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Effect of long term fertilization and manuring on soil quality and productivity under sorghum (*Sorghum bicolor*)-wheat (*Triticum aestivum*) sequence in Inceptisol

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ABSTRACT

A permanent field experiment is continued since 1984-85 at Research Farm, AICRP on Cropping Systems Research Unit, Akola, Maharashtra with a view to find out effect of integrated nutrient management on soil quality and productivity of sorghum [*Sorghum bicolor* (L.) Moench] -wheat (*Triticum aestivum* L.) crop sequence. The long term impact of organic, inorganic and integrated nutrient management practices on soil quality and productivity were studied after 27th cycle (2010-11). The treatments comprised different levels of recommended dose of fertilizers (RDF), viz. 50, 75 and 100% and RDF in combination with farmyard manure, wheat straw, leucaena loppings and the farmer's practice. The results indicated that, application of 50% RDF + 50% N through FYM recorded highest sorghum (24.58 q/ha) and wheat (26.23 q/ha) grain yield as well as sorghum grain equivalent yield (61 q/ha). The uptake of N, P, K and S by sorghum (83.98, 23.14, 98.67 and 18.60 kg/ha) and wheat (96.17, 18.79, 74.69 and 13.53 kg/ha) was maximum with the integrated nutrient management. The improvement in soil fertility status was observed under the same treatment with concomitant increase in sustainability yield index (0.494) and soil quality index (2.33). The overall increase in the soil quality index (1.98-2.33) was recorded under INM, whereas only chemical fertilizers caused considerable decrease in the SQI (1.19-1.87). The hydraulic conductivity contributed substantially in governing sorghum yield (63.09%) and wheat yield (98.75%). The soil organic carbon contributed substantially in sorghum yield (29.01%). The parameters like hydraulic conductivity (94.7%), OC (5.14%) and DHA (0.07%) contributed in SQI.

Key words: Dehydrogenase activity, Inceptisols, Soil quality, Sorghum grain equivalent yield, Sustainability yield index

Though India is a food surplus nation at present with about 259 million tonnes foodgrain production, it will require about 4-5 million tonnes additional foodgrains each year if the trend in rising population persists (Anonymous 2012). It is anticipated that in India in the year 2025, total foodgrain demand will reach 291 million tonnes comprising 109 million tonnes of rice, 91 million tonnes of wheat, 73 million tonnes of coarse grains and 15 million tonnes of pulses against the limitation of expansion of the cultivable land area (Kumar and Shivay 2010). One of the alternatives to achieve this goal is to raise crop productivity through improved varieties and the matching production technology to sustain soil fertility and crop productivity in the future. Intensive cultivation and growing exhaustive crops have made the soil deficient in macro as well as in micronutrients. The success of any cropping system depends upon the appropriate management of resources including balanced use of manures and fertilizers. Conjoint use of organic manures and chemical fertilizers may prove a viable option for sustaining the productivity of cereal based cropping sequence in view of the mere availability of macro as well as micronutrients due to intensive cultivation and heavy feeding habits of this crop sequence. The present investigation mainly focused on impact of long term manuring and fertilization on soil quality, crop productivity and sustainability of sorghum [*Sorghum bicolor* (L.) Moench] -wheat (*Triticum aestivum* L.) cropping sequence.

MATERIALS AND METHODS

A long-term field experiment on sorghum-wheat cropping sequence was initiated during 1984-85 at AICRP on Integrated Farming System Research, Central Research Station, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The objective was to study the long-term effect of integrated nutrient management on soil quality, crop productivity and

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sustainability. The soil of the experimental field belong to clayey montmorillonitic, hyperthermic, shallow, family of Vertic Haplustepts. The twelve treatments (Table 1-3) were laid out in a randomized block design with four replications.

