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Variability in soil physico-chemical properties and leaf macronutrient composition of groundnut in semi-arid soils of Tirupati district, Andhra Pradesh

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Abstract

The present study was conducted to evaluate the influence of soil physico-chemical properties on leaf macronutrient composition of groundnut cultivated in the semi-arid region of Puttur division, Tirupati district, Andhra Pradesh. Twenty surface soil samples were collected from major groundnut growing locations and the soil samples were analyzed for pH, electrical conductivity, organic carbon, calcium carbonate and cation exchange capacity using standard analytical procedures. Index leave samples of groundnut were also collected and analyzed for nitrogen, phosphorus, potassium and sulphur contents. The soils varied from moderately acidic to slightly alkaline in reaction with pH values ranging from 5.97 to 7.74, whereas electrical conductivity indicated non-saline nature of the samples. Organic carbon content ranged from 0.34 to 0.65 per cent. Calcium carbonate content varied from 1.95 to 4.25 per cent, whereas cation exchange capacity ranged from 18.61 to 36.41 cmol (p⁺) kg⁻¹. Leaf nitrogen, phosphorus, potassium and sulphur contents ranged from 2.27 to 3.39, 0.131 to 0.266, 1.82 to 2.60 and 0.27 to 0.55 per cent, respectively. The results revealed that variations in soil physico-chemical characteristics considerably influenced nutrient availability and nutrient uptake by groundnut. The study further highlighted the necessity of site-specific nutrient management practices for maintaining soil fertility and improving groundnut productivity under semi-arid conditions.

Keywords: Groundnut, macronutrients, physico-chemical properties, semi-arid soils.

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the important oil seed crops cultivated in tropical and semi-arid regions of India. It plays a significant role in edible oil production and contributes considerably to agricultural economy. The productivity of groundnut is greatly influenced by soil fertility status and balance in water and management. Macronutrients are essential for proper plant growth, nodulation, photosynthesis, energy transfer and yield formation. Deficiency or imbalance of these nutrients adversely affects crop growth, nutrient uptake and productivity (Kumar *et al.*, 2023) [13]. The availability and uptake of nutrients by crops are largely controlled by soil physicochemical properties. These properties influence nutrient solubility, mobility, retention and transformation in soils. Variability in soil properties under semi-arid regions often leads to differences in nutrient dynamics and crop response (Gudla *et al.*, 2023) [8].

Leaf nutrient analysis is considered as effective diagnostic tool for evaluating the nutritional status of crops because it reflects the actual nutrient uptake by plants. Combined assessment of soil properties and plant nutrient composition provides better understanding of nutrient availability and nutrient use efficiency under varying soil conditions. Such studies are useful for identifying nutrient related constraints on developing suitable nutrient management practices for sustaining crop productivity and soil health (Rajesh *et al.*, 2023) [18]. Soil organic carbon dynamics and nutrient availability are also greatly influenced by management practices and variability in semi-arid soils (Gorooei *et al.*, 2023) [7].

The soils of semi-arid regions often exhibit considerable heterogeneity in their physico-chemical characteristics due to variations in parent material, topography and pedogenic processes. Such variability influences nutrient retention, transformation and crop uptake patterns (Baradwal *et*

al., 2023) [2]. Hence, the present study was undertaken to evaluate leaf macronutrient composition and its relationship with soil physico-chemical properties for developing site-specific nutrient management strategies in groundnut growing soils of Puttur division in Tirupati district, Andhra Pradesh.

Materials and Methods

Study area description

The present investigation was conducted in the groundnut growing soils of Puttur division situated in Tirupati district of Andhra Pradesh. The Puttur division is located in the southern part of the district, lying between the latitudes of 13° 24' and

13° 58' N and longitudes of 79° 23' and 79° 59' E. The climate of the study area is characterized as semi-arid and monsoonic, with three distinct seasons: summer, winter and rainy seasons. The mean annual air temperature for the area is 27.68°C with the yearly rainfall averaging around 1092 mm. The Puttur division consists of four mandals: Puttur, Narayanavanam, Vadamalpeta and Ramachandrapuram mandal. Granite-gneiss is the dominant parent material in the study area. Groundnut is the most prevalent crop in the study area together with other significant crops like rice, sugarcane, mango, coconut, banana, cowpea, niger and chilli. The site characteristics of the surface soils collected are presented in Table 1.

