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A Study on Soil Particle Distribution and Nutrient Availability in Maize-productive Zones of Jagtial District, Telangana, India

Jogender. P [a*], Srijaya. T [b++], Madhavi. A [c#] and Padmaja. B [d++]

[a] Department of Soil Science and Agricultural Chemistry, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad, Telangana, India.
[b] Agricultural Research Station, Tornala, Siddipet, Telangana, India.
[c] AICRP on STCR, Institute of Soil Health Management, Agricultural Research Institute, Rajendranagar, Hyderabad, Telangana, India.
[d] AICRP on Weed Management, Rajendranagar, Hyderabad, Telangana, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The current investigation involved a comprehensive field survey aimed at analysing the distribution of particle sizes and the availability of essential nutrients in maize soils cultivated during the rabi season (2022-2023) across three distinct productivity zones in Jagtial district, Telangana. These zones were categorized based on their maize yield: low (<2726 kg ha^{-1}), medium (2726-2924 kg ha^{-1}), and high (<2924-3122 kg ha^{-1}). Prior to sowing the rabi maize crop, a total of 225 surface soil samples (0 - 15 cm depth) were meticulously gathered using a stratified random sampling method.

[++] *Principal Scientist;*
[#] *Principal Scientist & Head;*
**Corresponding author: E-mail: jogenderchouhan007@gmail.com;*

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This sampling approach ensured representation from each of the three productivity regions based on maize yield, amounting to 75 samples per region. These samples are now undergoing thorough analysis to assess soil texture and quantify the availability of key nutrients such as nitrogen (N), phosphorus (P), and potassium (K). The sand, silt, and clay content in low, medium, and high productivity regions are 44.56%, 44.00%, and 42.84% for sand; 23.60%, 23.36%, and 21.97% for silt; and 31.84%, 32.64%, and 35.19% for clay, respectively. These figures show a slight decrease in sand and silt content and an increase in clay content as productivity increases. This trend suggests that high productivity soils have a denser texture with higher clay content, which can impact water retention and nutrient availability, important factors for plant growth and soil management practices. The respective available nitrogen (N), phosphorus (P), and potassium (K) showed mean values of 172.36 kg/ha, 189.05 kg/ha, and 198.80 kg/ha for N; 27.18 kg/ha, 30.64 kg/ha, and 59.37 kg/ha for P; and 337 kg/ha, 350.47 kg/ha, and 363.85 kg/ha for K in low, medium, and high productivity regions, respectively. These values indicate an increase in available N, P, and K with increasing productivity, indicated by large standard deviation and coefficient of variation values across productivity regions, suggesting that higher productivity regions have more nutrient-rich soils, which can support more robust plant growth and contribute to higher agricultural yields.

Keywords: Productivity; particle size analysis; primary nutrients; available nitrogen; available phosphorus; available potassium.

1. INTRODUCTION

Soil quality refers to the capacity of soil to support agricultural activities without degradation or environmental harm [1]. This concept is pivotal for sustainable agricultural production. Regular assessments of soil quality are essential for enhancing yields and guiding management strategies to address various soil-related challenges. Defined as the ability of soil to function within ecosystem boundaries, soil quality aims to sustain biological productivity, preserve environmental integrity, and promote health in plants, animals, and humans [2].

Soil quality assessments are typically more site-specific and complex compared to evaluations of water and air quality, which have established legal requirements [3]. Quantitative evaluations of soil quality can provide crucial insights into whether the soil resource base can meet the growing global demand for food and fibre. Studying soil quality is essential for identifying effective soil management approaches and informing decisions about land use. By understanding and assessing soil quality, we can better ensure sustainable agricultural practices and the long-term productivity of agricultural lands. Soil quality fluctuates due to inherent variability in soil properties, changes in land use practices, and the requirements of crops for optimal growth under varying climatic conditions, management techniques, and occasional natural events [4,5]. Various physical, chemical, and biological indicators have been proposed to assess soil quality, reflecting its multifaceted nature and the diverse impacts of human and environmental factors [6,7]. These indicators are crucial for evaluating soil health and guiding sustainable soil management practices to maintain or improve agricultural productivity while preserving environmental quality.

