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Evaluating the Soil Quality Indicators in Various Yield Zones of Pulses in Tamil Nadu, India

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ABSTRACT

Background: In recent years, there is growing demand for pulses in Tamil Nadu and the government has implemented various schemes and programmes to promote cultivation. However, the evaluation and categorization of soils for pulse production is crucial in determining the suitability of land for pulse cultivation and offer improvement through the adoption of improved crop management practices.

Methods: A systematic soil quality assessment survey was taken up during 2020-2022 in the major pulse growing blocks of Virudhunagar district *viz*., Sattur, Aruppukottai and Thiruchuli based on past ten years yield data and it was classified into three categories *viz*., low yielding (< 400 kg ha^{-1}), medium (400 to 700 kg ha^{-1}) and high yielding (>700 kg ha^{-1}) categories. Three hundred samples were collected from these zones.

Result: The positive effects of soil physical, chemical and biological qualities on the yield of pulse crops were justified through the yield data of the high yielding zone which ranged from 769 to 989 kg ha^{-1} with an average pulse yield of 880 kg ha^{-1}. This may be attributed tothe favourable soil physical environment in terms of soil texture (sandy clay loam), higher mean percentage of water stable aggregates (51%) and an optimum pH of 7.52. These parameters coupled with lower bulk density (1.23 Mgm^{-3}), optimum infiltration rate (1.76 cm hr^{-1}) and maximum mean organic carbon status (1.38 mg kg^{-1}) contributed to higher range of soil cation exchange capacity (28.7 to 47.2 cmol p^{+} kg^{-1}). In addition, the soil respiration rate with mean respiration rate of 4.48 mg CO_2 kg^{-1} d^{-1} in high yield category compared to that of 2.34 mg CO_2 kg^{-1} d^{-1} in low yield category. Therefore, this study formulates a clear understanding of the variations in soil quality parameters for adopting efficient nutrient management practices towards obtaining maximum productivity of pulse crops.

Key words: Macronutrients, Pulses, Soil organic matter, Soil quality, Soil respiration.

INTRODUCTION

Pulses are the essential sources of proteins, vitamins and minerals, popularly known as “poor man’s meat” and “rich man’s vegetable” that contribute significantly to nutritional security and are valued as soil-building crops as they have a positive influence on soil quality (Singh *et al*., 2015). The production of pulses in India during 2019-20 is 22.14 million tonnes and is projected to be about 39 million tonnes by 2050, which necessitates an annual growth rate of 4.0%. The pulses’ current productivity varies from 700-790 kg ha^{-1} in India and 710 kg ha^{-1} in Tamil Nadu state, which is still well below the world’s average productivity (840 kg ha^{-1}) (Hosamani *et al*., 2017). An increase in yield per hectare of legumes was observed only ~1.4 times compared with ~3.0 times increase in cereals. The yields can be maximized only when the soil has the capacity to supply sufficient nutrients in a balanced proportion, which requires optimum fertilizer application, that is, soil application of a recommended dose of fertilizer (RDF) along with micronutrients (Yadav *et al*., 2007).

Further, root exudates released by pulses and organic matter added to the soil make unavailable soil nutrients in plant-available forms. In general pulse crops remove about 30-50 kg N, 2-7 kg P_2O_5, 12-30 kg K_2O, 3-10 kg Ca, 1-5 kg Mg, 200-500 g Mn, 5 g B, 19 g Cu and 0.5 g Mo from soil for producing one tonne of biomass. The nutrient imbalance is one of the major abiotic constraints limiting the productivity of pulses (Shukla *et al*., 2012). Furthermore, 90% area under pulses and more than 75% area under oilseed are in rainfed conditions.

Since the poor soils are low in organic matter content, organic manures play a vital role in improving soil physical condition, providing essential plant nutrients and maintaining the soil’s long-term productivity (Saliha *et al*., 2020). The crisis of shortage of pulses has aggravated the problem of malnutrition (Hussainy and Vaidyanathan, 2019). Thus, there is an urgent need to increase pulses production to meet the requirement by manipulating production technologies appropriately.

