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Research Article

Effect of Long-Term Application of Different Organic Resources on Soil Properties and Soil Quality Index of an Aridisol Under Mustard System

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Abstract

Aridisols are structurally poor and very low in fertility, organic matter (OM) and biological activities. Application of organics in Aridisols can enhance soil quality by improving its physical, chemical and biological properties. To quantify the influence of organic resources on soil quality indicators and indices, an experiment was conducted with five treatments - T1: Control, T2: FYM (4 t ha^{-1}), T3: Vermicompost (4 t ha^{-1}), T4: Dhaincha green manure (kharif crop incorporated in soil at 40 DAS) and T5: Cowpea green manure (kharif crop incorporated in soil at 40 DAS), replicated thrice in a randomized block design. Mustard (RH-30) was grown during the rabi season. The field experiment was conducted at the Hisar centre (CCS Haryana Agricultural University) of All-India Coordinated Research Project for Dryland Agriculture, and the laboratory studies were conducted at ICAR-Central Research Institute for Dryland Agriculture, Hyderabad. Key soil quality indicators identified for mustard system in Aridisols of Hisar were available P, exchangeable Mg, and available Zn and Fe. Soil quality index (SQI) values varied from 0.71 to 1.04 and the relative soil quality index (RSQI) values, between 0.65 and 0.95 across treatments. Among the treatments, the application of FYM @ 4 t ha^{-1} showed the highest soil quality index of 1.04 which was statistically at par with all the other treatments. The relative order of performance in influencing soil quality in terms of SQI was: T2: FYM (4 t ha^{-1}) (1.04) > T5: Cowpea green manure (40 DAS) (1.00) > T3: Vermicompost (4 t ha^{-1}) (0.95) > T4: Dhaincha green manure (40 DAS) (0.89) > T1: Control (0.71). The average percent contribution of key indicators towards soil quality indices was: available Zn (63%), exchangeable Mg (13%), available Fe (11%) and available P (7%). The results of this study could be useful for improving the soil quality indicators in Aridsols and to enhance the soil productivity.

Keywords: Soil Quality Indicators; Soil Quality Indices; Organic Manurial; Mustard; Aridisols

Introduction

Aridisols, which occupy about 18% of the earth's land surface [1] account for significant area under rainfed agriculture in India. These soils suffer from a number of soil constraints, particularly low clay content in upper horizons, poor water holding capacity, surface crusting, non-optimal hydraulic conductivity, poor soil nutrients status, low organic carbon, salinity, etc., which severely limit the crop choice [2]. Aridisols are mostly present in arid and semi-arid regions of the world. These soils are mostly present in South Asia, northern and northeastern Africa, Australia, southwestern South America, southwestern and northern USA, South Africa and Russia [3]. In India, they occupy about 4% of the total land surface area, and a significant area is present in Rajasthan, Gujarat, Karnataka, Andra Pradesh, Punjab and Haryana states [2,4].

In general, these soils are structurally poor and critically low in fertility, organic matter (OM) and biological activities [5,6]. The high temperature, particularly in the summer season accelerates the organic matter decomposition rate. Lack of plant available soil moisture is another constraint for crop production in these soils; low soil moisture also limits nutrient uptake. Consequently, these soils support low crop yields leading to poverty among the farmers. Application of organic resources can play an important role in ensuring high crop productivity on long term basis in these soils. Meta-analysis of data carried out by [7] revealed that organic amendments can boost yields by as much as 60% compared with the non-amended soils. Similarly, results of another meta-analysis revealed that increases in the crop yield from organic amendment ranged from 52 ± 12% in humid to 37 ± 7% in arid regions [8].

It has been reported that application of organics in soil can enhance soil quality by improving its physical, chemical and biological parameters [9-11]. Both macro and micro-nutrients can be supplied directly by organic amendments. Advantages of organic amendments depend upon the type of organic resource, rate and duration of its application, type of soil reaction (acid, saline and alkaline), etc., [7,12]. Organic amendments of low C: N ratio have more pronounced long-term residual effects. In soils with low inherent fertility (total N and available P), low soil organic C content and neutral soil pH, the advantages of the organic amendments were demonstrated to be predominantly driven by the supply of nutrients [13]. In neutral or slightly alkaline soils with low soil organic carbon (SOC) and N status, applications of organics resulted in the most benefit to SOC and the soil microbial biomass. The advantages of additions of organics to the soil structure and water-holding capacity are not immediately obvious [14]. Therefore, their application at regular intervals is very much essential in these soils to boost the crop production and to maintain the soil quality at its optimum level.