Physical characteristics such as soil texture, bulk density, total porosity, air-filled porosity, hydraulic conductivity, soil crusting, and depth play crucial roles in shaping root formation, thereby influencing plant growth and performance. Soil texture affects root penetration and nutrient availability, while bulk density and porosity determine the soil's ability to retain water and air, crucial for root respiration and nutrient uptake. Hydraulic conductivity influences water movement in the soil, affecting the accessibility of water and dissolved nutrients to roots. Soil crusting can inhibit root penetration and nutrient uptake, while adequate soil depth provides space for root expansion and anchorage, essential for plant stability and nutrient absorption. Managing these physical soil characteristics is essential for optimizing root development and ultimately enhancing agricultural productivity sustainably.

Contribute to physical characteristics, soil fertility profoundly influences plant growth, primarily through the availability of water, micronutrients, organic matter, and essential nutrients like nitrogen (N), phosphorus (P), and potassium (K). The NPK ratio, which represents the balance of these nutrients, is critical for determining crop productivity, quality, and yield. Proper fertilization practices aimed at maintaining a balanced NPK ratio are essential for maximizing agricultural output while minimizing environmental impact [8]. This approach ensures that crops receive optimal nutrition for robust growth, enhancing both economic returns and sustainability in agriculture.

In India, the maize is used as human food (23%), poultry feed (51 %), animal feed (12 %), industrial (starch) products (12%), beverages and seed (1 % each). In addition, it is basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc., It can be cultivated round the year. In Telangana, maize is the second major crop occupies an area of 5.6 lakh ha with a production of 16 lakh tones annually (https://pjtsau.edu.in/crop.html). Among the various maize growing districts in Telangana highest area was observed in Kamareddy, Nirmal, Warangal (rural & urban), Khammam and Jagtial districts [9]. Among the above districts the yields recorded in Jagtial district is less compared to other districts. Therefore, recognizing the crucial role of soil properties in influencing maize productivity, this study aims to investigate the variations in soil characteristics across different productivity levels of maize fields. By examining key soil properties such as nutrient content, pH, and physical structure, the study seeks to uncover the factors contributing to varying yields in maize cultivation. The findings will inform the development of sustainable land management practices tailored to enhance grain yield and promote agricultural sustainability in maize-growing regions.

2. MATERIALS AND METHODS

2.1 Location of Study Site

Jagtial is a district of Telangana with its geographical locations 18.7895° North latitude and 78.9120° East longitude. Its elevation is 258 meter above mean sea level. Jagtial is carved out from erstwhile Karimnagar district of Telangana state and is spread over an area of 2,419 sq.km. This district shares its boundaries with Nirmal, Mancherial, Karimnagar and Nizamabad districts (https://Jagtial.telangana.gov.in/about-district/). Fig. 1 provides an illustration of the maize soil regions in Jagtial district, Telangana, India, where the study was conducted.

2.2 Soil Sample Collection

The current study involved surveying and collecting soil samples from the study area where rabi maize was cultivated. The mandals of the district were divided by following the statistical procedure (Descriptive Statistics-range, mean and standard deviation), they were categorized into low (<2726 kg ha^{-1}), medium (2726-2924 kg ha^{-1}), and high (<2924-3122 kg ha^{-1}) productive regions based on area and yield data obtained from the District Agriculture Office, Jagtial. A total of 225 samples were collected, with 75 samples from each productive region, specifically from the topsoil layer (0 – 15 cm deep), before the sowing of the rabi maize crop during the 2022-2023 season, using a stratified random sampling method. These samples were air-dried, crushed to pass through a 2 mm sieve, stored in plastic bags, and subjected to further laboratory analysis.

2.3 Laboratory Analysis

The collected soil samples were analysed for several parameters. Soil texture was determined using the Bouyoucos hydrometer method, which provides particle size distribution information as described by Piper [10]. Available nitrogen content was assessed using the alkaline permanganate method [11]. Available phosphorus was measured using Olsen's method with colorimetric analysis at 660 nm [12]. Available potassium was determined by extracting the soil with neutral normal ammonium acetate and measuring with a flame photometer [13]. These analyses aimed to explore the relationship between soil characteristics and maize productivity in the three regions of Jagtial district.

