications and the data analysed for Pearsons correlation coefficient. Leaf nutrient concentration, soil nutrient status was included along with the different plant growth parameters. Fruits were also checked on quality parameter in relation to weight, size, and juice content. The correlation analyses related to soil nutrients and leaf nutrients with each other have been carried out in view of the plant growth and co-relationship with fruit quality. In the subsequent approach, some insight into the possibilities of nutrient management for optimizing the health and fruit production of the plant is presented. Additionally, Principal Component Analysis (PCA) were used to explore complex relationships among multiple variables. The results provided insights into the effectiveness of optimizing nutrient application in Nagpur mandarin orchards.

Results and Discussion

Soil leaf nutrient relation

Figure 1 represents the correlations between various nutrients in soil and leaves, highlighting both the strength and direction of these relationships. Understanding these relationships is crucial in Nagpur mandarin production, as they can influence plant health, nutrient uptake, and soil management practices.

Strong positive correlation between leaf nitrogen and leaf phosphorus implies that a high content of nitrogen in a leaf would most likely be accompanied by a high content of phosphorus and the two nutrients are therefore absorbed or utilized jointly. Nitrogen and phosphorous are two important elements in plants, since nitrogen is incorporated into amino acids and proteins, while phosphorous is used in energy transfer (ATP), nucleic acids, and phospholipids. The strong correlation indicates that the nutrients increase together, and this can perhaps be attributed to their participation in important physiological processes such as photosynthesis and cellular growth. Soil nitrogen and soil phosphorus were positively correlated, implying that they might be in most instances derived at the same time into the soil from the same source or fertilization practice. The significant observed relationships among soil nutrients indicate that balanced fertilization is crucial. A very strong positive correlation between the soil N and P points toward the fact that excess application of one nutrient may require the addition of another so that balance remains to a certain degree to prevent nutrient imbalance but sometimes it may have some detrimental effect on plant growth. Similarly, Song *et al.* (2022) [9] found a significant positive correlation between leaf carbon and leaf phosphorus, emphasizing the role of phosphorus in photosynthesis and its impact on chlorophyll and protein content in plants. Additionally, Huang *et al.* (2021) [3] demonstrated a strong positive correlation between soil total nitrogen and total phosphorus with leaf nitrogen and phosphorus concentrations, indicating a relationship between soil resources and leaf traits. A strong association was found in leaf phosphorus and leaf copper shows a strong positive relationship that increased phosphorus availability may enhance uptake of copper or vice versa. A correlation of leaf phosphorus and leaf copper indicates a significant positive relationship. The latter is an important micronutrient for plant enzymes participating in redox reactions and lignin synthesis; phosphorus is a key constituent of plant metabolism as an element constituting storage and energy transfer. This interaction could be suggesting that high levels of phosphorus make copper more available or useful through better root growth or enzyme activity. Soil Zn showed a relatively high positive correlation with soil N and moderate correlations with other nutrients hence, it is an important cofactor in soil nutrient dynamics. Nitrogen uptake in plants can be increased by ensuring that the soil has an adequate amount of zinc, which may improve the plant's protein synthesis and general vigour. The high correlation between leaf nitrogen and soil zinc shows the closely linked soil zinc levels with the nitrogen content of leaves probably is related to either zinc's role in nitrogen metabolism or a nitrogen fixing enzyme functions of plants. Zinc is a vital trace element in the enzyme activities, protein synthesis, and growth regulators. Probably, the interactive effect of zinc with nitrogen on the soil may be said to have a synergistic relationship. Since nitrogen is an all important nutrient and affects plant development, this may ultimately have a direct or indirect effect on zinc from the soil being made available to the plants. Association between an adequate zinc in the soil and enhanced nitrogen assimilation by the plant and thereby growth, which ultimately could contribute to increased protein synthesis. Understanding the interactions between nutrients in leaves is vital for plant growth. Leaf nitrogen and phosphorus concentrations play a crucial role in determining plant growth limitations, with the N:P ratio indicating shifts between nitrogen and phosphorus limitation (Chen *et al.*, 2011) [2]. Additionally, the availability of macronutrients and micronutrients significantly impacts plant development and crop yields (Mankotia, 2024) [13]. It can be interpreted that moderate positive correlations are present between soil and leaf copper, while soil copper availability can influence leaf copper levels. It correlated less with soil and leaf nutrients than manganese, indicating that the availability of manganese and its uptake might be influenced by different factors or that it does not interact with other measured nutrients. Lower correlations are noted for Mn associated with other nutrients in the soil, suggesting a nutrient of concern requiring specific management practices possibly due to its complexity in interaction with soil pH and organic matter. Similarly, the strong correlation that existed in leaf Mn with leaf Cu suggested strong relationships. Mn is considered an essential element in photosynthesis and the assimilation of nitrogen and acts as an enzyme cofactor however, Cu is an essential nutrient in responses towards oxidative stress. Correlation between the two elements could reflect their joint involvement in the defence mechanism and metabolic processes of the plant. The relationships of soil Mn with other nutrients were generally low, suggesting that soil Mn interacts sparingly. This might be due to the fact that manganese behaves in a complex way in soils, its availability strongly dependent on soil pH, redox conditions, and the content of organic matter. The negative correlation with some nutrients, like leaf iron, might point to competing absorption processes or inhibitory interactions in the soil or plant system. Studies have established a positive relationship between leaf copper content and leaf zinc, manganese, and boron contents (Yildiz *et al*., 2022) [11]. This suggests that changes in one nutrient may influence the uptake or availability of others. Moreover, an increase in copper supply has been shown to enhance phosphorus content and uptake in plants. By using this inter relationship data, one can check the Cu content of the soil and think about how it interacts with other minerals, for example, phosphorus. Similarly, soil Mn has an extremely limited role could help avoid unnecessary applications that are not associated with high Mn levels in plants.

