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Impact of Rainfall Variability and Soil Characteristics on Rainfed Agricultural System in Ananthapuramu District, Andhra Pradesh

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Abstract

The Ananthapuramu district in Andhra Pradesh is predominantly characterized by dryland agriculture, primarily cultivating three key crops: groundnut, pigeon pea and cotton. This approach to farming often overlooks the land's carrying capacity, which can result in soil degradation and a swift decline in soil fertility. The focus of soil fertility assessment and land management in this region is to analyze the soil resource database, identifying both biophysical constraints and opportunities to enhance agricultural productivity and soil health, particularly in the context of fluctuating rainfall patterns. This research employs an exploratory methodology, utilizing soil analytical data from the prevalent soil series. The weighted averages of each soil series were calculated, taking into account various pedogenic properties such as particle size distribution, pH, electrical conductivity, organic carbon content, calcium carbonate levels, cation exchange capacity, exchangeable bases, base saturation, and soil depth. The soils in this area were typically featured clay-rich sub soils, particularly in granitic terrains, exhibiting slightly acidic to neutral pH levels, high cation exchange capacity, and gravelly profiles. However, these soils displayed poor structural stability and have low to moderate fertility indices, indicative of significant organic carbon depletion. The findings revealed a dichotomy in soil fertility across the research area, with some regions classified as high fertility and others as low. The latter included land units situated on steep slopes and lacking effective land management practices. Key limiting factors affecting soil fertility were texture, organic carbon content, cation exchange capacity, phosphorus, and total potassium levels. It is recommended that organic fertilizers can be applied to enhance the fertility of these farming areas.

Keywords: Soil fertility; Rainfall variability; Dryland; Ananthapuramu; Soil series.

INTRODUCTION

Ananthapuramu district predominantly consists of arid land. The primary challenges associated with the agricultural use of this dry land stem from low soil fertility, which is hindered by chemical barriers that restrict plant growth, particularly issues related to nutrient availability. The soil in these areas exhibits low fertility levels and a deficiency of organic matter. This situation is further aggravated by the minimal application of organic fertilizers, particularly during the annual groundnut cycle. Additionally, the natural levels of soil organic matter in tropical regions are

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rapidly diminishing, with reductions of 30-60% occurring within a decade (Brown and Lugo, 1990). Conversely, excessive tillage practices contribute to the decline in the productivity of dry land. Research indicates that over-tillage can compromise soil structure. Therefore, effective land management strategies, based on the chemical fertility of the soil, are essential to meet the specific requirements of the cultivated plant species. This study employs pedogenic soil parameters to evaluate the fertility status of the soil.

The assessment of soil fertility was conducted through a meticulous analysis of soil series and crop performance, aimed at providing fertility recommendations to enhance land productivity (FAO, 1988). The evaluation of the soil fertility index was derived from pedological datasets collected during a semi-detailed soil survey in the Ananthapuramu district, employing the square root method (Gilman, 1983, Sardiana 2017). This study utilized chemical analyses to ascertain the current status of soil fertility. Essential parameters for this evaluation included soil chemical properties such as cation exchange capacity, base saturation, organic carbon, and exchangeable bases. Understanding these chemical properties is crucial, as they often serve as limiting factors across various soil series. A comprehensive soil testing approach encompasses the interpretation, evaluation, and formulation of fertilizer recommendations based on soil test results, alongside the collection of soil samples. The distribution of soil fertility status can be effectively mapped through exploratory survey (Bhaskar and Ramamurthy, 2024), which also aims to assess land units and the potential of soil nutrient elements to support crop growth, as determined by laboratory analyses (Boul 1972, Bhaskar 2019). Soil indicators can be divided into three main types: physical, chemical, and biological. By tracking changes in these indicators, we can evaluate the overall quality of the soil (Larson and Pierce, 1991; Ditzler and Tugel, 2002) and create a single measure called the soil quality/fertility index (SQI/SFI). It is important to examine how soil properties change with different land cover or land use. This helps us to understand how these changes affect soil and water quality, biodiversity, and global climate systems, which in turn impact natural resources and ecological processes (Abbasi 2010). Recognizing the significance of soil fertility, it is imperative to evaluate the status of soil fertility in the dry lands of Ananthapuramu to develop land management strategies that can be implemented by farmers, thereby bolstering the groundnut-based crop production system in the region.

MATERIALS AND METHODS

Details of study site

Ananthapuramu District is situated in the Rayalseema plateau spans an area of 19,300 square kilometers, located between 13°40´4″ to 15°14´46″ N and 76°47´12″ to 78°27´44″ E. Of this total area, 92% is composed of crystalline rocks, which exhibit a high capacity for direct runoff and significant evapotranspiration. The district experiences hot summer climate characterized as arid to semi-arid, with an average annual rainfall of 573 mm, approximately 56% of which is supplied by the Southwest monsoon. The Planning Commission of the Government of India (1973) provided the definition that we utilized to determine how frequently droughts occur. Drought years are those that get less than 75% of the long-term mean rainfall. There were 12 of these drought years between 1911 and 1989, or around 1 in 6-7 years. It only rained less than 200 mm in 1984. Thirty-eight percent of the years had more than 600 mm of rainfall, compared to eighty-two percent (65 out of 79) of the years with more than 400 mm. The likelihood of 800 mm or more of precipitation is about 7.6% (Naveen 1991). The landscape is primarily dominated by pediplains, followed by pediments and denudation hills. The Pennar basin makes up 80% of the area, while the Krishna basin, along with its tributaries Jayamangala, Chitravathi, and Vedavathi, accounts for the remaining 20%. In the pediment-pediplain zone of the study area, have shallow red and sandy (alfisols) soils with dense and compact root restricting subsurface layers. The depth of the stored soil moisture is between 100 and 115 mm. The soils have a neutral reaction, low levels of organic matter, and are deficient in nitrogen, phosphorus, zinc, and potassium. Various soil types such as loamy calcareous and clayey soils of alfisols, inceptisols, vertisols and entisols were identified, originating from denudational processes on the granitic craton (Bhaskar and Ramamurthy, 2024). This district is known for Groundnut (A. *hypogaea* L.) and mostly grown by small and marginal farmers with low yields due to low and erratic distribution of monsoon rainfall. The mean pod yield was 516 kg/ha but varies from 200 kg/ha and 1200 kg/ha from year to year. The studies on seasonal rainfall on yield reported that if there is evidence from 10% less of normal seasonal rainfall, there is 42% of reduction in pod yield (Bapuji Rao 2015). There is just a little of groundnut and pigeon pea intercropping. During the late monsoon season, foxtail (Setaria), pearl millet, and sorghum are also sowed but they are substituted with the more lucrative nuts. Ananthapuramu district covers a total area of 1,913,000 hectares, with about 13% of this area being forested. The total area used for crops is 1,136,000 hectares, and 69.6% of the total area is actively farmed. The cropping intensity in the district is 106%. Non-agricultural land makes up only 10.5%, while permanent pastures account for 2.2%. This district has the highest amount of cultivated land per person at 0.29 hectares. The population stands at 3,640,478, with 589,465 households in rural areas. In addition to these problems, monsoon patterns of rainfall distribution to the groundnut cultivation in Anantapuramu. The simulation studies in recent times using CROPGRO-Peanut model showed that there is a scope to increase pod yields on average by 1.0%, 5.0%, 14.4%, and 20.2%, following the adoption of heat tolerance, drought tolerant cultivars, supplemental irrigation and a combination of drought tolerance cultivar and supplemental irrigation at 60 days after sowing (Kadiyala 2015).

