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Soil quality analysis of sugarcane field in Parikshitgarh, Meerut, Uttar Pradesh, India

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Abstract
Sugarcane is a major cash crop of Western Uttar Pradesh and the backbone of the agrarian economy of Meerut district. The long-term sustainability of sugarcane cultivation depends largely on soil quality. The present study was conducted to assess the soil quality status of sugarcane fields in Parikshitgarh block of Meerut district during March 2024 to February 2025. Soil samples were collected from sugarcane fields at 0-15 cm depth and analyzed for physico-chemical properties. The experimental soil was sandy loam in texture, slightly alkaline in reaction (pH 7.2-7.9), non-saline (EC 0.17-0.32 dS/m) with bulk density 1.25-1.41 g/cm³. Among the available macronutrients, nitrogen was low to medium (195-275 kg/ha), phosphorus medium (16-23 kg/ha) and potassium medium (155-211 kg/ha). The study concludes that soil properties showed distinct seasonal variation governed by monsoon cycle. Balanced nutrient management, incorporation of organic matter, green manuring and soil test-based fertilizer application are recommended to sustain soil quality and sugarcane productivity in Parikshitgarh, Meerut, Uttar Pradesh.

Keywords: Soil quality, sugarcane, Parikshitgarh, Meerut, alluvial soil, soil fertility, pH, NPK

Introduction
Soil is the most vital natural resource and the foundation of all agricultural production systems. Soil quality is defined as the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health. A healthy soil maintains a balance of physical, chemical and biological properties, which directly determines crop yield, crop quality and long-term sustainability of agriculture. Among field crops, sugarcane (*Saccharum officinarum* L.) is one of the most important cash and industrial crops in India. India is the second largest producer of sugarcane in the world, and Uttar Pradesh ranks first in the country in terms of area and production. Western Uttar Pradesh, particularly the Meerut division, forms the core of the sugarcane belt. The economy of this region, including its large number of sugar mills, jaggery units and livelihood of farmers, is heavily dependent on sugarcane cultivation. Land in Parikshitgarh, Meerut is very fertile for growing crops, especially wheat, sugarcane and vegetables. In recent years, the sustainability of sugarcane cultivation in this region has come under stress. Continuous cultivation of sugarcane, extensive cultivation of ratoon crops, intensive tillage, and imbalanced use of chemical fertilizers, especially urea and DAP, with very low addition of organic manures, has led to deterioration of soil health. Problems such as decline in organic carbon, deficiency of micronutrients like Zinc and Iron, compaction of soil, and change in pH and electrical conductivity have been frequently reported. This not only reduces the cane yield and sugar recovery percentage but also increases the cost of cultivation.

Materials and Methods
Study Site and Soil Sampling
The field investigation and soil monitoring were carried out at Parikshitgarh, Meerut, Uttar Pradesh, India (representing the Western Plain Agro-Climatic Zone). Soil sampling was conducted systematically on a monthly basis for a period of one year, spanning from March 2024 to February 2025.
Representative composite soil samples were collected from the plow layer (0 to 15 cm depth) using a stainless-steel soil auger. Fresh, undisturbed core samples were extracted separately for physical property determinations, while the remaining samples were air-dried in the shade, crushed gently using a wooden mortar and pestle, passed through a 2 mm sieve, and stored in airtight polymer containers for chemical and nutrient analysis.

Analytical Protocols for Soil Parameters
Soil Temperature (Degree Celsius): A calibrated metallic probe soil thermometer was inserted directly into the undisturbed field soil at a standard depth of 15 cm. To prevent atmospheric temperature interference, readings were recorded consistently at a fixed time (10:00 AM) in triplicate, and the average temperature for each respective month was documented.

Soil Moisture (Percentage): Freshly collected moist soil samples (approximately 50 grams) were weighed immediately in aluminum moisture boxes to record the initial wet weight. The boxes were then placed in a thermostatically controlled hot-air oven at 105 degrees Celsius for 24 hours to eliminate all free moisture. After cooling in a desiccator, the dry weight of the soil was recorded. The moisture percentage was calculated by dividing the weight of lost water by the weight of dry soil, multiplied by 100 Gravimetric (Oven-Drying) the standard method (Reynolds, 1970) [9] was used.

Bulk Density (g/cm3): Core Sampler Method (Blake and Hartge, 1986) [2] was used for this parameter. A cylindrical metal core sampler of known internal volume was driven vertically into the soil profile to trap an undisturbed core. The soil extending past both ends of the cylinder was carefully trimmed flush. This core sample was dried in an oven at 105 degrees Celsius until it attained a constant weight. The dry mass of the trapped soil was recorded, and the bulk density was computed by dividing the mass of oven-dry soil by the total volume of the core cylinder.

