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Spatial Variability in Soil Fertility and Quality and its Influence on Crop Yield of Tribal Dominated Dhar District of Central India

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ABSTRACT

The objective was to assess the soil fertility and quality status and its influence on crop yield in tribal area of central India. Soil samples and yield data were collected from 780 farmers' fields across the region and analyzed. Soil quality index was calculated adopting a simple minimum dataset of indicators including intrinsic and dynamic soil properties. Further for comparison across the region, relative soil quality index (RSQI) and relative crop yield (RY) parameters were calculated. Soils in the region mostly had clayey (30.8%) and sandy loam (27.4%) texture with neutral to alkaline pH. The soils deficient in organic carbon, available N, P, K, S, Zn and Fe was 57.1%, 83.3%, 37.2%, 3.4%, 68.3%, 18.6% and 4.1%, respectively. More than 40% of soils were at least deficient in three nutrient elements. The soil quality was also poor (69% soils) and moderately poor (21%) categories with RSQI less than 70%. The soil indicators responsible for poor soil quality were shallow soil depth, poor organic C and microbial activity, and deficiency of N, S, P and Zn. The relationship between RY and RSQI was developed using linear regression model resulted in RY= 0.92×RSQI + 9.66 R^2=0.33 and was highly positive. This indicated that soil in the study area had poor soil fertility and quality status, and appropriate soil test based balanced integrated nutrient management practices along with soil and water conservative practices in shallow depth hilly terrain soils could restore or enhance the soil quality and improve the crop yield in the region.

Keywords Soil fertility, Nutrient index, Soil organic carbon, soil quality index, relative yield.

INTRODUCTION

Sustainability of any production system can be achieved by maintenance and improvement of soil

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quality. Assessment of soil quality is not a new concept. Several authors (Doran and Jones 1996, Andrews *et al.* 2004, Singh 2007, Kundu *et al.* 2012) have come up with indices to quantify soil quality. Soil quality is assessed by developing minimum data-set of soil indicators and giving scores and weights to them. The soil indicators are generally physical and chemical and biological parameters of soils. These indicators are quantitative and analytically repeatable (Doran and Jones 1996). These indicators are used as assessment tools for indexing soil quality at various scales and are represents the major functions of a soil which is the foundation for sustainable land management (Karlen *et al.* 2003). Periodic assessment, monitoring and management of soil quality are inevitable to sustain the production system. Several farmer-participatory programs for managing soil quality and health are in practice (Doran and Zeiss 2000, Singh 2007). However development of simple and easily adoptable soil quality assessment protocol that can be widely adopted for sustainable management is need of the hour.

Inappropriate management practices are leads to soil erosion, deficiency and mining of nutrients and soil biological degradation. Soil degradation is becoming a major problem and causes declining of crop productivity. Dhar is a rural agricultural district in Madhya Pradesh (central India) with more tribal population (more than 60% of total) mainly dependent on agricultural related activities for their livelihood. Average crop productivity of the region is very low and low agricultural income leads to poor socio-economic status and increase in poverty causes migration of large population to nearby cities for their livelihood. The low crop productivity in the district is due to improper and inadequate supply of nutrients, mono-cropping, soil erosion, low rainfall and poor water availability, low water holding capacity of soil, etc. (Agricultural Statistics 2012). Though there are many factors that constraints the crop yields in the district, the information on different soil indicators, their status and their effect on crop productivity is lacking. With this background, it is attempted to assess the soil fertility and quality status of tribal population predominating area of central India. This study is also aimed to identify the major soil indicators/factors that affect the soil quality and crop yield in the region and to understand the relationship between soil quality parameters and crop yield for enhancing crop productivity and livelihood status of the farmers through sustainable management of soil. Further this work focuses on major soil constraints that influence the crop yield for their meaningful management.