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In order to restore the quality of degraded soils and to prevent them from further degradation, it is of paramount importance to evaluate the soil quality in terms of physical, chemical and biological characteristics and to standardize a set of soil quality criteria for improving the productivity of pulses in various yield zones of Tamil Nadu.

The present research study aims to evaluate the soil properties and fertility status in low, medium and high yield zones and compare the productivity of pulse crops mainly blackgram (*Vigna mungo* L.) and greengram (*Vigna radiata* L.) followed by red gram (*Cajanus cajan* L.) and chickpea (*Cicer arietinum* L.) among these zones in relation to the soil parameters.

MATERIALS AND METHODS

Description of the study area

Geographically the study area is located in Virudhunagar district lying at the foot of Western Ghats between 90°20' and 90°72′ North latitude and 77°20′ and 78°70′ East longitude. It is bounded by Madurai district in the north, Sivagangai and Ramanathapuram in the east, Thoothukudi and Tirunelveli districts in the south and Kerala state in the west. The past decade weather information indicated a bimodal rainfall pattern with mean annual rainfall of 805.5 mm. The mean minimum, mean maximum and average air temperatures are 38.5, 30.2 and 34.5°C, respectively. The details of blocks and villages covered for assessing soil quality is given in Table 1.

Survey and collection of soil samples

The present investigation was conducted during 2020-2022 at the Department of Agronomy, Agricultural College and Research Institute, Madurai.

Based on the yields of the pulse crops (Blackgram and Greengram) for the past ten year and farmers database the sampling area for soil quality assessment and leaf nutrient analysis was divided into three categories *viz*., low yielding (<400 kg ha^{-1}), medium yielding (400 -700 kg ha^{-1}) and high yielding (>700 kg ha^{-1}) which are also indicated as low, medium and high soil quality categories.

About 50 surface samples (0-15 cm) for each zone @ 50 samples per block in two replications were collected from three blocks covering the low, medium and high yielding zones amounting to 300 number of soil samples representing the variability in soils of the pulse growing regions of Virudhunagar district.

For fixing the sample size (25) in the different category of low, medium and high fertility soil samples the "proportionate to size sampling method" was used by adopting the formula as given below:

$$n_i = (N_i/N) \times n$$

Where,

i= Unit sample size.

N_i = Unit sample population size.

N = Population size.

Soil bulk density (ρ_b), particle density, aggregate stability and infiltration rate

The bulk density and particle density of soil surface samples (0-15 cm) were determined from the apparent and true volumes of the soil measured by adding a known quantity of water to a measuring cylinder containing a weighed quantity of soil (Baruah and Barthakur, 1997). Using the Mass-Volume relationship, the bulk density and particle density of soil were calculated (Blake and Hartge, 1986).

The soil aggregate stability was determined by wet sieving method (Yoder, 1936) where 50 g soil was placed on a nest of three sieves with apertures of 2.0, 1.0 and 0.5 mm, respectively. The percentage aggregate stability was calculated by using the equation:

$$\%\ \text{Aggregate stability} = \frac{[(\text{Mass of aggregates + Sand}) - (\text{Mass of sand})]}{(\text{Mass of soil sample - Mass of sand})} \times 100$$

Infiltration rate or water intake rate of the soil samples were measured by using double ring infiltrometer (Blake, 1965).

Soil pH, organic carbon, calcium carbonate and cation exchange capacity

The pH of the sample was determined in 1:2 soil-water suspension using a combined pH meter (Jackson, 1973). The representative soil samples from the study area were air dried, finely ground and passed through 0.2 mm sieve for organic carbon estimation. The organic carbon present in organic matter of the soil sample was determined by the chromic acid wet digestion method of (Walkley and Black, 1934).