Table 1: Site characteristics of surface soils in the study area

Location (Village)	Latitude (N)	Longitude (E)	Elevation (m)	Crop
Kammapalle	13° 33' 16.90" N	79° 27' 02.60" E	177	Groundnut
T.C. Agraharam	13° 34' 14.90" N	79° 32' 10.00" E	126	Groundnut
Padiredu	13° 33' 15.50" N	79° 32' 14.70" E	132	Groundnut
Seetharamapuram	13° 31' 02.80" N	79° 29' 24.20" E	161	Groundnut
Motavari kandriga	13° 30' 38.10" N	79° 25' 45.40" E	202	Groundnut
C.K. Palli	13° 30' 07.50" N	79° 21' 31.30" E	228	Groundnut
Anupalli	13° 28' 54.60" N	79° 17' 13.40" E	329	Groundnut
S.V. Puram	13° 32' 29.70" N	79° 31' 27.20" E	139	Groundnut
Thaduku	13° 29' 02.90" N	79° 32' 07.90" E	173	Groundnut
Chowtoor	13° 26' 52.40" N	79° 24' 49.60" E	147	Groundnut
Thiruvatyam	13° 26' 18.40" N	79° 35' 37.20" E	153	Groundnut
Boppa Raju Palem	13° 24' 14.60" N	79° 36' 24.70" E	145	Groundnut
Vethala Thaduku	13° 24' 31.60" N	79° 36' 59.5" E	140	Groundnut
Veluthuru kandriga	13° 24' 43.20" N	79° 38' 59.90" E	120	Groundnut
Thumbur	13° 24' 46.80" N	79° 39' 06.80" E	125	Groundnut
Rayalacheruvu	13° 30' 10.30" N	79° 22' 57.50" E	220	Groundnut
KBR Puram	13° 21' 16.00" N	79° 31' 08.50" E	197	Groundnut
Nandhimangalam	13° 24' 53.40" N	79° 33' 11.10" E	151	Groundnut
Mutharasu kandriga	13° 24' 15.20" N	79° 32' 38.20" E	166	Groundnut
Pathiputhuru	13° 33' 30.90" N	79° 28' 23.10" E	155	Groundnut

Soil sampling and analysis

Twenty surface soil samples were collected in groundnut growing soils of Puttur division in Tirupati district, Andhra Pradesh based on the soil variability and land use pattern. The soil samples were collected, processed and analyzed for physico-chemical properties following standard procedures. Soil pH (1: 2.5 soil:water) and 1 N KCl suspensions were quantified potentiometrically, alongside EC (1: 2.5 soil:water) via conductivity meter (Jackson, 1973) [9]. Organic carbon content was analysed by the Walkley and Black's wet oxidation method (Jackson, 1973) [9]. Free calcium carbonate in the soil was estimated by treating the sample with a known volume of standard HCl, followed by back titration of the excess acid with standard alkali using bromothymol blue as an indicator (Piper, 1966) [17]. CEC (cmol (p⁺) kg⁻¹ soil) was assessed by NH₄OAc (pH 7.0) displacement following NaOAc (pH 8.2) saturation and ethanol leaching and sodium in the extract was measured by flame photometer (Bower *et al.*, 1952) [4].

Collection, processing and analysis of plant samples

Index leaf samples (Recently matured leaflets) collected from the plants growing in and around each profile site. The collected leaf samples were washed thoroughly with distilled water and extra moisture was wiped out and dried in shade. Finally, the samples were dried in hot air oven at 70°C, powdered and stored for analysis. The powdered samples were analysed for macronutrients using standard analytical procedures. Nitrogen content was determined by microkjeldahl method (Bremner, 1965) [5], phosphorus was estimated by vanadomolybdo

phosphoric yellow colour method (Jackson, 1973) [9], potassium by flame photometer (Muhr *et al.*, 1963) [16] and sulphur by turbidity method (Cottenie *et al.*, 1979) [6].

