

Soil quality assessment of sesame-growing soils with different productivity in the Northern Telangana Zone, India

ABSTRACT

Present study was carried out in major sesame growing areas of Northern Telanganazone in districts namely; Nizamabad, Jagtial, Nirmal and Kamareddy. The main objective of this study is to assess the soil quality and to find out the relation between sesame yield and soil quality index. Based on the seed yield data of sesame, the above mentioned districts were divided into high, medium and low productivity zones. 50 samples from each productivity zone with a total of 150 surface soil samples (0-15 cm) were collected and analysed for various physical, physico-chemical, chemical and biological properties. Physical properties included texture, bulk density and water holding capacity. Physico-chemical properties like pH, EC and organic carbon were analysed. Chemical properties of soil namely available nitrogen, available phosphorus, available potassium, available sulphur, exchangeable bases like exchangeable calcium and magnesium, potassium and sodium, available micronutrients like iron, copper, manganese and zinc were analysed. Biological properties like urease, acid and alkaline phosphatase and labile carbon were analysed. After principal component analysis, minimum data set was derived which contained available nitrogen, sand, pH, available phosphorus, exchangeable calcium and magnesium and urease with 70.81% variance. These are identified as the key indicators of soil quality. Mean soil quality index values were 0.669, 0.549 and 0.443 for high, medium and low sesame productivity zones respectively and is in the order of high > medium > low sesame productivity zones. Percent contribution of MDS to SQI are in the order of, available nitrogen (44.44%) > pH (16.85%) > exchangeable calcium (9.87%) > exchangeable magnesium (8.89%) > urease (7.86%) > available phosphorus (7.38%) > sand (4.89%). This study concluded that the SQI was more significantly positively correlated with sesame yield, which revealed that soil variables from the minimum data set had biological significance and effectively evaluated the status of the sesame growing soils of Northern Telangana Zone.

Keywords: minimum dataset, quality, sesame, Telangana, urease

INTRODUCTION

Soil is a fundamental, basic, natural and an important resource of the earth whose quality is being degraded in the present days. Soil quality is defined as "the soil's ability to keep plant and animal productivity, maintain or improve water and air quality and also provide human health and habitation in both natural and managed ecosystems" (Cao and Zhou, 2008; Doran and Parkin, 1994).

The development of the idea of soil quality may be traced back to two distinct theories that either placed a greater focus on the natural characteristics of the soil or on the results of human management. Mausel (1971), who defined soil quality as "the ability of soils to yield corn, soybean and wheat under conditions of high-level management," made the first mention of it in the scientific literature.

Sesame is an important oilseed crop of India since past. The yield of sesame was significantly getting lowered for the past few years. The decrease in yield of sesame might be due to the decreasing soil quality and the main reason for low productivity of sesame is use of low yielding varieties, poor soil fertility and imbalanced nutrition (Ranganatha, 2013). In addition to improving the physical conditions of the soil, the application of chemical and organic fertilisers in sesame helps increase in yield of the crop (Verma *et al.*, 2014). However, use of fertilisers along with FYM improve the yield of sesame (Parmar *et al.*, 2020).

Soil quality degradation is becoming a major issue for declining sesame productivity in low sesame productivity areas of Northern Telangana Zone. Soil quality and crop productivity are governed by nutrients in the soil, as well as other physical properties, chemical processes and biological activities. Assessing soil quality and identifying differences between sesame growing soils with varying productivity are critical for developing sustainable land use management and increasing sesame productivity. With this background in mind, the present investigation titled - Soil quality assessment of sesame growing areas in Northern Telangana Zone was carried out.

MATERIAL AND

METHODS SOIL SURVEY AND

SAMPLING

A soil sampling survey was carried out in major sesame growing areas of Northern Telangana Zone in districts; Nizamabad, Jagtial, Nirmal and Kamareddy (Figure 1). Based on the previous year's sesame yield data, the above mentioned districts were divided into high, medium and low sesame productivity zones. 50 surface soil (0-15 cm) samples from each productivity zone, with a total of 150 surface soil samples were collected.

LABORATORY ANALYSIS

Physical properties analysed were soil texture by using bouycous hydrometer method (Piper, 1950). Bulk density was analysed by using the coresampler method (Blake and Hartge, 1986). Water holding capacity of soil was determined by using Keencup (Keen Rhoezwoski, 1921).

Soil pH and EC were analysed by using pH meter and EC meter with 1:2 and 1:2.5 soilwater suspensions respectively (Jackson, 1973). Soil organic carbon was determined by using rapid titration method (Walkley and Black method, 1934).

Available nitrogen was analysed by alkaline permanganate method (Subbiah and Asija, 1956). Available phosphorus was analysed by using sodium bicarbonate method (Olsen *et al.*, 1954). Available potassium was analysed by using neutral normal ammonium acetate method (Jackson, 1973). Available sulphur was analysed by using turbidimetric method (C.H. Williams and A. Steinbergs, 1962).

Exchangeable properties like exchangeable calcium and magnesium were analysed by using the method demonstrated by Tandon, 1989. Exchangeable sodium was determined by using Chapman's sodium acetate method (1965). Exchangeable potassium was determined by Flame photometer method (Malo *et al.*, 2005). Available micronutrients namely iron, copper, manganese and zinc were analysed by DTPA extractant method (Lindsay and Norvel, 1978).

Biological properties analysed were urease activity of soil by method given by Tabatabai and Bremner, 1972. Acid and alkaline phosphatase activity of soil were analysed by the method given by Tabatabai and Bremner, 1969. Labile carbon pool of soil was analysed by using the method given by Chan *et al.* (2001) and Mandal *et al.* (2008).

