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Assessment of Soil Fertility Status and Spatial Variability at Farm Level using Geostatistical Tools

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***Abstract*— *Soil quality and spatial variability of soil properties are essential considerations for sustainable nutrient management, particularly at the farm level. The present study was conducted from 2023 to 2025 at the Agricultural Research Sub-Station (ARSS), Vallabhnagar, Udaipur, to assess the soil fertility status and map the spatial distribution of soil properties using geospatial techniques. In Kikawas Village 34 sample points—were selected, and soil samples were collected from two depths: 0–15 cm and 15–30 cm. A comprehensive physico-chemical analysis was performed on each sample, including pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), exchangeable sodium (Na), ESP, cation exchange capacity (CEC), and micronutrients such as iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn). The soils of were alkaline (mean pH 8.16–8.27), with EC variability up to 30%. OC declined from 0.63% to 0.51% between depths, and available macronutrients were lower in the subsoil. Micronutrients, particularly Fe and Mn, showed high spatial variability and limited availability across 40–50% of the farm area.*

***Keywords*— Spatial variability, Geostatistics, Global positioning system, Geographic information system, Site-specific nutrient management**

I. INTRODUCTION

Soil is one of the most vital natural resources that support life on Earth. It plays a crucial role in agricultural productivity by providing nutrients and a medium for plant growth. Composed of mineral matter, organic matter, water, and air, soil exhibits complex physical and chemical properties that directly influence its fertility. Key parameters such as soil texture, pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), and micronutrients like zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) are essential for crop growth and soil health. Declining soil fertility is a major concern in Indian agriculture (Gruhn *et al.*, 2000). Fertility is not only determined by the presence of nutrients but also by the soil's ability to retain and supply them in available forms. Human-induced factors, including continuous cropping and unbalanced fertilizer use, often lead to spatial variability in nutrient distribution (Deshmukh, 2012a). Regular monitoring of soil fertility is therefore necessary to sustain agricultural production and manage nutrient imbalances effectively. Assessment of soil fertility status and mapping of its spatial distribution are vital for precise and site-specific management. Fertility mapping enables targeted interventions and reduces input costs while improving crop productivity. Geospatial technologies such as Remote Sensing (RS), Geographic Information Systems (GIS), and Global Positioning System (GPS) have become powerful tools for studying spatial variability in soils (Das, 2004). These technologies allow accurate recording of sampling locations, generation of thematic maps, and identification of nutrient-deficient areas. Singh *et al*. (2017) emphasized that GIS-based soil fertility maps help optimize fertilizer application and support long-term soil health management. Electrical conductivity is a useful indicator of soluble salt concentration in soil and may vary with depth and topography (Deshmukh *et al*., 2012b; Dutta and Ram, 1993). Soil pH influences nutrient solubility and microbial activity (Rai *et al.,* 2011), while organic carbon is critical for improving soil structure and nutrient retention (Kekane *et al*., 2015). Cation Exchange Capacity (CEC) reflects the soil's ability to hold essential cations such as Ca^{2+}, Mg^{2+}, and K^{+}, which are vital for plant nutrition (Elfaki *et al.,* 2015). Techniques such as soil mapping, remote sensing, and geostatistical methods are employed to characterize and manage soil variability effectively (Cambardella *et al*., 1994).

II. MATERIALS AND METHODS

Study Area

The present investigation was carried out at the Agricultural Research Sub-Station (ARSS), Vallabhnagar, situated in the Udaipur district of Rajasthan. ARSS, Vallabhnagar is the largest research farm under the Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, comprising. Kikawas farm covers 19.73 hectares. Geographically, Kikawa's farm is positioned at 24°65’ N latitude and 74°04' E longitude. The study region falls under the Sub-Humid Southern Plain and Aravalli Hills Agro-Climatic Zone (Zone IV-A) of Rajasthan.

Soil Sampling and Processing

To assess the spatial variability of soil fertility, the entire research area was systematically divided into uniform grids of 75 m × 75 m using Google Earth Pro. This grid-based sampling framework ensured comprehensive spatial coverage and high-resolution representation of field-level variability. Within each grid, two to three composite soil samples were randomly collected to capture intra-grid variability. A stratified random sampling technique was adopted to ensure proportionate representation of different field blocks across the station. Soil samples were collected from two standard depths: 0–15 cm (surface) and 15–30 cm (subsurface) and the samples were labelled with unique identification codes. The collected samples were transported to the laboratory in sterile polythene bags. Upon arrival, they were air-dried under shade to preserve the physico-chemical integrity of the soil. The dried samples were gently crushed using a pestle and mortar to break down clods without disturbing the mineral composition. The soil was then sieved through a 2 mm mesh to achieve uniform particle size, suitable for standard laboratory analysis.