MATERIALS AND METHODS

Study area

Dhar district is located in the Malwa region of western Madhya Pradesh state in central India. The district has a geographical area of 8,153 km². It is divided into 5 sub-divisions, 7 tehsils and 13 administrative/developmental blocks (Dhar, Tirla, Naalcha, Badnawar, Sardarpur, Dharampuri, Manawar, Umarban Gandhwani, Kukshi, Bagh, Dahi and Nisharpur). About 61.5% of total population is scheduled tribes in the district, mostly in the rural areas; the average literacy rate of the district is 60.57%. Its 61.25% total geographical area is under cultivation with 147% cropping intensity and area under irrigation is only 42.87% of cultivable area (Agriculture Statistics 2012). Soybean, maize, wheat, chickpea, cotton, chillies, garlic, potato, onion and tomato are the major field crops grown in the districts. Nearly 60% are shallow to medium deep soils. Black cotton soil and loamy soils are major soil types in the district. About half of the areas of the district are hilly terrain and remaining areas are mainly plain lands.

Soil sampling and analyses

Soil samples were collected from all the 13 administrative blocks of the district. In each block 10 representative villages were selected, further in each village 6 numbers of samples were collected based on the economic strata of the village (i.e distribution of small and marginal, medium and big farmers). In total 780 samples were collected across the district. The soil sampling was done after harvest of winter crops in 2015. Soil depth information was collected from the farmers and State Agricultural Department Workers in the respective villages. The collected soil samples were air dried and processed to pass through 2 mm sieve and stored. All the physicochemical parameters were analyzed following standard analytical procedures as mentioned in Singh *et al.* (2005).

Nutrient index (NI) was calculated using following equation:

$$NI = \frac{(1 \times N_l + 2 \times N_m + 3 \times N_h}{N} \quad \text{.................. Eq (1)}$$

Where, N_l= Number of soil samples in low category, N_m= Number of soil samples in medium category, N_h= Number of soil samples in high category, and N= Total number of soil samples. Based on the nutrient index value, the soils were categorized into three classes as follow: NI value less than 1.67 meant for low fertility status, 1.67-2.33 for medium fertility status and more than 2.33 is for high fertility status. The soil fertility maps were prepared using GIS software-ArcInfo (Figs. 1– 2).

Assessment of soil quality

In order to make comparative analysis of soils, relative soil quality index tool was used with minimum dataset of indicators. Each indicator was divided into four classes namely, Class- I, Class- II, Class- III and Class- IV with an assigned mark of 1, 0.75, 0.5 and 0.25, respectively. Experts have given scoring and weight to the minimum dataset for vertisols of AESR 10.1 (Kundu *et al*. 2012) (Table 1).

The soil quality index (SQI) was calculated by adopting the following equation:

$$SQI = \sum (W_i{*}I_i) \quad \text{...... ....Eq (2)}$$

Where, W_i indicates the weight of the indicator, and I_i indicates the marks/score of the indicators classes. As per the minimum dataset followed in the study, the maximum and minimum values of SQI could be 1.0 (best quality) and 0.25 (poor quality soil), respectively. In order to judge the SQI value of any site against the theoretical maximum value of SQI

