International Journal of Plant & Soil Science

Volume 35, Issue 20, Page 490-497, 2023; Article no.IJPSS.106524
ISSN: 2320-7035

Evaluating the Primary Macronutrients and their Correlations with pH, Electrical conductivity, Organic Carbon and Soil Nutrient index in the Arid and Semi-Arid Climatic Zones of Anantapur District, Andhra Pradesh, India

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Authors' contributions

This work was carried out in collaboration between all authors. Author SLG designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors ND and SR managed the analyses of the study. Author MV managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i203832

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/106524

Original Research Article

Received: 15/07/2023
Accepted: 20/09/2023
Published: 25/09/2023

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ABSTRACT

In the year 2022, the study was carried at Agricultural Research Station, Anantapur aimed to assess macronutrient levels and their correlation with soil physico chemical properties in the arid and semi-arid regions of Anantapur district, Andhra Pradesh. A total 42 samples were collected from farmers field under different land use. The soil analysis revealed a pH range of 6.53 to 8.94, with a mean pH of 7.89 and a majority of samples exhibiting alkaline properties. Soil electrical conductivity (EC) varied from 0.05 to 0.83 dS/m, with a mean EC of 0.22 dS/m, and most samples falling within the non-saline and very low salinity categories. Organic carbon content ranged from 0.07% to 1.15% with a mean of 0.38%, and a significant proportion of samples displayed low organic carbon levels. Available nitrogen content ranged from 50.4 to 264.6 kg/ha (mean: 139.44 kg/ha), mostly below the critical threshold. Phosphorus availability was medium (range: 16.1 to 44 kg/ha, mean: 29.97 kg/ha), while available potassium content varied widely (range: 15.68 to 311 kg/ha, mean: 129.65 kg/ha), with a substantial proportion of samples indicating low levels. The nutrient index categorized nitrogen and potassium as low in fertility and phosphorus as medium, reflecting values of 0.71, 1.37, and 1.09 (L, M, L) respectively. Correlations showed EC negatively related to pH (-0.056), while organic carbon positively correlated with EC (0.288*), and nitrogen displayed positive correlations with both organic carbon (0.283*) and pH (0.257). Phosphorus exhibited a positive correlation with organic carbon (0.224), and potassium displayed robust positive correlations with EC (0.592**) and moderate positive correlations with organic carbon (0.392**), nitrogen (0.311*), and a slight negative correlation with pH (-0.253). This result helps to understand nutrient status in the arid and semi-arid areas of Anantapur and recommended to incorporate compost, crop residues and green manure crops and use cover crops as live mulching helps to increase organic carbon, nitrogen and potassium and it also decrease nitrogen losses through volatilization.

Keywords: pH; electrical conductivity; nitrogen; organic carbon; phosphorus; potassium.

1. INTRODUCTION

In India, arid and semi-arid regions occupy a substantial portion of the country's landmass, particularly in the northwestern and western parts, including states like Rajasthan, Gujarat, Haryana, and parts of Madhya Pradesh, Rayaalaseema region of Andhra Pradesh and Maharashtra. These regions are characterized by limited and erratic rainfall, high temperatures, and water scarcity, making them particularly vulnerable to soil-related challenges. Arid and semi-arid regions of India often exhibit soil conditions characterized by low organic carbon content, nutrient deficiencies (particularly nitrogen and phosphorus), alkaline pH levels, and salinity challenges [1,2].

In dryland agriculture, managing soil properties like pH (acidity/alkalinity), electrical conductivity (EC), and organic carbon (OC) is essential for maximizing crop productivity and sustainability. Soil pH affects nutrient availability to plants, with many dryland soils tending to be alkaline (high pH), which can lead to nutrient imbalances and reduced crop yields [3]. Electrical conductivity, which indicates soil salinity, is a critical parameter in drylands as excessive salinity can harm crops, making it crucial to monitor and manage soil salinity levels [4]. Organic carbon is essential for maintaining soil structure, water-holding capacity, and microbial activity, all of which are vital for dryland soils' resilience to drought and sustainable agriculture [5].

Macronutrients, including nitrogen (N), phosphorus (P), and potassium (K), play a crucial role in dryland agriculture by influencing crop productivity, water use efficiency, stress tolerance, and soil health. Proper nutrient management, guided by soil testing and balanced fertilizer application, can enhance crop yields and economic viability for farmers in water-scarce regions [6]. These macronutrients not only improve plant growth but also contribute to environmental sustainability by reducing nutrient runoff and preserving fragile ecosystems [7]. In dryland environments, where resource limitations and climate variability pose significant challenges, the effective utilization of macronutrients is essential for ensuring food security and sustainable agriculture.