SOIL QUALITY EVALUATION

In order to evaluate soil quality index, three basic steps were followed namely; 1. Determining the minimum data set (MDS) 2. Transformation of minimum data set indicators into scores and 3. Integration of individual scores and weights into soil quality index.

Determining the minimum data set:

Principal component analysis was used to determine the minimum data set. PCA was performed by using SPSS version 20. Among all the soil parameters analysed (physical, physico-chemical, chemical and biological), those parameters whose eigen values are greater than 1 under each PC were considered suitable under the minimum data set (Kaiser, 1960). Varimax rotation was performed in order to maximise the correlation between PC's and the soil properties by distributing the variance (Waswa *et al.*, 2013). Under each PC, highly weighted variables were selected as soil quality indicators. If there are more than one variable under each PC, correlation was performed between the variables (Andrews *et al.*, 2004) and if the variables were significantly correlated, then the one with highest factor loading and absolute factor loading within 10% of highest value were retained and the remaining were eliminated in order to avoid redundancy. If the parameters are non-correlated then they are considered equally important and were retained in the PC.

Transformation of minimum data set indicators into scores:

Selected parameters which are under minimum data set were transformed into scores ranging from 0-1 using linear scoring score functions; (1) - more is better, (2) - less is better and (3) - optimum is better based on their importance in soil. This is as follows; For - more is better indicators, score is obtained by dividing each observation with the highest value in the dataset such that highest value gets score of 1. For - less is better indicators, score is obtained by dividing lowest value in the dataset by each observation such that the lowest value gets the score of 1. For - optimum is better indicators, the observations are considered as more is better upto threshold value and less is better above the threshold value. (Andrews *et al.*, 2004; Vasu *et al.*, 2016; Lenka *et al.*, 2022).

Integration of individual scores into soil quality index:

After obtaining the scores, they were multiplied by the factor loading which was obtained by dividing variance of single PC by cumulative variance of all PC's (Kumar *et al.*, 2022). Then the scores and weight factors were multiplied for each variable in the minimum data set. These values were integrated by using weighted additive method to obtain soil quality index (Cherubinet *et al.*, 2017).

Soil quality index was calculated by using the formula, $\sum_{i=1}^n (W_i \times S_i)$

where, W_i = Factor loading derived from PC S_i =

Score for subscripted variable

n = number of variables in minimum dataset

STATISTICAL ANALYSIS

Pearson Correlation test was used to do the correlation study among the properties. One way analysis of variance (ANOVA) and least significant difference (LSD) were used to separate the mean difference between parameters at probability of 0.05. SPSS (version 20.) was used to perform principal component analysis and MS EXCEL was used to calculate the scores and weights of minimum dataset and soil quality index.

RESULTS AND DISCUSSION

Soil physical properties

The percentage of sand, silt and clay in high, medium and low productivity zones ranges from 10.00 to 88.00, 0.20 to 61.30 and 3.0 to 60.50 respectively. Among the three sesame productivity zones, the mean of sand content in the medium and low zones was considerably greater than in the high productivity zone, but silt content shown no significant differences. In high sesame productivity zone, clay content was significantly higher. Variations in the soil texture might be due to the difference in nature and composition of parent material.

Bulk density was found to range from 1.10 to 1.63 Mg m⁻³. It had a significant difference among the three sesame productivity zones. The low productivity zone has significantly greater bulk density over the high and medium productivity zones, which restricts root growth and affects the transport of nutrients in the soil. This is in line with Liu *et al.*, 2015.

Mean water holding capacities of soils were 46.02, 41.06 and 40.16 percent in high, medium and low productivity sesame zones, respectively. The results demonstrated that significantly higher water holding capacity was found in high sesame productivity zone soils compared to medium and low sesame growing areas of Northern Telangana zone (Table 1). This is in accordance with Paul *et al.*, 2014.

Soil physico-chemical properties

pH of soils in different sesame productivity zones ranged from 7.11 to 7.82, 6.45 to 8.51 and 6.81 to 7.46 respectively for high, medium and low sesame productivity zones. High soil pH values in high and medium sesame productivity zones compared to low sesame productivity zones, might be due to less base leaching, which reduces the activity of exchangeable Al^{3+} ions in soil solution through chelation (Hue, 1992).

EC varies in this study from 0.12 to 0.56 dSm^{-1} , which is considered safe for sesame cultivation. These results are in line with Vilakare *et al.*, 2021.

Mean soil organic carbon content observed was 0.71, 0.50 and 0.42% in the three productivity zones. Among the three zones, mean soil organic carbon content was significantly higher in high sesame productivity zone (Table 2). This is because of application of farmyard manure and biomass (Bhagwan *et al.*, 2023).

Soil chemical properties

Available nitrogen content varied from 176.20 to 279.70, 116.50 to 261.50 and 76.40 to 139.80 $kg\ ha^{-1}$ in HPZ, MPZ and LPZ respectively. Low content of available nitrogen in medium and low sesame productivity areas might be due to lower amounts of organic matter. This result is in line with the findings of Verma *et al.* (2021) and Prasad *et al.* (2022).

Mean available phosphorus was found highest (41.50 $kg\ ha^{-1}$) in HPZ followed by MPZ (39.38 $kg\ ha^{-1}$) and lowest (26.88 $kg\ ha^{-1}$) in LPZ. The lower values of available phosphorus in the low sesame productivity zone might be due to the continuous removal without matching the application of phosphorus containing fertilizers as well as organic manures. This is in relevance with the reports of Seevagan *et al.* (2020) and Bhagwan *et al.* (2023).