Data collection

A detailed dataset encompassing 45 years of rainfall data, from 1966 to 2012, was acquired from the Ministry of Earth Sciences, specifically through the Additional Director General of Meteorology (Research) Climate Application Group of the India Meteorological Department (2015). Furthermore, annual data regarding the area and yield of groundnut, pigeon pea, and cotton was obtained from ICRISAT (2020). Soil resource information was extracted from the NBSS&LUP (2008) report pertaining to Anantapuramu district in Andhra Pradesh. A semi-detailed soil survey was conducted at a scale of 1:63,360, adhering to the methodologies established by the Soil Survey Division Staff (2017). This study incorporated soil transect investigations to establish relationships between soil and landforms, as well as field soil correlation that involved matching soils with geomorphic surfaces, resulting in the identification of 36 distinct soil series (NBSS & LUP, 2008). Soil samples were collected according to the horizons in the soil profile. The samples were air-dried, crushed and sieved at 2 mm, and analyzed for the different soil fertility indicators: slope, soil texture, soil depth, organic matter content, calcium carbonate content ($CaCO^3$), cation exchange capacity (CEC), pH, and electrical conductivity (EC) were analyzed as per the procedures described by Jackson (1975). These datasets enabled the examination of rainfall trends in relation to crop area and productivity. A variety of statistical tools were utilized to enhance soil characteristics, which facilitated the determination of the soil fertility index and the development of strategies for rainfed agriculture in the district. The statistical analysis focused on assessing rainfall variability and calculating the soil fertility index using the soil series data in the district.

Rainfall variability

The rainfall variability index was calculated in the time series of rainfall data to the segregate existing precipitation time series into different climatic regimes, such as normal, wet, very wet, dry and very dry climatic year (L'hote 2002). The rainfall variability index (Di) was calculated from the equation given as:

$$Di = (Pi - \mu)/\sigma$$

Where,

Di represents the rainfall variability index for year i, and Pi is the annual rainfall of year i. σ and μ are the standard deviation and mean of the annual precipitation series, respectively, for duration under the study at the given station. The value of Di within ± 0.5, between + 0.5 and + 1 and more than + 1 is categorized as a normal, wet and very wet climatic year, respectively. Correspondingly, when the value of Di lies in between −0.5 and −1 and less than −1 a dry and very dry, climatic year, respectively, is indicated. Classification of CV levels according to their ranges (Gomes, 1985). Classification of CV Ranges of CV was listed as: Low CV < 10%; Medium 10% ≤ CV < 20%; High 20% ≤ CV < 30% and Very high CV ≥ 30

Structural stability index

Pieri (1992) proposed that risk of structural degradation in cultivated soils could be assessed via the "structural stability index", SSI (%):

$$SSI = 1.724XOC/Silt + Clay \times 100;$$

Where, OC (wt.%) is soil organic carbon content and (Silt + Clay) (wt.%) is the soil's combined silt and clay content. An SSI of 9% indicates stable structure, 7% < SSI ≤ 9% indicates low risk of structural degradation, 5% < SSI ≤ 7% indicates high risk of degradation, and SSI ≤ 5% indicates structurally degraded soil. Note that since SI is based on OC and texture, it does not relate directly to the porosity aspects of soil structure, but rather to the "resilience" of the structure.

Statistical analysis

The soil series data was used to calculate profile weighted means of soil properties (Weighted mean

= thickness of horizon X value of soil property/ total thickness). These soil properties were used to calcuculate descriptive statistics (mean, Standard deviation (SD) and coefficient of variation (CV% = σ/mean*100) using statistics kingdom package.

Soil fertility index

These properties were utilized to calculate the soil fertility index (SFI). The parametric method known as Square-Root was employed (Sağlam and Dengiz 2014).

SFI was determined for qualitative soil fertility categories through a parametric technique that utilized fifteen parameters for each soil sample location. To establish this model and identify the threshold levels of each SFI category were referenced (..........). SFI was calculated and using the value of factor rating for each factor as (Table 1.1) given under:

SFI = [Rmax X √A/100 X B/100 X ---------] × 100

Rmax = (A+B+----------P)/number of properties (n)

Table 1: Rating scheme for soil fertility evaluation in this study

Diagnostic factors	Factors rating				
	100	80	50	20	10
Ex.Ca (cmol/kg)	17.5-50	5.75-17.5	1.19-5.75	>50	<1.19
Ex.Mg (cmol/kg)	1.33-4.00	4.0-12.5	0.42-1.33	>12.5	<0.42
Ex.K (cmol/kg)	0.28-0.74	0.74-2.56	0.13-0.28	>2.56	<0.28
Ex.Na (cmol/kg)	0.0-0.20	0.21-0.30	0.31-0.70	0.71-2.0	>2.0
CEC (cmol/kg)	>25	25-15	10-15	5-10	<5
SOM (%)	>30	20-30	10-20	5-10	<5
$CaCO^3$ (%)	5-15	1-5	15-25	>25	0-1
EC (dSm^{-1})	0-2	2-4	4-6	6-8	>8
pH (1:2.5 soil water ratio)	6.5-7.5	7.5-8.5	5.5-6.5	4.5-5.5	<4.5- >8.5
Textural class	cl, scl, sicl	vfsl, l, sil, si<50%c	>50%c, sc, sic	sl, fsl	s,ls

cl=clay loam, scl=sandy clay loam, sicl=silty clay loam, vfsl=very fine sandy loam, l=loam, sil=silt loam, si=silt, sc=sandy clay, sic=silty clay, sl=sandy loam, fsl=fine sandy loam, s=sandy, ls=loamy sand