Ten gram of soil sample was treated with an excess standard 0.2 N HCl and back titrated the unreacted acid with standard alkali to determine the presence of free calcium carbonate (Piper, 1966).The cation exchange capacity of soil was determined by using Neutral Normal Ammonium Acetate solution in which the quantity of cations (NH_4^+) adsorbed by the soil was estimated by distillation (Bower *et al*., 1952) and the CEC was expressed as cmol (p^+) kg^{-1} soil.

Soil available nitrogen, phosphorus, potassium, sulfur and micronutrients

For estimating the available N content, a known weight of the soil was treated for with excess of alkaline potassium permanganate and distilled in the presence of sodium hydroxide as per Subbaiah (1956) method. Phosphorus content of the soil was extracted using 0.5 M sodium bicarbonate and measured colorimetrically using a red filter at 660 nm (Olsen, 1954). The available potassium in the soil was extracted by using Neutral Normal NH_4OAc and the concentration of K ions in the solution was determined using flame photometer (Stanford and English, 1949). Available sulphur in the soil samples was extracted with 0.15 percent $CaCl_2.2H_2O$ and estimated by turbidimetric method (Cottenie *et al*., 1979).

Available micronutrients in the soil *viz*., Fe and Zn were extracted using DTPA (Diethylene Triamine Penta Acetic acid) and subsequent measurement of micronutrient concentrations in the filtrate by using an Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978).

Soil respiration and dehydrogenase activity

Soil respiration was determined by CO_2 evolution method in which 25°C field moist soil was placed in a 50 mL beaker and incubating the sample in dark for 10 days in a one litre airtight sealed jar containing 10 mL of 1 M NaOH (Anderson, 1982). The activity of dehydrogenase in soils was assayed according to the method prescribed by Cassida *et al.* (1964).

Table 1: Details of blocks and villages covered for assessment of soil quality in Pulse growing areas of Virudhunagar district.

Name of the blocks	Name of the villages
Aruppukottai	Kovilangulam
	Kattakudi
	Pallavanadham
	Chettikurchi
	Pandalkudi
	Meenakshipuram
	Aruppukottai
	Vellayadhapuram
	Udaiyanadhapuram
	Amanakkunatham
Thiruchuli	Kathalampatti
	Konganakurchi
	Aladipatti
	Kallurani
	Kulampatti
	Bommakottai
	Kalyanasundarapuram
	Sengulam
	Savaspuram
	Silukkapatti
	Puthuyenthal
	Veppilaicheri
Sattur	Pothireddipatti
	O.Mettupatti
	Nalli
	M.Nagalapuram
	Pappakudi
	Ammapatti
	Karisalpatti
	Mulliseval
	Padanthal

Statistical analysis

One-way analysis of variance (ANOVA) was conducted to compare the effect of different soil quality categories on soil properties. All statistical analysis was conducted using SAS version 9.4 (SAS, 2013). Statistical significance was determined at α=0.05 level (McLean, 1982). The relationship between soil properties were determined by Pearson's correlation matrix using RStudio 1.1.453 (Allaire, 2012).

RESULTS AND DISCUSSION

Soil bulk density, particle density, aggregate stability and infiltration rate

Data on soilbulk density, particle density, aggregate stability and infiltration rate for low, medium and high soil quality categories are presented in Table 2. The significantly low bulk density (1.23 Mgm^{-3}) of high soil quality category at p<0.05 indicated better soil physical environment for pulse crop growth compared to the other two zones. Potential root restriction occurred in soils with bulk density >1.4 Mg m^{-3} for clay and >1.6 Mg m^{-3} for sand (Sakin, 2012). The water stable aggregate percentage was significantly influenced by medium and high-quality soils (48.4 and 51.1, respectively).

Infiltration rate of any soil type is prerequisite for soil quality assessment. Soils with less than 0.5, 0.5 to 2.0 and 2.0 to 4 cm hr^{-1} are considered to have slow, moderately slow and moderate infiltration rates, respectively. Soil organic matter is a key attribute of soil quality that impacts soil aggregation and water infiltration (Franzluebbers, 2002).