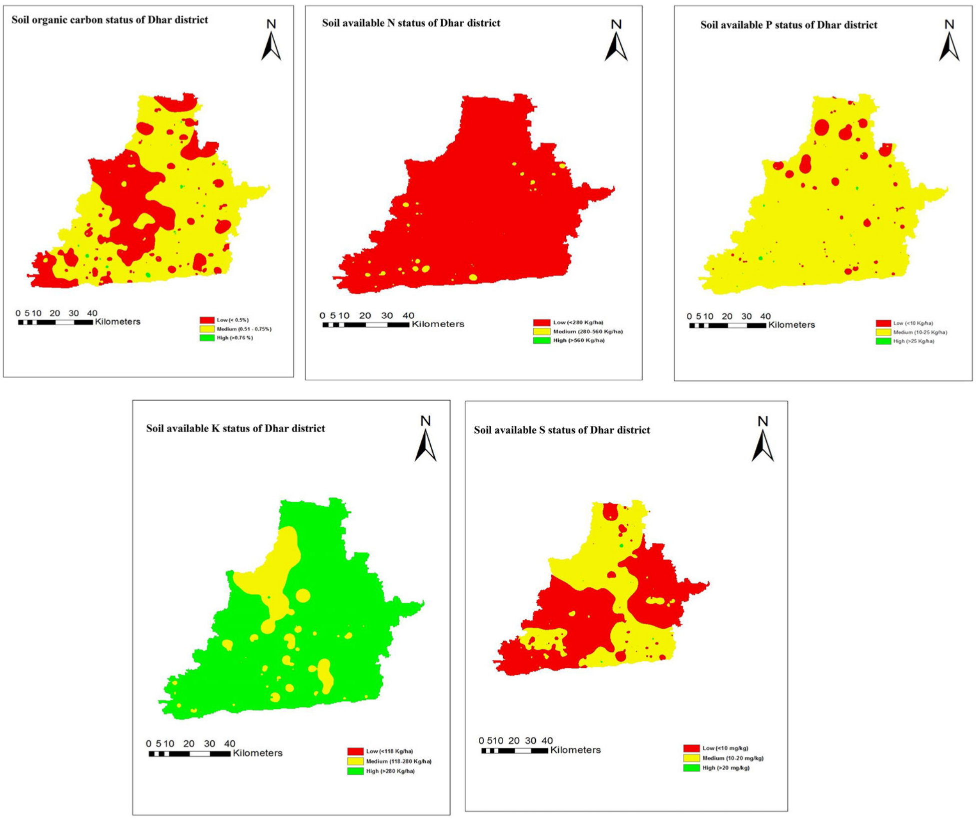

Fig. 1. Spatial variation in soil organic carbon, available N, P, K and S fertility status of the tribal area of central India.

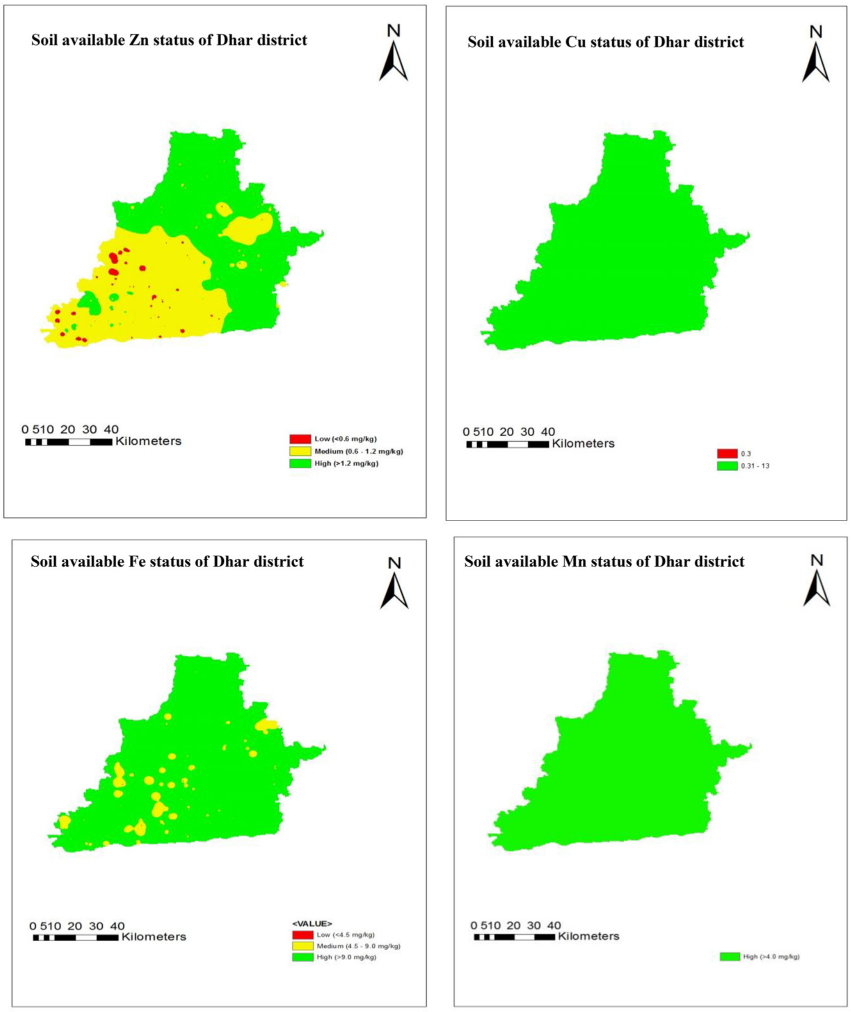

Fig. 2. Spatial distribution of DTPA-extractable micronutrients of soils of the tribal area of central India.

