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Soil Quality Indicators as an Assessment Tool to Maximize the Productivity of Pulse Crops

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Authors' contributions

This work was carried out in collaboration among all authors. Author BBS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RI and CP managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The present research investigation was taken up during 2017-2019 to evaluate the properties and fertility status of soils through physical, chemical and biological indicators of soil quality in the major pulse growing regions which were classified into three categories viz., low yielding (< 400kg ha^{-1}), medium (400 to 700 kg ha^{-1}) and high yielding (> 700 kg ha^{-1}). 300 samples collected from these zones were subjected to analysis and weight ages were assigned to each soil quality attribute through Principal Component Analysis (PCA) and those that explain at least 5% of the variation in the data were examined by using SPSS software. The mean percentage of water stable aggregates was the highest (51%) in high yielding soils which can be attributed to the beneficial effect of organic manure application and balanced fertilizer usage. Most of the samples in the high yielding soils were neutral to slightly alkaline (pH of 7.20 to 7.85), while that of medium and low yielding soils were moderately alkaline and neutral to slightly alkaline respectively. However low yield category had an average cation exchange capacity of 12.2 c mol (p^+) kg^{-1}, whereas that of medium and high yield categories recorded 21.8 and 36.9 c mol (p^+) kg^{-1} respectively. The soils of high, medium and low yield zones recorded 282,234 and 138 kg ha^{-1} of available nitrogen respectively. The sulphur status

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in pulse growing soils revealed deficiency in 88 percent of the samples from low yielding zones which needs due attention. The overall results of the study concluded that the 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 yield category indicating the importance of these soil quality indicators for improving the pulse productivity in low yield zones.

Keywords: Soil quality; physical; chemical; biological indicators; pulses; crop yield; organic carbon; cation exchange capacity; dehydrogenase activity.

1. INTRODUCTION

Soil quality is defined as "the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health" [1]. Pulse crops grown with improper nutrient management practices under both rainfed and irrigated conditions encounter diversity of constraints broadly on account of poor physical, chemical and biological soil quality and ultimately end up with poor functional capacity [2]. 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 characteristics in terms of physical, chemical, biological indicators and to standardize a set of soil quality criteria for improving the productivity of pulses. In Tamil Nadu, the total area under pulses is around 9.5 lakh ha with an annual production of 6.5 lakh tonnes. Out of the 32 districts in Tamil Nadu, the area of pulses in Virudhunagar district is about 9000 ha out of which 62 percent of the area is under rainfed conditions. The average productivity of pulses is 600 kg ha^{-1} which is far below the state average of 712 kg ha^{-1} [3]. Proper nutrient management practices based on soil analysis, developing region specific nutrient database and mapping the availability of nutrients are the key areas to be focused for improving the soil quality and thus the productivity in predominant pulse growing regions [4] of Tamil Nadu. Keeping in view the importance of soil quality database, the present research investigation was meticulously planned to compute optimum soil quality parameters to enhance the productivity of pulses in low yield zone, to maximize the yield in medium quality zone and to sustain the yield in high quality zone.

The present investigation aims to evaluate the properties and fertility status of soils through physical, chemical and biological indicators of soil quality in the major pulse growing regions and to compute optimum soil quality parameters required to enhance the productivity of pulses.

2. MATERIALS AND METHODS

2.1 Characteristics 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. The past decade weather information (2008– 2017) revealed that the area has a bimodal rainfall pattern and a mean annual rainfall of 805.5 mm. Based on the yields of pulse crops (Blackgram and Greengram) for the past ten years (2008–2017) and farmers database, the sampling area for soil quality assessment 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}) soils. About 50 surface (0-15 cm depth) soil samples for each zone at the rate of 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 of soil in terms of physical, chemical and biological quality. The soil samples were then processed and preserved in polythene bags for further analysis of various soil quality parameters.

2.2 Evaluation of Soil Quality Parameters

The soil quality parameters studied were physical, chemical and biological in nature. Physical indicators used for determining soil quality were bulk density, aggregate stability and infiltration rate [5]. Chemical parameters analyzed were soil reaction (pH), electrical conductivity, calcium carbonate content, Cation Exchange Capacity (CEC), organic carbon, available nitrogen, available phosphorus, available potassium, available sulphur, available iron and zinc. The biological parameters comprised of soil respiration rate and dehydrogenase enzyme activity and the rationale for assessment was based on the procedure proposed by Singer and Ewing [6].