The concept of soil quality is useful to assess the condition and sustainability of soil and to guide soil research, planning, and conservation policy [15]. It is considered as a decisive tool for land managers and researchers to determine the most appropriate soil management for crop production. The soil quality indicator approach has been widely used in recent times [13]. In soil quality indicators approach, the response of soil quality attributes to management practices across a diverse range of farming systems is key to identifying a robust minimum data set (MDS). [16] identified total soil N, available P, dehydrogenase activity and mean weight diameter of the aggregates as the key indicators for alluvial soils. In rainfed Alfisols in semiarid tropical India under sorghum - mungbean system, [17] identified easily oxidizable N ($KMnO_4$ oxidizable -N) DTPA extractable zinc (Zn) and copper (Cu), microbial biomass carbon (MBC), mean weight diameter (MWD) of soil aggregates and hydraulic conductivity (HC) as the key indicators of soil quality. In another study in Alfisols under sorghum–castor system, the key soil quality indicators identified were available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC) [18].

Keeping this background in view, we initiated long-term studies systematically on soil quality improvement and assessment in rainfed, hot, arid tropical Aridisols under mustard system with these specific objectives: (i) to quantify the influence of use of organic resources of nutrients on soil quality indicators, and (ii) to identify the key soil quality indicators that influence the soil functions most, and the best soil and nutrient-management options from the viewpoint of improving soil quality.

Materials and Methods

The long-term study was conducted at the Hisar Centre (CCS Haryana Agricultural University) of All India Coordinated Research Project for Dryland Agriculture, and the laboratory studies were conducted at the ICAR- Central Research Institute for Dryland Agriculture, Hyderabad. The field study was conducted with five treatments - T1: Control, T2: FYM (4 t ha^{-1}), T3: Vermicompost (4 t ha^{-1}), T4: Dhaincha green manure (*kharif* crop, local variety incorporated in soil at 40 DAS) and T5: Cowpea green manure (*kharif* crop, variety CS-88 incorporated in soil at 40 DAS), replicated thrice in a randomized block design. Mustard (RH-30) was grown as the test crop during the *rabi* season.

The climate of the experimental site is hot arid with a normal annual rainfall of 416 mm, of which 81% is received through the southwestern monsoon.

The soil of the site is an Aridisol, deep, loamy, desert soil. Soil reaction is neutral, electrical conductivity is suitable, and organic carbon is low. The soil is characterized by high infiltration rate and low water-holding capacity. Soil samples from the experimental plots were collected after 7th year of study and were analyzed for 19 soil quality parameters.

Soil sampling and analysis

After 7 years of the experimentation (1998-2005), surface soil samples were collected after the harvest of crops during 2005, from plough layer (0-15 cm depth). These samples were ground, partitioned and passed through standard prescribed sieves for further use in different kinds of analyses. Air dried soil samples passed through 8 mm sieve and retained on the 4.75 mm sieve were used for aggregate analysis, while the samples passed through 0.2 mm sieve were used for estimating organic carbon (OC) as well as labile carbon (LC). For the rest of the soil quality parameters viz., chemical and biological parameters, air dried soil samples passed through 2 mm sieve were used. For the estimation of microbial biomass carbon (MBC), a portion of soil samples passed through 2 mm sieve was stored in a Horizontal Refrigerator at 4-5^{0}C, and before analysis, the soil samples were taken out of the refrigerator and primed in an incubator at Field capacity (15% v/v). Soil pH was measured in 1:2 soil water suspension and measured with pH meter [19]. The electrical conductivity was measured in 1:2 soil water suspension using conductivity meter [20]. Organic C was determined by the modified Walkley-Black method [21]. Available nitrogen (N) was estimated by alkaline-$KMnO_4$ method [22]. Available P in soil was estimated using 0.5 M sodium bicarbonate ($NaHCO_3$) (pH of 8.5) extraction method [23] and the P in the extract were determined colorimetrically. Available potassium (K) was extracted with neutral normal ammonium acetate solution [24] and the extract was analyzed for potassium using inductively coupled plasma spectrophotometer. Exchangeable Ca and Mg were also extracted by using 1N ammonium acetate solution and was determined using atomic absorption spectrophotometer [25]. Sulphur was extracted with 0.15% $CaCl_2$ reagent [26] and was estimated turbidimetrically with a spectrophotometer at 340 nm. Micronutrients (Zn, Fe, Cu, and Mn) in soil were extracted with DTPA reagent and were determined by using ICP-OES, GBC, Australian model [27]; and the boron was estimated using DTPA-Sorbitol extraction method [28].

