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Physicochemical Properties and Micronutrient Status of Agricultural Soils in Three Blocks of Kangra District, Himachal Pradesh, India

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Abstract: Soil testing is central to site-specific nutrient management, fertilizer rationalization and long-term soil fertility conservation. The study evaluated soil reaction, electrical conductivity, organic carbon and selected available micronutrients in 22 surface soil samples (0–15 cm) collected from agricultural fields of Dharamshala, Bhawarna and Baijnath blocks of Kangra district, Himachal Pradesh, India. Soil pH and electrical conductivity were measured in soil-water suspension, organic carbon was determined by the Walkley-Black wet oxidation method, and DTPA-extractable Fe, Mn, Cu and Zn were estimated by atomic absorption spectrophotometry. The soils had low electrical conductivity (EC 0.01–0.50 dS m^{-1}; mean 0.15 dS m^{-1}) and were acidic to neutral (pH 4.40–7.30; mean 5.99). The reported organic carbon values ranged from 0.50 to 2.80, with a mean of 1.25. Available Fe, Cu and Mn were above conventional critical limits in all or most samples, while Zn was sufficient to high. Kruskal-Wallis analysis indicated significant block-wise differences for EC ($H = 15.77$, $p < 0.001$, epsilon$^2 = 0.72$), whereas pH, organic carbon, Fe, Mn, Cu and Zn did not differ significantly among blocks. Spearman correlation analysis did not identify any statistically significant association among the retained soil parameters. The findings indicate that the sampled soils have low measured EC and possess adequate available cationic micronutrient status, while acidic soil reaction warrants attention in soil fertility management.

Keywords: soil fertility; DTPA micronutrients; Kangra Valley; acidic soils; organic carbon; zinc; Himachal Pradesh

1. INTRODUCTION

Soil fertility is a dynamic expression of the soil's capacity to supply plant nutrients in adequate amounts and balanced proportions. It is governed by several factors, including parent material, topography, climate, vegetation, texture, organic matter turnover, soil reaction, salinity, biological activity and fertilization history. In India, soil testing has gained particular relevance because the Soil Health Card programme was designed to provide field-level information for addressing nutrient deficiencies and improving fertilization practices [1].

Micronutrients are required in small concentrations but have significant functional implications for plant metabolism. Iron participates in redox reactions and chlorophyll-associated processes; manganese is involved in photosynthetic oxygen evolution and several enzyme systems; copper occurs in electron-transfer proteins and plays a role in lignification; and zinc is essential for enzyme structure, auxin metabolism, protein synthesis and membrane stability [2,3]. The availability of these elements to plants depends not only on their total concentration in soil but also on pH, redox conditions, organic matter, clay minerals, carbonate content, soil moisture and root-zone chemistry [4,5].

Soil pH has considerable diagnostic value because it regulates nutrient solubility and the potential for toxicity. Strongly acidic conditions can increase the risk of aluminium and manganese toxicity, whereas alkaline conditions commonly reduce the phytoavailability of Fe, Zn, Mn, Cu and phosphorus [3,5]. Electrical conductivity (EC) provides an estimate of soluble salt status and helps identify salinity-related stress. Organic carbon (OC) improves soil aggregation, water retention, cation exchange capacity and microbial activity, while also facilitating micronutrient chelation, making it a key component of soil health [6].

Kangra district, located in the western Himalayan region of Himachal Pradesh, exhibits considerable physiographic and microclimatic heterogeneity. Such variability can result in field-to-field differences in soil reaction and nutrient availability, even over relatively short distances. The present study re-analyses a block-level dataset from Dharamshala,

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Bhawarna and Baijnath using corrected data handling, standard descriptive and non-parametric statistical approaches, and transparent data-quality notes. The aim is to transform the project-level information into a scientifically robust manuscript suitable for publication as a regional soil fertility note.

2. MATERIALS AND METHODS

2.1 Study area and sampling design

The study covered agricultural fields in three blocks of Kangra district, Himachal Pradesh: Dharamshala, Bhawarna and Baijnath. Twenty-two surface soil samples were collected from cultivated fields at 0-15 cm depth. Samples 1-8 represented Dharamshala, samples 9-15 Bhawarna, and samples 16-22 Baijnath. A composite sampling approach was followed within fields using grid/zigzag movement while avoiding atypical points such as field bunds, recently fertilized patches, irrigation channels, manure heaps and areas directly below trees.