Table 2: Classes and values of soil fertility index

	description	Soil fertility index
S1	Good	>80
S2	Moderate	80-50
S3	Marginal	50-20
N	Poor	<20

RESULTS AND DISCUSSION

Area productivity and rainfall characteristics

The data pertaining to area and productivity (1966 to 2012) in relation to rainfall and its variability for three principal crops such as Groundnut (*Arachis hypogeae* L), Pigeon pea (*Cajanus cajan*) and cotton (*Hibiscus spp.*) grown in Ananthapuramu district is presented in Table 1.3. The mean area under groundnut is 556.45 ± 230.19 (000ha) with very high coefficient of variation (41.37%) and mean productivity of 678.28 ± 290.27 kg/ha and CV of 42.79 %. the mean area under pigeon pea is 26.99 ± 9.94 (00ha) with CV of 36.81 and low mean productivity of 204.72kg/ha and CV of 61.26% whereas, mean area under cotton is 16.66 ± 11.01 (000ha) with CV of 66.06% but productivity of 142.66 ± 78.53 kg/ha and high CV of 55.05%. The area receives mean annual rainfall of 540.12 ± 125.13mm with high CV of 23.17%. Three consecutive years from 1984 to 1986 received total rainfall less than 400mm whereas 2003 received total rainfall of 387.7mm and 2012 with total of 412.8mm. The rainfall variability as expressed as Di shows negative sign as dry period and positive sign for wet period of rainfall. The mean monsoon rainfall is 310.85 ± 110.61mm with very high variability (CV of 35.5%).The results of regression analysis for area and productivity in relation to rainfall variability is shown as below:

Groundnut

Productivity (kg/ha) = 365.1874 + 1.0072 (monsoon rainfall, mm)

The simple linear regression between yield/ha and monsoon rainfall shows a significant medium positive relationship with correlation coefficient of $r = 0.371$ at probability level of (p) = 0.012. The multiple linear regression indicated that there is a weak collective significant effect between the area (000ha), Productivity (kg/ha), and Rainfall variability (Di) with (F value (1, 45) = 5.44, p =0.024, R^2 = 0.11, R^2 adj = 0.09). The regression equation explains only 11% of variability in rainfall variability with area and its relation is expressed as:

Di = 0.183767 - 0.000329482 area (000ha)

Pigeon pea

The simple linear regression between productivity and total rainfall yielded coefficient of determination (R^2) of 0.19 with F value of (1, 45) =10.48 and significant at p level of 0.002. The predicted regression equation is given as under:

Productivity (kg/ha) $\hat{Y}$ = -30.5658+0.4356 (total rainfall (mm)

The results of the multiple linear regression indicated that there was a moderate collective significant effect between the area (000ha), productivity (kg/ha), and Di, (F(1, 45) = 10.42, p = 0.002, R^2 = 0.19, R^2 adj = 0.17). The correlation matrix shows a negatively significant relation between Di and productivity (r =-0.44*)

Di = 0.163916 - 0.0007986 productivity (kg/ha)

Table 3: Area, productivity and rainfall variability (1966 to 2010) in Ananthapuramu district

Year	Groundnut		Red gram		Cotton		Rainfall(mm)			DI
	Area (000ha)	Productivity (kg/ha)	Area (000ha)	Productivity (kg/ha)	Area (000ha)	Productivity (kg/ha)	Total	class	monsoon	
1966	168	654.76	29	172.41	42	47.62	623.9	normal	375.3	-0.16
1967	225	635.56	22	454.55	35	28.57	515.5	normal	295.6	0.05
1968	205.5	739.66	21.4	420.56	31.5	31.75	493.7	normal	269.6	0.09
1969	236.2	560.12	20.8	120.19	33.6	47.62	485.4	normal	219.4	0.10
1970	275.5	529.58	22.7	290.75	31	41.94	475.1	normal	256.1	0.12
1971	264.9	761.42	19.6	142.86	30.9	51.78	461.9	normal	236.9	0.14
1972	225	671.56	20.7	183.57	19	42.11	491.5	normal	196.3	0.09
1973	277.7	852.36	24.6	89.43	26.7	48.69	601.6	normal	362.3	-0.11
1974	300.3	837.83	20.3	157.64	20.8	144.23	589.9	normal	326	-0.09
1975	324.4	723.80	22.4	80.36	11.8	59.32	589.9	normal	326	-0.09
1976	323	276.78	15.8	31.65	9.8	71.43	319.4	dry	219.1	0.41
1977	294.3	933.06	23.1	121.21	28	103.57	643.1	normal	327.8	-0.19
1978	335.1	798.27	21	147.62	26	61.54	502	normal	297.5	0.07
1979	364.9	727.87	18.2	137.36	27.6	76.09	599.3	normal	387.9	-0.11
1979	364.9	727.87	18.2	137.36	27.6	76.09	599.3	normal	387.9	-0.11
1980	323.4	381.88	17.7	50.85	28.3	123.67	383.5	dry	214.4	0.29
1981	391.4	938.43	20.4	93.14	32	106.25	627.1	normal	439.1	-0.16
1982	395.7	659.59	18.1	121.55	29.9	96.99	489.7	normal	259.4	0.09
1983	451.2	1169.77	20.8	177.88	32.2	145.96	507	normal	384.6	0.06
1984	473.4	615.12	19.2	125.00	17.2	279.07	351	dry	205.5	0.35
1985	486.6	659.47	22.6	137.17	16.8	166.67	300.8	dry	161.1	0.44
1986	442	943.44	23	173.91	4	100.00	387.7	dry	254.3	0.28