2.3 Processing Analytical Data

The analytical data on soil quality parameters were processed with statistical parameters as suggested by Gomez and Gomez [7]. The principal components (PCs) receiving high eigen values and variables with high factor loading were assumed to be variables that best represent systems attributes. Therefore, PCs with eigen values ≥ 1 and those that explain at least 5% of the variation in the data were examined by using SPSS software [8].

3. RESULTS AND DISCUSSION

3.1 Soil Physical, Chemical and Biological Parameters of Yield Zones

The status of each attribute was categorized into three classes *viz*., class I (high yield category), class II (medium yield category) and class III (low yield category) and is presented in Table 2. The bulk density of the low yielding soils ranged from 1.32 to 1.64 Mgm^{-3} while that of high yielding soils ranged between 1.12 and 1.33 Mgm^{-3}. The low yielding zones were predominantly sandy clay in texture while most of the soil samples in the high yield zone were sandy clay loam in texture which is the most preferred texture for pulse cultivation. The mean percentage of water stable aggregates was the highest (51%) in high productive soils which can be attributed to the beneficial effect of organic manure application and balanced fertilizer usage as already reported by Bandyopadhyay et al. [9]. In the low yield category, cultivation of pulses for many years without proper soil management practices has reduced the stability of soil aggregates and lowered the soil organic carbon values that might have contributed to lesser mean percentage (37%) of water stable aggregates.

Most of the soils in the high yield zone were neutral to slightly alkaline (pH 7.20 to 7.85), while that of medium and low yield zones were moderately alkaline and neutral to slightly alkaline respectively. Since cation exchange capacity is the most important soil property that influences the adsorption, release, mobility and uptake of nutrients, it was assigned a weightage of 8 towards maximizing pulse production. Pulse growing soils should have a minimum cation exchange capacity of 18 c mol (p^+) kg^{-1}.However the class III low yielding category had an average cation exchange capacity of 12.2 c mol (p^+) kg^{-1}, whereas that of medium and high yield categories recorded 21.8 and 36.9 c mol (p^+) kg^{-1} respectively. The CEC of high yielding soils was significantly higher with 47.2 cmol (p^+) kg^{-1} than the other two categories. The higher level of CEC in high yield zones may be due to relatively higher soil organic matter content and higher clay content which in turn might have contributed to better availability of nutrients for crop uptake and thus higher yield of pulses.

Assessment of soil organic carbon status which was assigned a maximum weightage of 15 percent was found to have an average content of 6.68 g kg^{-1} in class I category thus resulting in an average pulse yield of 880 kg ha^{-1} compared to that of class II and class III categories with average organic carbon content of 4.14 and 1.74 gkg^{-1} respectively. The available N status in low yield zone ranged between 112 kg ha^{-1} and 158 kg ha^{-1}due to improper N fertilization, insufficient application of organic manures and ignorance of N management practices in contrast to the high yield zone with only 36 percent of soils reporting low status of available N. Hence due attention has to be given to enhance the N use efficiency for soils and crops by the farmers of low yield zone. The soils of medium and high yield zones registered 282 and 316 kg ha^{-1} of available nitrogen respectively. The better N status of high yield zone may be due to high amount of organic carbon in these soils and also steady mineralization of N from the stable N components released during the decomposition of manures periodically added by the progressive farmers of this region. About 48 percent of the soil samples in the high yield category recorded moderate status of available P and 64 percent of the soils recorded higher available P status. Regular application of enriched FYM and adoption of TNAU fertilizer recommendation by the farmers might have contributed to high available P status which is in alignment with the findings of Jemila et al., [10]. The mean available K status in class III soils was moderate while that of class II and class I soils were high (> 280 $kgha^{-1}$). The results indicated that K is not a much limiting nutrient for pulse production.

However sulphur (with a weightage of 8 percent) which is considered as a fourth major nutrient was found to be deficient in low yield category with a mean available S content of 8.5 kg ha^{-1} as against 12.5 and 15.6 kg ha^{-1} in the medium and high yield categories respectively. The declining sulphur levels in low yield soils may be due to decreased use or no usage of S containing fertilizers like Ammonium sulphate, Single Super Phosphate and insufficient application of organic manures as reported by Joshi et al., [11]. The range of available Fe content in low yield zone was 1.67 to 4.22 mg kg^{-1} with 76 percent of these soils exhibiting deficiency (less than 3.7 for non calcareous and less than 6.3 for calcareous soils). Continuous crop removal and neglecting application of micronutrients in the fertilizer recommendation schedule was found to decrease the available Fe content. These results warrant attention for correcting Fe deficiency in the low yielding zone either through continuous application of organic manures like farmyard manure or enriched farmyard manure or TNAU recommended micronutrient mixture to stabilize the pulse productivity. However the soil samples categorized under class II and class I were found to have sufficient Fe content. Available Zinc content with the critical value of 1.2 mg kg^{-1} was found to be sufficient in the high yield zone whereas 32 and 76 percent of the soil samples collected from class II and class III zones respectively were deficient in zinc. The relatively higher deficiency in the low soil quality category may be due to high pH, presence of $CaCO_3$ and low organic carbon content.

