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Thokchom Biren Singh

Cluster Coordinator & Jr. Scientist,
Integrated Organic Farming
Demonstration Project, The Green
Foundation, Imphal, Manipur,
India

Sagolsem Sumangal Singh

Sr. Scientist, Department of
Agriculture Extension, The Green
Foundation, Imphal, Manipur,
India

Variability of soil properties and their implications for agricultural management in the central plain of Manipur, India

Thokchom Biren Singh and Sagolsem Sumangal Singh

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Abstract

Soil fertility is essential for sustainable agricultural productivity and regional development. This study examines the variability of soil properties across five different farmlands in the Central Plain of Manipur, India. The analyses of soil samples revealed significant differences in physical and chemical characteristics. The clay content was highest in Khurkhul (59.3%) and moderate in Mayang Imphal (34.8%), which influences water retention and drainage. Both Lamalai and Khurkhul had higher nutrient availability due to greater organic matter and cation exchange capacity (CEC). While Khurkhul exhibited high moisture retention, Iroishemba had high readily available water despite its high bulk density. Statistical analyses showed positive correlations between soil structure, stability, and nutrient availability. These findings suggest that Khurkhul and Lamalai have potential for agriculture due to their favourable soil properties. Conversely, the high bulk density in Iroishemba indicates a compact structure that may restrict root penetration and aeration. Therefore, proper nutrient management practices are essential to enhance soil health in this area. This study highlights the importance of considering the variability in soil properties when developing agricultural management strategies to maximize the agricultural potential of the Central Plain of Manipur.

Keywords: Soil fertility, nutrient availability, soil health, agricultural management, central plain of Manipur, readily available water

Introduction

Sustainable agricultural practices are essential for achieving long-term food security, especially in the face of a growing global population and finite resources (Sanchez, 2010); Bouwman and Smale, 1999) ^[14, 3]. To optimize land use and agricultural productivity, it is necessary to understand the variability in soil properties (Godfray *et al.*, 2010; Tilman *et al.*, 2001) ^[6, 15]. These properties, such as soil texture, organic matter content, and nutrient availability, play a significant role in influencing crop growth and yield. Identifying regions with soil conditions that are particularly suited to specific crops can lead to the development of targeted management strategies, unlocking the full agricultural potential of an area (Brady and Weil, 2008; Marschner, 2012) ^[5, 11].

The Central Plain of Manipur, a region with substantial agricultural potential, currently lacks detailed information on soil nutrient distribution. This knowledge gap hinders the development of effective soil management strategies. A thorough understanding of soil property variability is imperative for optimizing fertilizer application, improving water management, and enhancing overall agricultural productivity. To bridge this knowledge gap and inform the development of site-specific management practices, a comprehensive assessment of soil properties is essential (Johnston, 1991) ^[9]. This study addresses the knowledge gap by investigating the variability of soil properties across farmlands in the Central Plain of Manipur. Our primary objective is to elucidate the variability of these properties and their potential implications for agricultural management in the region. By identifying areas with favourable soil conditions for specific crop types, this research aims to contribute to sustainable agricultural practices that maximize the potential of the Central Plain of Manipur. Beyond characterizing soil variability, this study aims to bridge the gap between research and practice by providing actionable recommendations for farmers.

Corresponding Author:

Thokchom Biren Singh

Cluster Coordinator & Jr. Scientist,
Integrated Organic Farming
Demonstration Project, The Green
Foundation, Imphal, Manipur,
India

By integrating soil property information, development of site-specific management strategies, including fertilization, organic matter management, and tillage practices, this research seeks to improve soil health, enhance crop yields (Yuan *et al.*, 2011; Blanco-Canqui and Lal, 2010) ^[16, 21]. Ultimately, this research contributes to sustainable agricultural practices that enhance food security and promote the economic well-being of the region's farming communities.

Materials and Methods

Study Area and Sampling Sites

The Central Plain of Manipur, India, is situated between

latitudes 24.4777° and 25.8278° and longitudes 93.0822° and 94.7972°, with elevations ranging from 740 to 850 meters. This region experiences a subtropical climate, receiving 1,500 mm of annual rainfall and temperatures ranging from 10 °C to 35 °C. Five farmlands at Khumbong, Lamlai, Mayang Imphal, Khurkhul, and Iroishemba were selected for the study (Figure 1). These sites were chosen due to their diverse agricultural activities and distinct soil characteristics. The study aims to provide insights into how local conditions affect soil health and productivity, offering valuable information for optimizing agricultural practices and ensuring sustainability in the Central Plain region.