Available potassium in the studied area ranges from 213.00 to 562.00, 126.25 to 585.00 and 182.50 to 562.50 $kg\ ha^{-1}$ in HPZ, MPZ and LPZ respectively. Higher available potassium content in HPZ might be due to the potassium mineralization from organic residues, which is same as the result of Urkurkar *et al.*, 2010; Ramulu and Reddy, 2018; Vilakare *et al.*, 2021.

Available sulphur in the study area ranges from 15.33 to 24.84, 10.34 and 2.35 to 9.53 $mg\ kg^{-1}$ in high, medium and low sesame productivity zones respectively. Less sulphur content in medium and low sesame productivity zones was due to the lack of sulphur addition (Pulakeshi *et*

al., 2012). Similar results were also reported by Ravi *et al.* (2017) in rice growing soils of Northern Telangana Zone.

Exchangeable calcium ranged from 18.30 to 28.40 c.mol(p+) kg⁻¹ in the high productivity zone, from 16.00 to 28.00 c.mol(p+) kg⁻¹ in the medium productivity zone, from 11.00 to 32.50 c.mol(p+) kg⁻¹ in the low productivity zone. Exchangeable magnesium ranged from 5.90 to 19.00 c.mol(p+) kg⁻¹ in the high productivity zone, from 3.80 to 18.00 c.mol(p+) kg⁻¹ in the medium productivity zone and from 7.50 to 17.10 c.mol(p+) kg⁻¹ in the low sesame productivity zone. Higher level of exchangeable calcium and magnesium under high sesame productivity zone was due to the regular addition of farmyard manure, which has a higher adsorption capacity and may have adsorbed calcium and magnesium that would otherwise have leached down. Similar results were obtained by Vasu *et al.* (2016).

Exchangeable potassium content ranges from 0.23 to 0.92, 0.21 to 0.57 and 0.20 to 0.65 c.mol (p+) kg⁻¹ and exchangeable sodium contents varies from 1.10 to 1.52, 0.59 to 1.90 and 0.56 to 1.65 c.mol (p+) kg⁻¹ in high, medium and low productivity zones respectively. The results are in line with the Narasaiah *et al.* (2018).

The DTPA Fe levels ranged from 1.35 to 26.40 mg kg⁻¹. It significantly differed in high productivity zone from that of medium and low productivity zone, due to higher organic carbon content which resulted in higher production of complexing agents which promoted better extractability of Fe in these soils (Ankitha Sharma, 2022).

Copper ranges from 1.22 to 4.01 mg kg⁻¹ from 1.02 to 3.05 mg kg⁻¹ and from 0.12 to 1.98 mg kg⁻¹ in high, medium and low sesame productivity zones respectively. Significant difference was observed for phosphorus in all the three zones. Copper content is higher in HPZ due to its association with organic carbon, which is in accordance with Rajeshwar and Ariff Khan, 2007.

Manganese ranges from 12.30 to 19.90 mg kg⁻¹, from 10.50 to 15.00 mg kg⁻¹ and from 1.32 to 9.65 mg kg⁻¹ in high, medium and low sesame productivity zones respectively. High amount of manganese in high sesame productivity zone is due to its presence in the reduced forms, higher biological activity and organic carbon in the soils (Malavath and Thurpu, 2019).

Zinc ranges from 0.34 to 1.95 mg kg⁻¹ from 0.11 to 1.63 mg kg⁻¹ and from 0.12 to 1.81 mg kg⁻¹ in high, medium and low sesame productivity zones respectively. It shows significant difference in high and medium sesame productivity zones, but no significant difference was observed for medium and low sesame productivity zones. Low zinc content in low productivity zone could be associated with the formation of insoluble products of Zn and low organic matter content (Table 3). This is in line with the findings of Santhi *et al.* (2018).

Soil biological properties

Urease activity was recorded and it ranges from 1.02 to 1.68, from 1.02 to 1.87 and from 1.03 to 1.32 $\mu\text{g NH}_4^+ \text{-N g}^{-1} \text{ h}^{-1}$ in high, medium and low sesame productivity zones respectively. It shown significant difference in high and medium productivity zones but no significant difference was observed for medium and low productivity zones. With increase in nitrogen content of soil urease activity also increases. Thus, urease activity is more in high productivity zone compared to medium and less in low productivity zone. This is similar with the results of (Strache *et al.*, 2017).

Acid phosphatase activity ranges from 59.30 to 172.00, from 21.00 to 102.00 and from 10.00 to 46.00 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$ in high, medium and low productivity zones respectively. Alkaline phosphatase activity ranges from 22.00 to 58.00 from 11.00 to 36.00 and from 6.00 to 28.00 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$ in high, medium and low sesame productivity zones respectively. Higher significant difference for acid and alkaline phosphatase was observed in high productivity zone compared to medium and low. It is mainly due to the higher application of FYM, as it has high level of microbial activity, similar in trend with that of Manda *et al.* (2008).

Labile carbon of soils ranges from 1.07 to 3.88 Mg ha^{-1} , from 1.14 to 2.65 Mg ha^{-1} and from 0.38 to 3.11 Mg ha^{-1} in high, medium and low sesame productivity zones respectively. Higher significant difference for labile carbon was observed in high productivity zone compared to medium and low (Table 4). This might be due to application of manures which increase microbial diversity by increasing the storage of labile C in the soil (Hegals *et al.*, 2010 and Zhen *et al.*, 2014).