Soil organic carbon content, soil respiration rate and dehydrogenase enzyme activity are the biological indicators assessed for evaluating the soil quality. 100 percent of the soils from class II and class III recorded low organic carbon status (less than 5 g kg^{-1}) whereas 80 percent of soils from class I exhibited medium to high organic carbon content (4.3 to 8.5 g kg^{-1}). Soil organic carbon or organic matter is a key indicator of soil quality which influences other soil properties, crop nutrient uptake and yield. Regular soil application of farmyard manure, enriched farmyard manure or vermicompost, foliar application of panchagavya or vermiwash as organic sources by the farmers of the high yielding zones might have contributed to higher organic matter content in these soils. Soil respiration rate assessed as an indicator of biological quality registered a mean respiration rate of 4.48 mg CO_2 kg^{-1} d^{-1} in high yield category compared to 2.34 mg CO_2 kg^{-1} d^{-1} in low yield category. The higher soil respiration rate is well correlated with better soil organic matter content which is also in line with the findings of Jeevika et al. [12]. On the other hand, with reduced soil respiration, nutrients are not released from the soil organic matter to feed the plant thus resulting in lesser yield of pulses as shown by the yield data in low yield zones.

Table 1. The proposed minimum data set (MDS) for assessing soil quality

Indicators of soil quality	Optimum values
Physical	
1.Soil bulk density (Mgm^{-3})	1.1 to 1.4
2.Water stable aggregates (Percentage)	40 to 45
3.Infiltration rate(cm hr^{-1})	3.5 to 5.0
4. Soil texture	Sandy clay to Sandy clay loam
Chemical	
1. Soil pH	6.5 to 7.5
2.Electrical conductivity	Less than 4
3. CEC (c mol (p^+) kg^{-1})	Red soil-20 Black soil-30
3.Available Nitrogen(kg ha^{-1})	280 to 560
4. Available Phosphorus(kg ha^{-1})	11 to 22
5. Available Potassium(kg ha^{-1})	118 to 280
6. Available Sulphur (kg ha^{-1})	10
7. Available Iron (mg kg^{-1})	3.7 for non calcareous soils 6.3 for calcareous soils
8. Available Zinc (mg kg^{-1})	1.2
I. Biological	
1.Soil Organic Carbon (gkg^{-1})	More than 5
2.Soil respiration rate (mg CO_2 kg^{-1} d^{-1})	More than 3

Source: Singer and Ewing [13]

Table 2. Mean physical, chemical and biological attributes of soil quality in various yield zones of pulses

Soil quality indicators	Weightage (%)	Class I (High yield category)	Class II (Medium yield category)	Class III (Low yield category)
Physical Indicators				
Bulk density (Mgm^{-3})	2	1.12 – 1.33 (1.23)*	1.20– 1.46 (1.31)	1.32 – 1.64 (1.44)
Texture	8	Sandy clay loam	Clay loam	Sandy clay
Water stable aggregates (Percentage)	4	34- 68 (51)	32- 63(48)	28- 48 (38)
Infiltration rate (cm hr^{-1})	5	1.75- 5.20 (3.27)	0.56- 4.40 (2.47)	0.94-2.44 (1.76)
Chemical Indicators				
Soil pH	5	7.20 – 7.85 (7.52)	7.76 – 8.40 (8.34)	8.31 – 8.85 (8.58)
Cation exchange capacity (c mol (p^+) kg^{-1})	8	28.7 – 47.2 (36.9)	19.2 – 25.8 (21.8)	16.3 – 8.40 (12.2)
Available N (kg ha^{-1})	9	221 – 316 (282)	186 – 282 (234)	112 – 158 (138)
Available P (kg ha^{-1})	6	7.63 – 12.44 (9.18)	3.83 – 7.54 (5.65)	2.46 – 5.62 (3.84)
Available K (kg ha^{-1})	11	220 – 367 (290)	165 – 291 (225)	121 – 221 (168)
Available S (kg ha^{-1})	8	8.88– 21.82 (15.64)	6.40– 19.32 (12.54)	6.23 – 10.65 (8.5)
Available Fe (mg kg^{-1})	9	5.78– 12.26 (9.18)	3.66 – 8.75 (6.36)	1.67 – 4.22 (3.15)
Available Zn (mg kg^{-1})	4	1.26 – 2.88 (2.07)	0.73 – 2.08 (1.51)	0.23 – 1.45 (0.85)
Biological indicators				
Organic Carbon (g kg^{-1})	15	4.33 – 8.55 (6.68)	1.18 – 4.87 (4.14)	0.62 – 3.14 (1.74)
Soil respiration rate (mg CO_2 kg^{-1} d^{-1})	6	2.45 -7.45 (4.48)	2.08 – 4.33 (3.21)	1.45 – 3.24 (2.34)