Year	Groundnut		Red gram		Cotton		Rainfall(mm)			DI
1987	542	959.41	25	120.00	6	66.67	487.3	normal	241	0.10
1988	717.3	980.34	31.6	104.43	7.8	153.85	825.8	wet	639.8	-0.53
1989	739.2	689.12	29.1	147.77	13.9	266.19	592	normal	534.8	-0.10
1990	741.46	663.85	26.85	71.14	15.13	169.86	453.9	normal	168.9	0.16
1991	720.59	689.02	24.43	275.07	14.51	233.63	580.1	normal	249.5	-0.07
1992	742.75	679.68	26.39	231.15	14.14	243.28	478.5	normal	245	0.11
1993	731	1010.94	24	250.00	10	289.00	584.4	normal	290.2	-0.08
1994	687	621.54	23	217.39	9	245.56	425.9	normal	137.8	0.21
1995	745	1326.17	26	269.23	12	297.50	532.6	normal	368.8	0.01
1996	759	731.23	25	360.00	11	262.73	790.6	wet	511.6	-0.46
1997	670	373.13	21	142.86	7	242.86	531	normal	327.3	0.02
1998	781	1157.49	27	333.33	14	157.86	658.71	normal	424.41	-0.22
1999	716.65	383.48	23.22	167.10	9.45	189.42	498.5	normal	285.4	0.08
2000	814.61	1115.63	30.73	257.08	12.03	227.76	677.6	normal	378.3	-0.25
2001	777.47	466.92	27.95	272.99	8.55	180.12	698.4	normal	352	-0.29
2002	750	372.00	33	212.12	8	148.75	420	normal	151.4	0.22
2003	686	302.74	41.18	169.01	4.21	171.02	387.7	dry	171.6	0.28
2004	872.32	809.66	32.75	240.92	8.93	134.38	490.7	normal	249.7	0.09
2005	899.04	435.99	35.01	676.95	3.3	178.79	768.1	wet	426.6	-0.42
2006	662.11	93.85	26.24	134.91	1.51	218.54	439.6	normal	203.2	0.19
2007	896.83	1260.14	36.58	466.92	3.49	77.36	654.1	normal	529.5	-0.21
2008	870.46	114.89	34.07	385.97	1.61	130.43	760.9	wet	432.6	-0.41
2009	530.38	267.69	20.59	291.89	2.06	101.94	579.4	normal	357.8	-0.07
2010	834.07	576.69	66.01	169.07	4.34	117.51	752.23	wet	397.9	-0.39
2011	753.84	275.10	51.75	82.90	19.3	106.22	466	normal	231.4	0.14
2012	729.7	452.17	56.59	142.07	27.64	218.89	412.8	dry	289.4	0.24
mean	556.45	678.28	26.99	204.72	16.66	142.66	540.12		310.85	
sd	230.19	290.27	9.94	125.42	11.01	78.53	125.13		110.61	
cv	41.37	42.79	36.81	61.26	66.06	55.05	23.17		35.58	

Cotton

The formula for the relationship between productivity and total rainfall is productivity (kg/ha) = 125.7824 + 0.03125 (total rainfall, mm). This equation has a poor R^2 of 0.0025 with $F(1,45) = 0.11$ at the $p = 0.740$ probability level. A very weak collective non-significant effect between the area (000ha), productivity (kg/ha), and Di was found by the multiple linear regression results ($F(1,45)=1.32$, p+2.56, $R^2 = 0.03$, R^2 adj = 0.01).

Di = -0.0586763 + 0.00354762 area (000ha)

Soil characteristics

Particle size distribution

The soils in question predominantly exhibit a gravelly composition, with an overall mean gravel content of 24.62%±17.48% and a notably high coefficient of variation (CV) of 71.01% (Table 1.4). The Kothacheruvu series (KTC) records a zero gravel content, while the Rampuram series (RMP) shows gravel content exceeding 77.03%. The presence of gravel in granite soils has been documented in the Ananthapuramu region

(Bhaskar 2024; Srinivasan 2021). Among the sand fractions, coarse sand is the most prevalent, with a mean value of 32.20%±21.03% and a high variability (CV of 65.30%). The minimum coarse sand content is observed at 4.63% in Velamakuru (VMK), whereas the maximum is recorded at 74.91% in Uravakond (URK). The mean fine sand content is 18.24%±15.59%, with a CV of 85.47%, and the maximum fine sand content reaches 59.10% in the Penner soil series (PNR). Collectively, these soils exhibit a mean total sand content of 50.29%±18.29%, with a minimum of 13.47% in the Mincheri series (MCI) and a maximum of 82.52% in the Batrepalli series (BTP), accompanied by a high CV of 53.33%. The mean silt content is 12.44%±7.35%, with a CV of 32.48%. The Kondapuram series shows a silt content of 3.03%, while the Tamballapalle series (TMP) has a maximum of 32.02%. The mean sand-to-silt ratio is 7.64±5.99, with a very high CV of 78.39. Ratios below 1 are found in four series: Hagalur (HGL), Kadavakallu (KDK), Mincheri (MCI), and Velamakuru (VMK). These series display relative uniformity, whereas other soils characterized by high sand and low silt content yield elevated sand-to-silt ratios, suggesting the presence of variable colluvial deposits and young stratified soils in the area. The sand-to-silt ratio and its depth distribution have been identified as effective indicators for recognizing lithological discontinuities within these soils (Bhaskar 2000). The average clay content in these soils is 37.26±14.27%, with a minimum of 4.87% recorded in Wajrakarur (WJK) and a maximum of 65.5% observed in Velamakur (VMK). The mean silt-to-clay ratio for this soil series is 0.44±0.63, with a coefficient of variation exceeding 100. Soils exhibiting a silt-to-clay ratio greater than 0.15% are classified as young and moderately weathered, indicating a higher potential for weathering (Ahukaemere 2017). In contrast, the Gooty, Madakasira, and Kondapuram series display silt-to-clay ratios below 0.15%, suggesting a higher degree of weathering relative to other soils in the study area.

Chemical characteristics

The average pH level is 7.32±0.8, indicating a neutral reaction with low variability and salt content, as evidenced by a mean electrical conductivity (EC) of 0.41±1.12 dSm^{-1}. Soils in Perur and Ananthapuramu are classified as strongly alkaline (pH >8.5), while Kothacheruvu exhibits moderate acidity with a pH of 5.85. Vemalakur soils show an EC greater than 1, suggesting slight salinity (Haldar 2020). These soils have very low organic carbon (OC) content, averaging 0.31±0.15% with a coefficient of variation (CV) of 48%. The Tadipatri and Wajrakarur series contain 0.1% OC, whereas Satrarlapalle (STP) has 0.7%, resulting in an efficiency factor of 48.26 (Table 1-4). The findings of this study align with those reported by Prabhavati. (2015) and Nalina. (2016) regarding the soils in the northern and eastern dry zones of Karnataka. Low organic carbon levels in these soils can be attributed to the semi-arid conditions, which accelerate the degradation of organic matter, combined with minimal addition of organic fertilizers and sparse vegetation cover, leading to limited organic carbon accumulation. The soil organic carbon to clay ratio (SOC:clay) is recorded at 0.01±0.01, exhibiting significant variability (CV of 126.01%). This ratio is a critical indicator in soil quality management, with threshold values established in Switzerland, where SOC:clay ratios indicate soil structure quality ranging from very good (>1:8) to degraded (<1:13) (Ophélie Sauzet 2024). The low SOC to clay ratio in these soils categorizes them as degraded according to these standards. The dryland agricultural environmental management in Ananthapuramu district may not meet the soil health thresholds for the SOC: clay ratio due to the low SOC values observed regionally, and the presence of clay-rich argillic subsurface horizons necessitates an assessment of the structural conditions of the corresponding soil groups, as the observed structural quality does not align with the established thresholds (Johannes 2017). The importance of this ratio cannot be ignored without thorough agronomic and pedological studies, as noted by Poeplau and Don (2023). The average $CaCO_3$ content in these soils is 3.19±6.01%, showing significant variability. The Veldandla series has a $CaCO_3$ level of 28.68%, while 13 out of 36 soil series have none. The average CEC is 26.26±14.23 cmol/kg, with a coefficient of variation of 54.2%. Batreplle and Chitravati soils have a CEC less than 10 cmol/kg, while 15 series fall between 10 to 20 cmol/kg, and 12 series exceed 25 cmol/kg. Multiple linear regression results show a strong combined effect of clay (%), silt (%), pH, and CEC (cmol/kg) with $F(3, 32) = 69.82$, $p < .001$, $R^2 = 0.87$, $R^2adj = 0.86$. The equation for CEC (cmol/kg) is -27.4 + 0.7 clay (%) + 0.6 silt (%) + 2.8 pH, which accounts for 87% of the variability in soil CEC.