Bulk density was measured by Keen's box method [29]. The distribution of water stable aggregates was determined by wet sieving technique using sieves of 4.75, 2.0, 1.0, 0.5, 0.25 and 0.1 mm sizes [30] and mean weight diameter (MWD) was computed after oven drying the fractions [31] by using the following relationship...

$$MWD = \sum_{i=1}^{n} x_i \, w_i$$

Where x_i the mean diameter of any particular size range of aggregates separated by sieving, and is the weight of aggregates in that size range as a fraction of the total dry weight of soil.

The percentage of water stable aggregates (% SA) was calculated using the relationship given by [32].

$$\%\ SA = 100x\,\frac{(\text{weight retained}) - (\text{weight of sand})}{(\text{total sample weight}) - (\text{weight of sand})}$$

Dehydrogenase activity (DHA) in the soils was measured by TTC (triphenyl tetrazolium chloride) method [33] and the results were expressed as mg TPF (Triphenyl formazan) formed per hour per g soil. Soil microbial biomass carbon (MBC) was determined using the chloroform fumigation incubation technique [34]. Soil MBC was calculated using the following relationship:

MBC (μg g^{-1} of soil) = $(EC_F - EC_{UF})/K_{EC}$

Where EC_F is the total weight of extractable carbon in fumigated sample, EC_{UF} is the total weight of the extractable carbon in unfumigated sample and $K_{EC} = 0.25 \pm 0.05$ represents the efficiency of extraction of MBC. Labile carbon (LC) was estimated using the method suggested by [35].

Computation of soil quality indices

The data set obtained for all the 19 soil quality parameters was statistically analyzed for their level of significance using randomized block design (RBD). After the statistical analysis, the parameters which were found significant were subjected to principal component analysis (PCA) using SPSS software (Version 12.0). The principal components (PCs) which received eigen values ≥ 1 and explained at least 5% of the variation in the data [36,37] and variables which had high factor loading were considered as the best representative of system attributes. Within each PC, only highly weighted factors (having absolute values within 10% of the highest factor loading) were retained for the minimum data set (MDS). The final MDS variables were regressed with the yield as management goals. The variables qualified under these series of steps were termed as the "key indicators" and were considered for computation of soil quality index (SQI) after suitable transformation and scoring.

All the observations of each of the identified key MDS indicators were transformed using linear scoring technique [38]. To assign the scores, indicators were arranged in order depending on whether a higher value was considered "good" or "bad" in terms of soil function. In case of "more is better" indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For "less is better" indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of 1. After the transformation using linear scoring method, the MDS indicators for each observation were weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage when divided by the total percentage of variation explained by all PCs with eigenvectors > 1, gave the weighted factors for indicators chosen under a given PC. After performing these steps, to obtain SQI, the weighted MDS indicator scores for each observation were summed up using the following function:

$$SQI = \sum_{i=1}^{n} (W_i \times S_i)$$

Where, S_i is the score for the subscripted variable and W_i is the weighing factor obtained from the PCA.

Here the assumption was that, higher index scores meant better soil quality or greater performance of soil function. For better understanding and relative comparison of the long-term performance of the conjunctive nutrient use treatments, the SQI values were reduced to a scale of 0-1 by dividing all the SQI values with the highest SQI value. The numerical values thus obtained, clearly reflect the relative performance of the management treatments, and hence were termed as the "relative soil quality indices (RSQIs)". Further, the percent contributions of each final key indicator towards SQI were also calculated and plotted in the form of pie charts.