Table 1 Effect of long term manuring and fertilization on productivity of sorghum and wheat (27th cycle)

Treatment		Yield (q/ha)		Sorghum	System
Sorghum	Wheat	Sorghum	Wheat	grain equivalent (q/ha)	Productivity (kg/ha/day)
Control	Control	2.55	4.58	8.90	2.44
50% RDF	50% RDF	19.67	13.28	38.12	10.44
50% RDF	100% RDF	20.66	19.18	47.29	12.95
75% RDF	75% RDF	21.99	17.79	46.70	12.79
100% RDF	100% RDF	26.50	23.26	58.80	16.11
50% RDF + 50% N -FYM	100% RDF	24.58	26.23	61.00	16.71
75% RDF + 25% N -FYM	75% RDF	23.76	21.03	52.96	14.51
50% RDF + 50% N -WS	100% RDF	21.64	21.47	51.46	14.10
75% RDF + 25% N -WS	75% RDF	22.81	20.12	50.75	13.90
50% RDF + 50% N -LL	100% RDF	23.75	22.06	54.40	14.90
75% RDF + 25% N -LL	75% RDF	24.38	20.30	52.58	14.41
*FP (50:25:00)	FP (40:25:12.5)	18.74 (30.00)	11.90 (10.50)	35.26	9.66
SE(m) ±		0.84	1.08	1.75	0.48
LSD (0.05)		2.42	3.10	4.92	1.35

FYM- Farmyard manure, WS- wheat straw, LL- leucaena loppings. *Initial year yield

The various combinations of chemical fertilizers with organics like FYM, green manure and crop residues were studied. FYM was applied before sowing to sorghum which contains 0.63% N, 0.25% P and 0.74% K. The leucaena loppings were applied to sorghum to substitute 25 and 50% N. Leucaena loppings (3.36% N) were applied @ 1.8 and 0.90 tonne/ha to substitute 25 and 50% N. The recommended dose of fertilizers were 120:60:60 kg N, P_2O_5 and K_2O/ha for both sorghum and wheat. The organic carbon, available N, P, K and S were determined following standard prescribed method. Soil quality index was determined by linear scoring method from principal component analysis of variables described by Doran and Parkin (1994). The PCA was run with 24 soil parameters followed by correlation sum of highest weighted factor and selection of minimum data set. The scoring of minimum data set was carried out and the soil quality index was worked out as per Sharma *et al.* 2005. The sustainability yield index (SYI) was computed as per Singh *et al.* (1990) and Sharma *et al.* (2005).

RESULTS AND DISCUSSION

Sorghum and wheat yields and system productivity

The results revealed that, the substitution of 50% N by FYM along with chemical fertilizers (50% NPK) significantly increased the grain yield of sorghum (24.50 q/ha) and wheat (26.23 q/ha) and was superior among all the treatments (Table 1). Application of organics (Farmyard manure, wheat straw and leucaena loppings) in conjunction with chemical fertilizers recorded higher yields over only chemical fertilizers. This indicates role of addition of organics in improving soil quality and subsequently crop productivity. Although the higher yield of sorghum and wheat was recorded in the initial years of experiment under only chemical fertilizers in comparison with integrated nutrient

Table 2 Effect of long term manuring and fertilization on uptake of nutrients by sorghum and wheat (27th cycle)

