

1 Depth-wise fertility status of soil under high yielding 2 citrus orchards in medium deep black soils of Madhya 3 Pradesh 4

5 ABSTRACT

6 Soil fertility is one of the important components for better citrus fruit production and produce quality. Soil
7 with lower fertility status imposed a big threat to achieving higher citrus productivity. In this regard, the
8 management of major and micronutrients is essential for the sustainable productivity of citrus in high-yield
9 orchards. Thus, measurement of soil fertility status can provide an efficient way to develop strategies for
10 citrus production. Therefore, the present study was conducted to assess the macro and micronutrient
11 status in the citrus-producing area in medium black soils of Madhya Pradesh. For this purpose, a high-
12 intensity survey was conducted and 65 soil samples at depths of 0-20 and 20-40 cm were collected from
13 well-established orchards and analyzed for soil pH, EC, organic carbon content, N, P, K, Ca, Mg, Zn, Cu,
14 Fe, Mn and B content. Descriptive statistics were calculated for exploratory analysis of data. Results
15 showed that in depth of 0-20 cm, soil pH ranged from 6.83 to 8.84 with a mean value of 7.70, EC varied
16 from 0.07-0.34 dS m⁻¹ (0.18 dSm⁻¹), organic carbon (OC) 0.13-0.89% (0.45%), available nitrogen N102-
17 288 kg ha⁻¹ (mean 186 kg ha⁻¹), available P 7-76 kg ha⁻¹ (mean 29.7 kg ha⁻¹), available K 259-775 kg ha⁻¹
18 (mean 474 kg ha⁻¹), Ex Ca 1406-4568 mg kg⁻¹ (mean 2784 mg kg⁻¹), Ex Mg 461-1799 mg kg⁻¹ (Mean
19 1033 mg kg⁻¹), available S 5.6-30 mg kg⁻¹ (Mean 16.7 mg kg⁻¹). Meanavailable Zn, Fe, Mn, Cu, and B
20 were 0.95, 16.6, 11.3, 1.12, and 0.75 mg kg⁻¹, respectively. At the lower depth (20-40 cm), soil pH was
21 slightly higher while soil EC and SOC was slightly lower compared to the upper depth. All the major and
22 micronutrients were lower in subsurface (20-40 cm) as compared to surface depth (0-20 cm) except Ex
23 Ca content which was higher in subsurface depth. Correlation analysis revealed that soil pH was
24 negatively and significantly correlated with available P, Ex. Mg, available Zn, Fe and Mn while soil EC
25 was positively correlated with available P, Zn, and Cu. Orchard soils were found to be suboptimal for
26 available N, K, Zn, Cu, and Mn. So, for attaining high production and sustainable production integrated
27 nutrient management practices should be opted.

28 **Keywords:** Citrus, EC, pH, Macronutrients, Micronutrients,
29

30 1. INTRODUCTION

31 Globally, citrus is grown in more than 150 nations as one of the most important perennial fruit crops. India
32 is the third-highest citrus producer in the world after China and Brazil Kumar et al., (2023). India
33 contributes about 7–8% of the global citrus production. Citrus ranks third in the country after mango and
34 banana and is cultivated in 10.86 lakh hectares with an annual production of 142.62 lakh tonnes

Comment [EU1]: Reduce the introduction

35 (NHB,2022). Madhya Pradesh, Punjab, Maharashtra, Rajasthan, and Haryana are the top-ranking states
36 with the highest area under cultivation and production in the country. In fact, Madhya Pradesh alone
37 contributes over 32 percent to the total production in the country. The districts of Chhindwara, Agar
38 Malwa, Shajapur and Rajgarh are the important orange clusters in the state. The yield of citrus crops
39 depends on soil fertility, crop management and environmental factors (rainfall, temperature and disease
40 incidence etc.). The nutrient status of orchards is directly related to the orchard health and longevity of the
41 orchard. Orchard soil health is very important to sustain yield of crops.

42 Healthy soils have been shown to support more stable, yields up to more extent, by increasing
43 our understanding of the biological and physical as well as chemical properties of soil to increase root
44 health, moderate nutrient and water stress, and increase the yield potential of orchards (DuPont, 2020).
45 Soil physico-chemical characteristics and soil nutrient status influence the requirement of different
46 nutrients by the crop the proper knowledge of soil nutrient status is very helpful along with plant nutrient
47 content in understanding tree health status and production. Soil factors like soil organic carbon (SOC),
48 soil pH, and electrical conductivity (EC) are important factors that affects nutrient availability. Soil organic
49 carbon is obtained from soil organic matter (SOM). The decomposition of SOM releases many cations
50 and anions along with organic acids which influence soil nutrient availability (Tisdale et al., 1985). pH of
51 Soil solution influences nutrient solubility and phyto-availability, because hydrogen ion or H⁺ ions on soil
52 surface occupy the negatively charged spaces by displacing the nutrient ions . Soil EC is related to
53 several soil properties influencing nutrient availability and crop productivity (Behera and Shukla, 2015;
54 Asbin et al., 2022). Macro and micronutrient deficiency decreased the yield and the quality of citrus fruit. It
55 is the need of the hour to measure soil fertility status under well-established high yielding orchards in
56 medium-black soils (Ahmad et al., 2022). Low availability of both macro and micro nutrients and their
57 inefficient management affects crop production in different parts of the world (Alloway, 2008; Jones et al.,
58 2013). Understanding orchard nutrition status can facilitate the proper management of orchards for higher
59 fruit yield and quality (Chen et al., 2022; Bhardwaj et al., 2024). The phyto-availability of nitrogen (N),
60 phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), iron
61 (Fe), manganese (Mn), and boron (B) in soil depends upon various soil, environmental, and plant factors
62 (Schjoerring et al., 2019). Yield of citrus is known to be influenced by soil characteristics up to a depth of
63 40 cm (Srivastava and Singh ,2002). Thus, surface and subsurface soil samples were collected to assess
64 the fertility status of soil for optimum citrus yield. Identification of optimum fertility limit has been
65 repeatedly emphasized for sustained productivity of citrus orchards, besides helps to minimize the
66 occurrence of the alternate bearing of fruiting cycle. There is a dearth of information about orchards
67 nutrient status of Rajgarh district. This study aimed to understand the nutritional status of established
68 high-yielding citrus orchards in medium black soil and establish relationships of soil attributes at the
69 surface and subsurface depth with citrus yield.