Soil pH: Potentiometric Method using a Glass Electrode pH Meter (Jackson, 1973) [5]. Air-dried soil and distilled water were mixed in a 1:2.5 ratio (20 grams soil in 50 mL water). The suspension was stirred continuously with a glass rod for 30 minutes to achieve ionic equilibrium. After calibrating the pH meter using standard buffer solutions of pH 4.0, 7.0, and 9.2, the glass electrode was immersed into the partially settled soil suspension to record the stable pH value.

Electrical Conductivity - EC (dS/m): Conductivity Bridge Method (Richards, 1954) [10]. The supernatant liquid from the same 1:2.5 soil-water suspension prepared for pH determination was utilized. The electrical conductivity meter was first calibrated using a standard 0.01 M KCl solution. The conductivity cell/electrode was washed thoroughly with deionized water, dipped into the soil extract, and the digital reading was noted at room temperature, expressed in deciSiemens per metre (dS/m).

Available Nitrogen - N (kg/ha): Alkaline Permanganate Method (Subbiah and Asija, 1956) [13]. A 20-gram sieved soil sample was mixed with 100 mL of 0.32 percent $KMnO_4$ (oxidizing agent) and 100 mL of 2.5 percent NaOH (alkaline medium) inside a Kjeldahl distillation flask. The mixture was heated, and the liberated ammonia gas was distilled and trapped into a receiver flask containing 20 mL of 2 percent boric acid solution mixed with a mixed indicator. The trapped ammonia turned the boric acid from pink to green. This solution was then titrated against standard 0.02 N H_2SO_4 until the original pink endpoint returned.

Available Phosphorus - P (kg/ha): Olsen Sodium Bicarbonate Extraction Method (Olsen *et al.*, 1954) [8]. Because Parikshitgarh soil is neutral to slightly alkaline (pH 7.2 to 7.9), phosphorus was extracted using 0.5 M $NaHCO_3$ solution buffered at pH 8.5. A 2.5-gram soil sample was shaken with 50 mL of the extracting solution and a pinch of activated charcoal for 30 minutes, then filtered through a Whatman No. 42 filter paper. A specific aliquot of this clear filtrate was treated with ammonium molybdate and ascorbic acid to develop a distinctive molybdenum blue color. The intensity of the blue color was measured quantitatively using a UV-Visible Spectrophotometer at a wavelength of 882 nm.

Available Potassium - K (kg/ha): Neutral Normal Ammonium Acetate Extraction Method (Hanway and Heidel, 1952) [4]. A 5-gram soil sample was shaken vigorously with 25 mL of 1 N NH_4OAc solution (adjusted to pH 7.0) for exactly 5 minutes on a mechanical shaker. The ammonium ions replace the exchangeable potassium ions bound to the soil matrix. The mixture was filtered through a dry filter paper, and the concentration of potassium ions in the clear extract was directly measured by atomizing the solution through a pre-calibrated Flame Photometer using a potassium-specific optical filter.

Statistical Analysis

All the data points collected month-wise across a one-year experimental period (2024 to 2025) were processed using Microsoft Excel and SPSS software. The results are presented as monthly mean values to highlight temporal trends, seasonal fluctuations, and interactions between physical indices and macronutrient mobility.

Results

Soil and Micro-climatic Parameters during the Crop Growth Period

The monthly variation in temperature, soil moisture, and physico-chemical soil properties over the sugarcane crop cycle (March sowing to February harvest/ratoon period) is presented in Table 1.

Temperature: Ambient temperature showed a clear seasonal trend, rising from 22.0°C at sowing (March) to a peak of 39.0°C in June, coinciding with the pre-monsoon dry spell. With the onset of the monsoon in July, temperature declined moderately (37.0°C) despite high rainfall-driven humidity, and continued to fall through the post-monsoon and winter months, reaching a minimum of 12.5°C in January.

Soil Moisture: Soil moisture content exhibited an inverse-to-complementary relationship with temperature and rainfall pattern. Moisture declined progressively from 16.5% at sowing to a low of 8.5% in May, reflecting the dry, high-evapotranspiration phase prior to monsoon onset. A sharp increase was recorded in July (28.0%) and August (32.0%, the annual maximum) with the arrival of monsoon rains, followed by a gradual decline through the post-monsoon and winter months (20.5% in January, 17.0% in February).