Statistical analyses

Analysis of variance (ANOVA) was performed using "Drysoft" design package. Randomized block design was used for the experiment and the differences were compared by least significant difference (LSD) test at a significance level of $p < 0.05$ [39]. Principal component analysis (PCA) was performed using SPSS version 12.

Results and Discussion

Effect of organic resource treatments on soil quality parameters

Soil pH and EC with different organic resources varied from 7.62 to 7.67 and 0.15 to 0.16 dS m^{-1}, respectively and were not differ significantly with treatments (Table 1). Organic carbon and available N in the soils varied from 2.61 to 3.22 g kg^{-1} and 136.4 to 167.0 kg ha^{-1}, respectively across the treatments. Conspicuous influence of the treatments was observed on available P and K. Available P ranged from 14.4 to 25.9 kg ha^{-1} while available K ranged from 384.7 to 476.5 kg ha^{-1} across the treatments. Application of cowpea green manure (40 DAS) recorded the highest available P (25.9 kg ha^{-1}), which was at par with other organic materials. Application of FYM @ 4 t ha^{-1} recorded the highest available K (476.5 kg ha^{-1}) which was at par with other organic resources (Figure 1).

Treatments	pH	EC (dS m^{-1})	OC (g kg^{-1})	N	P	K
				(kg ha^{-1})		
T1: Control	7.62	0.16	2.61	136.4	14.4	384.7
T2: FYM (4 t ha^{-1})	7.62	0.16	3.07	165.7	21.6	476.5
T3: Vermicompost (4 t ha^{-1})	7.67	0.16	3.07	167.0	21.4	444.5
T4: Dhaincha green manure (40 DAS)	7.62	0.15	2.93	160.2	20.3	454.7
T5: Cowpea green manure (40 DAS)	7.67	0.15	3.22	166.7	25.9	472.0
LSD_p = 0.05%	NS	NS	0.25	17.4	5.98	58.5

Table 1: Influence of organic resources on soil physico-chemical and chemical soil quality parameters under mustard system in Aridisols of Hisar.

The influence of the organic resources was conspicuous on all secondary nutrients except exchangeable Ca and on all micronutrients except available B (Table 2). Exchangeable Ca content varied between 4.34 and 5.89 cmol kg^{-1} while available B ranged from 0.96 to 1.17 μg g^{-1} across the treatments. Application of cowpea green manure (40 DAS) recorded the highest exchangeable Mg (0.98 cmol kg^{-1}) as well as available S (29.0 kg ha^{-1}), which was at par with application of Vermicompost (4 t ha^{-1}). Among the micronutrients, available Zn, Fe, Cu and Mn contents varied from 1.04 to 1.61, 3.51 to 4.80, 0.067 to 1.68 and 0.96 to 1.17 μg g^{-1}, respectively across the treatments. The highest available Zn (1.61 μg g^{-1}), Fe (4.80 μg g^{-1}) and Mn (10.6 μg g^{-1}) contents were observed under application of FYM (4 t ha^{-1}) while the highest available Cu content of 1.68 μg g^{-1} was observed under application of Vermicompost (4 t ha^{-1}).

Treatments	Ca	Mg	S (kg ha^{-1})	Zn	Fe	Cu	Mn	B
	(cmol kg^{-1})			(μg g^{-1})				
T1: Control	4.34	0.72	18.5	1.04	3.51	0.67	7.42	0.96
T2: FYM (4 t ha^{-1})	5.79	0.84	33.7	1.61	4.80	1.28	10.6	1.02
T3: Vermicompost (4 t ha^{-1})	5.89	0.96	28.1	1.45	3.73	1.68	8.51	1.17
T4: Dhaincha green manure (40 DAS)	5.19	0.80	20.8	1.36	3.65	0.71	8.21	1.00
T5: Cowpea green manure (40 DAS)	5.79	0.98	29.0	1.51	3.64	1.16	9.87	1.02
LSD$_{p=}$ 0.05%	NS	0.08	6.73	0.11	0.84	0.20	1.05	NS

Table 2: Influence of organic resources on chemical soil quality parameters under mustard system in Aridisols of Hisar.