Ratings for nutrient contents in leaf samples

The nutrient contents in leaf samples were classified as severely deficient, deficient, marginally adequate and adequate categorized as per the limits suggested by Bell (1990) [3] (Table 2).

Table 2: Sufficiency limits of nutrients for groundnut crop

Element*	Severely deficient	Deficiency	Marginally Adequate	Adequate
Nitrogen (%)	< 3.2	3.2 – 3.7	3.8 – 4.1	4.2 – 4.5
Phosphorus (%)	< 0.19	0.19 – 0.23	0.24 – 0.26	0.27 – 0.40
Potassium (%)	< 0.70	0.70 – 1.3	1.4 – 1.7	1.8 – 2.5
Sulphur (%)	< 0.15	0.16 – 0.20	0.21 – 0.25	0.26 – 0.30

Results and Discussion

Physico-chemical properties of soil

The physico-chemical properties of the surface soils are presented in Table 3. The soils of the groundnut growing areas were moderately acidic to slightly alkaline in reaction. The pH of the 1:2.5 soil water suspension ranged from 5.97 to 7.74. The highest value (7.74) is observed in T.C. Agraharam village and the lowest value (5.97) is observed in Anupalli village. The pH measured in 1 N KCl ranged from 4.43 to 6.98. The lowest value (4.43) was recorded in T.C. Agraharam village, while the highest value (6.98) occurred in Anupalli village. pH measured

in KCl was consistently lower than that measured in water, indicating the presence of appreciable quantities of silicate clay minerals with predominantly permanent negative surface charges. The observed variation in soil reaction among the surface soils can mainly be attributed to differences in parent material and landscape position. The relatively lower pH values observed in red soils are largely associated with the presence of iron hydroxide species, which contribute to a higher concentration of H^+ ions (Vasanthi *et al.*, 2023) [22].

Electrical conductivity of the soil water extract was ranged from 0.13 to 0.53 dS m^{-1} , indicating the non-saline nature of the soils. The overall low electrical conductivity (EC) values reflect favourable drainage conditions and effective leaching of soluble salts under groundnut cultivation, which facilitates the downward movement and removal of released bases through percolating water (Jayasree *et al.*, 2022) [11]. As the threshold level of soluble salts for groundnut is less than 2 dS m^{-1} , all the studied soils are suitable for groundnut growth with respect to salinity.

Organic carbon concentrations varied greatly among the surface soils, ranging between 0.34 and 0.65 per cent and exhibiting low to medium organic carbon levels. Relatively higher soil organic carbon in surface soils are primarily due to greater inputs from

crop residues and farmyard manure than in sub-surface soils. Generally, soil organic carbon levels are low because of the rapid decomposition of organic matter and the limited areas of vegetative cover usually typical of tropical climates restrict build-up of soil organic carbon (Shahi *et al.*, 2021) [20].

Calcium carbonate content ranged from 1.95 to 4.25 percent. The highest $CaCO_3$ content (4.25 per cent) is observed in T.C. Agraharam village, whereas the lowest $CaCO_3$ content (1.95 per cent) is observed in Anupalli village. The vertical distribution of calcium carbonate within the soils generally reflects downward movement of calcium with percolating water followed by precipitation in lower soils (Warhade *et al.*, 2022) [23].

The cation exchange capacity (CEC) of the groundnut growing soils ranged from 18.61 to 36.41 cmol (p^+) kg^{-1} , indicating substantial variation both among and within the soils. The highest CEC value of 36.41 cmol (p^+) kg^{-1} was recorded in C.K. Palli village, whereas the lowest value of 18.61 cmol (p^+) kg^{-1} occurred in Padiredu village. The variation in CEC is closely related to the amount and nature of exchange sites present in the soil matrix. Soils with lower pH generally possess fewer exchangeable base cations, which in turn contributes to lower CEC values (Surwase *et al.*, 2023) [21].