70 2. Materials and Method

Comment [EU2]: Recast

Comment [EU3]: Recast

Comment [EU4]: Core of the study. The relationship is not in the abstract. Please include.

Comment [EU5]: Upper case

71 **Description of study area and calculation of cutoff yield**

Comment [EU6]: 2.1 Sub heading

72 The study area was located under Rajgarh District of Madhya Pradesh state the Northern region of Malwa
73 Plateau. Study area extends between the parallels of Latitude 23 27' 12" North and 24 17' 20" North and
74 between the meridians of Longitude 76 11' 15" and 77 14' East. A high-intensity survey was conducted to
75 calculate the cutoff yield based on the yield of each well-established orchards. As per the literature and
76 citrus grower response during the survey, a cutoff yield was selected as 50 kg per tree (reference) and we
77 selected healthy orchards having a high yield that was more than or equal to cutoff yield.

Comment [EU7]: Add in

Comment [EU8]: Extend from or is within

Comment [EU9]: Not clear

Comment [EU10]: Avoid

78 **Collection of soil samples**

Comment [EU11]: Subsection number

79 In present study, soil samples were collected from 65 highyielding citrus orchard sites. Soil samples were
80 collected at the depth of 0-20 and 20-40 cm depth beneath trees and sampling points at specified
81 locations were recorded with GPS (Fig 1). Collected soil samples were processed at laboratory and used
82 for soil fertility evaluation.

Comment [EU12]: Consider "in the study"

Comment [EU13]: Sampling method adopted not stated random or purposive?

83 **Soil Fertility evaluation**

Comment [EU14]: Sub heading number and capitalize each word

84 Soil pH was measured in 1:2.0 soil-to-water ratio and supernatant obtained from soil pH measurement
85 was utilized for the determination of electrical conductivity using a conductivity meter (Jackson, 1973).
86 Chromic acid oxidation method was used for the determination of organic carbon content in soil (Walkley
87 and Black, 1934). Available nitrogen (AN) was estimated by following standard procedure under Kjeldahl
88 method of Subbiah and Asija (1956) in which distillation followed by titration method. Available
89 phosphorus (AP) was measured by Olsen's method in which intensities of blue color were measured with
90 spectrophotometer to estimate phosphorus content (Olsen et al., 1954). Available potassium (AK) was
91 determined by ammonium acetate method (Hanway and Heidel, 1952). Exchangeable calcium (Ex. Ca)
92 and exchangeable magnesium (Ex. Mg) in soil samples were determined by extracting soil samples with
93 neutral normal ammonium acetate (1N) solution then required aliquote was taken and calcium and
94 magnesium concentrations in aliquot measured by using atomic absorption spectrophotometer (AAS)
95 (Shukla et al., 2019). Available sulfur (AS) in samples was measured by a turbidimetric (Williams and
96 Steinbergs, 1959). Micronutrients in soil samples were analyzed for Available zinc (Zn) (AZn), available
97 copper (Cu) (ACu), available iron (Fe) (AF_e), and available manganese (Mn) (AMn)] after soil samples
98 extracted by DTPA extractant and estimated using AAS (Lindsay and Norvell, 1978). Available boron was
99 estimated by hot-water extraction (Gupta, 1967).

100 **Calculation of Nutrient index**

101 The Nutrient Index Value was determined by assessing the distribution of soils across low, medium, and
102 high categories of available nutrients. The nutrient index was calculated as follows:

$$\text{Nutrient index (NI)} = \frac{(\text{NL} \times \text{x1}) + (\text{NM} \times \text{x2}) + (\text{NH} \times \text{x3})}{\text{NT}}$$

Comment [EU15]: Equation number missing. Please add.

103

104 Nutrient index in both surface and sub surface soil for nitrogen, phosphorus and potassium were
105 calculated according to formula suggested by Parker (1951), NI indicated nutrient index for a particular
106 nutrient under consideration, NL were number of samples under lower category, NM were number of
107 samples under medium category, NH were number of samples under high category and NT were total
108 number of samples.
109

110 **Statistical analysis**

111 The datasets obtained after analysis of studied soil parameters were subjected to descriptive statistics
112 parameters viz. minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV),
113 skewness, and kurtosis using SAS software (SAS, 2011). Pearson's correlation coefficient was computed
114 to visualize relationships between soil fertility status and citrus yield.