The ratio of Cation Exchange Capacity (CEC) to clay content ranges from 0.36 to 1.06, serving as a valuable tool for estimating clay mineralogy. When this ratio is multiplied by 100, the result is expressed in cmol(p+)/kg of clay. The typical ranges for various clay mineral classes are as follows: less than 0.2 indicates kaolinitic clay; between 0.2 and

0.3 suggests either kaolinitic or mixed clay; from 0.3 to 0.5 points to mixed or illitic clay; 0.5 to 0.7 indicates mixed or smectitic clay; and greater than 0.7 signifies smectitic clay. According to the Soil Survey Staff (2010), the average CEC/clay ratio for these soils is 0.68±0.18 cmol/kg, with a coefficient of variation of 18.79%, reflecting a predominance of mixed or smectitic clay types. The Chitravathi soil exhibits a minimum of 0.36 cmol/kg (mixed-illitic), while the Itigi series reaches up to 1.06 cmol/kg (smectitic). The pronounced variations in soil aggregate stability across different land uses can be attributed to the effects of cultivation. This includes both the direct disruption of soil aggregates and the resultant increase in soil respiration and organic carbon loss. The inherent tendency of these soils to slake is highlighted by an average Slake Index (SI) of 2.8 for soils with 25% or more clay content and a CEC to clay ratio of less than 0.5, particularly under perennial ground cover in pasture lands. Cultivation has significantly intensified this natural tendency, with average SI values rising to 4.8 in dryland cropping areas and 5.0 in irrigated sites (Jones 2021). The CEC to clay ratio emerges as a crucial parameter, indicating the type of clay minerals present, which in turn influences slaking due to its role in the shrink-swell behavior of soils. A correlation between clay content and the CEC to clay ratio has been observed. In the northern regions of the study area, high-clay-content soils are prevalent in the floodplain areas of Tungabhadra, characterized by a greater proportion of shrink-swell clay minerals like smectite. Conversely, the granitic terrain in the southern and central regions features alfisols and associated soils with lower clay content and also a lower CEC: clay ratio, indicating the dominance of low-CEC phyllosilicates, such as kaolinite or illite.

It is important to note that soil series with clay content less than 25% exhibited minimal slaking. In contrast, for soils with clay content of 25% or greater, the ratio of cation exchange capacity (CEC) to clay was a significant predictor of slaking behavior. For instance, soils with approximately 40% clay content demonstrated low to moderate slaking when the CEC:clay ratio was below 0.5, while moderate to extreme slaking was observed when this ratio exceeded 0.5. Distinct threshold values were identified, with extreme slaking occurring exclusively in soils with a clay content of 25% or more and a CEC:clay ratio greater than 0.5. The relationships between the measured soil properties and the observed slaking index (SI) values were modeled independently for each soil class, as different critical values were anticipated to influence the behavior of various soil types (Loveland and Webb, 2003). Soils characterized by low organic carbon (OC) content (less than 0.3%) and high clay content (greater than 25%), along with elevated CEC:clay ratios were found to be particularly susceptible to slaking. A threshold OC value of 1.1% was identified, below which slaking behavior did not correlate with any of the measured soil properties, and the most extreme SI values were recorded. In this study, the slaking index was calculated using the pedotransfer function represented by the equation $SI = -0.22 - 0.19 \times OC + 0.09 \times clay$ ($R^2 = 0.77$, RMSE = 0.7, $p = 0.000$, Jones 2021). This regression analysis suggests that while OC content significantly influences observed SI values, its impact is less pronounced in these soils. Furthermore, a multiple linear regression analysis was conducted, yielding the following relationship: $Ln(SI) = 1.197722\ Ln(CEC) - 1.591194\ Ln(pH) - 1.073687\ Ln(CEC/clay)$. The results from the multiple linear regression indicated a very strong collective significant effect among CEC, pH, and CEC/clay on SI ($F(3, 33) = 557.55$, $p < .001$, $R^2 = 0.98$, adjusted $R^2 = 0.98$).The analysis of individual predictors revealed that both Cation Exchange Capacity (CEC) ($t = -14.658$, $p < .001$) and clay content ($t = -14.21$, $p < .001$) were significant contributors to the predictive model.

Soil fertility index and structural stability index

The soil fertility index, derived using the square root method, indicates that the soils exhibit a mean Soil Fertility Index (SFI) of 15.7 ± 10.95, with a coefficient of variation (CV) of 69.73%. According to the established rating scheme, these soils are classified as having a poor fertility index, which suggests a severe loss of organic carbon (OC) and an accumulation of calcium carbonate ($CaCO_3$). Specifically, the SFI for Perur soil is recorded at 1.35, while Batrepalle soil has an SFI of 48.5, reflecting marginal fertility levels. The majority of the soil series fall within the marginal to poor fertility index range. Results from the multiple linear regression analysis demonstrated a robust collective significant effect among the variables CEC, clay, pH, Ex. Ca/Ex. Mg, Ex. K/Ex. Na, CEC/clay, and SFI, with the model yielding $F(2, 34) = 156.09$, $p < .001$, $R^2 = 0.9$, and adjusted $R^2 = 0.9$. The significant predictor in the model is expressed as:

$$SFI = 1.135422 \cdot CEC^{1.04589}$$

The Structural Stability Index (SSI) similarly indicates a value of less than 5, which suggests a high level of degradability (Pieri, 1992). The mean SSI is recorded at 1.19 ± 0.66, with values ranging from 0.31 to 3.1. Results from the multiple linear regression analysis revealed a very strong collective significant effect among the variables of clay percentage, silt percentage, organic carbon, and the SSI, with the following statistical parameters: $F(3, 32) = 107.46$, $p < .001$, $R^2 = 0.91$, and adjusted $R^2 = 0.90$. The regression equation can be expressed as:

$$SSI = 1.2 - 0.03(clay\%) - 0.03(silt\%) + 4(OC\%).$$

Importance soil fertility in climate sensitive dryland farming systems of Ananthapuramu district