The study revealed a significant influence of the treatments on all the biological soil quality parameters (Table 3). Dehydrogenase activity in the soils was recorded to the extent of 5.55 to 7.62 μg TPF hr^{-1}g^{-1} across management treatments, while microbial biomass carbon and labile carbon ranged between 130.8 to 196.7 and 219.5 to 271.0 μg g^{-1} of soil respectively. It was observed that, of all the treatments, application of FYM @ 4 t ha^{-1} recorded the highest DHA activity (7.62 μg TPF hr^{-1} g^{-1}), microbial biomass carbon (196.7 μg g^{-1}) as well as labile carbon (271.0 μg g^{-1}). Of the physical soil quality parameters, bulk density was conspicuously influenced by the treatments and varied from 1.22 to 1.33 Mg m^{-3}. Mean weight diameter varied from 0.13 to 0.16 mm across the treatments.

Table 3: Influence of organic resources on biological and physical soil quality parameters under mustard system in Aridisols of Hisar.

Treatments	DHA (μg TPF hr^{-1} g^{-1})	MBC (μg g^{-1})	LC (μg g^{-1})	BD (Mg m^{-3})	MWD (mm)
T1: Control	5.55	130.8	219.5	1.33	0.13
T2: FYM (4 t ha^{-1})	7.62	196.7	271.0	1.22	0.16
T3: Vermicompost (4 t ha^{-1})	6.21	158.5	247.0	1.25	0.15
T4: Dhaincha green manure (40 DAS)	6.05	172.8	240.7	1.23	0.16
T5: Cowpea green manure (40 DAS)	7.04	167.5	241.2	1.23	0.14
LSD$_{p=}$ 0.05%	0.72	20.7	26.3	0.05	NS

Results of principal component analysis

The long-term influence of organic resource treatments practiced under mustard system on 19 soil quality indices was statistically analyzed and it was observed that out of 19 soil quality parameters, five variables viz., pH, EC, exchangeable Ca, available B and MWD were insignificant and hence were dropped from further PCA analysis. In the PCA of 14 variables, three PCs had eigen values >1 and explained 79.7% variance in the data set (Table 4). In PC1, and PC3, only single variables viz., available Zn and available P qualified as highly weighted variables respectively while in PC2, two variables viz., exchangeable Mg and available Fe were the highly weighted variables. The correlation matrix run for the variables qualified under PC2 revealed no significant relation between the variables and hence both of them were considered for final MDS (Table 5). On the whole, surprisingly very few indicators viz., available P, exchangeable Mg, and available Zn and Fe qualified for the final MDS. These indicators were taken as key indicators for mustard system in Aridisols of Hisar and used for computing the soil quality indices.

Soil quality indices

Soil quality indices were computed using four key soil quality indicators viz., available P, exchangeable Mg, and available Zn and Fe. The soil quality indices varied from 0.71 to 1.04 across the treatments practiced for mustard system (Table 6). For simple understanding, the soil quality indices were reduced to a scale of one, termed as ‘relative soil quality indices’ (RSQI) which varied between 0.65 and 0.95. Among all the treatments practiced, the application of FYM @ 4 t ha^{-1} showed the highest soil quality in-

Table 3: Influence of organic resources on biological and physical soil quality parameters under mustard system in Aridisols of Hisar.

Treatments	DHA (μg TPF hr^{-1} g^{-1})	MBC (μg g^{-1})	LC (μg g^{-1})	BD (Mg m^{-3})	MWD (mm)
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T5: Cowpea green manure (40 DAS)	7.04	167.5	241.2	1.23	0.14
$LSD_{p=}$ 0.05%	0.72	20.7	26.3	0.05	NS

Table 4: Principal component analysis of soil quality parameters as influenced by different organic resources under mustard system in Aridisols of Hisar.