(i.e. 1.0), the concept of relative soil quality index (RSQI) used (Singh 2007).

$$RSQI = \frac{SQI_{sample}}{SQI_{max}} \times 100 \qquad \text{....................Eq (3)}$$

Where, SQI_{sample} is the SQI calculated for particular sample using Eq (2); SQI_{max} is maximum possible SQI value (in this case, SQI_{max} is 1.0). Based on the RSQI value, soils of tribal areas were grouped under different categories.

Relative yield

The yield data collected from each sampling point during survey and soil sampling activities used for relative yield calculations. As soil samples were collected from soybean, maize and wheat cultivated fields, the wheat equivalent yield was calculated for soybean and maize using following formulae.

$$\text{Wheat equivalent yield (kg ha}^{-1}) = \frac{\text{Yield of soybean (kg ha}^{-1})\times \text{Price of soybean (Rs kg}^{-1})}{\text{Price of Wheat (Rs kg}^{-1})} \qquad \text{............Eq (4)}$$

Table 1. Soil indicators and their weights and classes for soil quality evaluation.

Soil quality indicators	Weights	Class I	Class II	Class III	Class IV
Physical indicators					
Soil Depth (m)	0.10	>2	1-2	0.5-1	<0.5
Texture	0.10	Loam	CL /SL	Clay/SC	Sand
Bulk density (Mg m^{-3})	0.05	1.3-1.4	1.3-1.2/1.4-1.5	1.2-1.1/1.5-1.6	<1.1/>1.6
Biological indicators					
Organic carbon (%)	0.15	>1	1-0.75	0.75-0.5	<0.5
DHA (μg TPF g^{-1} 24 h^{-1})	0.10	>20	20-15	15-10	<10
Chemical indicators					
Soil pH	0.05	6.5- 7.5	6.5- 6/7.5-8	6- 5.5/8-8.5	<5.5 />8.5
Avail. N (kg ha^{-1})	0.10	>560	560-420	420-280	<280
Avail. P (kg ha^{-1})	0.10	>25	15-25	15-10	<10
Avail K (kg ha^{-1})	0.05	>280	280-200	200-120	<120
Avail. S (mg kg^{-1})	0.05	>25	25-15	15-10	<10
Avail. Zn (mg kg^{-1})	0.05	>2.0	2.0-1.0	1.0-0.5	<0.5
Avail. Fe (mg kg^{-1})	0.04	>10.0	10-5.5	5.5-2.5	<2.5
Avail. Mn (mg kg^{-1})	0.03	>10.0	10.0-4.0	4.0-2.0	<2.0
Avail. Cu (mg kg^{-1})	0.03	>2.0	2.0-0.5	0.5-0.2	<0.2
Score	1.00	1.0	0.75	0.50	0.25

$$\text{Wheat equivalent yield (kg ha}^{-1}) = \frac{\text{Yield of maize (kg ha}^{-1})\times \text{Price of maize (Rs kg}^{-1})}{\text{Price of wheat (Rs kg}^{-1})} \quad \text{............Eq. (5)}$$

The following values were used for calculation:

Soybean: Price= Rs 30 kg^{-1}, yield range in the study area= 7.5 – 18.5 q ha^{-1}
Wheat: Price= Rs 18 kg^{-1}, yield range in the study area = 19.5 – 32.0 q ha^{-1}
Maize: price= Rs 15 kg^{-1}, yield range in the study area = 15.0 – 26.0 q ha^{-1}

From the wheat equivalent yields, relative yield was calculated from the following equation as below:

$$\text{Relative yield \%} = \frac{\text{Wheat equivalent yield of particular location (kg ha}^{-1})}{\text{Maximum yield (kg ha}^{-1})} \times 100 \quad \text{...Eq (6)}$$

The linear regression model was adopted to depict the relationship between relative yield (RY) and RSQI.