In the drought stricken regions of Ananthapuramu district, comprehensive soil surveys were conducted to innovate and rejuvenate dryland farming systems, aiming to cultivate robust and productive agricultural soils that can sustain yield-stable cropping practices amidst the challenges of climate change. However, we find ourselves at a crossroads; despite extensive agricultural research initiatives at the regional level, encompassing field experiments, laboratory analyses, and sophisticated modeling frameworks, the current empirical knowledge derived from local farming practices remains scarce. This lack of insight has hindered any significant improvement in the productivity of locally cultivated crops. A thorough review was undertaken to reassess soil data, emphasizing soil fertility through pedological insights and the characteristics of soil properties in Ananthapuramu district. This analysis highlights the critical importance of soil fertility, associated soil attributes, and the necessary agronomic management strategies essential for enhancing soil fertility (Troeh and Thompson, 2005).

The important soil properties for dryland farming that are helpful for researchers and local farmers include: (1) water storage capacity, (2) rootability, (3) SOC to clay ratio, (4) CEC/clay ratio, (5) structural stability index, (6) soil fertility index, and (7) slaking index (Table 4). These factors support practices like catch cropping, diverse crop rotations that maintain a good humus balance, and keeping ground cover or mulch throughout the year as effective farming strategies. For evaluating soil fertility, key aspects include analyzing soil structure, biological indicators, yield and biomass production, soil nutrient tests, and adjusting field experiments to focus on organic carbon storage. Simple indicators and reference values are essential for assessing soil fertility in response to future climate changes (Bayu and Li, 2020). In higher risk of drought stress under climate change in the region, the erratic rainfall during monsoon and of extreme weather events, such as storms or heavy rainfall events, which greatly amplify the risk of soil erosion and floods and significantly increase production risk for farmers (Ray 2019). This was also reflected more in recent times and have a negative impact on production. The farmers who reported more unseasonal rainfall to promote severe top soil erosion and high risk of protecting crop as seen during field survey. The best agronomic practice identified was 'year-round soil cover.' This method is a key part of conservation agriculture. It helps lower the chances of soil erosion and water loss through evaporation, while also benefiting soil life and enhancing how water enters the soil (Williams 2018) but scope is limited in the study area. This research highlights that maintaining stable yields, or minimizing the risk of production dropping below a critical level, is essential in the face of climate change. Farmers in the area consider this even more important than overall yield. An examination of rainfall changes over the past 46 years shows no significant increase in yield per hectare for groundnut, pigeon pea, and cotton. This aligns with recent studies. Even with crop failures and regular droughts, farmers in dry regions are reluctant to take on production risks. Soil analysis indicates weak structural stability, while crops need good structure and macro porosity for healthy roots and proper air and water balance. To improve soil health, it is suggested to use diverse crop rotations and catch cropping to increase soil organic matter and carbon. This is crucial for stabilizing soil structure, enhancing water retention, and promoting root growth, all of which are important for climate resilience and yield stability in groundnut systems. Additionally, different crop types can improve the availability of nutrients like phosphorus, iron, zinc, and manganese, as they have different abilities to mobilize soluble inorganic nutrients (Piotrowska-Długosz and Wilczewski, 2020; Stomph 2020).

This study highlights that Ananthapuramu is primarily recognized for its cultivation of groundnuts and pigeon peas. However, the practice of leaving crop residues on the field is not common due to the demand from livestock, resulting in a lack of organic matter return. Additionally, there is insufficient application of organic and mineral fertilizers, as the soils have already reached threshold levels of soil organic carbon (SOC) relative to clay and slaking index in relation to Cation exchange capacity (CEC) and clay ratio, leading to poor soil fertility and structural stability.