Parameters	PC1	PC2	PC3
Total Eigen values	8.534	1.590	1.032
% of Variance	60.95	11.36	7.37
Cumulative %	60.95	72.31	79.69
Eigen Vectors			
OC	0.824	-0.320	0.243
N	0.801	-0.193	-0.192
P	0.759	-0.386	-0.425
K	0.731	-0.137	-0.59
Mg	0.677	-0.645	0.197
S	0.839	0.073	0.289
Zn	0.963	0.032	0.078
Fe	0.568	0.620	-0.252
Cu	0.673	-0.271	0.289
Mn	0.846	0.281	0.016
DHA	0.834	0.283	0.105
MBC	0.812	0.304	-0.095
LC	0.753	0.387	0.325
BD	-0.774	0.034	0.082

Table 5: Pearson's correlation matrix for highly weighted variables under PC's with high factor loading.

Variables under PCs	Mg	Fe
Mg	1.00	-0.075
Fe	-0.075	1.00
Correlation sum	-1.075	-1.075

dex of 1.04 and it was observed to be almost at par with all the other treatments. Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T2: FYM (4 t ha^{-1}) (1.04) > T5: Cowpea green manure (40 DAS) (1.00) > T3: Vermicompost (4 t ha^{-1}) (0.95) > T4: Dhaincha green manure (40 DAS) (0.89) > T1: Control (0.71). The average percent contribution of key indicators towards soil quality indices was: available Zn (63%), exchangeable Mg (13%), available Fe (11%) and available P (7%) (Figure 1).

Figure 1: Percent contribution of key indicators towards soil quality indices under mustard system in Aridisols of Hisar.

Earlier, it has been reported that the addition of organic matter through green manuring, vermicompost, farmyard manure and crop residues play a crucial role in determining the physical, chemical and biological functional capacity of soils [2,40,41]. It has also been reported that soil organic carbon significantly improves soil quality parameters by supplying organic matter, carbon and energy to various microbes, which secrete various enzymes and enhance soil aggregation, which in-turn results in positive effect on crop productivity [6]. The magnitude of influence of addition of different organic sources on soil properties and nutrient availability in soil is predominantly determined by their C:N ratios [42]. Therefore, in the present study, the variable results obtained with the application of different organic sources might be associated with the C:N ratio of the added materials. From the results presented above, it was evident that application of organic sources of nutrients played an important role in influencing key indicators of soil quality and in improving the SQIs under the mustard system in rainfed Aridisols. Earlier studies have also revealed the significant and positive effect of sole application of organics and organic sources coupled with inorganic sources of nutrient-management practices on various soil physico-chemical, chemical, physical and biological properties under different cropping systems viz., pearl-millet-based system [5], maize-blackgram system [43], rainfed maize–wheat [11], maize-wheat [44], fingermillet/groundnut-fingermillet system [45], and cotton-black gram and greengram-*rabi* sorghum [46]. These studies have reported better soil quality indices with sole application of organics or conjunctive nutrient- management practices. The results of the previous studies carried out by [11] revealed that among the nutrient-management treatments, application of 100% organic sources of nutrients gave the greatest SQI of 1.05, whereas the other two practices of 50% nitrogen (organic) + 50% (inorganic source) (0.92) and 100% N (inorganic source) (0.88) were statistically at par with each other under the pearl millet system in Inceptisols of Agra [5]. They clearly mentioned that the higher values of the different soil quality indicators (physical chemical and biological) were recorded in the 100% organic sources of nutrients as compared to the other combinations of the nutrient sources. [45] also reported that as compared to the RDF, application of the 4t ha^{-1} of organics (straw, compost and gliricidia green leaves) significantly improved the soil quality parameters such as pH, EC, N, P, K, Ca, Mg, S, DHA, BD, OC, Zn, Mn, Cu, Fe, MBC, LC and MWD in Vertisols at Indore [47]. The results of the present study are in close conformity with the findings of the above studies.

Conclusion

This study clearly established the influence of organic resource treatments on soil physical, chemical and biological quality indicators and soil quality indices. Among all the treatments practiced, the application of FYM @ 4 t ha^{-1} showed the highest soil quality index of 1.04 and its performance was observed to be at par with all the other treatments. The average percent contribution of key indicators towards soil quality indices was: available Zn (63%), exchangeable Mg (13%), available Fe (11%) and available P (7%). Thus, it can be concluded that organic resources are important in influencing the soil quality parameters and soil quality indices in Aridisols. The methodology adopted, and the results of this study will be highly useful in assessing and maintaining the soil quality for ensuring high mustard productivity in Aridisols and in other identical situations.

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