Maintaining proper soil pH, managing salinity, and increasing organic carbon and macronutrient content through practices like conservation tillage and organic matter incorporation are fundamental strategies for enhancing dryland agriculture's resilience and productivity [8] [5]. These soil properties, when managed effectively, can help dryland farmers mitigate the challenges of limited water resources and environmental stressors, contributing to food security and sustainable agriculture.

In the southern part of Andhra Pradesh, Specifically in Anantapur district, India, the predominant weather conditions are characterised by arid and Semi-arid climates, have given rise to specific soil challenges. Soil physical properties, characterized by low organic carbon content, are often a concern due to limited vegetation cover and minimal organic matter incorporation practices. Additionally, micronutrient deficiencies are common, with nitrogen, phosphorus, and potassium levels frequently falling below optimal ranges, which can hinder crop growth and productivity. Some areas in the district may also face soil salinity and alkalinity issues, further limiting agricultural options. Efforts to address these challenges in Anantapur District involve the adoption of improved farming practices, targeted nutrient management strategies, and soil conservation measures, all aimed at enhancing soil fertility and promoting agricultural sustainability [9] [10].

2. MATERIALS AND METHODS

2.1 Study Area

Ananntapur district is located within the geographical coordinates of 76º 47′ to 78º 26’E longitude in the east and 13º 41′ to 15º 14’N latitude in the north. It shares its boundaries with Kurnool District to the north, Chittoor District to the southeast, YSR District to the east, and the state of Karnataka to the west and southwest. The typical range of temperatures in the region spans from a minimum of approximately 22.9°C to a maximum of around 34°C, while the average annual rainfall registers at approximately 556 mm.

2.2 Soil Sample Collection

A total 42 soil samples were randomly collected from farmers' fields under different land uses *viz.,* ground nut and millet crops like finger millet, foxtail millet, kodo millet, Barnyard millets etc in Penukonda division of the Sri Satya Sai district. With the help of Khurpi, Spade and metre scale the soil samples were collected randomly from 30 cm depth and air-dried and then sieved (>2 mm) for the analysis of soil fertility.

2.3 Soil Analysis

The pH was determined in 1:2 soil water suspensions using a digital pH meter [11]. The EC was determined in 1:2 soil water suspensions using a digital EC meter [12]. Organic carbon was measured by the chromic acid wet digestion method [13]. Available nitrogen(N) was determined by using the alkaline potassium permanganate method [14], and available phosphorus(P) in the soil was estimated calorimetrically by a Photoelectric Colorimeter [15], and available potassium (K) was determined by Flame Photometer [16].

Nutrient Index: The nutrient index categorization and calculation were done [17], which are discussed below:

$$N.I = \{(1 \times A) + (2 \times B) + (3 \times C)\}/ TNS$$

Where,

A = Number of samples in low category;
B = Number of samples in medium category;
C = Number of samples in high category,
TNS = Total number of samples.

Pearson’s correlation was applied to analyse the associations among different soil properties.

The Pearson correlation coefficient can take values between -1 and 1. *i.e.,* r = 1, it indicates a perfect positive linear relationship, r = -1, it indicates a perfect negative linear relationship, r = 0, it suggests no linear relationship between the two variables.

$$r = \frac{n(\sum xy) \ - (\sum x) \ - (\sum y)]}{\sqrt{[n(\sum x2) - (\sum x)2][n(\sum y2) - (\sum y)2]}}$$

Where:

- *n* is the number of data points (observations).
- *x* and *y* are the values of the two variables for each data point.

3. RESULTS AND DISCUSSION

3.1 pH

The estimation of soil pH is important for agricultural production, which affects soil acidity and base reactions [18]. The pH of the soil samples ranged from 6.53 to 8.94, with mean of

7.89. (Table 1). Most soil samples are more alkaline (pH 7.5 - 9.0), 33 of which are classified as such. There were also 9 neutral (pH 6.5 - 7.5) (Table 2). The alkaline pH of soils is due to the presence of high CaCO3 in the soils [19]. Calcium carbonate is a common alkaline substance that can raise soil pH when it reacts with water, releasing carbonate ions (Co_3^{2-}), and hydroxide ions (OH^-).