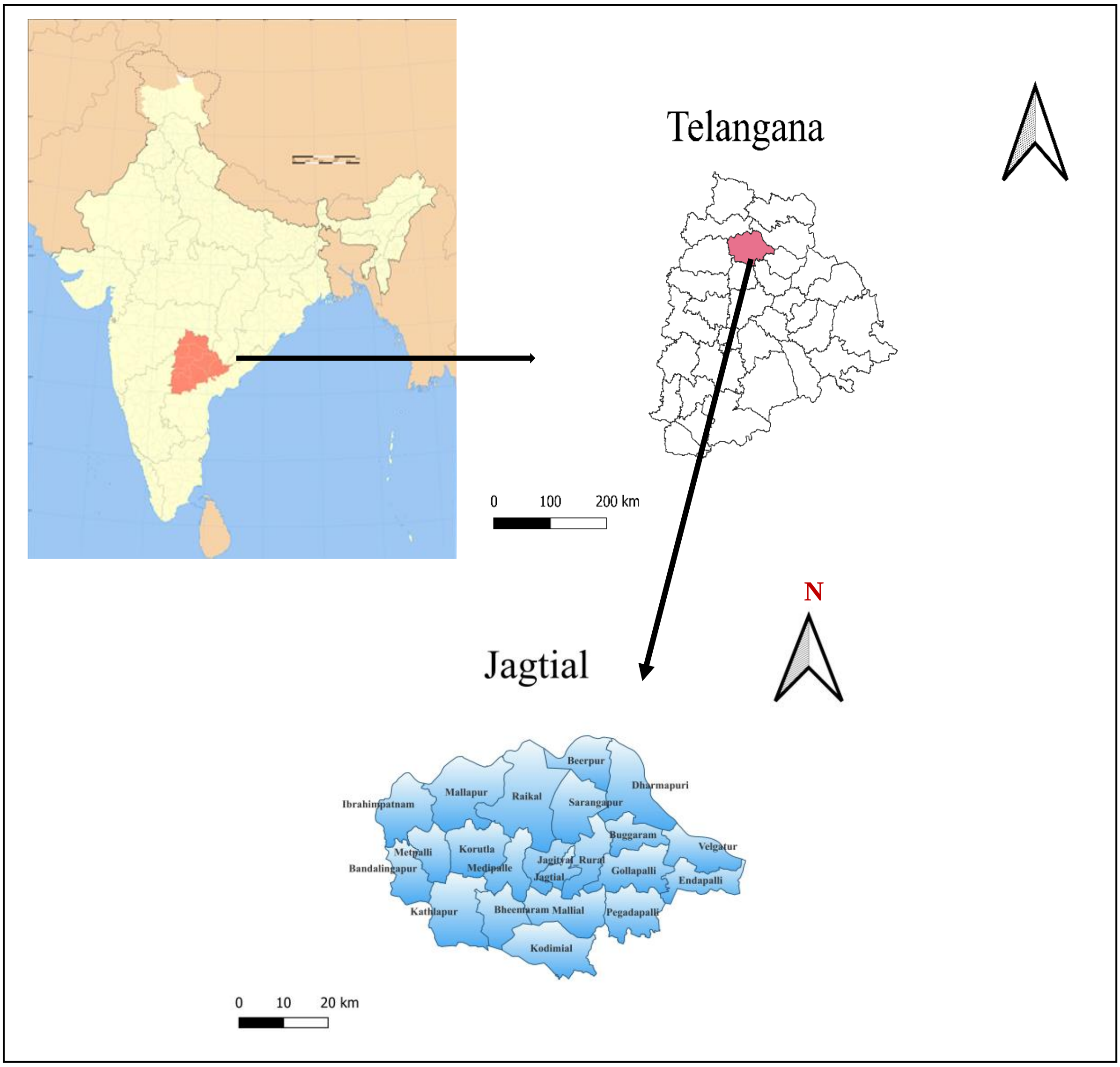

Fig. 1. Location of the Study Site

3. RESULTS AND DISCUSSION

3.1 Performing the Particle Size Analysis for Each of the Three Productivity Zones

In the study area, soil physical characteristics, as detailed in Table 1 and Fig. 2, illustrate the diverse particle size distribution across different soil types such as sandy clay loam, clay loam, clay, sandy clay, sandy loam, and loam. In low productivity regions, sand content ranged from 28.30% to 71.40%, averaging 44.56% with a standard deviation of 10.51 and a coefficient of variation of 23.58%. Medium productivity areas showed sand content ranging from 23.00% to 63.40%, averaging 44.00% with a standard deviation of 10.73 and a coefficient of variation of 24.39%. High productivity regions exhibited sand content ranging from 20.40% to 61.40%, averaging 42.84% with a standard deviation of 9.56 and a coefficient of variation of 22.31%. These findings highlight the variability in soil composition across different productivity zones within the study area.

In regions with low productivity, the silt content ranged from 2.90% to 32.80%, averaging 23.60% with a standard deviation of 6.56 and a coefficient of variation of 27.80%. Medium productivity areas showed silt content ranging from 9.97% to 34.10%, averaging 23.36% with a standard deviation of 5.74 and a coefficient of variation of 24.59%. High productivity regions exhibited silt content ranging from 10.00% to 36.00%, averaging 21.97% with a standard deviation of 6.05 and a coefficient of variation of 27.57%. These variations highlight the different silt compositions across varying productivity zones within the study area.

In regions characterized by low productivity, clay content ranged from 18.20% to 45.20%, with an average of 31.84%, a standard deviation of 6.83, and a coefficient of variation of 21.45%. Medium productivity areas exhibited clay content ranging from 20.40% to 49.20%, averaging 32.64% with a standard deviation of 7.43 and a coefficient of variation of 22.77%. High productivity regions displayed a clay content range of 22.80% to 52.70%, with an average of 35.19%, a standard deviation of 6.59, and a coefficient of variation of 18.72%. Fig. 2 visually represents the distribution of soil particles across these three distinct productivity regions, providing a clear depiction of the variation in clay content within the study area.