2.2 Sample preparation and laboratory analysis

Soil samples were air-dried in shade, gently crushed, cleared of visible roots and stones, passed through a 2-mm sieve, homogenized and stored in labelled containers prior to analysis. Soil pH and EC were determined in soil-water suspension using calibrated meters. Organic carbon was estimated by the Walkley-Black wet oxidation procedure [7]. Available Fe, Mn, Cu and Zn were extracted with DTPA and estimated by atomic absorption spectrophotometry following the method of Lindsay and Norvell [8].

2.3 Rating criteria and statistical analysis

Soil reaction, EC, OC and micronutrient cation values were interpreted using the soil-test rating criteria presented in Appendix Table B. For DTPA-extractable cations, the critical thresholds used were: Fe deficient <4.5 mg kg^{-1}, sufficient 4.5-9.0 mg kg^{-1} and high >9.0 mg kg^{-1}; Mn deficient <3.5 mg kg^{-1}, sufficient 3.5-7.0 mg kg^{-1} and high >7.0 mg kg^{-1}; Cu deficient <0.2 mg kg^{-1}, sufficient 0.2-0.4 mg kg^{-1} and high >0.4 mg kg^{-1}; and Zn deficient <0.6 mg kg^{-1}, sufficient 0.6-1.2 mg kg^{-1} and high >1.2 mg kg^{-1} [8].

Descriptive statistics included mean, standard deviation, minimum, median and maximum. Because sample size was small and block-wise replication was unequal, block-wise differences were tested using the Kruskal-Wallis test. When a variable showed a significant omnibus result, pairwise Mann-Whitney U tests with Holm adjustment were used as post-hoc comparisons. Effect size for the Kruskal-Wallis test was expressed as epsilon-squared. Relationships among variables were evaluated with Spearman rank correlation. Statistical significance was assessed at $p < 0.05$.

3. RESULTS

3.1 Soil reaction, electrical conductivity and organic carbon

Soil pH ranged from 4.40 to 7.30, with a mean of 5.99 ± 0.87. Based on the adopted rating scale, six samples were strongly acidic, four were moderately acidic, five were slightly acidic and seven were neutral. No sample was alkaline. Thus, soil acidity, rather than alkalinity, emerged as the principal soil-reaction constraint in the sampled dataset.

Electrical conductivity remained low in all samples, with values from 0.01 to 0.50 dS m^{-1}. All samples were below 1.0 dS m^{-1} and therefore belonged to the safe/non-saline category. Organic carbon ranged from 0.50% to 2.80%, with a mean of 1.25%. Based on the adopted OC rating scale, four samples were classified as having medium OC content, while the remaining 18 were classified as having high OC content.

3.2 Micronutrient cation status

DTPA-extractable Fe ranged from 9.22 to 22.78 mg kg^{-1}, and all samples exceeded the high-category threshold of 9.0 mg kg^{-1}. Available Mn ranged from 4.78 to 14.55 mg kg^{-1}; three samples were sufficient and 19 were high. Available Cu ranged from 0.93 to 2.13 mg kg^{-1} and all samples were high by the adopted threshold. Available Zn ranged from 0.92 to 2.84 mg kg^{-1}; eight samples were sufficient and 14 were high. Overall, the findings indicate that the supplied dataset provides no evidence of widespread deficiencies of Zn, Fe, Mn or Cu.

Table 1. Descriptive statistics of soil physicochemical properties and micronutrients across all 22 samples.

Parameter	Mean	SD	Minimum	Median	Maximum
pH	5.986	0.875	4.400	6.200	7.300
EC (dS m^{-1})	0.150	0.145	0.010	0.105	0.500
OC (%)	1.245	0.533	0.500	1.250	2.800
Mn (mg kg^{-1})	10.481	3.018	4.780	11.300	14.550
Zn (mg kg^{-1})	1.587	0.626	0.920	1.370	2.840

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Parameter	Mean	SD	Minimum	Median	Maximum
Cu (mg kg^{-1})	1.498	0.359	0.930	1.480	2.130
Fe (mg kg^{-1})	14.365	4.346	9.220	13.465	22.780

3.3 Block-wise variation in soil properties and micronutrient cation status

Kruskal-Wallis analysis showed significant block-wise differences for EC ($H = 15.77$, $p < 0.001$, epsilon$^2 = 0.72$). The block effect was not significant for pH, OC, Fe, Mn, Zn or Cu. The significant EC result reflects the very low EC values in Dharamshala compared with higher, but still non-saline, values in Bhawarna and Baijnath.

Table 2. Corrected fertility-class distribution of pH, EC, OC and micronutrient cations.