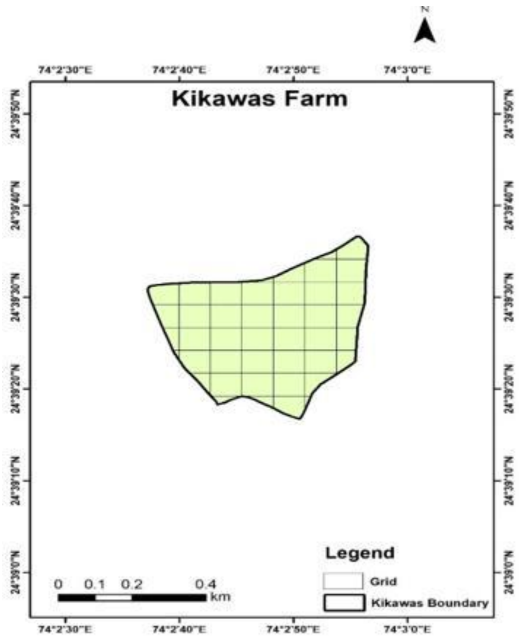

Fig. 1 Boundary and Grid map of sampling site

Laboratory Analysis

Laboratory analyses included soil pH, EC, OC, macronutrients (N, P, K, S, Ca, Mg), micronutrients (Fe, Zn, Cu, Mn), exchangeable sodium, ESP, and CEC. Standard analytical procedures were followed: pH and EC (Jackson, 1973), OC (Walkley and Black, 1934), available N (Subbiah and Asija, 1956), available P (Olsen et al., 1954), available K (Jackson, 1973), available S (Williams and Steinbergs, 1959), micronutrients via DTPA extraction (Lindsay and Norvell, 1978), exchangeable Ca and Mg (Tucker and Kurtz, 1961), exchangeable Na (Bower *et al.,* 1952), ESP (Richards, 1954), and CEC (Richards, 1968).

Descriptive statistical analysis

Descriptive statistical analysis was conducted to summarize the variability and distribution of soil fertility parameters. For each soil property, statistical indicators such as minimum, maximum, mean, median, standard deviation, coefficient of variation (CV), skewness, and kurtosis were calculated separately for both soil depths (0–15 cm and 15–30 cm). These computations were carried out using Microsoft Excel.

III. RESULT AND DISCUSSION

Descriptive Statistical Analysis

The descriptive statistics of Kikawas farm soil properties are given in Tables 1 to 5 . The soil pH ranged from 7.72 to 8.48 (mean 8.07) in surface (0–15 cm) and 7.822 to 8.709 (mean 8.263) in sub-surface (15–30 cm), indicating slightly alkaline conditions with low variability (CV < 3%) and platykurtic distribution, suggesting uniform soil reaction across samples (Rai *et al.*, 2011; Rathore *et al.*, 2023). Electrical conductivity showed moderate variability (CV 26–28%), with a slight increase in mean values from 1.48 to 1.637 dS/m, along with strong positive skewness at depth, indicating localized salt accumulation (Kumar *et al.* (2021). Organic carbon content decreased from 0.62% to 0.499% with depth and showed moderate variability (CV ~20%), reflecting reduced organic inputs in deeper layers (Gautam *et al.*, 2023). Macronutrients like nitrogen (316.08 to 271.50 kg/ha), phosphorus (20.48 to 17.44 kg/ha), and potassium (356.89 to 340.88 kg/ha) declined with depth, showing low to moderate variability (CV ~10–25%), influenced by leaching and crop uptake (Kothyari *et al.*, 2018; Meena *et al.*, 2020). Secondary nutrients—sulphur, calcium, and magnesium—also decreased with depth and showed moderate heterogeneity, indicating the effect of parent material and fertilization history (Anand *et al.*, 2025). Micronutrients like Fe, Cu, Mn, and Zn exhibited high to moderate variability (CV 30–40%) with lower values in subsoil, attributed to declining organic matter and microbial activity (Moharana *et al.*, 2020; Vasundhara *et al.*, 2024). Exchangeable sodium and ESP increased slightly with depth, while CEC remained stable (~22 cmol(+)/kg), suggesting uniform clay and organic matter distribution (Owliaie *et al.*, 2025).