RESULTS AND DISCUSSION

Soil depth, texture, bulk density and pH

The soil depth of the district varied from shallow (<0.5 m) to deep (>2.0 m). The percent of soil sample less than 0.5 m was 42.8%, 0.5-1.0 m was 34.7%, 1.0-2.0 m was 17.4% and more than 2.0 m was 5.1% (Table 2). Most of the soils in the district had clayey (30.8%) and sandy loam (27.4%) texture. The other textural classes were sandy clay loam, clay loam and sandy clay (Table 2). Soil bulk density varied from 1.27 to 1.48 Mg m^{-3} with average value of 1.36 Mg m^{-3}. The soil with 1.2-1.3 Mg m^{-3}, 1.3-1.4 Mg m^{-3} and 1.4-1.5 Mg m^{-3} were 12.7%, 59.2%, 30.1%, respectively. The soils in the district had moderately acidic to highly alkaline pH range. The soils with neutral pH were 37.1%, about 28.7%, 24.6% and 0.36% soils had slightly, moderately and highly alkaline pH range, respectively. The soils with slightly and moderately acidic were 6.03% and 3.21%, respectively (Table 2). There is a large variation in soil depth of study area. This might be due to variation in land terrain characteristics. The shallow deep soils were mostly found in hilly undulated terrains lands that lead to soil erosion and poor soil development and the deep soils are mostly found in plain lands (Meerveld and McDonnell 2006). The intrinsic properties such as texture, bulk density and soil pH are depends on mineral content of parent materials and combined effect of other soil forming factors (climate, time, relief or topography, and organisms) and pedogenic

Table 2. Spatial distribution of soil depth, texture, bulk density and pH of study area.

Soil depth	% distribution	Textural class	% distribution	Soil bulk density (Mg m^{-3})	% distribution	Soil pH range	Class	% distribution
< 0.5 m	42.8	Sandy loam	27.4	<1.2	-	5.0-6.0	Moderately acidic	3.21
0.5-1.0 m	34.7	Sandy clay loam	18.6	1.2-1.3	12.7	6.0-6.5	Slightly acidic	6.03
1.0-2.0 m	17.4	Clayey	30.8	1.3-1.4	59.2	6.5-7.5	Neutral	37.1
		Loam	12.4	1.4-1.5	30.1	7.5-8.0	Slightly alkaline	28.7
>2.0 m	5.1	Clay loam	9.52	1.5-1.6	-	8.0-8.5	Moderately alkaline	24.6
		Sandy clay	1.28	>1.6	-	>8.5	Highly alkaline	0.36

processes by which soil is formed (Brady and Weil 2016, Li *et al*. 2017).

Soil organic carbon and dehydrogenase activity (DHA)

Soil organic carbon (SOC) content varied from 0.14% to 1.24% with average value of 0.45%. According to the soil fertility classification of low (less than 0.5% SOC), medium (0.5-0.75% SOC) and high (more than 0.5% SOC), the soils with low, medium and high organic carbon in the district were 57.1%, 29.7% and 13.2%, respectively (Table 3, Fig. 2). Dehydrogenase activity of soils in the district varied from 6.02- 18.7 µg TPF g^{-1} 24 h^{-1}. More than 40% of soils had DHA of less than 10 µg TPF g^{-1} 24 h^{-1}. About 50% of soils had DHA between 10 µg TPF g^{-1} 24 h^{-1} and 15 µg TPF g^{-1} 24 h^{-1}. The overall SOC fertility status of the district is found to be low. The distribution of SOC is heterogeneous because of variation in soil properties, site characteristics, environment, land use and management (Davy and Koen 2013). The low soil organic carbon in the study area might be due to soil erosion, fast mineralization mediated by high temperature, less usage of organic matter and mono cropping, variation in soil texture. The DHA across study area is found to be low. This might be due to low organic matter content of soil, alkaline soil pH, poor water holding capacity. The microbial activity of soil is mainly depends on quality and quantity of organic matter present in the soil (Elbl *et al*. 2019). Several factors including soil moisture, redox potential, pH, organic matter content, depth of the soil profile, temperature, heavy metal contamination and soil fertilization or pesticide use can significantly affect DHA in the soil environment (Wolinska and Stępniewska 2012).