Regarding the analysis of the composition of clay, low productivity regions showcased a range of 18.20% to 45.20%, averaging at 31.84% with a standard deviation of 6.83 and a 21.45% coefficient of variation. In medium productivity areas, the range was 20.40% to 49.20%, averaging at 32.64% with a standard deviation of 7.43 and a 22.77% coefficient of variation. High productivity regions displayed a range of 22.80% to 52.70 %, with an average of 35.19%, standard deviation of 6.59, and a 18.72% coefficient of variation. Fig. 2 provides a graphical representation of distribution of soil particles in three productive regions.

The soil composition across the three productivity regions exhibited distinct characteristics. Sand content was highest in low productivity areas, while silt content showed significant variability, particularly in medium and low productivity zones. Clay content was notably higher in high productivity regions, with low productivity areas displaying considerable variation. High productivity regions typically had lower sand content and higher silt and clay contents, promoting better soil particle aggregation. This trend mirrors findings in previous studies on paddy soils by Liu et al. [14]. Particle size distribution, influencing soil texture, plays a crucial role in root development, water retention, and nutrient uptake. Clay-rich soils, for instance, enhance grain yield by retaining water and nutrients, resulting in more tillers, heavier seeds, and improved grain filling compared to sandy soils [15 and 16]. The variability in particle size distribution underscores the importance of soil aggregation for effective agricultural management.

3.2 Computation of Primary Nutrients in the Three Productivity Regions

3.2.1 Available nitrogen

Nitrogen is essential for plants, crucial for their metabolic processes and as a fundamental component of proteins. In soil, nitrogen exists in organic forms from decaying organic matter,

Table 1. Descriptive statistics of particle size distribution (%) in the three maize productivity soils

Low productivity regions (n = 75)					
Soil Property	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Sand (%)	28.3	71.4	44.56	10.51	23.58
Silt (%)	5.9	32.8	23.6	6.56	27.8
Clay (%)	18.2	45.2	31.84	6.83	21.45
Medium productivity regions (n = 75)					
Soil Property	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Sand (%)	23	63.4	44	10.73	24.39
Silt (%)	9.97	34.1	23.36	5.74	24.59
Clay (%)	20.4	49.2	32.64	7.43	22.77
High productivity regions (n = 75)					
Soil Property	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Sand (%)	20.4	61.4	42.84	9.56	22.31
Silt (%)	10	36	21.97	6.05	27.57
Clay (%)	22.8	52.7	35.19	6.59	18.72