Table 3: Physico-chemical properties of surface soils

Location (Village)	pH (H_2O)	pH (KCl)	EC	Organic Carbon (%)	$CaCO_3$ (%)	CEC
Kammapalle	7.18	6.52	0.17	0.65	3.90	27.23
T.C. Agraharam	7.74	6.98	0.27	0.52	4.25	27.07
Padiredu	6.47	5.87	0.35	0.53	3.10	18.61
Seetharamapuram	6.24	5.43	0.20	0.40	3.30	20.84
Motavari kandriga	7.44	6.54	0.15	0.54	3.95	27.91
C.K. Palli	7.55	6.71	0.13	0.57	2.15	36.41
Anupalli	5.97	4.43	0.13	0.40	1.95	20.00
S.V. Puram	6.75	5.95	0.22	0.54	3.30	29.18
Thaduku	7.42	6.62	0.16	0.51	3.10	27.88
Chowtoor	6.69	6.35	0.53	0.47	2.95	21.49
Thiruvatyam	6.64	6.36	0.50	0.34	3.20	20.98
Boppa Raju Palem	7.03	6.31	0.30	0.64	2.50	23.02
Vethala Thaduku	6.14	5.72	0.21	0.44	2.50	28.91
Veluthuru kandriga	6.27	5.67	0.31	0.40	3.50	24.81
Thumbur	6.34	5.70	0.32	0.60	3.50	26.41
Rayalacheruvu	7.63	6.63	0.19	0.58	3.50	24.81
KBR Puram	7.47	6.41	0.32	0.57	3.75	27.77
Nandhimangalam	7.55	6.42	0.21	0.39	4.00	26.06
Mutharasu kandriga	7.62	6.56	0.26	0.57	3.50	27.96
Pathiputhuru	7.58	6.91	0.37	0.65	3.00	28.07

Note: pH measured in 1:2.5 soil–water suspension; EC expressed as dS m^{-1} ; CEC expressed in cmol (p^+) kg^{-1} soil

Leaf macronutrient composition

The macronutrient composition of index leaves of groundnut collected from the study area is present in Table 4.

Nitrogen: Nitrogen content in index leaf samples of groundnut ranged from 2.27 to 3.39 per cent indicating severely deficient to deficient in the study area. The highest leaf nitrogen content of 3.39 per cent was recorded in groundnut crop grown in Taduku village, while the lowest nitrogen content of 2.27 per cent was recorded in Seetharamapuram village. The deficient leaf nitrogen status may be attributed to low organic carbon content, poor mineralization of organic matter under semi-arid conditions and coarse textured soils with low nitrogen retention capacity, which favoured nitrogen losses through leaching and volatilization. In addition, continuous cultivation and insufficient application of nitrogenous fertilizers may have further reduced nitrogen availability and uptake by the plants.

Similar observations regarding the influence of soil properties on nitrogen availability and nutrient uptake were reported by Rathore *et al.* (2021) [19] and Balagangathar *et al.* (2024) [1].

Phosphorus: Phosphorus concentration in index leaf samples of groundnut was varied from 0.131 to 0.266 per cent indicating severely deficient to marginally adequate in the study area. The highest phosphorus content was recorded in Veluthurukandriga village, while the lowest was observed in Anupalli village. The deficient phosphorus status in leaf samples may be attributed to phosphorus fixation under alkaline soil conditions and the presence of free calcium carbonate, which reduced phosphorus solubility and availability to plants. Further, low organic matter content and limited phosphorus mobility in semi-arid soils might have restricted phosphorus diffusion towards plant roots, thereby reducing uptake. The comparatively higher leaf phosphorus concentration observed in some locations may be due to

relatively favourable soil reaction and better phosphorus availability in the root zone, resulting in enhanced absorption by plants. Similar observations on phosphorus nutrition and nutrient uptake in groundnut were reported by Joshi *et al.* (2024) ^[12].

Potassium: Potassium concentration in index leaf samples of groundnut was ranged from 1.82 to 2.60 per cent indicating adequate level in the study area. The highest potassium content was observed in Kammappalli village, whereas the lowest value was recorded in Anupalli village. Higher leaf potassium concentration may be associated with greater potassium retention capacity of finer soil fractions and higher cation exchange capacity, which ensured sustained potassium availability to plants. Lower leaf potassium concentration may be due to reduced nutrient holding capacity and possible leaching losses, resulting in lower potassium availability and uptake by plants. Similar findings regarding the influence of soil properties on nutrient uptake and soil fertility in groundnut were reported by Jain *et al.* (2021) ^[10].