From Figure 2, the PCA biplot contributes to an overview of relationships between different measured variables and the observations that may be present. It demonstrates general data behaviour, as shown in M1, M2, M3, M4, M5, M6, and M7. The first two principal components (PC1 and PC2) take most of the variances of the data: 81.74% for PC1 and 8.08% for PC2. The red arrows represent the original variables; both the direction and length give the contribution and sign to the principal components. From Figure, it was observed that sugars, leaf zinc (Zn), leaf nitrogen (N), fruit weight, leaf phosphorus (P), ascorbic acid, TSS, juice content, leaf potassium (K), leaf copper (Cu), and leaf manganese Mn are positively correlated with PC1 and they contribute significantly to variance in PC1. In comparison, rind thickness, rag content, acidity, pomace content, and core diameter show negative loadings for PC1 and PC2 hence, an alternative trend pattern exists. M1, and M2, are quite similar hence their characteristic properties, concerning the contributing variables, are expected to be similar while, at larger distances M4 and M6 differ substantially from each other. The angle between the arrows indicates the correlation between variables acute angles are a strong positive correlation and obtuse are a negative correlation. The important factor that separates the observations along the first principal component are the sugars and nutrient content related variables. By contrast, the second component is physical and describes less variance. It is explained by physical characteristics such as core diameter and pomace percentage. Such PCA analysis underlines a dominant role of nutritional and compositional attributes in explaining variability among observations.

From Figure 3, it was observed that, several of the statistically significant relations between growth parameters and leaf nutrient levels are observed in the correlation matrix as indicated by an asterisk. A high degree of positive relationship of leaf area and chlorophyll of leaves between them suggests that leaves are large because they have more chlorophyll, thus providing an increased efficiency of photosynthesis. Simultaneously, a positive relationship of leaf area, number of flowers, and leaf chlorophyll shows that healthier, chlorophyll-laden plants should provide more flowers. The number of flowers has a high coefficient correlation with the number of normal fruits, and it is very strong, indicating that the more flowers, the higher the number of fruits. Yield has a significant positive correlation with factors like leaf area, the number of flowers, number of normal fruits, and nutrient concentrations of nitrogen, phosphorus, potassium, zinc, and copper. This means that plants with more leaf area, higher chlorophyll, and essential nutrients would have greater yields. There is high negative correlation of deformed fruits and yield, increase in deformed fruits suggests decrease in total yield. Further, the correlation of Mn and Cu with distorted fruits was negatively correlated, indicating that the desirable concentration of these nutrients may be useful in reducing the occurrence of fruit distortion. All these significant correlations indicate how important nutrient balance and good plant health management are in attaining optimum yield and at the same time reducing unwanted outcomes like fruit distortion.