Soil pH, organic carbon, calcium carbonate content and cation exchange capacity

Data on soil pH, SOC, $CaCO_3$ and CEC for low, medium and high soil quality sites are presented in Table 3. The significant influence of soil pH was observed in the high soil quality (7.51) followed by medium soil quality (8.10) and low soil quality zones (8.58). In the low-quality zone of this study, 88 percent soil samples are under alkaline pH, which may tend to decrease the availability of nutrients creating

Table 2: Soil bulk density (r_b), particle density, water stable aggregates (WSA) and infiltration rate of various soil quality categories under pulses production.

Soil quality category	Soil r_b (Mgm^{-3})	Particle density (Mgm^{-3})	WSA (%)	Infiltration rate (cm hr^{-1})
Low	1.44[a†]	2.56[a]	37.8[b]	3.25[a]
Medium	1.31[b]	2.57[a]	48.4[a]	2.47[b]
High	1.23[c]	2.48[b]	51.1[a]	1.76[b]
		Analysis of variance (*p*>F)		
Category	<0.0001	0.001	<0.0001	<0.0001

†Mean values within the same column followed by different small letters for each site are significantly different at *p*<0.05.

an unfavourable condition for plant growth as already reported by Meena *et al.* (2006).

The mean soil organic carbon (SOC) content (6.52 g kg^{-1}) was significantly high in high soil quality zone, which was 12 and 55 % more than the medium (2.92 g kg^{-1}) and low soil quality (1.72 g kg^{-1}) categories, respectively. The data on $CaCO_3$ content indicate that all the soil samples collected from the high yielding pulse farms were free from calcareousness (<2 %). The cation exchange capacity of soil depends on two main parameters, namely the soil organic matter content and soil texture, particularly the amount and nature of clay. An optimum CEC of 18 cmol (p^+) kg^{-1} is considered favourable for pulse cultivation (Hati *et al.*, 2007), but the average CEC was significantly low (11.9 c mol (p^+) kg^{-1}) in the low soil quality zone.

Available nitrogen, phosphorus, potassium, sulphur, iron and zinc

Data in Table 4 represent the available N, P, K, S, Fe and Zn for the three soil quality categories. Soil with less than 280, 281 to 450 and >450 kg per hectare of N is considered as low, medium and high in available N status, respectively (www.agritech.tnau.ac.in).

The mean available N content in the low soil quality zone (139 kg ha^{-1}) was significantly low by 20 and 50% from the medium (227 kg ha^{-1}) and high (283 kg ha^{-1}) soil quality zones, respectively. This might be due to improper N fertilization, insufficient application of organic manures and ignorance of soil-test based N management practices. Lakshmi *et al.* (2015) reported similar results while assessing the response of pulse crops to nutrient management.

Phosphate compounds in plant are called 'energy currency' and for pulses, it plays an important role in root proliferation and initiate nodule formation (Liu *et al.*, 2018). Soil containing below 11, 11 to 22 and >22 kg available $P_2O_5 ha^{-1}$ are considered as low, medium and high in P supply (agritech.tnau.ac.in), respectively. The available P content in the soils of low soil quality zone was significantly low (3.8 kg ha^{-1}).

The mean available K in the soils of low soil quality zone was significantly low (168 kg ha^{-1}) relative to other two zones, which may be due to the insufficient application or complete avoidance of K application by the farmers. Similar observation has been made by (Singh, 2017).The critical limit of available sulphur status is 10 kg ha^{-1}, below and above which are considered as deficient and sufficient in available S respectively (Tandon, 2005).

Among the micronutrients, Fe and Zn were found to be of serious concern in Tamil Nadu (Shukla *et al.*, 2014). The available Fe content analysed for the low soil quality zone registered deficiency in 72% soil samples. The critical limit for available zinc is 1.2 mg kg^{-1}. The relatively higher deficiency in the low soil quality category may be due high pH, presence of $CaCO_3$ and low SOC content. These observations were in accordance with the findings of (Chahal *et al.*, 2005).