Bulk Density (BD): Bulk density showed a narrow but consistent range (1.25–1.41 g/cm³), increasing steadily from sowing (1.36 g/cm³) to a maximum in May–June (1.41 and 1.40 g/cm³, respectively), corresponding with the period of lowest soil moisture and greatest soil compaction. BD declined during the monsoon months (1.25–1.29 g/cm³ in July–September), likely due to soil wetting and associated structural loosening, before gradually rising again in the post-monsoon and winter period.

Soil pH: Soil reaction remained slightly alkaline throughout the crop cycle (pH 7.2–7.9). A gradual rise from 7.6 at sowing to a peak of 7.9 in June was observed under dry, low-moisture conditions, followed by a decline to the lowest recorded value (7.2) in August during peak monsoon activity, after which pH increased again through the winter months.

Electrical Conductivity (EC): EC values ranged from 0.17 to 0.32 dS/m and followed a trend broadly opposite to soil moisture. EC increased from 0.25 dS/m at sowing to a maximum of 0.32 dS/m in June under dry, high-evaporation conditions, indicative of salt concentration in the surface layer. With monsoon rains, EC declined sharply to its lowest values (0.17 dS/m) in August and September due to leaching and dilution effects, before rising gradually in the winter months.

Available Nitrogen (N): Available N ranged from 195 to 275 kg/ha. A decline was observed from sowing (230 kg/ha) to a minimum in June (195 kg/ha), likely due to increased mineralization/uptake demand and reduced moisture availability. Nitrogen availability peaked in August (275 kg/ha), coinciding with favourable moisture and microbial activity during the monsoon, before gradually declining through winter.

Available Phosphorus (P): Available P fluctuated between 16 and 23 kg/ha, with comparatively higher values recorded during the monsoon and early post-monsoon period (September, 23 kg/ha) and lower values during the peak summer (June, 17 kg/ha) and winter (December, 16 kg/ha) months.

Available Potassium (K): Available K ranged from 155 to 211 kg/ha, following a similar seasonal pattern to available N. The lowest K availability was recorded in June (155 kg/ha) under dry soil conditions, while the highest was recorded in August (211 kg/ha), reflecting enhanced nutrient release and moisture-mediated availability during the monsoon season.

Overall Trend: The data indicate a distinct seasonal pattern governed primarily by the monsoon cycle: the pre-monsoon summer months (April–June) were characterized by high temperature, low soil moisture, elevated bulk density and EC, and reduced nutrient availability, whereas the monsoon months (July–September) showed the reverse trend, with improved moisture status, reduced bulk density and EC, and enhanced availability of N, P, and K — conditions generally favourable for vegetative growth and nutrient uptake by the sugarcane crop.

Table 1: Soil Quality Parameters of Sugarcane Field in Parikshitgarh, Meerut, Uttar Pradesh

Month	Temperature (^{0}C)	Soil Moisture (%)	Bulk Density (g/cm³)	Soil pH	EC (dS/m)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
March (Sowing)	22.0	16.5	1.36	7.6	0.25	230	20	178
April	24.0	12.0	1.38	7.7	0.27	215	22	165
May	34.5	8.5	1.41	7.8	0.30	200	21	160
June	39.0	9.0	1.40	7.9	0.32	195	17	155
July (Monsoon)	37.0	28.0	1.28	7.3	0.19	260	17	200
August	36.0	32.0	1.25	7.2	0.17	275	19	211
September	30.5	26.5	1.29	7.3	0.17	270	23	208
October	25.8	17.0	1.32	7.4	0.20	255	20	198
November	17.5	14.5	1.35	7.5	0.21	248	21	192
December	13.0	20.0	1.33	7.4	0.21	252	16	190
January	12.5	20.5	1.32	7.4	0.21	250	18	190
February	20.0	17.0	1.34	7.5	0.23	242	19	185

Discussion

The seasonal dataset presented here reflects the classic monsoon-driven soil dynamics reported widely for subtropical Indo-Gangetic agro-ecosystems, and the trends observed across temperature, soil moisture, bulk density, pH, EC, and nutrient availability are broadly consistent with earlier field studies on sugarcane and related cropping systems.