Treatment		Total uptake (kg/ha)							
Sorghum	Wheat	Sorghum				Wheat			
		N	P	K	S	N	P	K	S
Control	Control	8.3	2.6	13.4	1.83	13.3	2.2	12.4	1.45
50% RDF	50% RDF	57.1	15.6	57.6	10.83	48.0	7.6	37.7	5.48
50% RDF	100% RDF	59.5	16.5	61.1	11.73	64.4	10.8	46.4	7.38
75% RDF	75% RDF	66.1	17.7	72.2	13.34	63.0	10.9	49.5	7.86
100% RDF	100% RDF	85.1	23.0	99.2	16.83	81.8	15.8	65.6	10.77
50% RDF + 50% N -FYM	100% RDF	83.9	23.1	98.7	18.60	96.2	18.8	74.7	13.53
75% RDF + 25% N -FYM	75% RDF	72.9	20.3	85.1	14.16	74.4	12.8	58.7	8.66
50% RDF + 50% N –WS	100% RDF	66.2	18.8	77.7	14.50	78.0	13.2	60.9	9.64
75% RDF + 25% N - WS	75% RDF	69.1	19.2	82.4	13.71	70.3	11.8	55.9	8.47
50% RDF + 50% N – LL	100% RDF	74.5	21.1	88.5	15.69	79.8	13.9	64.9	11.07
75% RDF + 25% N - LL	75% RDF	73.6	20.5	87.6	14.60	72.5	11.7	57.2	8.67
FP (50 :25 :00)	FP (40 :25 :12.5)	51.7	12.7	61.27	10.30	37.4	6.0	27.6	4.27
SE(m) ±	3.25	0.87	3.46	0.77	2.74	0.72	2.18	0.42	
LSD (P=0.05)	9.36	2.49	9.95	2.21	7.90	2.06	6.27	1.20	

Table 3 Effect of long term manuring and fertilization on soil fertility under sorghum-wheat sequence after 27th cycle

Treatment		Available Nutrients (kg/ha)			Available	Organic carbon
Sorghum	Wheat	N	P	K	S (mg/kg)	(g/kg)
Control	Control	182	4.93	265	8.93	3.88
50% RDF	50% RDF	226	13.48	290	17.04	4.73
50% RDF	100% RDF	229	15.79	296	17.21	5.02
75% RDF	75% RDF	232	16.70	295	17.53	4.99
100% RDF	100% RDF	239	19.72	327	19.34	5.69
50% RDF + 50% N -FYM	100% RDF	255	23.44	370	20.83	6.50
75% RDF + 25% N -FYM	75% RDF	243	18.51	342	18.28	5.91
50% RDF + 50% N –WS	100% RDF	249	20.12	359	20.19	6.21
75% RDF + 25% N - WS	75% RDF	244	18.41	348	17.64	5.95
50% RDF + 50% N – LL	100% RDF	247	19.21	352	19.85	6.10
75% RDF + 25% N - LL	75% RDF	241	18.51	316	17.43	5.84
FP (50 :25 :00)	FP (40 :25 :12.5)	222	11.97	282	15.73	4.84
SE (m) ±	4.30	0.395	6.30	0.62	0.124	
LSD (P=0.05)	12.3	1.137	18.12	1.80	0.358	

management, the INM was gradually become superior indicating advantage of readily available chemical fertilizers during initial years which subsequently recorded on par yields suggesting the gradual improvement in soil quality under organics.

The grain yield of wheat under the integrated nutrient management involving 50% N through organics followed by 100% recommended dose of fertilizer to wheat shown superior yields because of residual effect of organics. Ravankar *et al.* (2005) also reported that the highest yield of sorghum and wheat were obtained with the application of full recommended dose of NPK + 10 tonnes FYM/ha in Vertisol. This increase in crop productivity may be due to the combined effect of nutrient supply, synergism and improvement in soil physical and biological properties (Manna *et al.* 2005, Mandal *et al.* 2007).

System productivity in terms of sorghum equivalent yield

The average system productivity including yields of both sorghum and wheat in sorghum equivalent yield was higher at integrated use of FYM along with chemical fertilizers (Table 1). It was drastically reduced at imbalanced fertilizer application, unfertilized control and farmers practice indicating soil quality decline, which is evident from the data on soil quality index.

Although the yields of crops did not show the consistent trend over the years at only chemical fertilizers and INM treatments the data on sustainability yield index and sorghum grain equivalence further supports the fact that the soils under intensive cereal-cereal cropping system are undergoing mining of nutrients and depleted the fertility of soils in addition to deterioration in soil physical properties also more prominently under only chemical fertilizers and although not revealed very prominently in crop yields the integrated nutrient management using organics recorded improvement in sustainability yield index, sorghum grain equivalent as well as enhanced soil quality index.