Comment [EU16]: Laboratory analysis of soil components or variables.

115

116 3. Results and discussion

Comment [EU17]: Upper case

117 Yield of citrus orchards

118 Results from this study revealed that from survey of high yielding citrus orchards of Rajgarh district of
119 Madhya Pradesh that observed yield ranged between 50 kg tree⁻¹ to 240 kg tree⁻¹ with mean observed
120 mean yield of 117 kg tree⁻¹ with coefficient of variation 47.1 % for the particular study area.

Comment [EU18]: Recast

Comment [EU19]: Data analysis table with result

121 Nutrient status of citrus orchards at surface and subsurface depth

Comment [EU20]: In text table of result may be better please

122 Results showed that in depth of 0-20 cm, soil pH ranged from 6.83 to 8.84 with a mean value of 7.72, EC
123 varied from 0.07-0.34 dS m⁻¹ (mean EC 0.18 dS m⁻¹), organic carbon (OC) ranged from 0.13-0.89% (mean
124 SOC 0.45%) (table 1). The CV were 4.89, 27.2 and 46.4% for pH, EC and SOC, respectively. Available
125 N 102-288 kg ha⁻¹ (mean 186 kg ha⁻¹), available P 7-76 kg ha⁻¹ (mean 29.7 kg ha⁻¹), available K 259-775
126 kg ha⁻¹ (mean 474 kg ha⁻¹). The CV value for available N, P and K were 20.0, 53.5 and 27.8%,
127 respectively. Exchangeable Ca in orchard soils was ranged from 1406 to 4568 mg kg⁻¹ while Ex. Mg
128 varied from 461 to 1799 mg kg⁻¹. Average plant available S was 16.7 mg kg⁻¹. The CV value for
129 secondary nutrients ranged between 31 to 34%. Available Fe in study sites varied from 7.21 to 30.3 mg
130 kg⁻¹ with an average value of 16.6 mg kg⁻¹. Average plant available Zn, Mn, Cu and B were 0.95, 11.3,
131 4.55, 0.75 mg kg⁻¹, respectively. The corresponding values of CV were 53.7, 48.2, 44.8 and 29.6% (table
132 1).

133 Nutrient distribution at 20-40 cm soil depth was presented in Table 2. For subsurface depth of 20
134 to 40 cm, the mean value of soil attribute viz. pH, EC and SOC were 7.90, 0.16 dS m⁻¹ and 0.27 %,
135 respectively, while CV was 4.54, 23.1, and 55.2 % respectively. It was observed that pH was higher while
136 lower SOC content was observed in subsurface depth than surface layer. Available N varied from 72 to
137 258 kg ha⁻¹ with a mean value of 148 kg ha⁻¹ which was found to be less than surface depth (0-20 cm).
138 Mean value of available P for subsurface layer was 22.3 kg ha⁻¹. Available K ranged between 191 to 597
139 kg ha⁻¹. The CV among primary nutrients was highest for available P (54.7%) whereas it was 24.5 and
140 26.4 % for available N and available K, respectively. For secondary nutrients, it was observed that the
141 mean exchangeable Ca content was 3150 mg kg⁻¹ which was higher than surface depth, thus a
142 decreasing trend was observed from surface to subsurface depth. Exchangeable Mg ranged from 328 to
143 1860 mg kg⁻¹. Mean available S in soil was 17 mg kg⁻¹. Among micronutrients, it was observed that the
144 concentration of micronutrients was lower than their surface layer (table 1 and 2). The mean value of
145 available Zn, Cu, Fe and Mn were 0.67, 0.84, 15.1 and 8.95 mg kg⁻¹, respectively. Similar to the depth of
146 0-20 cm, the highest CV was observed for soil Zn in the depth of 20-40 cm. Available boron content
147 ranged from 0.08 to 1.24 mg kg⁻¹ with a mean of 0.26 mg kg⁻¹ and CV value was 50.2%. Soil pH of study
148 area was near neutral to alkaline in range. Similar to the findings of Sharma et al., (2001) who reported
149 that pH of arable land of Rajgarh was 7.9 and EC 0.2. Accordingly, Behera et al (2022) reported that farm
150 lands of Bhopal, Madhya Pradesh is near neutral to alkaline in nature. The higher pH of soils in the
151 medium black soil might be due to higher Ca and Mg content in soil which is also observed in this soil.
152 With the depth, soil pH was increased, this is in line with the findings of Surwase et al., (2016) and Singh et
153 al., (2022) mentioned that increased pH with soil depth under citrus orchards and optimum pH for better
154 citrus crop growth is ranged from pH 7.6 to 8.5 (Dahule, 2020; In our study mean value of EC were found