Table 4: Macronutrient content in index leaf of groundnut

Tentative Soil series	N (%)	P (%)	K (%)	S (%)
Kammappalli	2.47	0.136	2.60	0.40
T.C. Agraharam	2.60	0.158	1.85	0.51
Padiredu	2.79	0.162	2.32	0.50
Seetharamapuram	2.27	0.168	1.88	0.27
Motavari kandriga	2.31	0.172	2.59	0.45
C.K. Palli	3.23	0.235	1.86	0.32
Anupalli	2.28	0.131	1.82	0.3
S.V. Puram	2.49	0.134	1.94	0.38
Taduku	3.39	0.161	1.98	0.46
Chowtoor	2.85	0.203	2.15	0.31
Thiruvatyam	2.65	0.144	2.06	0.47
Bopparajupalem	2.31	0.138	1.83	0.34
Vethalathaduku	2.67	0.165	2.03	0.37
Veluthurukandriga	2.52	0.266	1.91	0.44
Thumbur	2.57	0.197	1.93	0.46
Rayalacheruvu	2.46	0.155	1.87	0.42
KBR Puram	2.40	0.156	1.97	0.43
Nandhimangalam	2.68	0.145	2.02	0.39
Mutharasu Kandriga	2.46	0.155	1.97	0.33
Pathiputtur	2.53	0.181	1.83	0.55

Sulphur: Sulphur content in index leaf samples of groundnut varied from 0.27 to 0.55 percent indicating adequate level in the study area. The highest sulphur concentration was absorbed in Pathiputtur village, whereas the lowest value was recorded in Seetharamapuram village. Variability in leaf sulphur concentration among the study sites may be attributed to differences in organic matter status, nutrient dynamics and management practices, which influenced sulphur availability and uptake by plants. Similar results on sulphur nutrition and nutrient uptake in groundnut were reported by Kumar *et al.* (2024) ^[14] and Maindar *et al.* (2024) ^[15].

Overall, the variability observed in leaf macronutrient composition indicated that soil physico-chemical properties such as pH, organic carbon and cation exchange capacity played an important role in nutrient availability and uptake in groundnut growing soils of Puttur division. The results emphasized the importance of site-specific nutrient management for sustaining soil fertility and crop productivity in the region.

Conclusion

The representative surface soils of Puttur division exhibited considerable variation in physico-chemical properties and leaf macronutrient composition of groundnut. Soil reaction ranged

from slightly acidic to moderately alkaline, while electrical conductivity indicated the non-saline nature of the soils. Organic carbon status ranged from low to medium in most locations, whereas higher cation exchange capacity was associated with finer fractions. Leaf nitrogen, phosphorus, potassium and sulphur concentrations also varied across the study sites due to differences in nutrient availability and related physico-chemical characteristics. The findings demonstrated the influence of soil physico-chemical properties on nutrient dynamics and nutrient uptake, indicating the need for site-specific nutrient management strategies for sustainable groundnut production in Puttur division of Tirupati district in Andhra Pradesh.

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References

- Balagangathar K, Kalaiyaran C, Kandasamy S, Madhavan S, Jawahar S. Impact of nitrogen and sulphur application on the growth and yield of groundnut (*Arachis hypogaea* L.). *Crop Research*. 2024;59(3-4):138-142.
- Baradwal H, Ghosh A, Singh AK, Jiménez-Ballesta R, Yadav RK, Misra S. Soil nutrient dynamics under silviculture, silvipasture and hortipasture as alternate land-use systems in semi-arid environment. *Forests*. 2023;14(1):125.
- Bell RM. Crop nutrition. In: Department of Primary Industries and Fisheries, editor. *The State of Queensland*. 2007.
- Bower CA, Reitemeier RF, Fireman M. Exchangeable cations analysis of saline and alkali soils. *Soil Science*. 1952;73:251-261.
- Bremner JM. Total nitrogen. In: Black CA, editor. *Methods of soil analysis. Part 2: Chemical and microbiological properties*. Madison (WI): American Society of Agronomy; 1965. p. 1149-1178.
- Cotten A, Verloo M, Velghe G, Kiekens L. *Analytical methods for plants and soils*. Ghent (Belgium): State University of Ghent; 1979.
- Gorooei A, Ayneband A, Rahnama A, Gaiser T, Kamali B. Cropping systems and agricultural management strategies affect soil organic carbon dynamics in semi-arid regions. *Frontiers in Sustainable Food Systems*. 2023;6:1016000.
- Gudla SL, Devarakonda N, Ray S, Varikuppala M. 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. *International Journal of Plant & Soil Science*. 2023;35(20):490-497.
- Jackson ML. *Soil chemical analysis*. New Delhi: Oxford & IBH Publishing; 1973.
- Jain NK, Yadav RS, Jat R. Drip fertigation influences yield, nutrient uptake and soil properties of peanut (*Arachis*