Uptake of nutrients

The conjoint use of 50% RDF + 50% N through FYM recorded significantly highest uptake of nitrogen by sorghum (83.98 kg/ha) and wheat (96.17 kg/ha). The increase in N uptake on application of inorganic in combination with organics is due to increase in yield, effective root system and increased concentration of nutrients in soil solution as well as better soil physical environment coupled with sufficiency of water and nutrients helped in better uptake of water and nutrients. This clearly indicated that amongst the organic material, FYM application helped to absorb N more efficiently as compared to wheat straw and leucaena loppings. The narrow C:N ratio of FYM could be the possible reason to absorb N more efficiently as compared to wheat straw and leucaena loppings. Pathak *et al.* (2005) also supported that, substitution of inorganic fertilizers by FYM either at 50% or 25% is helpful in increasing uptake of nitrogen.

The organics also helped in enhancing phosphorus in soil by reducing fixation of phosphorus. The application of organics with chemical fertilizers was also found beneficial for improving uptake of potassium and sulphur.

Nutrient status

The available N after 27th crop cycle was found to increase substantially from 209 kg/ha (Initial status) to 255 kg/ha under chemical fertilizers + 50% N through FYM. The application of NPK through chemical fertilizers with FYM recorded 1.11 times more available N status, as compared to use of only chemical fertilizers. The favourable soil conditions under FYM addition might have helped in mineralization of soil N leading to build up of higher available N (Santhy *et al.* 1998, Kumar *et al.* 2008). The available N status although showed increase under INM, it has not been increased much due to the prevailing climatic condition accelerating oxidation of organic matter as well as the nature of nitrogen forms in soil in the form of its losses through volatilization and leaching. In this view, the

Table 4 Principal Component Analysis of soil parameters based on 12 treatments

Soil parameters	Factor loadings					
	PC1	PC2	PC3	PC4	PC5	PC6
Water retention 33 kPa	0.848	0.265	0.231	0.253	0.194	0.180
Mean weight diameter	0.845	0.307	0.228	0.124	0.202	0.104
Alkaline phosphatase	0.839	0.286	0.214	0.222	0.209	0.179
Water retention 1500 kPa	0.830	0.272	0.249	0.243	0.177	0.176
AWC	0.829	0.246	0.201	0.251	0.205	0.176
Available K	0.825	0.184	0.222	0.130	0.223	0.281
Available Zn	0.803	0.299	0.221	0.202	0.260	0.129
Hydraulic conductivity	0.793	0.241	0.239	0.267	0.264	0.246
Available Mn	0.775	0.402	0.154	0.153	0.272	0.196
Organic carbon	0.775	0.312	0.260	0.231	0.295	0.130
DHA	0.763	0.386	0.273	0.243	0.226	0.191
Available Fe	0.728	0.411	0.304	0.234	0.096	0.226
Urease	0.707	0.487	0.301	0.204	0.225	0.199
CO_2	0.681	0.454	0.345	0.166	0.206	0.229
Available P	0.642	0.500	0.295	0.275	0.263	0.197
SMBC	0.637	0.454	0.306	0.267	0.278	0.266
Bulk density	–0.587	–0.476	–0.395	–0.222	–0.107	–0.318
Available N	0.524	0.501	0.402	0.245	0.332	0.173
Available S	0.408	0.670	0.387	0.202	0.305	0.200
Available Cu	0.543	0.597	0.164	0.374	0.201	0.258
Fungi	0.354	0.282	0.816	0.175	0.211	0.179
pH	–0.299	–0.198	–0.153	–0.903	–0.135	–0.094
Actinomycetes	0.407	0.245	0.216	0.166	0.813	0.154
Bacteria	0.458	0.358	0.293	0.161	0.231	0.694