155 to be $< 0.2 \text{ dSm}^{-1}$ our results were similar to findings of Kanwar and Randhawa (1960) and Dahule
156 (2020) that soil EC below 0.50 dSm^{-1} as safe limit for citrus. The SOC value was (0.13 to 0.89%) with a
157 mean 0.45% in surface depth indicating a lower SOC rating as established for crop production in India.
158 Many reports suggested that SOC content decreased with soil depth in orchards of Madhya Pradesh
159 (Singh et al., 2022) and Nagpur mandarin (Surwase et al., 2016). The variation in soil properties was
160 measured with coefficient of variation (CV), In present study we found $<10\%$ CV for soil pH and other
161 properties values ranged between 10-100 indicating low variability and moderate variability,
162 respectively. Bogunovic et al. (2017) reported low, medium, and high variability for pH, organic matter and
163 EC respectively in soils of Rasa River valley of Croatia. Low variability for pH and EC while moderate
164 variability for SOC content in Indian acid soils confirmed by Behera and Shukla (2015). Similarly, low
165 variability for pH and medium for EC and organic matter in soils of Alequeva reservoir of Portugal
166 reported by Ferreira et al., (2015). Our results for higher available iron content in surface layer than
167 subsurface layer were in confirmation with reports of Reddy and Rao (1991) in sweet orange orchards of
168 Rayalaseema region in Andhra Pradesh and Ratnam et al. (2001) in sapota growing soils of Andhra
169 Pradesh that surface soils had significantly higher available iron content as compared to the sub-surface
170 soils which might be due to the higher organic matter content in the surface soils further, this decrease in
171 the available iron with depth might be also due to absorption of iron from lower layers and their deposition
172 in surface layer by leaf shedding. Similarly in case of available copper the trend of decrease in available
173 copper with depth was also reported in citrus orchards of the Jammu region (Gupta et al., 2004).

174 For determining soil suitability criteria for citrus, optimum available nutrient ranges for P, K and Zn
175 were 4 to 10 ppm, 60-150 ppm and 0.6 to 1.0 ppm, respectively, while critical limit of Fe, Mn and Cu were
176 suggested as 4.0 ppm, 2.8 ppm and 0.5 ppm respectively suggested for citrus (Srivastava and Kohi,
177 1997). In another study by Srivastava et al. (2022) reported optimal soil fertility norms for Nagpur
178 mandarin in central India for N, P, K, Ca, Mg, as 94.8-154.8 for (N), 6.6-15.9 (P), 146.8-311.9 (K), 408.1-
179 616.0 (Ca), 85.2-163.3 (Mg), 10.9-25.2 (Fe), 7.5-23.2 (Mn), 2.5-5.1 (Cu) and 0.59-1.26 (Zn). Further
180 Srivastava and Singh (2002) reported optimum soil fertility limits for available N, P, K, Fe, Mn, Cu, and Zn
181 were 118.8, 10.1, 241.2, 14.8, 13.4, 1.3, and 1.2 mg kg^{-1} , respectively, at 0-15 cm depth for an optimum
182 yield of 16.2 tons ha^{-1} . While for 15-30 cm, were obtained as 100.1, 8.4, 268.0, 10.1, 8.8, 0.96, and 0.88
183 mg kg^{-1} , N, P, K, Fe, Mn, Cu, and Zn, respectively.

184 Based on the above criteria an attempt has been made to classify surface soil and subsurface soil
185 fertility, results revealed that as per the limits of Srivastava et al., (2022) for surface depth available
186 nutrients viz N, P, K, Ca, Mg, Zn, Fe, Cu and Mn range (mean) varied from 45.5-128 (83.03), 3.12-33
187 (13.25), 115-345 (211), 1406-4568 (2784), 461-1799 (1033), 0.34-2.29 (0.95), 0.21-30.3 (16.6), 0.29-
188 2.4 (1.12) and 4.55-26.3 (11.3) mg kg^{-1} respectively, corresponding value for subsurface depth was
189 32.1-115 (Mean 66.07), 3.03-24.1 (9.90), 85.3-265 (164), 1806-4900 (3158), 328-1860 (990), 0.21-1.66
190 (0.672), 7.58-25.8 (15.1), 0.22-1.92 (0.84), and 3.65-19.82 (8.95) mg kg^{-1} respectively. For surface
191 depth nutrient ranges were suboptimal for available nitrogen, potassium and copper were suboptimal
192 according to optimum fertility norms of Srivastava et al., (2022). In both depths mean values of nutrients
193 according to optimal soil fertility limits of Srivastava and Singh (2002) in available
194 N, Available K, available Zn, available Cu were found to be suboptimal whereas Mn was suboptimal in
195 surface soil.

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198

199 **Nutrient index in orchard soils**

Comment [EU21]: Table or schematic comparison should be considered. Result too crowded to decipher.

200 Nutrient index (NI) of macronutrients was calculated for study area. Results revealed that NI value for
201 plant available N, P and K at depth 0-20 cm was 1.06, 2.46 and 2.96, respectively. The rating of NI
202 indicated that low fertility levels for nitrogen and high fertility level for available P and available K was
203 recorded. Similarly. For subsurface layer (20-40 cm) the nutrient index values were 1.00,2.27and 2.83 for
204 available N, available P and available K respectively, revealing that low, medium and high fertility levels
205 were recorded for available N, P and K respectively. Nutrient index rating defined as < 1.67, 1.67-2.33,
206 >2.33 for low, medium and high fertility rating by Parker et al. (1951) while Ramamoorthy and Bajaj
207 (1969) redefine the NI rating as <1.5, 1.5 -2.5 and >2.5 for low, medium and high fertility. Based on the
208 above ratings, most deficient nutrient in soil was N followed by P and K. our findings are in conformity with
209 Gehlot et,el (2019 ,2023) that nutrient index for nitrogen and phosphorus indicated low and medium
210 fertility respectively for soils of Ujjain Tehsil of Madhya Pradesh