Principal component analysis

The analysed data was subjected to principal component analysis and the final minimum dataset (MDS) included all the highly weighted variables from seven principal components with eigenvalues ≥ 1 . PC's showed a cumulative variance of 70.81% after varimax rotation. Variables showing an absolute value within 10% of highest factor under each PC were considered under MDS (Vasu *et al.*, 2016; Kumar *et al.*, 2022). Correlation was performed in PC1 and PC3 among the variables with highest factor loadings as shown by Vasu *et al.* (2016). In PC1, correlation was performed between available nitrogen, available sulphur, available manganese and acid phosphatase. All the parameters are well correlated ($r > 0.6$). So, the one with the highest factor loading *i.e.* available nitrogen was considered under MDS from PC1. In PC3, correlation was performed between pH and exchangeable sodium. Both the parameters are well correlated, but as pH has the highest factor loading, it was taken under MDS from PC3. Hence, the final minimum dataset included available nitrogen, sand, pH, available P, exchangeable calcium, magnesium, urease.

Calculation of soil quality index

After assigning the scores by and weights to all the parameters of minimum dataset, soil quality index was calculated for three sesame productivity zones. The mean soil quality index of high, medium and low sesame productivity zones were 0.669, 0.549 and 0.443 (Fig 2).

Validation of soil quality index

Correlation was performed between soil quality index and sesame yield. Correlation analysis indicated that soil quality index and sesame yield were linearly correlated ($R^2 = 0.6835^{**}$) (Fig 3). This is in accordance with the findings of Li *et al.* (2019); Kumar *et al.* (2022). Sesame yield increased with increase in soil quality. Significant positive correlation between soil quality index and sesame yield indicates that the established minimum data set are biologically significant and they best represent the soil quality status of sesame growing soils in Northern Telangana Zone.

Contribution of retained minimum dataset in SQI

The percent contribution of each variable of minimum dataset towards soil quality index is in the order, available nitrogen (44.44%) > pH (16.85%) > exchangeable calcium (9.87%) > exchangeable magnesium (8.89%) > urease (7.86%) > available phosphorus (7.38%) > sand (4.89%) (Fig 4.0). This indicates that available nitrogen contributes highest towards SQI as it has highest variance among all other variables in the MDS (Liu *et al.*, 2015; Sharma *et al.*, 2015) and the sand contributes least which indicates that the available nitrogen is the most limiting factor in these same growing areas of Northern Telangana Zone.

Factors limiting sesame yield in Northern Telangana Zone

Due to its influence on soil quality, available nitrogen is one of the most significant predictors of soil fertility (Kumar *et al.*, 2021). It aids in enhancing the vegetative development of crop, which raises the amount of organic matter in the soil. Additionally, it is helpful in preserving the agricultural output in arid regions (Nabiollahi *et al.*, 2020). Therefore, available nitrogen is regarded as a crucial indicator of soil quality (Sharma *et al.*, 2015; Jian *et al.*, 2020; Biswas *et al.*, 2023; Kumar *et al.*, 2022; Qian *et al.*, 2023).

The availability of micro and macronutrients may be impacted by the variation in soil pH throughout these sesame production zones, which could have an impact on crop growth, yield, and microbial activity, which is important for the growth of sesame (Zuza *et al.*, 2023; Kumare *et al.*, 2022). Thus, soil pH is a crucial indicator of soil quality when evaluating soil quality (Andrews *et al.*, 2004; Gong *et al.*, 2015; Biswas *et al.*, 2017; Jiang *et al.*, 2020; Zhou *et al.*, 2022; Kumare *et al.*, 2022; Prasad *et al.*, 2023).

High adsorption rate and release into soil during weathering, exchangeable calcium is the most prevalent cation in soil (Pitty, 2014). Exchangeable magnesium is a necessary nutrient from the perspective of crop production since it is a significant component in chlorophyll (Ugwa *et al.*, 2022). Consequently, exchangeable calcium and magnesium are regarded as the crucial indicators of soil quality (Sharma *et al.*, 2015).

The hydrolysis of urea into carbon dioxide and ammonia by the urease enzyme is essential for the nitrogen cycle (Biswas *et al.*, 2023). Urease activity is positively impacted by the nitrogen level of the soil (Shalini *et al.*, 2020). So, it is considered as an indicator of soil quality (Gunasekharan and Kaliappan, 2021).

One of the most restricting nutrients for crops is often the available phosphorus that is present in the soil (Kumar *et al.*, 2022). Available phosphorus promotes root development, which enhances nutrient intake and supports crop growth and development. Hence, it is taken as a soil quality indicator in assessing soil quality (Yu-Dong *et al.*, 2013; Liu *et al.*, 2015; Mustikaningrum *et al.*, 2015; Sharma *et al.*, 2015; Zhou *et al.*, 2021; Kumar *et al.*, 2022; Shah *et al.*, 2022; Prasad *et al.*, 2023).

Sand content of the soil has great impact on crop growth and yield. It regulates water and nutrient intake and oxygen. So, it is regarded as an important soil quality indicator (Nabiollahi *et al.*, 2020).

CONCLUSION

In the present study, it is identified that the soil parameters namely, available nitrogen, available phosphorus, sand, pH, exchangeable calcium and magnesium and urease are the minimum dataset indicators affecting the soil quality. Among these, available nitrogen is concluded as the most limiting factor which influences the soil quality in the three sesame productivity zones of Northern Telangana Zone. High sesame productivity zone recorded higher soil quality index and there is significant positive correlation between the sesame yield and soil quality in sesame productivity zones of Northern Telangana Zone. From this study, it can be concluded that the combined application of organic manures and fertilizers to be recommended in the sesame growing areas of Northern Telangana Zone to enhance the yield and soil quality.