Parameter	Class	No. of samples	Percentage
pH	Strongly acidic	6	27.273
pH	Moderately acidic	4	18.182
pH	Slightly acidic	5	22.727
pH	Neutral	7	31.818
pH	Alkaline	0	0.000
EC	Safe/non-saline	22	100.000
EC	Potential concern	0	0.000
OC	Low	0	0.000
OC	Medium	4	18.182
OC	High	18	81.818
Fe	Deficient	0	0.000
Fe	Sufficient	0	0.000
Fe	High	22	100.000
Mn	Deficient	0	0.000
Mn	Sufficient	3	13.636
Mn	High	19	86.364
Cu	Deficient	0	0.000
Cu	Sufficient	0	0.000
Cu	High	22	100.000
Zn	Deficient	0	0.000
Zn	Sufficient	8	36.364
Zn	High	14	63.636

Table 3. Non-parametric comparison among the three sampled blocks.

Variable	Kruskal-Wallis H	p value	Epsilon-squared	Inference
pH	2.164	0.339	0.009	Not significant
EC (dS m^{-1})	15.769	<0.001	0.725	Significant
OC (%)	1.856	0.395	0.000	Not significant
Mn (mg kg^{-1})	0.438	0.803	0.000	Not significant
Zn (mg kg^{-1})	0.044	0.978	0.000	Not significant
Cu (mg kg^{-1})	3.632	0.163	0.086	Not significant
Fe (mg kg^{-1})	1.641	0.440	0.000	Not significant

Table 4. Holm-adjusted post-hoc comparisons for variables with significant Kruskal-Wallis results.

Variable	Comparison	Mann-Whitney U	raw p	Holm-adjusted p	Inference
EC (dS m^{-1})	Dharamshala vs Bhawarna	0.000	0.001	0.004	Significant
EC (dS m^{-1})	Dharamshala vs Baijnath	0.500	0.002	0.004	Significant
EC (dS m^{-1})	Bhawarna vs Baijnath	38.500	0.084	0.084	Not significant

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3.4 Correlation among soil properties and micronutrient cations

Spearman rank correlation analysis revealed generally weak to moderate associations among the measured soil properties and available micronutrient cations. Soil pH exhibited positive correlations with Zn ($\rho = 0.324$) and Mn ($\rho = 0.201$), while negative correlations were observed with Fe ($\rho = -0.317$), Cu ($\rho = -0.151$) and OC ($\rho = -0.127$). Organic carbon showed positive correlations with Fe ($\rho = 0.292$) and Cu ($\rho = 0.223$), whereas its correlations with Mn and Zn were negative. Among the micronutrient cations, Mn showed positive correlations with Cu ($\rho = 0.247$) and Fe ($\rho = 0.056$), while Zn exhibited negative correlations with Cu ($\rho = -0.129$) and Fe ($\rho = -0.226$). EC displayed weak positive correlations with all the other measured variables. Overall, the correlation coefficients indicated varying degrees of association among the soil properties and micronutrient cations, without any strong pairwise relationships.

Table 5. Spearman rank correlation matrix among soil pH, electrical conductivity, organic carbon and available micronutrient cations (Fe, Mn, Zn and Cu).

Variable	pH	EC (dS m^{-1})	OC (%)	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})
pH	1.000	0.150	-0.127	0.201	0.324	-0.151	-0.317
EC (dS m^{-1})	0.150	1.000	0.021	0.111	0.058	0.125	0.166
OC (%)	-0.127	0.021	1.000	-0.151	-0.013	0.223	0.292
Mn (mg kg^{-1})	0.201	0.111	-0.151	1.000	-0.081	0.247	0.056
Zn (mg kg^{-1})	0.324	0.058	-0.013	-0.081	1.000	-0.129	-0.226
Cu (mg kg^{-1})	-0.151	0.125	0.223	0.247	-0.129	1.000	0.207
Fe (mg kg^{-1})	-0.317	0.166	0.292	0.056	-0.226	0.207	1.000