**SD – Standard deviation, CV – Coefficient of Variation*

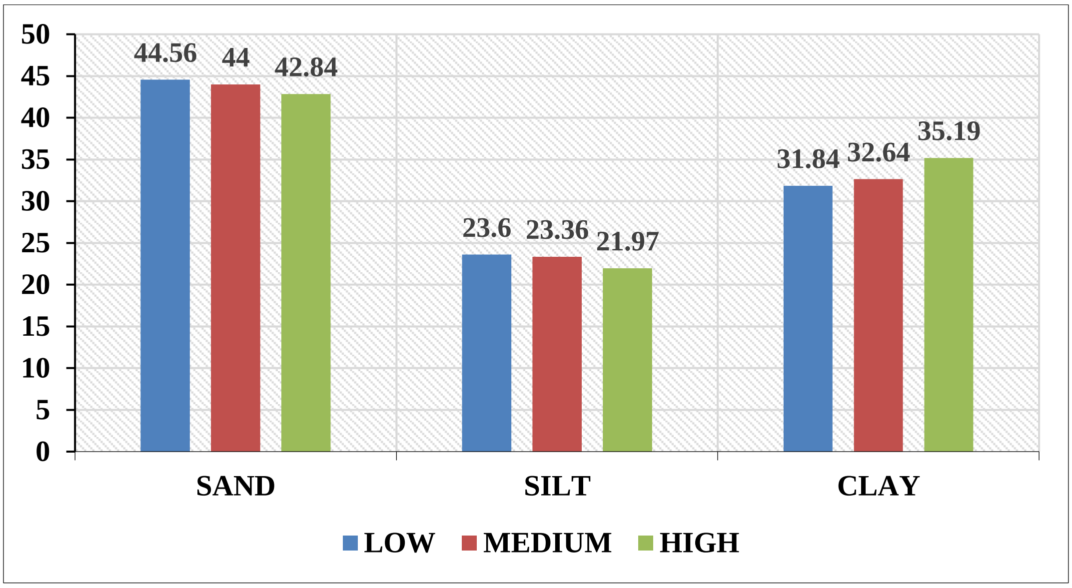

Fig. 2. Particle size distribution among the three productivity maize regions

Table 2. Descriptive statistics of primary nutrients among the three maize productivity regions

Low productivity regions (n = 75)					
Soil Property	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Available Nitrogen (kg ha^{-1})	108	263	172.4	34.3	19.9
Available Phosphorus (kg ha^{-1})	9.59	51.2	27.18	10.3	37.8
Available Potassium (kg ha^{-1})	207.23	521.01	337.8	80.2	23.7
Medium productivity regions (n = 75)					
Soil Property	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Available Nitrogen (kg ha^{-1})	113	299	189.1	42.2	22.3
Available Phosphorus (kg ha^{-1})	11.87	87.99	30.64	13.5	44.1
Available Potassium (kg ha^{-1})	211.08	559.79	350.5	78.7	22.5
High productivity regions (n = 75)					
Soil Property	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Available Nitrogen (kg ha^{-1})	120	298	198.8	41	20.6
Available Phosphorus (kg ha^{-1})	22.67	98.4	59.37	18.6	31.3
Available Potassium (kg ha^{-1})	188.36	752.63	363.9	99.1	27.2

**SD – Standard deviation, CV – Coefficient of Variation*

initially unavailable to plants. Through microbial activity, organic nitrogen is converted into mineral forms like ammonium and nitrate, which plants can absorb from the soil to support their growth and overall health. This dynamic process of nitrogen transformation ensures plants have access to the nutrients they need for optimal development.