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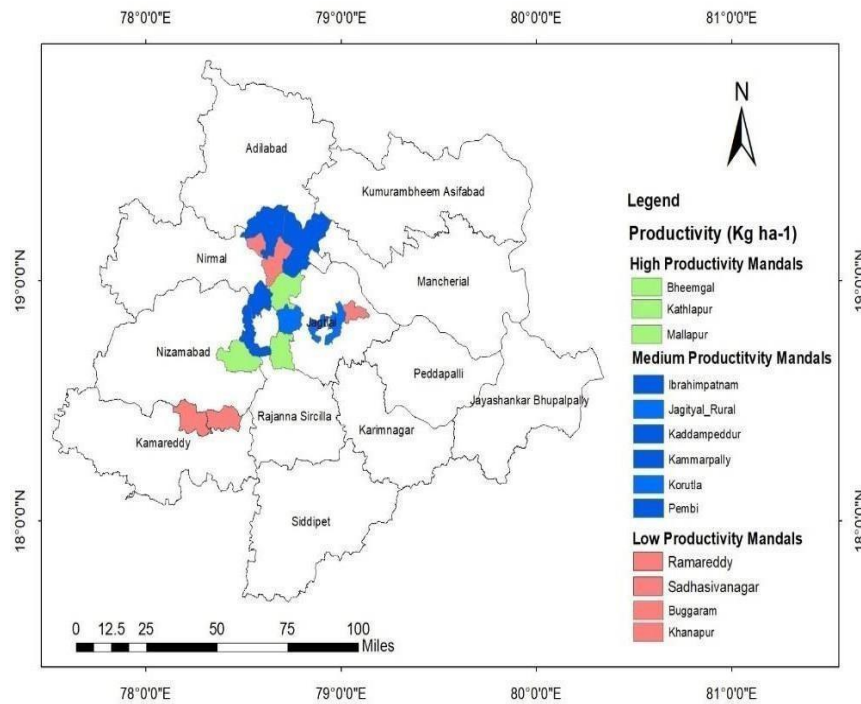


Fig 1. Geographical representation of sesame sampling areas in Northern Telangana Zone

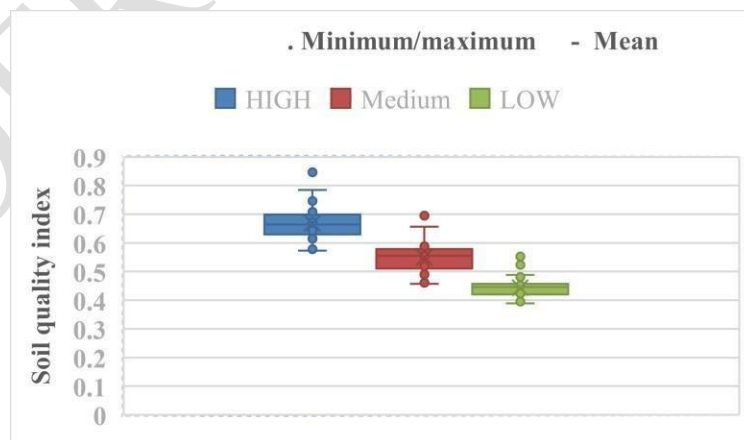


Fig 2. Graph showing the soil quality index of three sesame productivity zones of Northern Telangana Zone, India