IV. CONCLUSION

Based on the comprehensive analysis of soil samples collected from Kikawas at both surface (0–15 cm) and subsurface (15–30 cm) depths, it can be concluded that the soils of exhibited slightly alkaline reactions, with low variability in pH across depths. Electrical conductivity (EC) and organic carbon (OC) exhibited moderate variability, likely due to differences in land use, organic inputs, and irrigation patterns. Micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) showed high spatial variability, indicating inconsistent nutrient dynamics and possible localized deficiencies. Major nutrients including available nitrogen (N), phosphorus (P), and potassium (K) were found to decrease with depth, highlighting the influence of root distribution, organic matter content, and nutrient cycling processes. Overall, the study highlights considerable spatial variability in key fertility parameters, suggesting the need for site-specific nutrient management strategies. The information generated from this assessment serves as a scientific basis for informed fertilizer recommendations, improved input use efficiency, and sustainable soil fertility management at the farm level. Understanding and addressing such variability is essential for enhancing crop productivity and ensuring long-term soil health.

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Table 1: Descriptive Statistics of soil pH, electrical conductivity and organic carbon content of Kikawas farm

Parameter	**pH**		**EC (dS/m)**		**OC (%)**	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Minimum	7.82	7.89	0.42	0.64	0.36	0.3
Maximum	8.69	8.79	2.16	2.37	0.83	0.72
Mean	8.16	8.27	1.51	1.5	0.63	0.51
Sd	0.22	0.21	0.46	0.46	0.1	0.09
Cv %	2.64	2.53	30.29	30.4	16.02	17.22
Skewness	0.44	0.44	-0.34	0.18	-0.43	0.01
Kurtosis	-0.16	-0.14	-0.44	-0.84	0.67	0.77

Table 2: Descriptive Statistics of available nitrogen, phosphorus and potassium in Kikawas farm

Parameter	**N (kg/ha)**		**P (kg/ha)**		**K (kg/ha)**	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Minimum	234.69	186.17	13.21	10.09	274.73	267.37

Maximum	378.59	327.59	30.47	22.47	429.48	414.11
Mean	325.34	274.7	20.67	15.2	348.7	326.4
Sd	33.42	33.97	4.15	3.05	37.21	34.59
Cv %	10.27	12.37	20.08	20.09	10.67	10.6
Skewness	-0.66	-0.46	0.37	0.53	0.17	0.56
Kurtosis	0.37	-0.22	0.01	0.03	-0.21	0.34

Table 3: Descriptive Statistics of available sulphur, exchangeable Ca and Mg in Kikawas farm

Parameter	**S (mg kg^{-1})**		**Ca (Meq/L)**		**Mg (Meq/L)**	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Minimum	8.8	7.88	133.15	136.38	42.7	42.19
Maximum	23.59	20.69	201.4	203.66	94.21	95.81
Mean	16.72	14.91	167.2	169.53	70.12	71.43
Sd	3.28	2.97	18.81	18.63	12.82	13.46
Cv %	19.64	19.92	11.25	10.99	18.28	18.85
Skewness	-0.16	-0.18	0.04	-0.03	0.01	0.03
Kurtosis	-0.03	-0.15	-0.74	-0.69	-0.39	-0.31

Table 4: Descriptive Statistics of available Fe, Cu, Mn and Zn in soils of Kikawas farm

Parameter	**Fe (mg kg^{-1})**		**Cu (mg kg^{-1})**		**Mn (mg kg^{-1})**		**Zn (mg kg^{-1})**	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Minimum	1.13	1.03	0.03	0.03	0.9	0.92	0.24	0.21
Maximum	5.78	5.01	0.36	0.32	5.9	5.1	0.66	0.54
Mean	3.18	2.87	0.17	0.15	3.12	2.9	0.42	0.36
Sd	1.23	0.95	0.09	0.06	1.35	1.07	0.11	0.09
Cv %	38.76	33.13	51.88	43.64	43.31	36.92	25.15	24.82
Skewness	0.68	0.61	0.65	0.53	0.29	0.03	0.47	0.19
Kurtosis	0.16	0.53	0.28	0.72	-0.42	0.64	0.08	-0.93

Table 5: Descriptive Statistics of Exchangeable Na, ESP, and CEC in soils of Kikawas farm

Parameter	**Exch. Na (cmol/kg)**		**ESP (%)**		**CEC (cmol(+)/kg)**	
Depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Minimum	1.42	1.44	7.49	7.59	18.2	17.91
Maximum	3.16	3.3	14.89	15.74	26.17	26.67
Mean	2.48	2.48	11.36	11.68	21.88	21.82
Sd	0.45	0.45	1.42	1.58	2.3	2.38
Cv %	18.12	18.01	12.47	13.55	10.52	10.92
Skewness	-0.58	-0.44	-0.15	-0.02	0.31	0.43
Kurtosis	-0.1	-0.12	1.01	0.76	-0.65	-0.44