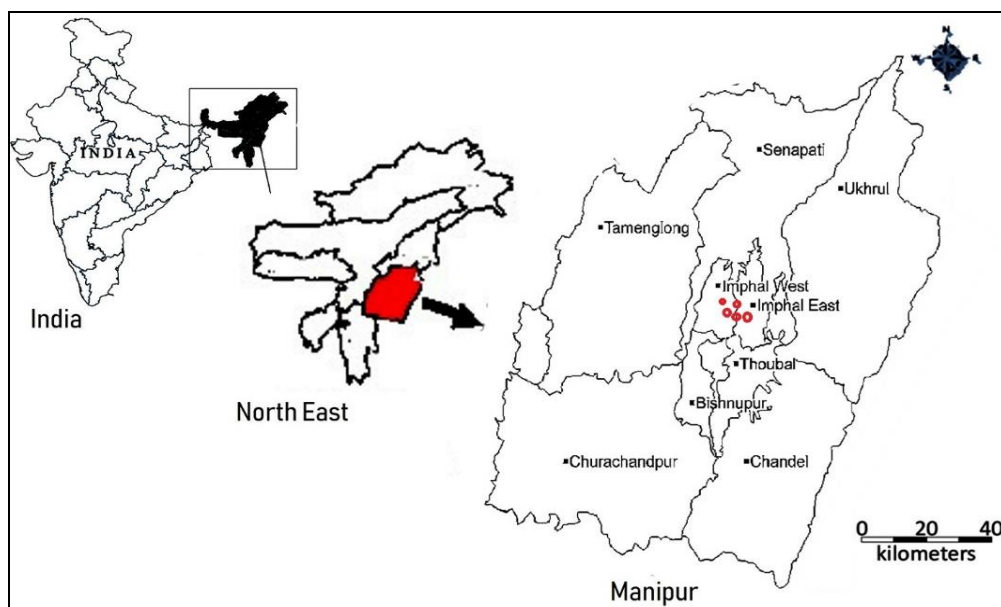


Fig 1: Map showing the study site

Cropping Profile

The primary crops cultivated in the selected farmlands include *Oryzasativa*, *Zea mays*, pulses, vegetables, and oilseeds. Among the vegetables, crops such as *Solanumlycopersicum*, *Capsicum annum*, and *Brassica oleracea* are prevalent. Fruit trees like *Mangiferaindica*, *Musa acuminata*, and *Carica papaya* are also commonly grown. These crops were chosen due to their economic importance and the traditional agricultural practices employed by the local farmers. Rice and maize serve as staple foods and are integral to the diet of the local population, while pulses provide essential proteins. Vegetables and fruits contribute to nutritional diversity and are often sold in local markets, contributing to the farmers income. Oilseeds, such as *Brassica juncea*, are important for oil production. The selection of these crops reflects the adaptation of traditional farming methods, which are sustainable and environmentally friendly, allowing the farmers to maintain soil fertility and ensure long-term productivity in these regions.

Soil Sampling and analysis

Soil samples were collected from the 0-30 cm depth at each sampling location using a soil auger in October 2023. To ensure representativeness, five subsamples were collected from different points within each site and thoroughly homogenized to form a composite sample. The composite samples were air-dried, ground to a fine particle size using a mortar and pestle, and passed through a 2 mm sieve. The sieved soil was stored in airtight glass containers for subsequent laboratory analyses. Soil pH was measured in a 1:2.5 soil-to-water suspension using

a potentiometric method with a glass electrode (Jackson, 1973) ^[8]. Electrical conductivity was determined in the soil-water (1:2.5) extract using a conductivity bridge (Jackson, 1973) ^[8]. Organic carbon content was estimated via the Walkley-Black rapid titration method (Jackson, 1973) ^[8] and soil texture was analyzed using the particle size distribution method (Bouyoucos, 1962) ^[4].

Bulk density and porosity were assessed using the core method (Jackson, 1973) ^[8] while water-stable aggregates were evaluated with the Kemper and Rosenau method (Kemper and Rosenau, 1986) ^[10]. Moisture content, available water capacity (AWC), and readily available water (RAW) were determined using established methods (Richards, 1949; Kemper and Rosenau, 1986) ^[10, 13].

Cation exchange capacity (CEC) was analyzed using the ammonium acetate method (Jackson, 1973) ^[8]. Exchangeable calcium and magnesium were measured using ammonium acetate extraction and atomic absorption spectrophotometry (AAS) (Nelson and Sommers, 1982) ^[12]. Free iron and aluminum were extracted using established methods (Berger and Truog, 1939; Jackson, 1958) ^[1, 7].

Statistical Analysis

Data were analyzed using SPSS software version 18. Descriptive statistics, including measures of central tendency and dispersion, were calculated to summarize the soil properties. Pearson correlation coefficients were used to assess the relationships between different soil properties and identify significant correlations.