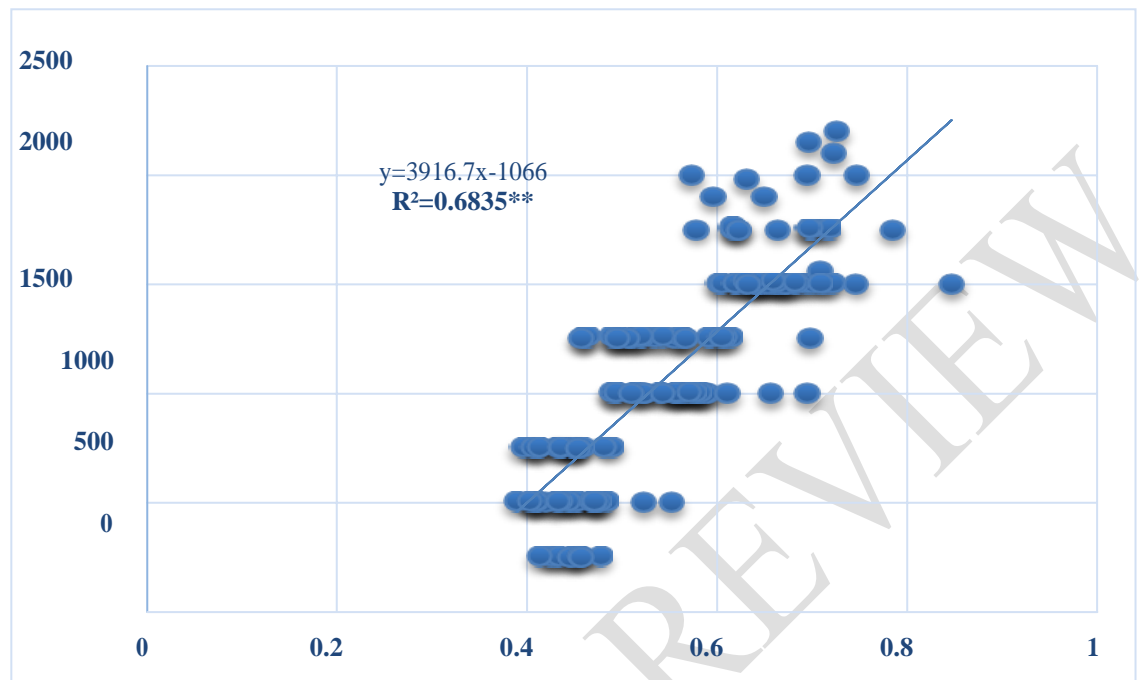


Fig 3. Graph showing the Correlation of soil quality index (SQI) with yield of sesame in Northern Telangana Zone [X axis = SQI; Y axis = yield (kg ha⁻¹)]

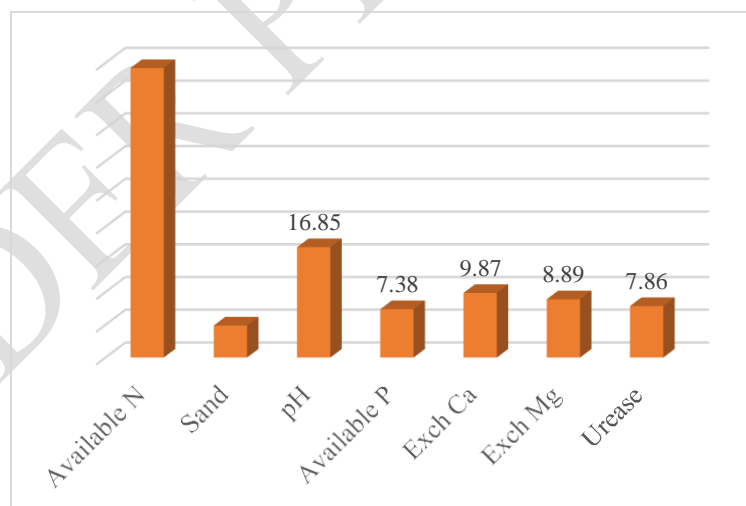


Fig 4. Contribution of each indicator of minimum dataset to soil quality index

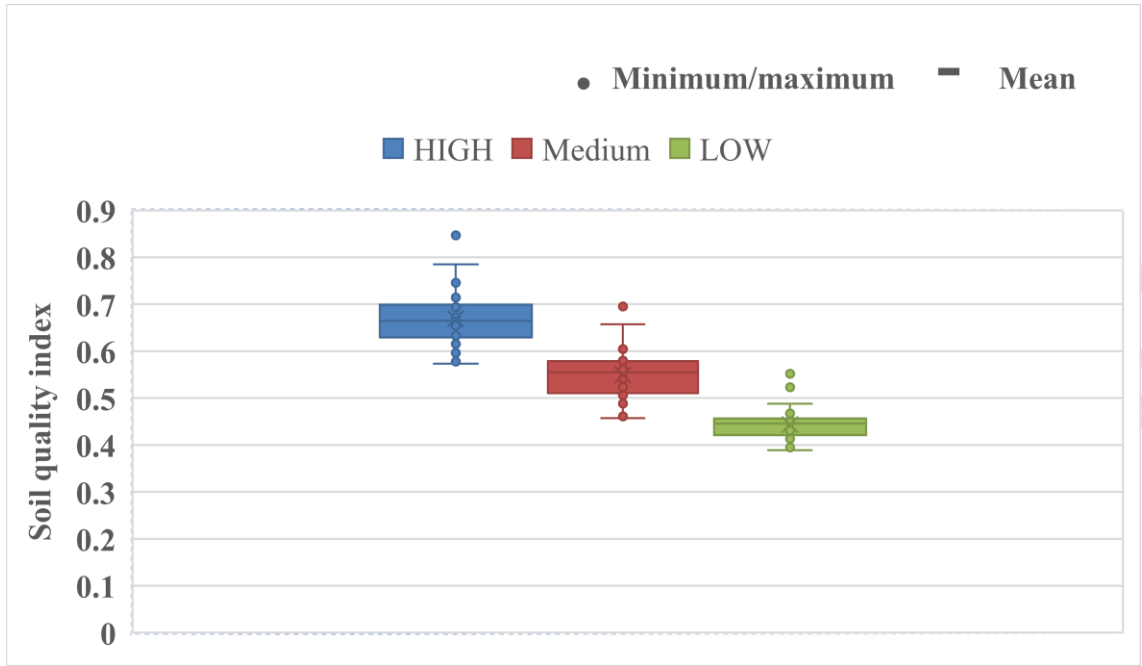


Fig.5. Soil quality index of high, medium and low sesame productivity zones of Northern Telangana Zone