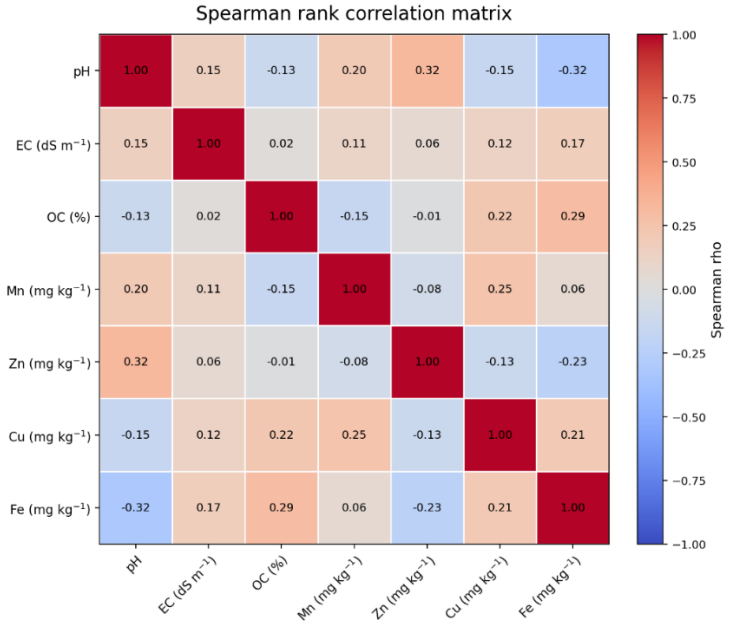


Figure 1. Spearman rank correlation heat map. Asterisks indicate $p < 0.05$.

4. DISCUSSION

4.1 Soil reaction and salinity

The corrected interpretation of soil pH substantially changes the overall fertility assessment of the dataset. The sampled soils are better characterised as acidic to neutral rather than predominantly alkaline. Acidic soil reaction is commonly encountered in humid hill environments, where rainfall-induced leaching results in the depletion of basic cations, while organic matter transformations may further contribute to soil acidity. Fields exhibiting moderately to strongly acidic conditions may require evaluation for lime application, particularly when cultivating pH-sensitive crops. However, blanket liming is not recommended, and any corrective measures should be based on crop requirements and field-specific soil assessments.

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The EC results indicate a favourable salinity status across all sampled fields. All recorded values were considerably below the threshold commonly associated with salinity stress, suggesting that soluble salt accumulation is unlikely to be a significant constraint to crop growth in the study area. The low EC values may be associated with effective leaching under the monsoon-influenced climatic conditions of the Himalayan region.

4.2 Organic carbon and soil-health implications

Organic carbon levels were generally favourable, provided that the laboratory reporting unit is confirmed as percentage. This has important implications for soil health, as organic matter plays a vital role in improving soil aggregation, water retention, nutrient buffering, cation exchange capacity and biological activity [6]. Relatively high OC levels may also contribute to micronutrient retention through chelation and organo-mineral interactions. Nevertheless, the reported OC values, particularly those exceeding 2%, warrant verification against the original laboratory records, as some laboratories report organic matter content or kit-derived indices rather than directly measured organic carbon percentage.

4.3 Micronutrient cation status

The DTPA-extractable Fe, Mn, Cu and Zn concentrations indicate an adequate to high status of these micronutrient cations in the sampled fields. In particular, the findings do not provide evidence of widespread Zn deficiency within the studied dataset. However, periodic monitoring of micronutrient availability remains important, as Zn deficiencies are widely reported in Indian agricultural soils, with their distribution varying considerably across regions and soil types [9,10]. The availability of these elements is influenced by several factors, including soil pH, texture, organic matter content, parent material and crop management practices. The observed sufficient-to-high micronutrient status may therefore be associated with the combined influence of these soil characteristics and nutrient management practices, although the absence of detailed cropping and fertilizer histories limits further evaluation of their individual contributions.

4.4 Comparison with previous studies and scope of inference

The overall pattern of non-saline soils with adequate to high micronutrient cation status is broadly consistent with earlier observations from Himalayan and Shiwalik-region soils, where micronutrient availability is known to vary with soil reaction, organic matter content, landscape position and local management practices [11]. National assessments have also demonstrated that micronutrient deficiencies in Indian soils exhibit considerable spatial heterogeneity rather than a uniform distribution [9,10].

The present findings therefore provide useful block-level information on selected soil fertility characteristics of the study area. However, the results should be interpreted within the scope of the available dataset and should not be extrapolated to represent the overall fertility status of Kangra district. The relatively limited sample size, unequal block-wise replication and absence of georeferenced sampling metadata restrict the spatial generalisation of the findings. Nevertheless, the corrected dataset provides a useful baseline for understanding selected soil fertility attributes and identifying areas requiring further soil assessment and monitoring.

5. CONCLUSION

The analysis of 22 cropland soil samples collected from Dharamshala, Bhawarna and Baijnath revealed predominantly non-saline conditions, with EC values considerably below 1 dS m^{-1}, and an acidic-to-neutral soil reaction, with no samples exhibiting alkaline conditions. Organic carbon content ranged from medium to high, subject to confirmation that the reported values represent OC percentage. DTPA-extractable Fe, Mn, Cu and Zn were found to be within the sufficient-to-high categories according to the adopted critical limits, indicating no evidence of widespread deficiencies of these micronutrient cations in the sampled soils. Block-wise differences were statistically significant for EC, whereas pH, OC, Fe, Mn, Zn and Cu exhibited no significant variation among the three sampled blocks. Overall, the findings provide a useful block-level assessment of selected soil fertility characteristics and highlight the importance of continued soil monitoring and site-specific nutrient management for sustaining soil health and agricultural productivity in the region.