results of present investigation suggest that the maintenance of soil available N levels is more challenging. This necessitates regular addition of organics for maintenance of soil fertility in the soils of semi-arid eco-regions. The available soil phosphorus was significantly improved with the application of chemical fertilizers (19.72 kg/ha) and further by integration with organics (23.44 kg/ha) (Table 2). The application of chemical fertilizers with 50% N through FYM (T_6) recorded 1.29 times more available P status than use of 100% NPK recommended fertilizer dose through only chemical fertilizers. The increase in available phosphorus status is due to use of FYM, being direct source of phosphorus and it might have also solubilized the native phosphorus in the soil through release of various organic acids which had chelating effect, that reduced phosphorus fixation. Similar findings are in conformity with findings of Verma *et al.* (2005). In view of the most widespread problem of the phosphorus fixation in black smectite soils and consequent low fertilizer use efficiency, the application of organics in a regular manner is a necessity on priority basis in these soils. The decomposition of organic matter is accompanied by the release of appreciable quantities of CO_2 when dissolved in water, forms carbonic acid, which is capable of decomposing certain primary minerals and release of nutrients (Bharadwaj *et al.* 1994). The appreciable build up in available phosphorus may be due to the influence of organic matter in increasing the labile phosphorus in soil through complexing of cation like Ca^{2+}, which are mainly responsible for fixation of phosphorus. Tolanur and Badanur (2003) also supported that organic manure with inorganic fertilizers had the beneficial effect on increasing the phosphate availability. The buildup of available P even under only inorganic fertilizers, may be ascribed to its fixation and lower uptake than amount added externally. The larger built up in soil P on conjunctive use of fertilizer and organic manure was because of additional supply of P through FYM and reduction in fixation of applied P or mobilization of native P by organic acids produced during organic matter decomposition (Singh and Wanjari 2007).

The available K status after a long term period of 27 years was relatively higher under use of organics over only chemical fertilizers. This could be attributed to the greater capacity of organic colloids to hold K ions on the exchange sites (Sheeba and Chellamuthu 1999). This can also be due to the reduction of potassium fixation and release of K due to the interaction of organic matter with clay, besides the direct K addition in available K pool to the soil (Tandon 1988 and Suresh *et al.* 1999).

As regards sulphur, the application of organics in conjunction with chemical fertilizers recorded higher sulphur status over only chemical fertilizers. However, although, it was higher than a critical value of 10 mg/kg, the results suggests that from soil sustainability point of view the organics are necessary to maintain the sulphur status which was observed to be drastically reduced over 27 years under control.

Organic carbon

The initial organic carbon content of the soil (1984-85) was 4 g/kg (0-15 cm) which was increased to 6.50 g/kg under INM (T_6), suggesting almost moderate built up. The organic carbon did not show much increase in spite of continuous manuring and fertilization over 27 years, which can be attributed to oxidation of organic matter in soil owing to prevailing high temperature in semi arid climatic areas. However, the conjoint use of chemical fertilizers with FYM, wheat straw and green manure was beneficial for maintaining organic carbon content compared to the use of only chemical fertilizers.

The organic carbon content in conjunctive use of chemical fertilizers with FYM recorded 1.19 times more organic carbon content (19.32% more) as compared to that under chemical fertilizers only.

The increase in organic carbon content under integrated use of chemical fertilizers and organic manure treatments might have been due to direct incorporation of organic matter, better root growth and more plant residues addition. The treatments of chemical fertilizers also recorded higher organic carbon in comparison to unfertilized control, which is due to the use of fertilizer, which helped in higher contribution of biomass to soil in the form of greater root biomass through crop stubbles and residues. The subsequent decomposition of these materials might have resulted into enhanced organic carbon content of soil.

Sustainability yield index (SYI)

The sustainability yield index (SYI) for sorghum (0.498) and wheat (0.264) were higher under integrated nutrient management as compared to only chemical fertilizers (T_5) (Fig 1). The data further indicated that imbalanced fertilizer application, unfertilized control and farmers practice caused decline in SYI due to decline in soil quality.