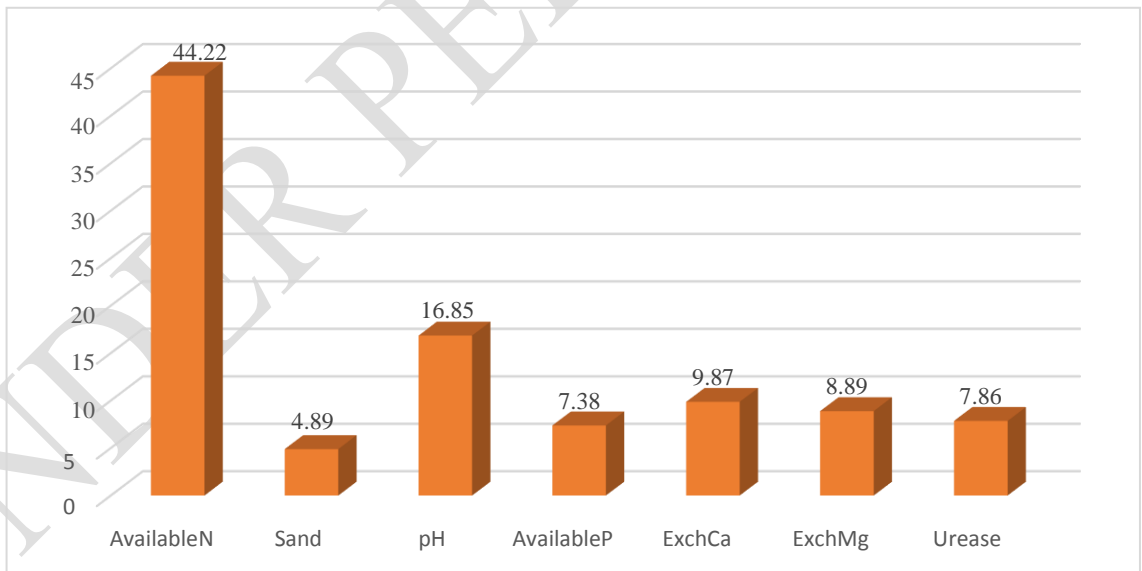


Fig.6. Percent contribution of MDS to soil quality index

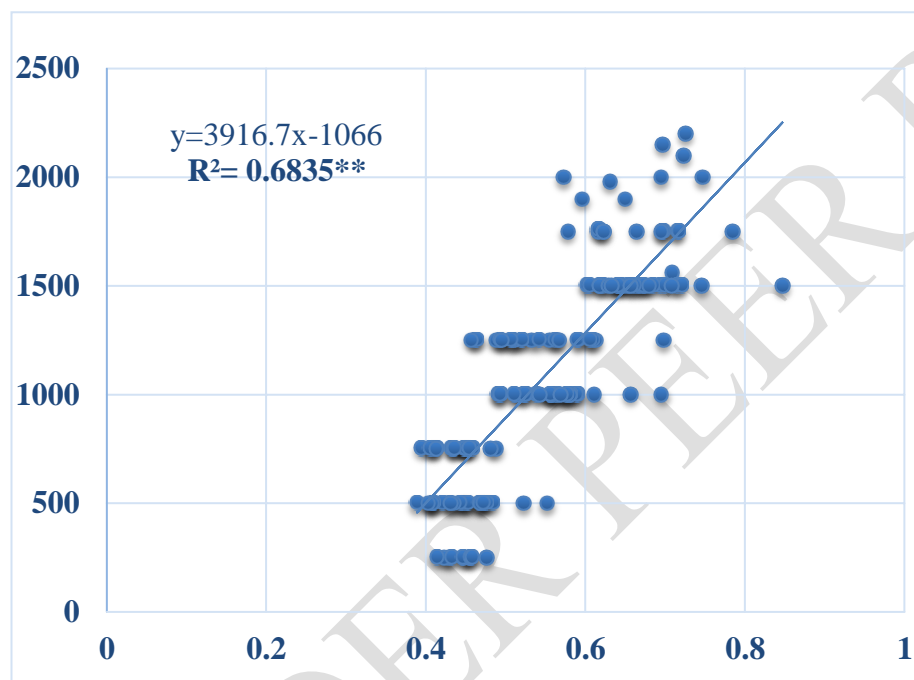


Fig.7Correlationofsoilqualityindex(SQI)withyieldof

sesameinNorthernTelanganaZoneX axis=SQI;Yaxis= yield(kg ha⁻¹)

Table 1. Summary statistics of measured soil physical properties of high (HPZ), medium (MPZ) and low (LPZ) sesame productivity zones of Northern Telangana Zone (mean \pm standard deviation and range of variation).

Parameters	HPZ			MPZ			LPZ		
	Mean	Range	CV(%)	Mean	Range	CV(%)	Mean	Range	CV(%)
Sand(%)	52.36±15.33a	10.00-82.00	29.27	55.15±15.3b	14.00-84.00	27.76	62.76±14.78b	28.00-88.00	23.55
Silt(%)	20.10±11.31a	4.00-61.30	56.26	17.06±12.03a	0.50-54.50	72.09	15.00±14.24a	0.20-54.00	9.93
Clay(%)	27.85± 6.16a	8.60-49.00	35.95	27.48±9.88b	3.00-60.50	22.11	22.25± 10.11b	15.80-43.00	45.43
BD	1.32±0.10a	1.10-1.56	7.57	1.41±0.1b	1.20-1.60	7.09	1.43±0.12c	1.20-1.63	8.39
WHC(%)	46.02± 6.35a	30.00-56.80	13.79	41.06± 9.17b	20.80-56.50	22.23	40.16 ±7.02c	19.60-51.70	17.48

Means for the same property with different letters indicate significant difference at $p \leq 0.05$.

Table 2. Summary statistics of measured soil physico-chemical properties of high (HPZ), medium (MPZ) and low (LPZ) sesame productivity zones of Northern Telangana Zone (mean ± standard deviation and range of variation).