Results and Discussion

Physical Properties

Analysis of soil samples revealed significant variations in soil texture across the study sites. Khurkhul had the highest clay content at 59.3%, resulting in dense soil with excellent water retention but poor drainage and aeration. In contrast, Mayang Imphal had the lowest clay content at 17.2% and the highest sand content at 51.4% (Figure 2), which promotes good drainage and aeration but limits water-holding capacity. These differences

in soil texture are essential for understanding their impact on agricultural practices. For instance, the high clay content in Khurkhul may benefit crops requiring consistent moisture but may need additional management to address drainage issues. Conversely, the sandy soil in Mayang Imphal, while well-drained, may require more frequent irrigation to support crop growth. Understanding these variations helps in proper agricultural practices to improve crop management and productivity in the region.

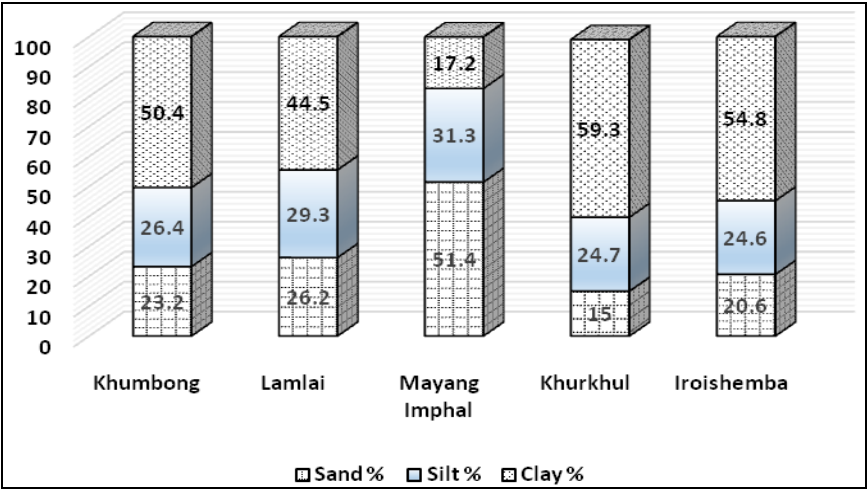


Fig 2: Showing the texture of soil of the various study site

Khurkhul exhibited the highest available water capacity at 0.21 m³/m³, while Iroishemba had the lowest at 0.17 m³/m³. Despite having lower overall moisture content, Iroishemba had the highest readily available water at 0.45 m³/m³, indicating efficient water utilization. Khumbong had an intermediate water retention and availability of 0.24 m³/m³. Significant differences were also observed in soil bulk density. The soil in Iroishemba had a high bulk density of 1.55 Mg/m³, which may impede root penetration and aeration. In contrast, Khurkhul's soil had the lowest bulk density at 1.46 Mg/m³, likely facilitating better root growth and soil porosity. Lamlai recorded the highest porosity at 37.4%, which supports root development

and gas exchange, compared to Khumbong's moderate porosity of 34.7%. Water-stable aggregate analysis revealed contrasting trends. Khurkhul's soil showed high macro-aggregate stability at 94.17%, indicating a robust soil structure and resistance to erosion. Conversely, Iroishemba's soil had lower macro-aggregate stability at 66.28%, suggesting a higher susceptibility to erosion. However, Iroishemba excelled in micro-aggregate stability at 33.72%, which may contribute to its compact nature. In contrast, Khurkhul had minimal micro-aggregates, with a stability of 5.83%, prioritizing macro-aggregate stability.

Table 1: Soil physical properties (Available water capacity and Readily available water, Bulk density, Particle density, Porosity (%), Water stable macro aggregate %, Water stable micro aggregate %) of different study site

Site	Available water capacity (m³m⁻³) (AWC) (Mean ± SD)	Readily available water (m³m⁻³) (RAW) (Mean ± SD)	Bulk density Mg.m⁻³ (Mean ± SD)	Particle density Mg.m⁻³ (Mean ± SD)	Porosity (%) (Mean ± SD)	Water stable macro aggregate % (Mean ± SD)	Water stable micro aggregate % (Mean ± SD)
Khumbong			1.52±0.06	2.33±0.11	34.7±3.2	93.74±6	6.26±1.3
Lamlai	0.18±0.05	0.24±0.05	1.47±0.04	2.35±0.15	37.4±4.1	93.22±9	6.78±1.5
Mayang Imphal	0.19±0.02	0.25±0.01	1.50±0.02	2.33±0.12	35.6±3.5	90.98±7	9.02±1.8
Khurkhul	0.18±0.01	0.28±0.06	1.46±0.04	2.24±0.14	34.8±5.1	94.17±5	5.83±1.1
Iroishemba	0.21±0.06	0.26±0.02	1.55±0.01	2.44±0.10	36.5±1.3	66.28±3	33.72±1.5