In the current study, available nitrogen (N) levels varied across different productivity regions (Table 2). In low productivity areas, nitrogen ranged from 108.00 to 263.00 kg ha^{-1}, with a mean of 172.36 kg ha^{-1}, a standard deviation of 34.26, and a coefficient of variation of 19.88%. Medium productivity regions showed nitrogen levels ranging from 113.00 to 299.00 kg ha^{-1}, averaging 189.05 kg ha^{-1}, with a standard deviation of 42.16 and a coefficient of variation of 22.30%. High productivity regions exhibited nitrogen levels ranging from 120.00 to 298.00 kg ha^{-1}, with an average of 198.80 kg ha^{-1}, a standard deviation of 41.01, and a coefficient of variation of 20.63%. These outcomes are in line with the findings of Li et al. [17]. The mean available nitrogen values showed an increasing trend from low to medium and then to high productivity regions. However, there was moderate variability in nitrogen levels across all three productivity zones, with higher variability observed in medium and high productivity areas. Overall, the categorization suggests a moderate level of nitrogen availability in the soils across the studied regions, influencing the productivity potential of these agricultural areas.

3.2.2 Available phosphorus

Phosphorus, being one of the macronutrients, is essential for the transformation of sugars and starches, photosynthesis, energy transfer, and nutrient flow inside plants. The current study's available phosphorus (P) in low productivity regions ranged from 9.59 to 51.20 kg ha^{-1}, with a mean of 27.18 kg ha^{-1}, a standard deviation of 10.26, and a coefficient of variation of 37.76 %. Medium productivity regions showed a wider range from 11.87 to 87.99 kg ha^{-1} with a mean of 30.64 kg ha^{-1}, having standard deviation of 13.52 and coefficient of variation 44.13 %. In high productivity regions, the range fluctuated between 22.67 to 98.40 kg ha^{-1} with a mean of 59.37 kg ha^{-1}, having standard deviation of 18.56 and coefficient of variation 31.26 %, respectively (Table 2).

Phosphorus is a vital macronutrient essential for numerous biochemical processes in plants, including the transformation of sugars and starches, photosynthesis, and energy transfer. In the current study, available phosphorus (P) levels varied significantly across different productivity regions (Table 2). Low productivity regions exhibited phosphorus levels ranging from 9.59 to 51.20 kg ha^{-1}, with a mean of 27.18 kg ha^{-1}, a standard deviation of 10.26, and a coefficient of variation of 37.76%. Medium productivity regions showed a broader range of phosphorus concentrations, ranging from 11.87 to 87.99 kg ha^{-1}, with a mean of 30.64 kg ha^{-1}, a standard deviation of 13.52, and a coefficient of variation of 44.13%. In high productivity regions, phosphorus levels ranged from 22.67 to 98.40 kg ha^{-1}, averaging 59.37 kg ha^{-1}, with a standard deviation of 18.56 and a coefficient of variation of 31.26%. These outcomes are in line with the findings of Dutta et al. [18]. These findings highlight significant variability in phosphorus availability across different productivity zones, underscoring the importance of tailored nutrient management strategies to optimize plant growth and agricultural productivity in each region.

3.2.3 Available potassium

Potassium, an essential component of soil minerals, is not easily accessible to plants due to its limited availability in exchangeable forms and the soil solution. Plants can only absorb a small portion of the total soil potassium. The accessibility of potassium is influenced by the type of soil parent materials and the effects of weathering processes, which determine how much potassium is released into forms that plants can utilize.