Soil respiration rate and dehydrogenase activity

The soil respiration rate in the surface soil samples of pulse crops is given in Fig 1. The high soil quality zone recorded significantly higher respiration rate of 4.48 mg CO_2 kg^{-1} d^{-1} that indicated the favourable influence of soil organic matter.

Table 3: Soil pH, organic carbon (SOC), calcium carbonate ($CaCO_3$) and cation exchange capacity (CEC) of various soil quality categories under pulses production.

Soil quality category	Soil pH	SOC (g kg^{-1})	$CaCO_3$ (%)	CEC cmol (p^+) kg^{-1}
Low	8.58^{a†}	1.72^{c}	2.67^{a}	11.9^{c}
Medium	8.10^{b}	2.92^{b}	2.14^{b}	21.8^{b}
High	7.51^{c}	6.52^{a}	1.46^{c}	36.9^{a}
		Analysis of variance (*p*>F)		
Category	<0.0001	<0.0001	<0.0001	<0.0001

†Mean values within the same column followed by different small letters for each site are significantly different at $p<0.05$.

Table 4: Soil available nitrogen (N), phosphorus (P), potassium (K), sulfur (S), iron (Fe) and zinc (Zn) content of various soil quality categories under pulses production.

Soil quality category	N	P	K	S	Fe	Zn
	-------------------(kg ha^{-1})-------------------				mg kg^{-1}	
Low	139^{c†}	3.78^{c}	168^{c}	8.51^{c}	3.15^{c}	0.85^{c}
Medium	227^{b}	5.57^{b}	225^{b}	12.5^{b}	6.36^{b}	1.50^{b}
High	283^{a}	10.3^{a}	290^{a}	15.6^{a}	9.18^{a}	2.07^{a}
			Analysis of variance (*p*>F)			
Category	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

†Mean values within the same column followed by different small letters for each site are significantly different at $p<0.05$.

The dehydrogenase activity in the soil samples of the low, medium and high yielding pulse growing soils of Virudhunagar district is given in Fig 2. The mean values of dehydrogenase activity in the low and medium soil quality zones in this study were 32 and 64 TPF µg $g^{-1}$of dry soil hr^{-1}, respectively. The average dehydrogenase activity in any fertile soil varies between 80-95 TPF µg g^{-1} of dry soil hr^{-1} (Sharma and Mandal, 2009).

Yield of pulse crop

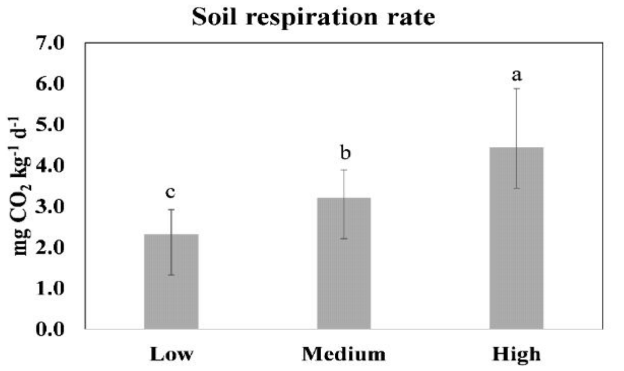
Pulse crops which are cultivated by the farmers of this study area over five decades are recently facing yield reduction in major pulse growing zones which is mainly attributed to soil fertility decline that prompted this research study. The pulse predominant zones were classified into three categories *viz*., low yielding (less than 400 kg ha^{-1}), medium (400 - 700 kg ha^{-1}) and high yielding (more than 700 kg ha^{-1}) and the yields were recorded from the farms involved in the soil quality assessment survey (Fig 3).