3.2 Electrical Conductivity (dS/m)

High or excessively low levels of soil electrical conductivity (EC) can significantly impact crop growth and indicate insufficient effective nutrients in the soil. Soil electrical conductivity is closely associated with various soil properties, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter levels, salinity, and subsoil characteristic [20]. In the present study, soil EC values ranged from 0.05 to 0.83 dS/m, with a mean of 0.22 (Table 1). Most of the soil samples were non-saline (EC < 0.1 dS/m), with 14 samples classified in this category. Furthermore, 17 samples exhibited very low salinity (EC ranging from 0.1 to 0.3 dS/m), 9 samples had moderate salt levels (EC ranging from 0.3 to 0.5 dS/m), and 2 samples displayed strong salinity (EC ranging from 0.5 to 1.0 dS/m) (Table 3). In arid and semi-arid regions, it is often considered normal for soils to have elevated electrical conductivity (EC) levels due to the limited rainfall in these environments [4].

3.3 Organic Carbon (OC%)

Organic carbon content in soil serves as a vital indicator of soil quality, with significant implications for nutrient availability, microbial activity, soil moisture retention, reduction in bulk density, and enhancement of crop productivity [21]. In the current study, soil samples exhibited a range of organic carbon content, ranging from 0.07% to 1.15% with a mean of 0.38(Table 1). Predominantly, most samples displayed low organic carbon levels (below 0.50%), with 34 samples falling into this category. Additionally, 7 samples featured medium carbon content (ranging from 0.50% to 0.75%), while 1 sample boasted a high carbon content exceeding 0.75%, (Table 4). Arid regions often experience high temperatures, which can accelerate the decomposition of organic matter in the soil, with microorganisms responsible for breaking down organic material being less active at higher temperatures, leading to reduced organic matter accumulation [22].

Table 1. The Mean, Median, Sd and Min - Max values of physicochemical and macronutrient of arid and semi-arid climate regions of Anantapur district, Andhra Pradesh, India

	Ph	EC	OC (%)	N	P	K
Min	6.53	0.05	0.07	50.40	16.10	15.68
Max	9.05	0.83	1.15	264.60	44.00	311.00
Mean	7.89	0.22	0.38	139.44	29.97	129.65
Median	7.84	0.16	0.38	126.00	30.00	113.00
Sd	0.59	0.18	0.21	48.02	6.45	60.96
CV%	7.48	81.82	55.26	34.44	21.52	47.02

Table 2. Soil Ph ranges

Category	pH	Count
Acidic	6.0 - 6.5	0
Neutral	6.5 -7.5	9
Alkaline	7.5 - 9.0	33
Total		42

Table 3. Soil EC ranges

Category	Range	Count
Non – Saline	0 - 0.1	14
Very Slightly saline	0.1 -0.3	17
Moderately saline	0.3-0.5	9
Strongly saline	0.5-1.0	2
Very Strongly saline	>1.0	0
Total		42

3.4 Available Nitrogen (Kg/ha)

Nitrogen, as a fundamental macronutrient for plant growth, plays an important role in shaping plant productivity [23]. In the present study nitrogen content, ranged from 50.4 to 264.6 kg/ha with a mean of 139.44 kg/ha (Table 1). Predominantly, a significant majority of soil samples exhibited low nitrogen content, with 41 samples falling below the critical threshold of 250 kg/ha, & 1 medium (250 to 500kg/ha) (Table 5). Low nitrogen status in soils could be due to a lack of organic carbon in the soils, and erratic precipitation has a significant impact on nitrogen availability [24].

Table 4. Soil OC ranges

Category	Range	Count
Low	<0.50	34
Medium	0.50 - 0.75	7
High	>0.75	1
Total		**42**

Table 5. Soil N ranges

Category	Range	Count
Low	<250	41
Medium	250 – 500	1
High	>500	0
Total		**42**

3.5 Available Phosphorus (kg/ha)

Phosphorus, an important nutrient for plant growth and development, assumes a multifaceted role in various physiological processes, including cell division, fruit maturation, and energy transfer from sunlight, thereby improving grain quality and yield. The characteristic symptoms of phosphorus deficiency [25], include dark green foliage, stunted growth, and reduced leaf size. In the present study, the available phosphorus(P) values ranged from 16.1 to 44 kg/ha with a mean of 29.97 (Table 1). Notably, among the 42 samples examined, 39 exhibited medium phosphorus, & 3 in low levels, as elucidated in (Table 6). This phenomenon can be attributed to the inherent phosphorus retention properties of dryland soils, along with limited leaching due to lower rainfall.