211 Relationships among soil properties and citrus yield

212 In the present study, at the depth of 0-20 cm, soil pH was negatively correlated with P ($r = -0.37^{**}$), Ex.Mg
213 ($r = -0.42^{**}$), available Zn ($r = -0.40^{**}$), available Fe ($r = -0.60^{**}$), available Cu ($r = -0.38^{**}$) and available Mn
214 ($r = -0.62^{**}$). Soil EC was positively correlated with available P ($r = 0.26^{**}$), available Zn ($r = 0.32^{**}$),
215 available Cu ($r = 0.30^{**}$). SOC was positively correlated with available P ($r = 0.31^{*}$) and available K (r
216 $= 0.33^{**}$). Citrus yield is significantly and positively correlated with soil properties and available nutrient
217 content in soils (table 3). Similar to the depth of 0-20 cm, in subsurface (20-40 cm), soil pH was negatively
218 correlated with available P ($r = -0.41^{**}$) and with micronutrient Zn ($r = -0.46^{**}$), Fe ($r = -0.56^{**}$), Mn ($r =$
219 0.69^{**}) and Cu ($r = -0.43^{**}$). EC is the only positively and significantly correlated with available N (r
220 $= 0.33^{**}$). SOC was significantly and positively correlated with available P ($r = 0.30^{*}$). Yield was positively
221 and significantly correlated with EC ($r = 0.29^{*}$) and available N ($r = 0.41^{**}$) (Table 4) similar findings
222 reported by Srivastava (2013) for significant positive correlation of citrus fruit yield with available
223 Nitrogen. The extent of correlation was higher in subsurface than surface soil for soil pH with available Fe
224 and Available Mn while correlation was higher for surface soil in rest of the micronutrient. The extent of
225 correlation with yield and EC, SOC, N and P was higher in surface soil than subsurface soil. Behera et al.
226 (2022) reported significant negative correlation of soil pH with available P, available Zn, available Fe,
227 available Mn in farmland of Bhopal Madhya Pradesh. Similar results were reported in soils of Harda
228 district of Madhya Pradesh (Subhash et al., 2019), citrus orchard soil for Layahh district of Pakistan
229 (Ahmad et al., 2022). The negative relationship observed between soil pH and the availability of cationic
230 micronutrients in our research underscores that variations in soil pH directly impact the levels of these
231 micronutrients in the soil (Shukla et al., 2018, Mishra et al., 2019). Lindsay (1979) indicates that for every
232 incremental increase in soil pH within the range of 4 to 9, the solubility of zinc (Zn), copper (Cu), and
233 manganese (Mn) decreases by 100-fold, while for iron (Fe), the reduction is even more significant, at
234 1000-fold. Positive correlation of SOC with available nutrients might be due to the fact that SOC is a
235 fundamental component of soil organic matter (SOM). Soil organic matter facilitates the availability of
236 nutrients to crop plants by releasing organic acids, and, upon mineralization, release nutrients into pools
237 accessible to plants.

238 The relationship obtained in our results were supported by findings of Ramana Murthy and Srivastava
239 (1994) who observed that positive and significant correlation of EC with available phosphorus.

240 In our findings yield is positively and significantly correlated with available nitrogen are similar with reports
241 of Srivastava and Singh (2002). Negative and significant correlation of pH and DTPA extractable Fe, Cu
242 and Mn. Positive correlation of soil organic carbon with available Sulphur, Zinc, Copper and Boron are
243 in confirmation in our results are similar with findings of Chouhan et al., (2012) for medium black soils of
244 Dewas district of Madhya Pradesh.

245 4. Conclusions

Comment [EU22]: Conclusion did not capture aim of the study as stated in the introduction "establish relationships of soil attributes at the surface and subsurface depth with citrus yield". Statistic relating yields to soil variables will help.

246 Our study concluded that the soils under high yielding orchards of citrus were having neutral to slight
247 alkaline pH, EC was $<0.5 \text{ dSm}^{-1}$ which indicated good condition for citrus cultivation .Mean value of SOC
248 content $<0.5\%$ indicated lower SOC content of soil.based on nutrient index rating macronutrient status as
249 per nutrient index value reflected that N was low in both the depth whereas P and K was higher in
250 surface soil .Based on suitability criteria, availableN,P,K, Zn, Cu and Mn were in suboptimal level .
251 Therefore for optimum production and maintenance of soil fertility one should opt integrated nutrient
252 management practices to improve soil health as well as sustainability in citrus production in which
253 organic manure ,macronutrient should be applied in optimal manner.

Comment [EU23]: Recast to present e.g. have neutral to slight

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256 References

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258 Ahmad, N., Hussain, S., Ali, M. A., Minhas, A., Waheed, W., Danish, S., ... & Datta, R. (2022). Correlation
259 of soil characteristics and citrus leaf nutrients contents in current scenario of Layyah
260 District. Horticulturae, 8(1), 61.

261 Alloway, B. J. (Ed.). (2008). Micronutrient deficiencies in global crop production. Springer Science &
262 Business Media.

263

264 Asbin, B. K., Pandey, K. R., Shrestha, B., Bhattarai, K., & Khatri, D. (2022). Assessment of soil nutrient
265 status of mandarin orchards in Syangja, Nepal. Fundamental and Applied Agriculture, 7(2), 112-120.