- hypogaea* L.). Indian Journal of Agricultural Sciences. 2021;91(2):258-262.
11. Jayasree B, Naidu MVS, Naga Madhuri KV, Bhaskar BP, Karuna Sagar G, Lavanya Kumari P. Production potential appraisal of soils of part of Palamaner division in Chittoor District, Andhra Pradesh, India. International Journal of Environment and Climate Change. 2022;12(11):1972-1978.
 12. Joshi T, Amin AU, Chaudhary K, Patel M. Effect of phosphorus and sulphur on nutrient content and uptake of summer groundnut. International Journal of Advanced Biochemical Research. 2024;8(Special Issue 6):269-272.
 13. Kumar S, Sharma SK, Dhaka AK, Bedwal S, Sheoran S, Meena RS. Efficient nutrient management for enhancing crop productivity, quality and nutrient dynamics in lentil (*Lens culinaris* Medik.) in the semi-arid region of northern India. PLoS ONE. 2023;18(2):e0280636.
 14. Kumar R, Debbarma V, Pareek D, Karnot MK. Influence of sulphur and liquid organic nutrient on growth and yield of groundnut (*Arachis hypogaea* L.). Journal of Advances in Biology & Biotechnology. 2024;27(6):336-342.
 15. Maindar SS, Joharika C, Maji P, Mondal S, Maurya P, Kumar S. Effect of sulphur and growth regulators on yield and economics of groundnut (*Arachis hypogaea* L.). International Journal of Advanced Biochemical Research. 2024;8(7):566-569.
 16. Muhr GR. Soil testing in India. New Delhi: Indian Council of Agricultural Research; 1963.
 17. Piper CS. Soil and plant analysis. New Delhi: Hans Publishers; 1966.
 18. Rajesh NL, Rao KN, Desai BRK, Sathishkumar U, Basavaraj K, Rudramurthy HV. Spatio-temporal variability of soil properties and nutrient uptake for sustainable intensification of rainfed pigeon pea (*Cajanus cajan*) in semi-arid tropics of India. Sustainability. 2023;15(5):3998.
 19. Rathore VS, Nathawat NS, Bhardwaj S, Yadav BM, Kumar M, Santra P. Optimization of deficit irrigation and nitrogen fertilizer management for peanut production in an arid region. Scientific Reports. 2021;11:5456.
 20. Shahi ND, Naidu MVS, Giridhara Krishna T, Prabhakar Reddy G. Vertical distribution of nutrients in groundnut growing soils in *Narayanavanam mandal* of Chittoor district, Andhra Pradesh. Andhra Pradesh Journal of Agricultural Sciences. 2021;7(4):210-216.
 21. Surwase SA, Singh SK, Reddy GP, Kadu PR, Mohekar DS, Naitam RK, *et al.* Characterization and classification of soils in a toposequence of the semi-arid basaltic landscape of western India. International Journal of Plant & Soil Science. 2023;35(19):876-887.
 22. Vasanthi BG, Chaitra BK, Mamatha B, Sathish A. Soil fertility evaluation and mapping of *Burugamaradoddi microwatershed* of Ramanagara Taluk, Ramanagara District, Karnataka. Agropedology. 2023;33(1):77-84.
 23. Warhade RM, Karthikeyan K, Tiwary P, Naitam RK, Kumar N. Characterization and classification of some typical cotton-growing soils of Samudrapur block of Wardha district, Maharashtra. Journal of the Indian Society of Soil Science. 2022;70(2):142-148.