Chemical Properties

Chemical analysis of soil samples revealed significant variations in properties affecting plant growth, as shown in Table 2. Soil pH varied notably across the study sites. Lamlai's slightly acidic pH (6.1 ± 0.52) is ideal for most crop species, while Khurkhul's more acidic pH (5.2 ± 0.64) could challenge nutrient availability and microbial activity, which are critical for soil health and plant growth. Organic matter content, an essential indicator of soil fertility and structure, also varied. Both Lamlai and Khurkhul had high organic matter levels (38.8 g/kg), indicating favorable conditions for nutrient retention and microbial activity. In contrast,

Iroishemba's lower organic matter content (15.0 g/kg) may limit soil fertility, potentially affecting crop yield and quality. Cation exchange capacity (CEC), which measures the soil's ability to hold essential cations, differed significantly among the sites. Khurkhul's higher CEC (11.5 cmol/kg) indicates a strong nutrient-holding capacity, which benefits plant root development. On the other hand, Khumbong's lower CEC (5.9 cmol/kg) suggests a reduced ability to retain nutrients, which may require careful nutrient management. Exchangeable cations such as calcium and magnesium are vital for plant nutrition. Khumbong's higher exchangeable calcium (3.30 cmol/kg) supports strong cell wall formation and root

development. In contrast, MayangImphal's elevated exchangeable magnesium (4.25 cmol/kg) is important for chlorophyll synthesis and enzyme activation, both essential for photosynthesis and overall plant metabolism. Regarding oxide content, MayangImphal's higher free iron

oxide (Fe_2O_3) levels (1.07%) might limit iron availability for plants, even though iron is a key micronutrient. Conversely, the low levels of free aluminum oxide (Al_2O_3) across all sites reduce the risk of aluminum toxicity, which can be harmful to plant growth.

Table 2: Soil chemical properties (pH, Organic matter, CEC, EC) of different study site

Sample No.	pH	Organic matter g.kg^{-1}	CEC C mole(P^+) kg^{-1}	EC C mole (P^+) kg^{-1} Ca	EC C mole (P^+) kg^{-1} Mg	Free Fe_2O_3 %	Free Al_2O_3 %
Khumbong	5.6±0.65	31.0±4.21	5.9±0.2	3.30±0.11	3.00±0.02	0.36±0.004	0.09±0.001
Lamlai	6.1±0.52	38.8±3.98	6.7±0.3	3.50±0.14	3.00±0.01	0.61±0.001	0.08±0.003
Mayang Imphal	5.4±0.46	33.1±3.78	6.5±0.5	2.50±0.15	4.25±0.02	1.07±0.003	0.08±0.001
Khurkhul	5.2±0.64	38.8±4.26	11.5±0.6	2.50±0.16	3.50±0.01	0.26±0.006	0.08±0.003
Iroishemba	5.7±0.61	15.0±5.72	8.8±0.7	3.00±0.13	2.50±0.01	0.13±0.005	0.06±0.001

Correlations

Analysis of soil properties revealed significant interrelationships that influence soil quality and potential crop productivity. The strong inverse relationship between clay and sand content ($r = -0.997$) indicates a distinct textural contrast across the study sites. A positive correlation between sand and silt ($r = 0.889$) suggests the predominance of loamy textures in the soils. Additionally, soil pH showed a positive association with exchangeable calcium ($r = 0.889$), implying a link between soil acidity and calcium availability.

Organic matter content emerged as a critical factor influencing soil structure. It exhibited a strong positive correlation with water-stable macroaggregates ($r = 0.943$) and a negative correlation with bulk density ($r = -0.938$). These findings highlight the role of organic matter in enhancing soil aggregation and porosity. Enriching soil with organic matter could therefore be a strategic management practice to improve soil physical conditions and water retention.

Furthermore, exchangeable calcium was positively correlated with pH ($r = 0.889$) and negatively correlated with free aluminum oxide ($r = -0.951$). These relationships suggest that calcium-based amendments could help ameliorate soil acidity and reduce aluminum toxicity risks.

Overall, these results underscore the complex interplay among soil properties and their implications for agricultural management in the Central Plain of Manipur. Targeted interventions to enhance organic matter content and manage soil pH could significantly improve soil health and crop performance.

Conclusion

The findings of this study highlight the significant variability in soil physical properties across the agricultural landscapes of Imphal Valley. The predominance of clayey textures underscores the necessity for site-specific management strategies. Strong positive correlations between bulk density and particle density, as well as between water-stable macroaggregates and silt content, emphasize the intricate interplay of soil components. Conversely, the negative correlation between microaggregation and clay content suggests potential challenges related to soil structure that need to be addressed.

To ensure the sustainable cultivation of Imphal Valley's agricultural lands, a comprehensive soil management framework is essential. This framework should include detailed soil mapping, regular monitoring of soil health, and the integration of these data into land-use planning. By implementing tailored management strategies such as incorporating organic matter amendments and precise water management techniques it is possible to address the challenges posed by the diverse soil

conditions and enhance agricultural sustainability in the region

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