Available nutrients

Available N status varied from 79.3-396 kg ha^{-1} with an average value of 242.3 kg ha^{-1}. About 83.3% of the soil samples were found to be low in N (< 280 kg N ha^{-1}) and remaining in the category of medium (280-560 kg N ha^{-1}) (Table 3, Fig. 1). The available P content of soils varied from 4.32 to 40.8 kg ha^{-1} with a

Table 3. Soil fertility status of tribal area of central India.

Parameters	Range	% distribution Low	Medium	High	NI	Remarks
Organic Carbon (%)	0.14-1.24	57.1 (<0.5)	29.7 (0.5-0.75)	13.2 (>0.75)	1.56	Low
Available N (kg ha^{-1})	79.3-396	83.3 (<280)	16.7 (280-560)	Nil (>560)	1.17	Low
Available P (kg ha^{-1})	4.32-40.8	37.2 (<10)	41.5 (10-25)	21.3 (>25)	1.84	Medium
Available K (kg ha^{-1})	94.2-787	3.4 (<118)	24.7 (118-280)	71.9 (>280)	2.69	High
Available S (mg kg^{-1})	3.16-29.2	68.3 (<10)	24.3 (10-20)	7.4 (>20)	1.39	Low
Available Zn (mg kg^{-1})	0.19-6.57	18.6(<0.6)	52.1 (0.6-1.2)	29.3 (>1.2)	2.11	Medium
Available Mn (mg kg^{-1})	4.12-50.8	Nil (<2.0)	Nil (2.0-4.0)	100 (>4.0)	3.00	High
Available Cu (mg kg^{-1})	0.22-15.7	Nil (<0.2)	7.8 (0.2-0.4)	92.2 (>0.4)	2.92	High
Available Fe (mg kg^{-1})	2.28-49.8	4.1 (<4.5)	36.4 (4.5-9.0)	59.5 (>9.0)	2.55	High

Note: Values in the parenthesis are critical values for respective category, NI- Nutrient index.

mean value of 12.83 kg ha^{-1}. Most of the soil samples (about 37.2%) were low (<10 kg P ha^{-1}), 41.5% under medium (10-25 kg P ha^{-1}) and 21.3% under high (>25 kg P ha^{-1}) category in available P (Table 3, Fig. 1). Status of available K in the soils ranged between 94.2 and 787 kg ha^{-1} with an average of 422 kg ha^{-1}. Most of the soil samples (71.9%) were found under high (>280 kg K ha^{-1}) range (Table 3, Fig. 2). The available sulfur status varied from 3.16-29.2 mg kg^{-1} with a mean value of 9.8 mg kg^{-1}. About 68.3% soils had deficient, 24.3% soils had medium and remaining 7.4% soils had high S fertility category in the region (Table 3, Fig. 1). The DTPA extractable Zn in soils varied from 0.19-6.57 mg kg^{-1} (Table 3). The soils in the region were deficient in available Zn (18.6%). The DTPA- Fe, Cu, and Mn status of the soils were found to be in sufficient range (Fig. 2). The low N and S in the soils are existed because the organic matter content of these soils is low as most of the soil N and S are found in organic form (Gregorich *et al.* 2006). The low to high available P in the soils of the study area might be the results of past fertilization, pH, organic matter content, texture, various soil management and agronomic practices. The high K in the soils might be due to the presence of the mica (biotite and muscovite) in finer clay fractions. Micronutrient availability in soil is mainly influenced by parent material, pH, and organic matter, red-ox potential and nutrient interactions (Moraghan and Mascagni 1991). The soils of the study area were found to deficient in multiple nutrients. The percent of soil samples at least deficient one-, two-, three-, four-, five- and six- nutrient elements were 94.36%, 71.92%, 41.15%, 11.80%, 0.38% and 0.13%, respectively and only about 5.67% soil samples were observed to be sufficient in respect to all the available nutrients studied. Around 40% of soil samples were at least deficient in more than three nutrient elements.