Conclusion

In conclusion, the chord diagram and correlation matrix provide important information regarding nutrient dynamics from soil to plants. Such understanding of the relationship will assist in devising improved agronomic practices, judicious use of fertilizers, and betterment of plant nutrition, thus ensuring better crop productivity and sustainable environmental management. The chord diagram, using the data represented by the correlation matrix, was used to visualize nutrient flows from soil to plants. These are vital insights for plant nutrition management, good soil management practices, and hence increasing agricultural productivity. Through the understanding of these complex interactions, the decisions that can be made for making sure that the crops are healthy and growing while minimizing environmental damage.

The relationship between leaf phosphorus and leaf copper is intricate and influenced by various factors such as nutrient availability, plant physiology, and environmental conditions. High phosphorus levels can enhance photosynthesis and leaf conductance, potentially affecting copper uptake. The interplay between different nutrients in leaves highlights the importance of considering multiple nutrient interactions for optimal plant growth and development.

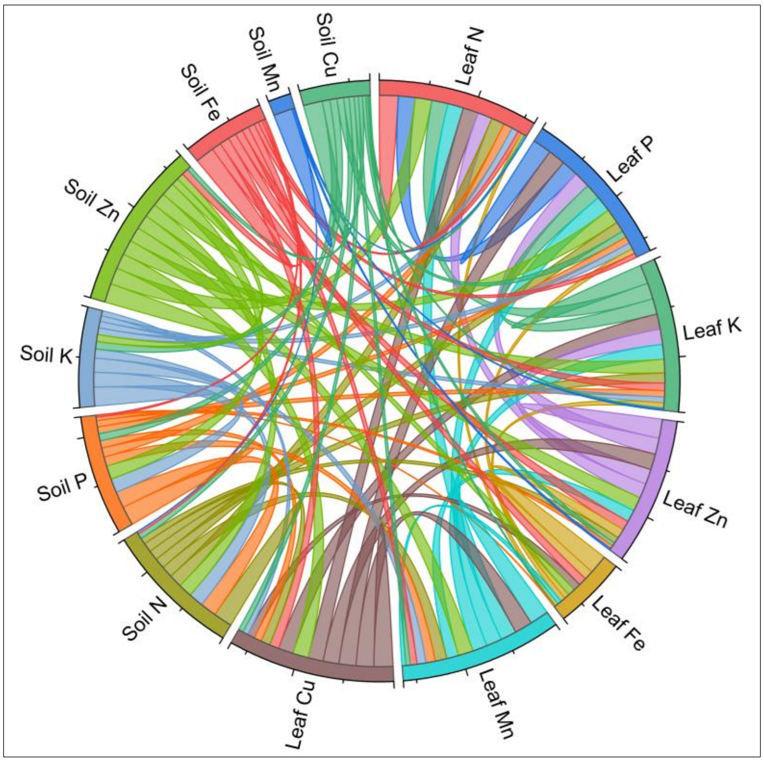

Fig 1: Dominance relationship between Soil and Leaf Nutrient of Nagpur mandarin

Note: Each element on the chord diagram corresponds to the elements in the matrix. The thickness and colour of the chords between two elements represent the magnitude and direction of their correlation. For example: Strong positive correlations are typically represented by thicker and possibly differently coloured chords compared to weaker or negative correlations.