266

267 Behera, S. K., & Shukla, A. K. (2015). Spatial distribution of surface soil acidity, electrical conductivity, soil
268 organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid
269 soils of India. Land Degradation & Development, 26(1), 71-79.

270 Behera, S. K., Shukla, A. K., Patra, A. K., Prakash, C., Tripathi, A., Kumar Chaudhari, S., & Rao, C. S.
271 (2022). Assessing farm-scale spatial variability of soil nutrients in central India for site-specific nutrient
272 management. Arabian Journal of Geosciences, 15(9), 848.

273

274 Bhardwaj, S., Behera, S.K., Sharma, S.K., Trivedi, S.K., Mishra, R., Shukla, V., Sikaniya, Y., Sikarwar, A.
275 and Yadav, S., 2024. GIS Interpolation and Mapping of Soil Physicochemical Properties in Deep Medium
276 Black Soils of Established Citrus Orchards. Journal of Scientific Research and Reports, 30(3), pp.150-
277 163.

278 Bogunovic, I., Pereira, P., & Brevik, E. C. (2017). Spatial distribution of soil chemical properties in an
279 organic farm in Croatia. Science of the total environment, 584, 535-545.

280

281 Chen, Y., Li, F., Wu, Y., Zhou, T., Chang, Y., Lian, X., Yin, T., Ye, L., Li, Y., & Lu, X. (2022). Profiles of
282 citrus orchard nutrition and fruit quality in Hunan Province, China. *International Journal of Fruit*
283 *Science*, 22(1), 779-793.

284 Dahule, D. D. (2020). Characteristics and properties of mandarin growing soils of Katol tahsil in
285 Nagpur. *Journal of Pharmacognosy and Phytochemistry*, 9(6S), 360-364.

286 DuPont, S. T., Granatstein, D., & Sallato, B. (2020). Soil health in orchards.
287

288 Ferreira, V., Panagopoulos, T., Andrade, R., Guerrero, C., & Loures, L. (2015). Spatial variability of soil
289 properties and soil erodibility in the Alqueva reservoir watershed. *Solid Earth*, 6(2), 383-392.
290

291 Gehlot, Y., Aakash, R. G., Bangar, K. S., & Kirar, S. K. (2019). Nature of soil reaction and status of EC,
292 OC and macro nutrients in Ujjain Tehsil of Madhya Pradesh. *Int J Chem Stud*, 7(6), 1323-1326.
293

294 Gehlot, Y., Gallani, R., Jadon, P., Singh, V., Kamle, S., Kamle, R., & Mandloi, S. (2023). Spatial Variability
295 of Soil Macronutrients and Chemical Properties in Ujjain Tehsil of Ujjain District of Madhya Pradesh,
296 India. *International Journal of Plant & Soil Science*, 35(21), 325-335.
297

298 Gupta, J. P, Sharma, M. P. and Bindroo, R. K. 2004. Characterization of healthy and unhealthy citrus
299 orchard soils and plants of sub tropical zone of Jammu region. *Journal of the Indian Society of Soil*
300 *Science*, 52(4): 473-475.
301

302 Gupta, U. C. (1967). A simplified method for determining hot-water-soluble boron in podzol soils. *Soil*
303 *science*, 103(6), 424-428.
304

305 Hanway, J. J., Heidel, H. 1952. Soil analyses methods as used in Iowa state college soil testing
306 laboratory. 57. *Iowa Agriculture* 1-31.
307

308 Jackson, M. L. (1973). *Soil chemical analysis*, pentice hall of India Pvt. Ltd., New Delhi, India, 498, 151-
309 154.
310

311 Jones, D. L., Cross, P., Withers, P. J., DeLuca, T. H., Robinson, D. A., Quilliam, R. S., ... &
312 Edwards-Jones, G. (2013). Nutrient stripping: the global disparity between food security and soil nutrient
313 stocks. *Journal of Applied Ecology*, 50(4), 851-862.
314

315 Kanwar, J.S. and Randhawa, N.S. (1960) *Punjab Agric. Univ. Hort. Adv.*, 4 :
316

317 Kumar, D., Bhattacharyya, S., & Ghosh, D. (2023). Assessing the export potential of Nagpur mandarin:
318 the promising citrus fruit of Central India. *Current Science*, 782-784.
319

320 Lindsay, W. L., & Norvell, W. (1978). Development of a DTPA soil test for zinc, iron, manganese, and
321 copper. *Soil science society of America journal*, 42(3), 421-428.
322

323 Mishra, R., Datta, S.P., Annapurna, K., Meena, M.C., Dwivedi, B.S., Golui, D. and Bandyopadhyay, K.,
324 2019. Enhancing the effectiveness of zinc, cadmium, and lead phytoextraction in polluted soils by using
325 amendments and microorganisms. *Environmental Science and Pollution Research*, 26, pp.17224-17235.