Accordingly, the yield range of pulses in low, medium and high soil quality categories were 143 to 390, 413 to 721 and 769 to 989 kg ha^{-1}, respectively. The soil quality indicators assessed in the low soil quality zone recorded significantly higher mean bulk density (1.44 Mgm^{-3}), lesser percentage of water stable aggregates (48%), significantly lower CEC (12.20 cmol (p^+) kg^{-1}), which created a relatively poor physico-chemical environment that constrained the availability of nutrients in terms of significantly low N status (138 kg ha^{-1}), moderate K status (168 kg ha^{-1}), low availability of P and S (3.84 and 8.51 kg ha^{-1}) and deficiency in Zn (0.85 mg kg^{-1}).

On the contrary, the positive effects of soil physical, chemical and biological properties on the yield of pulses were well proved through the yield data of the high soil quality zone which ranged from 769 to 989 kg ha^{-1} with a mean pulse yield of 880 kg ha^{-1}. Moderate N and P status of 316 and 12.4 kg ha^{-1} respectively, significantly high available potassium (367 kg ha^{-1}) and sulphur status (21.8 kg ha^{-1}). The micronutrient contents *viz*., DTPA Fe (9.18 mg kg^{-1}) and DTPA Zn (2.07 mg kg^{-1}) in high quality soils were well above the critical limits revealed better quality of these soils contributing to maximum pulse productivity in this zone.

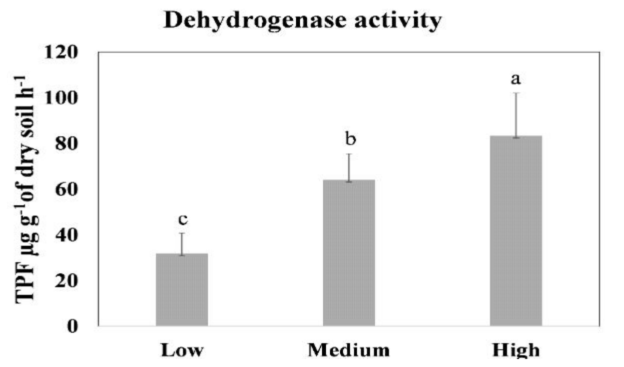
Correlation of parameters

The mean maximum pore space (41.3%) in the high soil quality zone is also ascribed to the lower bulk density values in these soils as evidenced in the correlation studies (r = -0.309*) indicating the importance of soil densities as a parameter for determining soil porosity (Table 5). The higher CEC in high soil quality zones may be due to relatively higher soil organic matter content (r= 0.505**) and higher clay content (r= 0.289*) which in turn might have contributed to better availability of nutrients for crop uptake and thus higher yield of pulses. A significant positive



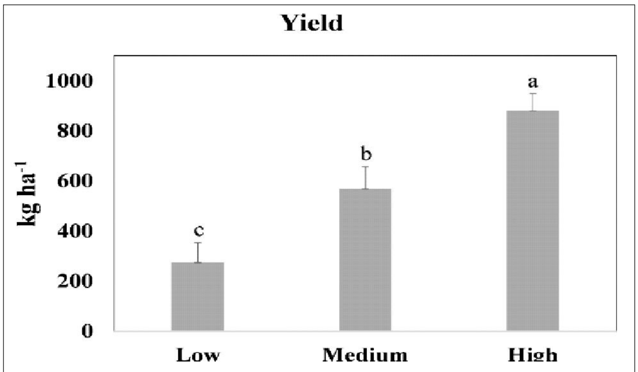
The different lowercase letters above the error bars for the same aggregates indicate significant differences at p<0.05.

Fig 1: Soil respiration rate (mg CO_2 kg^{-1} d^{-1}) of low, medium and high soil quality categories under pulses production.



The different lowercase letters above the error bars for the same aggregates indicate significant differences at p<0.05.

Fig 2: Dehydrogenase activity (TPF µg $g^{-1}$of dry soil h^{-1}) of low, medium and high soil quality categories under pulses production.



The different lowercase letters above the error bars for the same aggregates indicate significant differences at p<0.05.

Fig 3: Crop yield (kg ha^{-1}) of low, medium and high soil quality categories under pulses production.