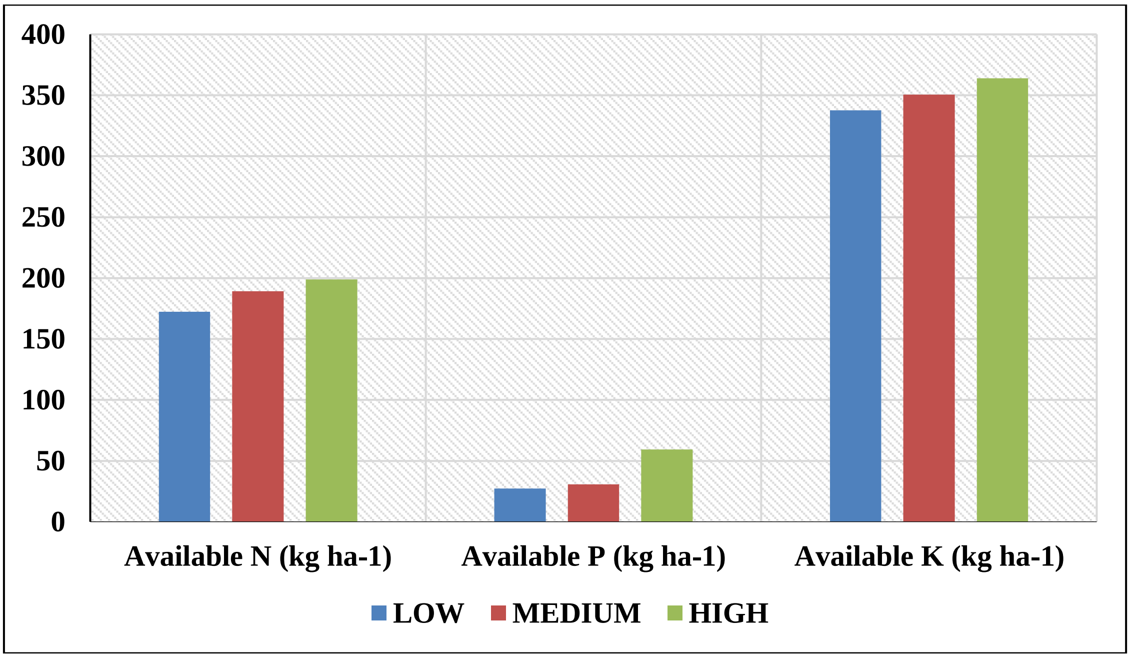

Fig. 3. Depiction of essential nutrients across three maize productivity regions

The available potassium (K) content in soils varied significantly across different productivity regions (Table 2). In low productivity areas, potassium levels ranged from 207.23 to 521.01 kg ha^{-1}, with a mean of 337.77 kg ha^{-1}, a standard deviation of 80.20, and a coefficient of variation of 23.74%. Medium productivity regions had potassium levels ranging from 211.08 to 559.79 kg ha^{-1}, with a mean of 350.47 kg ha^{-1}, a standard deviation of 78.71, and a coefficient of variation of 22.46%. High productivity regions exhibited potassium levels ranging from 188.36 to 752.63 kg ha^{-1}, with a mean of 362.85 kg ha^{-1}, a standard deviation of 99.09, and a coefficient of variation of 27.24%. These findings, categorized from medium to high, align with those reported by Sinha et al. [19] and Qian et al. [20]. Fig. 3 provides a graphical representation of primary nutrient values in the three productivity regions. The high standard deviation and coefficient of variation values across these regions suggest a wide dispersion of potassium levels, which may be attributed to factors such as soil composition, weathering, and environmental influences. Farmers and agronomists should consider these variations in soil conditions when implementing fertilization strategies to ensure optimal nutrient availability for crops [21,22].

4. CONCLUSION

The research reveals significant variances in the amounts of sand, silt, and clay, defining the various soil compositions that contribute to the specific features of each productivity zone. Low productivity zones were characterized by the highest mean sand levels, affecting soil particle aggregation and consequently reducing crop output. Silt content displayed considerable variation, particularly in medium and low productivity zones, influencing water retention and nutrient availability. Conversely, clay concentration varied, with the highest mean found in high productivity areas, favouring soil particle aggregation, improving soil structure, and enhancing moisture retention. The study revealed a downward trend in nitrogen availability from high to medium and medium to low productivity zones, with soils exhibiting low to medium nitrogen levels. Agricultural management techniques that account for phosphorus dynamics within each productivity category are crucial, as evidenced by documented changes in accessible phosphorus levels. The substantial standard deviation and coefficient of variation in potassium levels across productivity zones indicate wide distribution within each category. Consequently, agronomists and farmers should consider various soil parameters and factors affecting potassium availability when developing fertilization plans. Particle size distribution, which determines soil texture, affects water and nutrient uptake, thereby impacting root production and ultimately yield. These findings highlight the importance of understanding soil composition to optimize agricultural practices and boost productivity in different regions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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