326 ChouhanNarendra, N. C., Sharma, G. D., Khamparia, R. S., & Sahu, R. K. (2012). Status of sulphur and
327 micronutrients in medium black soils of Dewas district, Madhya Pradesh.
328

329 National Horticulture Board, Area production statistics for horticulture crops 2018–19 (Final), Ministry of
330 Agriculture and Farmers Welfare, Government of India, Gurugram, Haryana (accessed on 12 August
331 2022).
332

333 Olsen, S. R. (1954). Estimation of available phosphorus in soils by extraction with sodium
334 bicarbonate (No. 939). US Department of Agriculture.
335
336

337 Parker, F. W. Nelson, W. L., Winters, E. and Miles, J. E., The broad interpretation and application of soil
338 test summaries, *Argon Journal*, 43(3):103-112. (1951)

339 Ramamoorthy, B. and Bajaj, J.C., Available Nitrogen, Phosphorus and Potassium status of Indian Soils.
340 *Fertilizer News*, 14:25-36(1969)
341

342 Ramana Murthy, J. and Srivastava, P. 1994. Soil fertility status in relation to terrace management at
343 Majhera Farm in lower Shivaliks. *Journal of the Indian Society of Soil Science*, 42(1): 150-152.
344

345 Ratnam, U.V, Seshaiiah, B.V, Veeraiah, K. and Naidu, M. V. S 2001. Nutrient status of sapota (*Achras*
346 *sapota*) growing soils of Ulavapadu mandal of Prakasam district, Andhra Pradesh. *The Andhra*
347 *Agricultural Journal*, 48 (1&2): 42-47.
348

349 Reddy, V.S. R and Rao, S. M. 1991. Characterization of soils under sweet orange cultivation in
350 Rayalaseema region of Andhra Pradesh. *The Andhra Agricultural Journal*, 38: 385-387.
351

352 Schjoerring, J. K., Cakmak, I., & White, P. J. (2019). Plant nutrition and soil fertility: synergies for
353 acquiring global green growth and sustainable development. *Plant and Soil*, 434, 1-6.
354

355 Sharma, Y. Á., Sharma, B. Á., Khamparia, R. S., Dubey, S. B., & Gupta, G. P. (2001). Micronutrient
356 status in soils and plants of Rajgarh district of Madhya Pradesh.

357 Shukla AK, Behera SK, Datta SP, Meena MC (2019) Estimation of calcium and magnesium in soil. In:
358 Singh SK, Biswas DR, Srinivasamurthy CA, Datta SP, Jayasree G, Jha P, Sharma SK, Katkar RN,
359 Raverkar KP, Ghosh AK (eds) *Soil analysis*. Indian Society of Soil Science, New Delhi, India, pp 237–
360 248.
361

362 Shukla, A. K., & Behera, S. K. (2019). All India coordinated research project on micro-and secondary
363 nutrients and pollutant elements in soils and plants: Research achievements and future thrusts. *Indian*
364 *Journal of Fertilisers*, 15(5), 522-543.
365
366
367
368
369

370 Singh, P., Srivastava, R., Meena, R. K., Patle, N., Meena, K., Meena, R., & Singh, N. (2022). Soil Profile
371 Studies under Different Orchard Management System in Chhindwara District of Madhya Pradesh,
372 India. *International Journal of Plant & Soil Science*, 34(23), 711-717.
373

374 Srivastava, A. K. (2013). Nutrient management in Nagpur mandarin: Frontier developments. *Scientific*
375 *Journal of Agricultural*, 2(1), 1-14.
376

377 Srivastava, A. K., & Kohli, R. R. (1997). Soil suitability criteria for citrus-An appraisal. *Agric Rev*, 18(3),
378 139-146.

379 Srivastava, A. K., & Singh, S. (2002). Soil analysis based diagnostic norms for Indian citrus
380 cultivar. *Communications in Soil Science and Plant Analysis*, 33(11-12), 1689-1706.
381

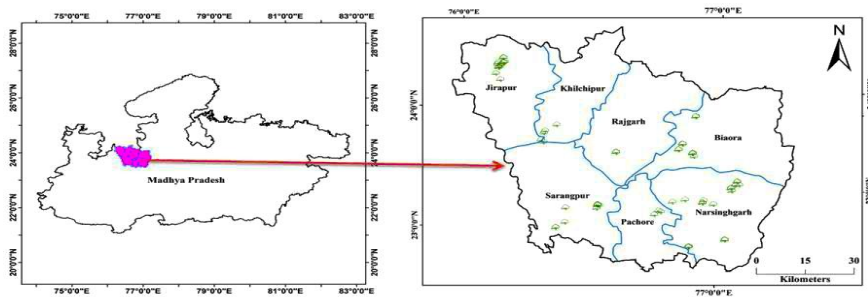
382 Srivastava, A., Hota, D., Dahat, S., & Sharma, D. (2022). Citrus nutrition: An Indian perspective. *Annals of*
383 *Plant and Soil Research*, 24(1), 1-15.