Table 5: Correlation co-efficient between important soil quality parameters of the pulse growing soils (0-15 cm) of Virudhunagar district, Tamil Nadu.

	BD	Porosity	Clay	WSA	IR	pH	EC	CaCO3	CEC	OC	AV. N	AV. P	AV. K	AV. S	DTPA.Zn	DTPA.Fe	SR	DHA	Yield
BD	1.000	-0.309*	-0.66**	-0.46	0.71**	-0.349*	-0.259*	-0.072	-0.345**	-0.367**	-0.276	-0.337*	-0.412**	-0.320*	-0.125	-0.287	-0.343**	0.112	-0.398**
Porosity		1.000	0.514**	0.188	-0.526**	0.204	-0.367**	-0.183	0.467**	0.406**	0.223	0.387**	0.307*	0.345*	-0.265	0.360**	0.414**	0.302*	0.678**
Clay			1.000	0.335*	-0.586**	0.418*	-0.376**	-0.280	0.289**	0.378**	0.306*	0.184	0.259	0.324*	0.192	0.345**	0.317**	0.345	0.510**
WSA				1.000	-0.327	-0.121	-0.186	-0.467*	0.392**	0.759**	0.476**	0.605**	0.564**	0.445*	0.278*	0.489**	0.205	0.672**	0.581**
IR					1.000	-0.045	0.326	-0.423*	-0.409**	-0.321*	-0.457*	-0.292	-0.449**	-0.504**	-0.312*	-0.532**	-0.521**	-0.705**	-0.672**
pH						1.000	-0.171	0.712**	0.102	-0.187	-0.027	0.098	-0.136	0.087	-0.285*	-0.298*	0.212	-0.256*	0.112
EC							1.000	0.184	-0.623**	-0.253	-0.412**	-0.318*	-0.258	-0.408**	-0.215	-0.253	-0.295*	-0.345*	-0.578**
CaCO3								1.000	-0.339*	-0.432**	-0.487**	-0.343*	-0.512**	-0.376*	-0.397**	-0.488**	-0.291*	-0.288*	-0.476**
CEC									1.000	0.505**	0.587**	0.612**	0.482**	0.486**	-0.512**	0.670**	0.487**	0.234*	0.685**
OC										1.000	0.716**	0.547**	0.605**	0.493**	0.541**	0.687**	0.221	0.456**	0.734**
AV. N											1.000	0.656**	0.443**	0.389**	0.412**	0.542**	0.418**	0.532**	0.712**
AV.P												1.000	0.319*	0.514**	-0.678**	-0.215*	-0.187	0.346**	0.568**
AV.K													1.000	0.423**	0.612**	0.764**	0.325*	0.456**	0.745**
AV.S														1.000	0.378**	0.443**	0.512**	0.376**	0.688**
DTPA.Zn															1.000	0.546**	0.296*	0.435	0.465**
DTPA.Fe																1.000	0.315*	0.267	0.718**
SR																	1.000	0.512**	0.632**
DHA																		1.000	0.634**
Yield																			1.000

Note: *Significant at 5% level; **Significant at 1% level.

relationship was also established between available P status and crop yield. Similar observation was made by (Harisudan *et al*., 2009).

CONCLUSION

From this study, it could be concluded that higher values of soil attributes such as aggregate stability, cation exchange capacity, organic carbon, available nitrogen, available potassium and extractable micronutrients corresponded well with the high soil quality category and aid in improving the pulse productivity in low yield zones. Adoption of TNAU recommended dose of fertilizers *viz*.,12.5:25:12.5:10 kg N, P_2O_5, K_2O and S per hectare or soil test-based application of nutrients along with regular and integrated application of enriched farmyard manure at 750 kg ha^{-1}, Azospirillum at 2 kg ha^{-1} and pulse wonder in high quality zone contribute for better soil quality for obtaining higher yield in pulses.

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Conflict of interest

The authors have no conflict of interest to declare.

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