** Vaules in paranthesis indicate the average values of soil quality parameters*

3.2 Pulse Crop Yield

The yield data of pulse crops were collected from the low, medium and high yielding farms where the soil quality assessment survey was taken up. The mean yields of pulses were 275, 569 and 880 kg ha^{-1} in the low, medium and high categories respectively. Significant variation was observed among the yield zones and maximum co-efficient of variance (CV) of 28 percent was recorded in the low yield category. The range of yield was 143 to 390 kg ha^{-1} as against that of 769 to 989 kg ha^{-1} in the high yield category (Table 3).

The soil quality indicators assessed in the low yield zone reflected higher mean bulk density (1.44 Mgm^{-3}), lesser percentage of water stable aggregates (48 percent), lower CEC (12.20 cmol (p^+) kg^{-1}), which might have created a relatively poor physico-chemical environment that constrained the availability of nutrients interms of low N status (138 kg ha^{-1}), moderate K status (168 kg ha^{-1}), low availability of phosphorus and sulphur (3.84 and 8.51 kg ha^{-1} respectively) and deficiency in zinc (0.85 mg kg^{-1}). Further the soil organic carbon content which is a major determinant of soil quality was reported to be low (1.74 g kg^{-1}) indicating the soil resource base degradation and depletion of soil fertility status. This is in alignment with the observations made by Bouajila et al. [14] who indicated that the decrease in soil organic matter status and deterioration in the physico- chemical and biological properties of the soil are the prime reasons for the declining yield in pulse crops during the recent years. Similar such observations were earlier made by Sathyamoorthi et al. [15]. The positive effects of soil physical, chemical and biological properties were well established as evidenced by the yield data of high yielding zone which recorded a mean pulse yield of 880 kg ha^{-1}. About 92 percent of the farms surveyed for soil quality assessment in the high yield zone registered an average pulse yield of 880 kg ha^{-1}. This may be attributed to the favourable soil environment in terms of soil texture (sandy clay loam), higher mean percentage of water stable aggregates (51 percent) and a neutral pH of 7.52. These parameters coupled with lower bulk density (1.23 Mgm^{-3}), optimum infiltration rate (1.76 cm hr^{-1}) and significantly higher organic carbon status (6.68 g kg^{-1}) contributed to higher soil CEC (36.9 c mol (p^+) kg^{-1}) resulting in better availability of macro, secondary and micro nutrients in high yielding soils.

Table 3. Yield data of various yield categories under pulse crop

	Yield (kg ha^{-1})		
Sample	**Low yielding**	**Medium yielding**	**High Yielding**
1	285	622	879
2	368	579	912
3	390	421	784
4	290	721	935
5	306	646	926
6	346	589	935
7	256	477	826
8	154	468	893
9	167	612	973
10	143	498	845
11	372	546	943
12	252	568	832
13	305	413	769
14	167	567	776
15	367	646	945
16	354	705	956
17	289	589	893
18	218	613	823
19	326	516	796
20	278	688	879
21	165	538	976
22	277	443	890
23	328	678	788
24	159	488	989
25	306	588	846
Max	390	721	989
Min	143	413	769
Mean	275	569	880
SD	78	86	92
CV(%)	28.36	15.46	7.72

4. CONCLUSION

The overall results of this study revealed that the higher values of soil quality attributes such as aggregate stability, cation exchange capacity, organic carbon, available nitrogen and extractable micronutrients corresponded well with the high yield category indicating the importance of these soil quality indicators for improving the yield of pulse crops. 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, regular soil application of enriched FYM (750 kg ha^{-1}), application of Azospirillum (2 kg ha^{-1}), foliar spray of DAP or TNAU pulse wonder at flowering stage results in higher yields of the pulse crop. Hence more attention should be given towards integrating the scientific results of soil quality assessment with the knowledge of soil quality degradation. Adoption of integrated nutrient management technologies and soil quality enhancement techniques by the pulse growing farmers is highly essential to maximize the productivity of pulses and sustain the environmental quality for future generations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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