384 Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils.
385

386 Surwase, S. A., P. R. Kadu, and D. S. Patil. "Soil micronutrient status and fruit quality of orange orchards
387 in Kalmeshwar Tehsil, district Nagpur (MS)." *Journal of Global Biosciences* 5.1 (2016): 3523-3533.
388

389 Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (1985). Soil fertility and fertilizers. Collier Macmillan
390 Publishers.
391
392
393 Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic
394 matter, and a proposed modification of the chromic acid titration method. Soil science, 37(1), 29-38.
395
396 Williams, C. H., & Steinbergs, A. (1959). Soil sulphur fractions as chemical indices of available sulphur in
397 some Australian soils. Australian Journal of Agricultural Research, 10(3), 340-352.
398
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405 Fig 1: Study area and sampling points



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407 **Table 1: Descriptive statistics of soil variable in high yielding orchards of citrus for 0-20 cm soil depth**
408 **(n=65)**
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0-20 cm	Mean	Minimum	Maximum	SD	CV%	Skewness	Kurtosis
pH	7.72	6.83	8.84	0.38	4.89	0.192	0.794
EC (dSm ⁻¹)	0.18	0.07	0.34	0.05	27.2	0.691	1.15
SOC (%)	0.45	0.13	0.89	0.21	46.4	0.346	-1.01
N (kg ha ⁻¹)	186	102	288	37	20.0	1.028	1.459
P (kg ha ⁻¹)	29.7	7	76	15.9	53.5	0.812	0.333
K(kg ha ⁻¹)	474	259	775	132	27.8	0.698	-0.184
Ca (mg kg ⁻¹)	2784	1406	4568	862	31.0	0.383	-0.881
Mg (mg kg ⁻¹)	1033	461	1799	351	34.0	0.508	-0.628
S (mg kg ⁻¹)	16.7	5.6	30.0	5.2	31.0	0.393	-0.005
Zn (mg kg ⁻¹)	0.95	0.34	2.29	0.51	53.7	1.28	0.955
Fe(mg kg ⁻¹)	16.6	7.21	30.3	6.01	36.2	0.49	-0.543
Cu(mg kg ⁻¹)	1.12	0.29	2.4	0.49	44.2	0.96	0.199
Mn(mg kg ⁻¹)	11.3	4.55	26.3	5.43	48.2	1.06	0.411
B(mg kg ⁻¹)	0.75	0.30	1.22	0.22	29.6	0.20	-0.702

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Table 2 : Descriptive statistics of soil variable in high yielding orchards of citrus for 20-40 cm soil depth (n=65)

20-40 cm	Mean	Minimum	Maximum	Standard Deviation	CV%	Skewness	Kurtosis
pH	7.90	7.16	8.55	0.36	4.54	-0.20	-0.90
EC (dSm ⁻¹)	0.161	0.08	0.24	0.04	23.1	0.18	-0.40
SOC %	0.271	0.03	0.56	0.15	55.2	0.49	-1.13
N (kg ha ⁻¹)	148	72.0	258	36.1	24.5	0.73	1.28
P(kg ha ⁻¹)	22.3	6.72	54.2	12.2	54.7	1.01	0.28
K(kg ha ⁻¹)	369	191	594	97.6	26.4	0.63	0.04
Ca (mg kg ⁻¹)	3158	1806	4900	826	26.2	0.33	-0.90
Mg (mg kg ⁻¹)	990	328	1860	370	37.4	0.53	-0.10
S (mg kg ⁻¹)	17	8.13	29.5	4.84	29.2	0.49	0.05
Zn (mg kg ⁻¹)	0.672	0.21	1.66	0.379	56.4	1.09	0.365
Fe(mg kg ⁻¹)	15.1	7.58	25.8	5.07	33.5	0.50	-0.78

Cu(mg kg⁻¹)	0.84	0.22	1.92	0.39	46.5	1.15	0.81
Mn(mg kg⁻¹)	8.95	3.65	19.82	4.40	49.1	1.03	0.07
B(mg kg⁻¹)	0.528	0.08	1.24	0.265	50.2	0.82	0.213

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Table 3: Correlation of soil nutrient with soil properties and yield (0-20 cm soil depth)

Soil variables	pH	EC	SOC	Yield
pH	1	-	-	.17
EC	0.13	1	-	.33**
SOC	0.08	0.23	1	.17
N	-0.06	0.16	.22	.42**
P	-0.37**	0.26*	.31*	.10
K	-0.16	-.03	.33**	.11
Mg	-0.42**	-.09	.02	-.07
S	-0.11	.20	.05	.16
Ca	0.2	.08	-.13	-.19

Zn	-.40**	.32**	.14	.02
Fe	-.60**	-.18	-.01	-.30*
Cu	-.38**	.30*	.17	.02
Mn	-.62**	-.21	-.10	-.05
B	0.03	-.01	.05	-.2
** Correlation is significant at the 0.01 level (2-tailed)				
* Correlation is significant at the 0.05 level (2-tailed)				

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Soil variables	pH	EC	SOC	Yield
pH	1	-	-	0.07
EC	0.40**	1	-	0.29*
SOC	-0.24	-0.15	1	0.01
N	0.04	0.33**	-0.051	0.41**
P	-0.41**	0.14	0.30*	0.1
K	-0.12	0.09	-0.07	0.12
Mg	-0.45**	-0.08	0.2	-0.05
S	-0.08	0.16	-0.12	0.19
Ca	0.22	-0.02	-0.01	-0.19
Zn	-0.46**	0.1	0.04	0.06
Fe	-0.56**	-0.18	0.07	-0.2

Cu	-0.43**	0.11	0.04	0.1
Mn	-0.69**	-0.12	0.07	-0.05
B	-0.13	-0.004	-0.1	0.15
** Correlation is significant at the 0.01 level (2-tailed)				
* Correlation is significant at the 0.05 level (2-tailed)				

439 Table 4: Correlation of soil nutrient with soil properties and yield (20-40 cm soil depth)

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