Table 4: Profile weighted means for soil properties of Anantapur district

Soil series	particle size distribution (%)					clay	sand/ silt	silt/ clay	pH	EC (dSm-1)	OC (%)	SOC/ C	CaCO3 (%)	CEC (cmol/ kg)	Exchangeable bases cmol/kg				CEC/ Clay	Ca/ Mg	k/Na	1.724*OC	Z+C	SSI	SFI	SI
	Gravel	Coarse sand	fine sand	Sand	Silt										Ca	Mg	Na	K								
Ananthapuramu (AP)		23.2	15.63	38.98	9.9	51.13	4.02	0.2	8.53	0.79	0.33	0.01	1.95	36.64	11.42	10.48	7.19	1.1	0.73	1.18	0.16	0.58	60.99	0.95	17.17	4.32
Batrepalle (BTP)	39.35	50.5	31.4	82.52	5.64	11.84	15.23	0.47	7.15	0.18	0.28	0.02	0	6.05	3.65	3.1	0	0.4	0.51	1.42	0.01	0.47	17.44	2.72	48.5	0.79
Bogalkatta (BGK)	19.37	8.56	13.78	22.57	19.93	57.49	1.13	0.35	8.02	0.28	0.29	0.01	4.32	50.25	30.86	16.07	3.32	0.74	0.88	2.02	0.37	0.5	77.22	0.65	11.68	4.90
Brahmanapalle (BMP)	9.47	62.38	0	62.28	4.63	33.1	15.93	0.14	5.83	0.23	0.52	0.02	0	17.4	9.03	0.32	0	0.21	0.52	29.3	0.01	0.89	37.73	2.36	2.03	2.66
Chitravathi (CTV)	26.57	12.83	55.81	67.86	9.47	22.67	9	0.51	7.01	0.1	0.29	0.01	0.49	7.9	5.92	5.2	4.94	0.65	0.36	1.32	0.16	0.5	32.25	1.56	3.22	1.77
Garudapuram (GDP)	22.68	35.38	21.72	57.38	9.26	33.36	6.38	0.28	7.57	0.29	0.47	0.01	6.77	18.88	12.12	4.33	1.19	0.6	0.57	7.29	0.5	0.81	42.58	1.91	19.97	2.69
Gollapalle (GLP)	28.12	44.62	0	45.03	10.84	44.13	4.26	0.24	8.14	0.4	0.37	0.01	0.85	26.91	20.56	0.67	2.58	0.58	0.62	30.87	0.23	0.63	54.87	1.15	9.11	3.68
Gooty (GTY)	40.39	41.27	0	41.66	5.38	52.96	9.16	0.11	6.33	0.1	0.14	0	0	19.37	12.21	1.3	0.22	0.3	0.38	9.39	1.41	0.24	58.29	0.42	11.06	4.52
Hagari (HGR)	3.85	8.75	50.99	60.05	13.06	26.89	5.73	0.47	7.8	0.31	0.23	0.01	0	19.85	11.4	3.46	1.1	0.26	0.74	4.46	0.42	0.4	39.89	1.01	24.74	2.16
Hagalur (HGI)	6.81	10.39	6.44	16.95	20.54	62.51	0.83	0.33	7.42	0.77	0.48	0.01	8.47	54.22	31.33	13.93	6.28	0.92	0.88	2.46	0.15	0.83	82.91	1	27.54	5.31
Itigi (ITG)	29.95	17.17	15.05	32.97	17.02	50.02	1.98	0.34	8.13	0.1	0.42	0.01	15.21	51.14	37.57	8.67	0.94	0.56	1.05	4.51	0.61	0.73	66.65	1.1	34.62	4.20
kadavakallu (KDK)	12.36	8.64	13.5	22.2	23.13	54.68	0.96	0.43	7.61	0.26	0.58	0.01	7.99	47.24	34.93	10.4	0.84	0.93	0.87	3.7	1.09	0.99	77.75	1.28	40.11	4.59
Kamalapadu (KMP)	28.7	34.96	16.11	52.13	11.47	36.4	5.62	0.32	7.7	0.19	0.3	0.01	0	29.3	13.38	13.33	2.82	0.31	0.85	1.63	0.31	0.52	47.64	1.1	14.8	3.00
Kondapuram (KDP)	38.13	39.45	20.63	57.64	3.03	39.33	18.9	0.11	6.12	0.1	0.24	0.01	0	18.87	10.12	4.67	0.31	0.23	0.5	2.06	1.23	0.42	42.48	0.98	15.08	3.27
Kottacheruvu (KTC)	0	66.78	0	69.31	5.39	25.3	15.16	0.21	5.89	0.1	0.4	0.02	0	14.38	8.88	2.88	0.35	0.2	0.59	3.05	0.68	0.68	30.5	2.24	11.38	1.98
Lakshmupalle (LKL)	51.02	10.97	39.4	49.2	6.47	44.33	7.51	0.15	7.13	0.1	0.27	0.01	0	20.78	16.62	2.37	0.27	0.3	0.45	6.86	1.13	0.47	50.95	0.93	30.34	3.72
Madakasira (MDK)	41.5	33.23	21.28	53.65	4.38	41.97	13.47	0.11	6.23	0.1	0.2	0	0	20.44	8.83	6.08	5.59	0.14	0.51	1.44	0.08	0.35	46.42	0.76	5.36	3.52
Mallreddipalle (MDP)	17.73	68.53	0	68.62	5.55	25.83	13.92	0.23	6.2	0.1	0.22	0.01	0	14.45	12.17	0.83	0.32	0.24	0.55	15.07	0.79	0.37	31.37	1.19	2.48	2.06
Manaesamudram (MED)	11.62	22.22	30.85	56.65	11.47	31.89	6.14	0.33	7.64	0.37	0.15	0	0.01	14.34	7.33	3.97	1.22	0.39	0.48	10.82	0.38	0.26	42.63	0.61	12.19	2.62
Mincheri (MCI)	6.96	5.38	7.59	13.47	27.08	59.45	0.5	0.46	7.41	0.19	0.59	0.01	1.75	49.55	23.94	28.93	0.89	1.07	0.87	0.85	1.27	1.02	85.51	1.19	25.99	5.02
Mussukota (MTK)	32.58	22.06	20.14	42.26	18.63	39.11	2.45	0.49	7.68	0.16	0.22	0.01	13.24	29.28	1.48	3.74	1	0.4	0.72	0.74	0.43	0.38	57.71	0.66	15.75	3.26