Table 6. Soil P ranges

Category	Range	Count
Low	<20	3
Medium	20-50	39
High	>50	0
Total		**42**

Table 7. Soil K ranges

Category	Range	Count
Low	<125	24
Medium	125-250	16
High	>250	2
Total		**42**

3.6 Available Potassium (kg/ha)

Potassium, a critical nutrient for plants, plays a vital role in promoting plant vigour, enhancing disease resistance, and facilitating vital processes such as photosynthesis and the synthesis of sugars, starches, and oils and improvement of fruit quality. Plants experiencing potassium deficiency often exhibit distinctive symptoms, including brownish and desiccated leaves, along with slender stems [26]. In this study, the available potassium content spanned a broad spectrum, ranging from 15.68 to 311 kg/ha, mean of 129.65 kg/ha (Table 1). Notably, a significant proportion of soil samples demonstrated low potassium content, with 24 samples falling below the threshold of 125 kg/ha and 16 samples exhibited medium potassium content (ranging from 125 to 250 kg/ha), while 2 samples displayed high potassium levels exceeding 250 kg/ha (Table 7). In arid regions, limited rainfall can lead to leaching and erosion of potassium from the soil. This process can wash away soluble potassium ions, making it less available for plants [27]. Arid soils often have low organic matter content, which can result in reduced potassium availability [28].

Table 8. Nutrient index values of macronutrients

Parameters	Nutrient index value	Fertility status
Nitrogen	1.02	Low
Phosphorus	1.92	Medium
Potassium	1.47	Low

Table 9. Correlation with physicochemical properties and macronutrient levels in the arid and semi-arid climate regions of Anantapur district, Andhra Pradesh, India

	pH	EC	OC	N	P	K
pH	1					
EC	-0.056	1				
OC	0.033	0.288*	1			
N	0.257	0.136	0.283*	1		
P	0.125	0.01	-0.146	0.224	1	
K	-0.253	0.592**	0.392**	0.311*	-0.154	1

3.7 Nutrient Index for Major Nutrients

The soil nutrient index was calculated to assess soil nutrient levels, with values less than 1.67 indicating low fertility, values between 1.67 and 2.33 indicating medium fertility, and values greater than 2.33 indicating high fertility. In this specific analysis, the major nutrients nitrogen (N) and potassium (K) were categorized as low in fertility, while phosphorus (P) was categorized as medium in fertility, with corresponding nutrient index values of 0.71, 1.37, and 1.09, respectively (Table 8).

3.8 Correlation

Electrical Conductivity (EC) exhibited a slight negative correlation with pH (-0.056) and Organic Carbon (OC) displayed a positive correlation with EC (0.288*) [29]. Additionally, Nitrogen (N) demonstrated a positive correlation with both OC (0.283*) and pH (0.257), supporting results reported in studies such as [30]. Phosphorus (P) exhibited a positive correlation with OC (0.224), in line with [1]. Moreover, Potassium (K) displayed a robust positive correlation with EC (0.592**) and moderate positive correlations with OC (0.392**), and N (0.311*), as seen in studies by [31], while also revealing a slight negative correlation with pH (-0.253), [23] (Table 9).

4. CONCLUSION

The mean pH of 7.89 indicates alkaline soils, while a majority of samples exhibited low organic carbon levels (mean 0.38%) and nitrogen content below the critical threshold (mean 139.44 kg/ha). Phosphorus availability was moderate (mean 29.97 kg/ha), but available potassium levels varied widely (mean 129.65 kg/ha), with many samples indicating low levels. The nutrient index categorized nitrogen and potassium as low in fertility and phosphorus as medium, reflecting values of 0.71, 1.37, and 1.09, respectively. These findings contribute to understanding the soil and nutrient dynamics in the arid and semi-arid regions of Anantapur. This helps to plan agricultural strategies to enhance crop production and promote sustainability in the area.

ACKNOWLEDGEMENT

We would like to express our gratitude to Agriculture Research Station for their financial support and supporting for sample analysis, which made this research possible. We also thank the dedicated research team and the local communities in Anantapur for their valuable contributions to this study. Finally, we appreciate the guidance of our mentors and the input of our colleagues, which greatly enriched our research efforts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/106524