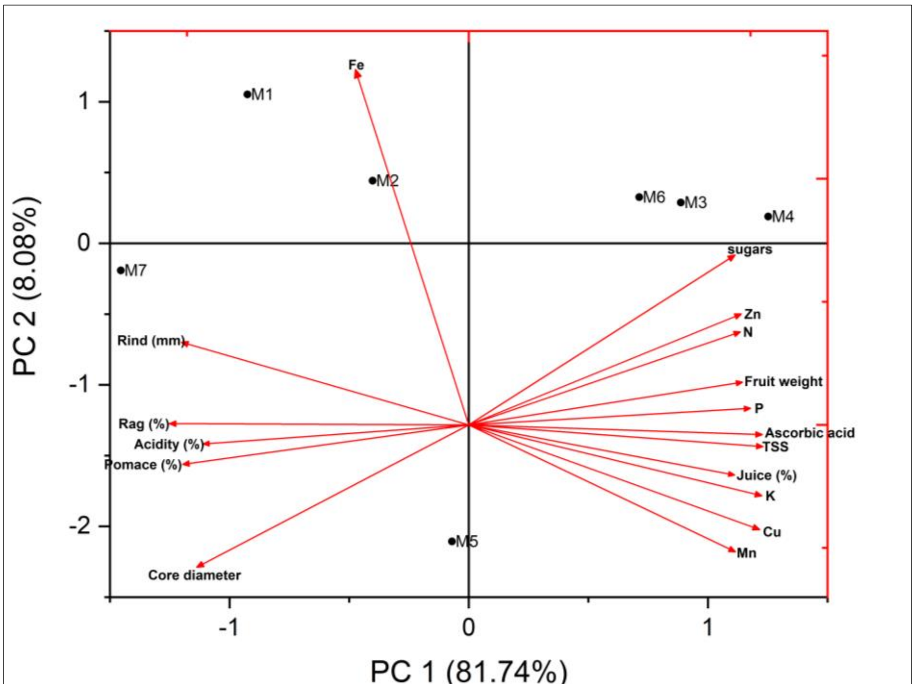

Fig 2: Relationship Between Leaf Nutrient and Fruit Quality Influenced by Different modules

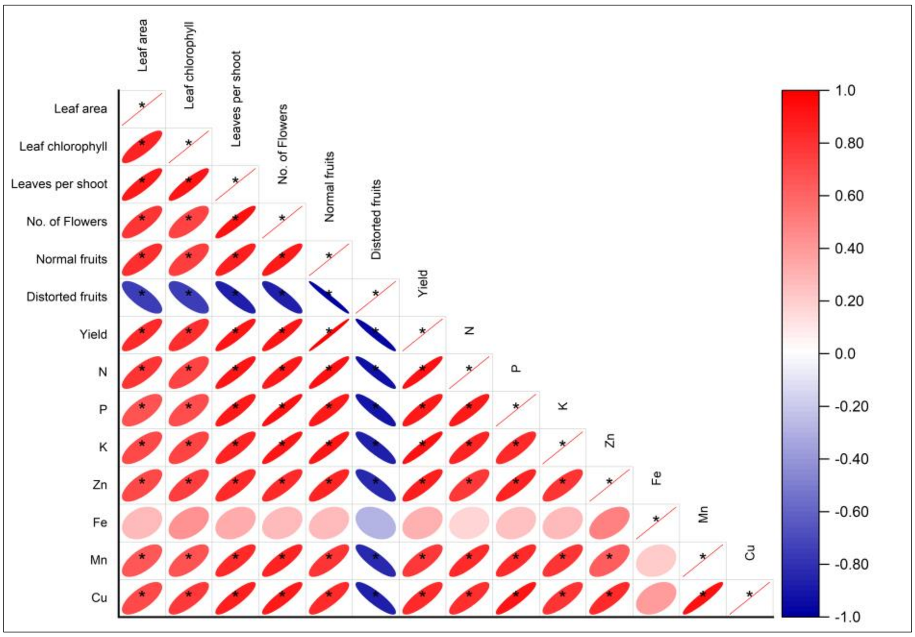

Fig 3: Pearsons Correlation coefficient between growth parameters and leaf nutrient of Nagpur mandarin.

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