Soil series	particle size distribution (%)					clay	sand/ silt	silt/ clay	pH	EC (dSm-1)	OC (%)	SOC/ C	CaCO3 (%)	CEC (cmol/ kg)	Exchangeable bases cmol/kg				CEC/ Clay	Ca/ Mg	k/Na	1.724*OC	Z+C	SSI	SFI	SI
	Gravel	Coarse sand	fine sand	Sand	Silt										Ca	Mg	Na	K								
Peddamallepalle (PMP)	32.58	22.06	20.14	42.26	18.63	39.11	2.45	0.49	7.68	0.16	0.22	0.01	13.24	29.28	1.48	3.74	1	0.4	0.72	0.74	0.43	0.38	57.71	0.66	11.48	3.26
Penner (PNR)	4.99	9.75	59.1	68.93	8.76	22.31	10.14	0.38	7.39	0.2	0.27	0.01	0	16.06	8.69	3.1	1.29	0.34	0.72	3.66	0.26	0.46	31.06	1.5	14.57	1.74
Perur (PRR)	26.78	37.33	28.95	64.78	5.86	29.36	11.32	0.21	8.65	0.88	0.35	0.01	0.58	19.64	6.67	6.89	5.26	0.68	0.66	1.22	0.15	0.6	35.36	1.7	1.35	2.36
Rampuram (RMP)	77.03	32.04	23.43	55.58	7.42	37	7.52	0.23	6.36	0.11	0.57	0.02	0	14.66	8.52	3.61	0.25	0.33	0.42	2.39	1.35	0.98	44.41	2.21	7.97	3.00
Satrarlapalle (STP)	8.76	60.43	0	60.89	9.45	29.66	9.13	0.34	6.08	0.1	0.7	0.02	0.01	15.21	9.81	2.8	0.28	0.2	0.52	3.46	0.75	1.21	39.04	3.1	16.64	2.32
Sazzaladinne (SZD)	8.87	22.19	19.37	41.43	17.12	41.45	5.42	0.42	7.82	0.55	0.4	0.01	0	23.39	6.9	8.9	4.67	1.34	0.57	1.04	0.32	0.68	58.62	1.17	10.39	3.43
Tadipatri (TDP)	8.09	37.43	15.69	53.9	12.18	33.91	4.96	0.36	8.44	0.28	0.1	0	4.19	24.77	12.72	8.41	2.97	0.68	0.73	1.52	0.57	0.17	45.92	0.38	14.45	2.81
Tamballapalle (TMP)	17.57	22.47	31.54	41.55	32.02	26.44	3.52	1.41	7.98	0.41	0.16	0.01	0	27.73	12.21	9.14	2.66	0.45	0.82	1.39	0.16	0.28	68.06	0.41	5.29	2.13
Teligi)TLG)	3.89	11.72	14.8	27.32	14.29	58.39	1.92	0.24	8.25	0.2	0.42	0.01	3.8	53.84	49.92	0	3.84	0.41	0.95	0.01	0.14	0.72	72.26	0.99	5.33	4.96
Uravakonda (URK)	24.55	74.91	0	73.07	3.13	23.79	25.5	0.16	6.72	0.1	0.15	0.01	0	15.88	9.96	1.45	0.31	0.24	0.65	8.93	0.8	0.26	27.01	0.97	26.54	1.89
Utakallu (UTK)	6.49	65.26	0	64.99	5.34	29.67	13.19	0.18	6.71	0.1	0.12	0	0	21.52	13.97	4.67	0.57	0.4	0.72	3.17	0.81	0.21	35.03	0.6	21.38	2.43
Vayalpad (VYP)	47.51	43.38	25.46	69.42	8.99	21.59	14.03	0.39	6.52	0.1	0.18	0.01	0	11.4	6.29	2.54	0.67	0.22	0.57	2.46	0.52	0.31	30.5	1.01	20.27	1.69
Velidandla (VLD)	44.15	21.25	19.67	42.97	22.62	34.41	2.12	0.65	7.5	0.1	0.27	0.01	28.68	32.89	18.66	12.98	0.69	0.23	1.02	1.53	0.39	0.47	55.95	0.84	11.41	2.83
Velmakuru (VMK)	35.45	4.63	8.75	13.66	21.31	65.02	0.63	0.34	7.82	1.18	0.32	0	3.25	54.99	28.79	15.19	6.18	0.76	0.86	2	0.22	0.55	85.89	0.65	5.53	5.57
Wajrakarur (WJK)	47.78	67.1	9.4	76.5	18.63	4.87	4.89	3.9	7.93	0.82	0.1	0.02	0	16.83	11.27	2.38	0.53	0.2	3.5	4.73	0.41	0.17	23.5	0.73	9.32	0.20
Mean	24.62	32.2	18.24	50.29	12.44	37.26	7.64	0.44	7.32	0.46	0.31	0.01	3.19	26.26	14.71	6.4	2.01	0.48	0.75	4.96	0.52	0.54	49.84	1.18	15.7	3.07
SD	17.48	21.03	15.59	18.29	7.35	14.27	5.99	0.63	0.8	1.12	0.15	0.01	6.07	14.23	10.9	5.9	2.12	0.3	0.5	6.99	0.4	0.26	18.36	0.66	10.95	1.27
CV (%)	71.01	65.3	85.47	36.36	59.05	38.29	78.39	142.8	10.97	243.99	48.26	126.02	190.34	54.2	74.06	92.09	105	61.6	67.03	140.7	76.59	48.26	36.84	55.49	69.75	638.90
Minimum	0	4.63	0	13.47	3.03	4.87	0.5	0.11	5.83	0.1	0.1	0	0	6.05	1.48	0	0	0.14	0.36	0.01	0.01	0.17	17.44	0.38	1.35	0.20
Maximum	77.03	74.91	59.1	82.52	32.02	65.02	25.5	3.9	8.65	6.82	0.7	0.02	28.68	54.99	49.92	28.93	7.19	1.34	3.5	30.87	1.41	1.21	85.89	3.1	48.5	5.57
EF (%)	31.96	39.23	30.86	53.33	32.48	53.85	28.57	8.92	52.66	5.34	35.68	27.51	11.12	41.29	27.31	22.14	28.02	28.79	12.57	16.05	36.32	35.68	47.33	29.72	30.42	

The region shows limited potential for organic fertilizers and relies heavily on synthetic alternatives. These factors contribute to the overall poor soil fertility and nutrient imbalances observed. The positive impact of conservation tillage in arid climates has been noted (Michler 2019), yet there is a lack of long-term trials and no universal recommendations for practices, emphasizing the need for tailored approaches at both site and farm levels. Furthermore, farmers express a desire for increased recognition and support for soil-conserving tillage methods, along with more financial and practical guidance, as indicated in survey feedback. The high costs of investment, delayed benefits, and the significant time and expertise required for management deter many farmers from adopting agroforestry practices (Wilson and Lovell, 2016).

In Ananthapuramu district, a similar situation exists regarding the adoption of conservation tillage and agroforestry practices at the farm level. Farmers face challenges due to their limited experience and the absence of demonstrations or on-farm trials. Transitioning to agroforestry requires permanent changes to land use, which carries both legal and economic consequences. Additionally, the regulatory framework surrounding agroforestry systems poses significant concerns for farmers. The effects of biostimulants or soil amendments, such as biochar, have been deemed minimal, leading to low recommendations and implementation rates among both farmers and institutional stakeholders. Enhancing soil fertility in dryland farming is essential, and new directives are necessary to promote conservation tillage and agroforestry systems to restore organic carbon levels and prevent topsoil erosion in the area. There is an urgent need to realign agricultural research programs at the regional level and to initiate agroecological research and extension activities that provide farmers with financial support for validating agronomic trials on their farms.

CONCLUSIONS

Soil data from surveys is essential for understanding soil fertility, which is crucial for creating climate-resilient and stable farming systems in Ananthapuramu district. The survey findings indicate that the soils range from neutral to strongly alkaline, with varying soil organic carbon to clay ratios, low structural stability, and marginal to poor fertility. There is a weak connection between total rainfall and the low productivity of pigeon pea and cotton, as well as between monsoon rainfall and groundnut yield in the area. The soil data highlights the need to prioritize fertility improvement, involving regional institutions for agroecological research, as outlined below: 1. Currently, soil fertility for crop production is rated as marginal to poor, necessitating crop diversification to enhance soil organic carbon in the future. 2. The primary goals for agronomic investments, based on the study's indicators, are to enhance climate resilience and yield stability in current cropping systems. 3. Key soil properties expected to improve with better fertility include water holding capacity, effective rooting depth, carbon stock and SOC to clay ratios, aggregate stability and soil fertility rates achievable through catch cropping, diverse crop rotations, and maintaining year-round soil cover. 4. For future advancements in promoting soil fertility in farming practices, there is a need for simple indicators and reference values for assessing soil fertility, along with workshops, field days, and field schools for training purposes.

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Conflict of Interest

There is no conflict of interest in publishing this article.

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