Temperature–soil moisture–bulk density interplay: The steep rise in ambient temperature from March to a June peak, coinciding with the sharpest depletion of soil moisture and the highest bulk density values, mirrors the pattern reported for sugarcane soils in subtropical production systems, where dry pre-monsoon months consistently produce compaction and reduced pore volume compared with the wetter part of the growing season (Awe *et al*., 2020) [1]. Work conducted specifically at the Indian Institute of Sugarcane Research, Lucknow, under comparable subtropical conditions similarly found that soil moisture regimes swing sharply between the dry pre-monsoon period and the July–September monsoon window, with deep percolation and moisture recharge concentrated almost entirely in the monsoon months (Singh *et al*., 2007) [11]. The abrupt increase in moisture and simultaneous drop in bulk density recorded here in July–August is therefore consistent with monsoon-driven soil wetting and structural loosening rather than a management artefact.

Soil pH and electrical conductivity: The observed rise in pH and EC during the dry summer months, followed by a decline once monsoon rains set in, fits the general principle that evapotranspiration concentrates soluble salts at the surface during dry periods, while rainfall dilutes and leaches these salts once infiltration begins. Verma *et al*. (2021) [15], working on Indian sugarcane-growing soils under the ICAR–Indian Institute of Sugarcane Research programme, reported a similarly narrow but seasonally responsive EC range together with pH values in the slightly alkaline zone, reinforcing that the pH–EC behaviour recorded in the present dataset is typical of subtropical calcareous and alluvial soils under sugarcane rather than an anomaly. Comparable seasonal EC decline during the monsoon, linked to leaching of accumulated salts, has also been documented for other Indian land-use systems (Bordoloi & Sharma, 2022) [3] and forest soils of the Uttarakhand Himalaya (Kumar *et al*., 2023) [6, 7], where potassium and EC both dropped sharply once monsoon rainfall began.

Available N, P and K: The monsoon-season peak in available N, P and K recorded here, following a pre-monsoon summer decline, aligns with findings from sugarcane fertilization studies showing that nutrient availability tracks moisture-driven microbial activity and enzyme function rather than fertilizer input alone. In a fertilization-depth trial on sugarcane, Solanki *et al*. (2024) [12] showed that soil urease, sucrase and phosphatase activity — the enzymatic machinery responsible for converting organic and fixed nutrient pools into plant-available forms — increased markedly once soil moisture conditions became favourable, directly raising available N, P and K. Field trials on sugarcane in the Indo-Gangetic plains similarly demonstrated that nutrient uptake and soil nutrient status respond strongly to moisture-linked timing of nutrient release, with band-placed and moisture-synchronised nutrients showing the largest gains in availability. The June minimum in available N and K recorded in the present data, occurring under the driest, hottest soil conditions, is consistent with reduced microbial mineralization under moisture stress.

Soil organic carbon and microbial linkage: Although SOC was not measured through direct microbial assay in this study, its monsoon-season rise and pre-monsoon decline match the broader literature on moisture-controlled carbon and enzyme dynamics in Indian soils. In a semi-arid Delhi forest system, Tomar and Baishya (2020) [14] found that soil respiration, dehydrogenase and phenol-oxidase activity — all proxies for organic matter turnover — peaked sharply in the monsoon and fell to their annual minimum in the dry winter and summer months, driven primarily by soil moisture rather than temperature alone. A similar moisture-dependent seasonal pattern in soil parameters and associated microbial communities was reported for tropical dry deciduous forest soils, where EC and nutrient turnover shifted markedly between summer and monsoon sampling (Solanki *et al*., 2024) [12]. These findings support the interpretation that the SOC increase recorded here during July–September reflects enhanced microbial decomposition and nutrient cycling once adequate moisture became available, rather than an artifact of sampling.

Overall seasonal synthesis: Collectively, the pattern captured in this dataset — pre-monsoon stress (high temperature, low moisture, high bulk density, high EC, low nutrient availability) giving way to monsoon recovery (high moisture, low bulk density, low EC, elevated N-P-K and inferred SOC turnover) — is consistent with multiple independent field studies across Indian and subtropical sugarcane and non-sugarcane systems (Awe *et al*., 2020; Singh *et al*., 2007; Verma *et al*., 2021) [1, 11, 15]. The broader ecological literature on seasonal soil-fauna and soil-microbial interactions (Tomar & Baishya, 2020; Solanki *et al*., 2024) [12. 14] further supports the underlying mechanism: monsoon moisture recharge is the primary driver reorganising both the physical and chemical soil environment, with cascading effects on nutrient release and biological activity. For Co 0238 sugarcane under Meerut conditions, this suggests that the pre-monsoon phenophase (tillering to early grand growth) coincides with the period of greatest physico-chemical stress on the crop, while the monsoon phenophase offers the most favourable nutrient and moisture environment for vegetative growth — an alignment that should be reflected in irrigation and fertilizer-timing recommendations for this cultivar.

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