Parameters	HPZ			MPZ			LPZ		
	Mean	Range	CV(%)	Mean	Range	CV(%)	Mean	Range	CV(%)
pH	7.26 ±0.17a	7.11-7.82	2.34	7.39± 0.56a	6.45-8.51	7.57	7.15 ±0.15b	6.81-7.46	2.09
Electrical conductivity (dSm ⁻¹)	0.47± 0.13a	0.32-0.46	27.65	0.41 ±0.07b	0.32-0.56	17.07	0.34 ±0.10c	0.12-0.56	29.41
OC(%)	0.71± 0.13a	0.48-1.08	18.30	0.50 ±0.14b	0.23-0.72	28.00	0.42± 0.11c	0.21-0.64	26.19

Means for the same property with different letters indicate significant difference at $p \leq 0.05$.

Table 3. Summary statistics of measured soil chemical properties of high (HPZ), medium (MPZ) and low (LPZ) sesame productivity zones of Northern Telangana Zone (mean \pm standard deviation and range of variation).

Parameters	HPZ			MPZ			LPZ		
	Mean	Range	CV(%)	Mean	Range	CV(%)	Mean	Range	CV(%)
Available N (kg ha ⁻¹)	218.59 \pm 26.79a	176.20-279.70	12.25	154.19 \pm 31.7b	116.50-261.50	20.55	97.19 \pm 13.82c	76.40-139.80	14.21
Available P (kg ha ⁻¹)	41.50 \pm 15.53a	13.41-82.33	37.42	39.38 \pm 15.66a	11.81-64.71	39.76	26.88 \pm 5.48b	19.98-49.06	20.38
Available K (kg ha ⁻¹)	411.86 \pm 83.85a	213.00-562.00	20.35	332.53 \pm 100.84b	126.25-585.00	30.32	300.5 \pm 88.79b	182.50-562.50	29.54
Available S (mg kg ⁻¹)	20.17 \pm 2.98a	15.33-24.84	14.77	12.85 \pm 1.21b	10.34-14.31	9.41	6.37 \pm 1.92c	2.35-9.53	30.14
Exchangeable Ca (c.mol(p+)kg ⁻¹)	23.78 \pm 2.68a	18.30-28.40	11.26	22.55 \pm 2.53a	16.00-28.00	11.21	21.38 \pm 4.39b	11.00-32.50	20.53
Exchangeable Mg (c.mol(p+)kg ⁻¹)	12.71 \pm 3.45a	5.90-19.00	27.14	12.50 \pm 3.3a	3.80-18.00	26.40	11.21 \pm 2.36b	7.50-17.10	21.05
Exchangeable K (c.mol(p+)kg ⁻¹)	0.47 \pm 0.14a	0.23-0.92	29.78	0.43 \pm 0.09a	0.21-0.57	20.93	0.35 \pm 0.11b	0.20-0.65	31.42
Exchangeable Na (c.mol(p+)kg ⁻¹)	1.27 \pm 0.10a	1.10-1.52	7.87	1.33 \pm 0.34a	0.59-1.90	25.56	1.24 \pm 0.19a	0.56-1.65	15.32
Available Fe (mg kg ⁻¹)	18.12 \pm 4.35a	10.36-26.40	24.00	12.62 \pm 1.64b	10.22-16.20	12.99	5.19 \pm 1.46c	1.35-8.62	28.13
Available Cu (mg kg ⁻¹)	2.57 \pm 0.96a	1.22-4.01	37.35	1.96 \pm 0.61b	1.02-3.05	32.10	0.87 \pm 0.52c	0.12-1.98	59.77
Available Mn (mg kg ⁻¹)	17.33 \pm 1.64a	12.30-19.90	9.46	12.84 \pm 1.41b	10.50-15.00	10.98	6.49 \pm 1.80c	1.32-9.65	27.73

Available Zn (mg kg ⁻¹)	1.29 ±0.38a	0.34-1.95	29.45	1.07± 0.36b	0.11-1.63	33.64	1.02± 0.52b	0.12-1.81	51.96
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Means for the same property with different letters indicate significant difference at $p \leq 0.05$.

UNDER PEER REVIEW

Table 4. Summary statistics of measured soil biological properties of high (HPZ), medium (MPZ) and low(LPZ) sesame productivity zones of Northern Telangana Zone (mean \pm standard deviation and range of variation).

Parameters	H P Z			M P Z			L P Z		
	Mean	Range	CV(%)	Mean	Range	CV(%)	Mean	Range	CV(%)
Urease ($\mu\text{gNH}_4^+\text{-N}$ $\text{g}^{-1}\text{soil h}^{-1}$)	1.31 \pm 0.14a	1.02- 1.68	10.68	1.24 \pm 0.20b	1.02-1.87	16.1 2	1.19 \pm 0.07b	1.03- 1.32	5.88
Acid P ($\mu\text{g PNP}$ $\text{g}^{-1}\text{soil h}^{-1}$)	99.34 \pm 25. 09a	59.30- 172.00	25.25	48.42 \pm 20. 33b	21.00- 102.00	41.9 8	22.12 \pm 9 .31c	10.00- 46.00	42.08
Alkali ne P(μg PNP g^{-1} soil h^{-1})	39.80 \pm 8.9 7a	22.00- 58.00	22.53	19.82 \pm 6.3 b	11.00- 36.00	32.1 3	13.16 \pm 4 .88c	6.00- 28.00	37.08
Labile C(M gha^{-1})	2.56 \pm 0.62a	1.07- 3.88	24.21	2.01 \pm 0.50b	1.14-2.65	24.8 7	1.39 \pm 0.49c	0.38- 3.11	35.25

Means for the same property with different letters indicate significant difference at $p \leq 0.05$.