Soil quality and crop yield

The soil quality of the study area was largely under poor quality category followed by moderately poor and medium category (Table 4). The soils with poor soil quality were 68.97%, moderately poor quality soils were 20.9%, medium quality soils were 9.1% and good quality soils were 1.03%. The poor soil quality of the study area was mainly due to low

Table 4. RSQI, classes and categories of soil quality of study area.

RSQI (%)	Class	Category	% distribution
>90	I	Very good	-
80-90	II	Good	1.03
>70-80	III	Medium	9.10
60-70	IV	Moderately poor	20.90
<60	V	Poor	68.97

Note: RSQI- Relative soil quality index.

soil organic carbon, poor microbial activity (DHA), deficient nutrients particularly N, S, P and Zn, and shallow soil depth. The selection of soil indicators could vary based on the nature of the soil function under consideration. The soil quality indicators used in the study are very common soil parameters and are highly influence the crop productivity (Havlin *et al.* 2013, Brady and Weil 2016). Moreover USDA (2006) has identified soil texture, bulk density, soil depth, pH and plan nutrient are the key indicators of soil quality and crop productivity, and were adopted in the study. Apart from these, soil organic carbon, a dynamic soil property, is highly influenced by land use and management practices selected in the study. Soil organic carbon/matter is the most frequently used and reliable soil quality indicators and is interrelated with most soil ecological functions (Lima *et al*. 2013, Bunemann *et al.* 2018). Among the soil enzymes dehydrogenase activity is considered as a good, sensitive and useful indicator of changes in soil quality (Salazar *et al.* 2011). It indicates the presence

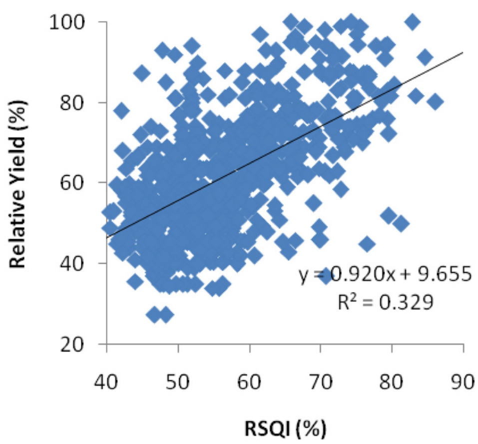

Fig. 3. Interrelationship between RSQI and relative yield.

of physiologically active microbes and involves in carbon cycles and soil organic matter and is linked with other soil enzymes and N (Błonska *et al.* 2016). Therefore it is appropriate to use DHA as a soil quality indicator. The major soil function considered in the study is production function. The linear relationship established between RSQI and relative yield RY=0.92 × RSQI + 9.66 (R^2=0.33) (Fig. 3) showed significant positive relationship. This indicates that soil quality indicators selected for minimum data set and method followed for soil quality estimation is well suited for the study area. Similarly soil quality index is correlated with crop yield by many workers (Vasu *et al.* 2016, Luo *et al.* 2017). Accounting all the factors those affecting crop yields of the wider study area is tedious. Therefore simple and practically suitable method of soil quality assessment developed in the study could be beneficial. Adopting best sustainable management interventions could improve the soil quality and crop productivity of the region.

CONCLUSION

Soil degradation is a major concern for declining crop productivity. Periodic monitoring and evaluation of soil fertility and quality is necessary to know the impact of management practices on sustainability of agrarian production systems. In this study, soil fertility and quality status of tribal population predominant area of central India was evaluated. Soil quality of the study area was found to be highly degraded. The major soil constraints were low SOC, poor soil microbial activity, deficiency of nutrients, and shallow soil depth. The method of SQI calculated is very simple and practically reliable. Nevertheless, the selected indicators include both static and dynamic soil properties that can be largely influenced by management practices. Therefore soil quality and crop productivity of the district can be improved by implementing the sustainable management interventions

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