6. PRACTICAL RECOMMENDATIONS

For acidic soils, lime requirements should be determined on a crop-specific basis before application, rather than adopting blanket liming practices. Soil organic matter should be maintained through the regular incorporation of farmyard manure, compost, crop residues, cover crops and green manures. Routine application of Fe, Mn, Cu and Zn fertilizers should be avoided in soils where their measured concentrations are already in the high category, as unnecessary applications may increase input costs and contribute to nutrient imbalances or antagonistic interactions. Future studies should incorporate GPS coordinates, elevation, soil texture, available N, P, K and S, exchangeable acidity, cropping and fertilizer history,

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and crop yield responses to generate more comprehensive assessments and develop reliable, site-specific fertilizer recommendations.

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AUTHOR CONTRIBUTIONS

Prerna Sharma: field sampling, laboratory data compilation and initial data organization. Bovinder Chand: conceptual guidance, data validation, statistical analysis, manuscript drafting and interpretation. Anuradha Sharma: supervision, academic review and manuscript revision. All authors reviewed and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this manuscript.

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Appendix A. Analytical Dataset Used for Statistics

Block	Sample	pH	EC (dS m^{-1})	OC (%)	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})
Dharamshala	1	6.900	0.050	2.100	14.010	1.080	1.210	11.260
Dharamshala	2	7.300	0.030	0.700	7.740	2.420	1.170	10.000
Dharamshala	3	7.300	0.030	1.500	4.850	1.120	1.350	9.940
Dharamshala	4	6.400	0.020	1.200	14.550	1.590	1.460	20.440
Dharamshala	5	6.100	0.010	1.300	12.980	2.300	1.740	13.830
Dharamshala	6	4.600	0.040	0.500	12.920	0.960	1.680	11.240
Dharamshala	7	4.900	0.010	1.200	8.590	0.920	1.500	15.090
Dharamshala	8	4.400	0.020	1.300	4.780	2.360	1.130	17.140
Bhawarna	9	6.400	0.300	1.500	12.050	1.350	0.930	20.540
Bhawarna	10	6.900	0.320	1.000	13.310	2.840	1.760	12.850
Bhawarna	11	6.400	0.110	1.000	12.140	2.120	1.240	9.420
Bhawarna	12	6.600	0.120	1.000	11.480	0.930	1.850	17.770
Bhawarna	13	5.300	0.460	1.300	12.020	0.970	1.750	22.780
Bhawarna	14	6.700	0.210	0.500	11.120	1.670	1.220	20.130
Bhawarna	15	6.300	0.500	1.100	8.250	1.380	1.000	12.230
Baijnath	16	5.500	0.100	1.300	5.640	1.700	1.140	9.590
Baijnath	17	4.900	0.050	1.400	10.510	1.010	1.970	13.740
Baijnath	18	5.300	0.210	1.300	13.650	1.340	1.890	14.810
Baijnath	19	5.500	0.070	0.500	9.700	1.020	1.130	10.190
Baijnath	20	5.600	0.140	1.900	9.130	2.840	1.930	13.190
Baijnath	21	6.900	0.220	1.000	13.490	1.630	1.770	9.220
Baijnath	22	5.500	0.270	2.800	7.680	1.360	2.130	20.640

Appendix B. Soil Test Rating Criteria

Soil-test parameter	Rating limits used / note
pH	<5.5 strongly acidic; 5.5-6.0 moderately acidic; 6.0-6.5 slightly acidic; 6.5-7.5 neutral; >7.5 alkaline
EC	<1.0 dS m^{-1} safe/non-saline; 1.0-2.0 critical for germination; 2.0-3.0 critical for salt-sensitive crops; >3.0 injurious to most crops
Organic carbon	<0.50% low; 0.50-0.75% medium; >0.75% high
Available Fe	<4.5 mg kg^{-1} deficient; 4.5-9.0 mg kg^{-1} sufficient; >9.0 mg kg^{-1} high
Available Mn	<3.5 mg kg^{-1} deficient; 3.5-7.0 mg kg^{-1} sufficient; >7.0 mg kg^{-1} high
Available Cu	<0.2 mg kg^{-1} deficient; 0.2-0.4 mg kg^{-1} sufficient; >0.4 mg kg^{-1} high
Available Zn	<0.6 mg kg^{-1} deficient; 0.6-1.2 mg kg^{-1} sufficient; >1.2 mg kg^{-1} high

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