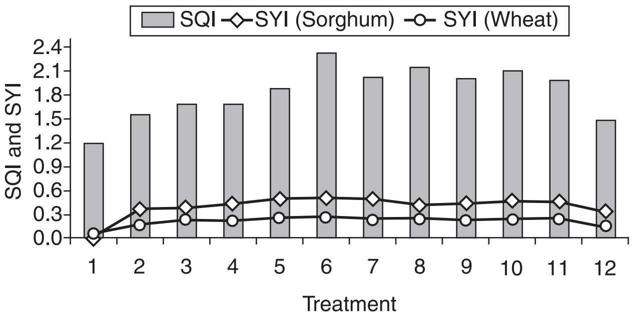

Fig 1 Long term effect of manuring and fertilization to sorghum-wheat sequence on soil quality and sustainability yield index

The SYI was considerably reduced at use of only chemical fertilizers devoid of organics. Although the SYI values showed comparable figures at 100% dose of only chemical fertilizers, it appears from soil quality evaluation that this productivity was achieved at the cost of soil quality decline. This indicates necessity of regular addition of organics in order to sustain crop productivity of cereal–cereal cropping system without declining the soil quality further (Katyal *et al.* 1999 and Manna *et al.* 2005).

Soil quality index

Application of NPK fertilizers in combination with FYM (T6) maintained significantly highest soil quality index of 2.33. The unfertilized control recorded significantly lowest soil quality with SQI of 1.19. The similar results were reported by Sharma *et al.* (2005) and Masto *et al.* (2007). It was interesting to note that the values of more than two at all the INM treatments while under chemical fertilizer soil quality index was lower than two after 27 years.

The SQI was drastically declined at all the treatments of only chemical fertilizers even at 100% dose of chemical fertilizers (T2–T5). This indicates overall improvement in soil quality in the long run due to regular addition of organics in combination with chemical fertilizers. The exhaustive cereal – cereal cropping system depletes the soil nutrients considerably causing soil health decline over the long run and the results of present investigation suggests the

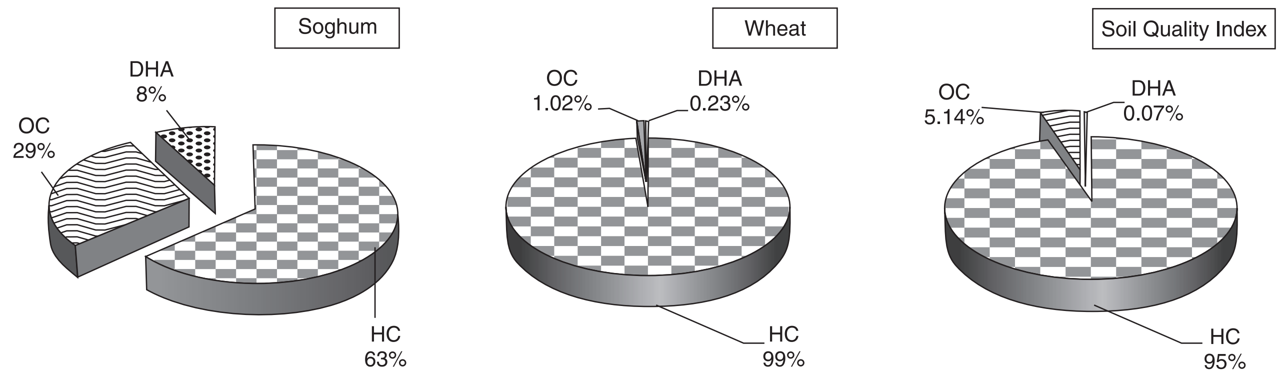

Fig 2 Per cent contribution soil quality indicators towards yield of sorghum, wheat and soil quality index

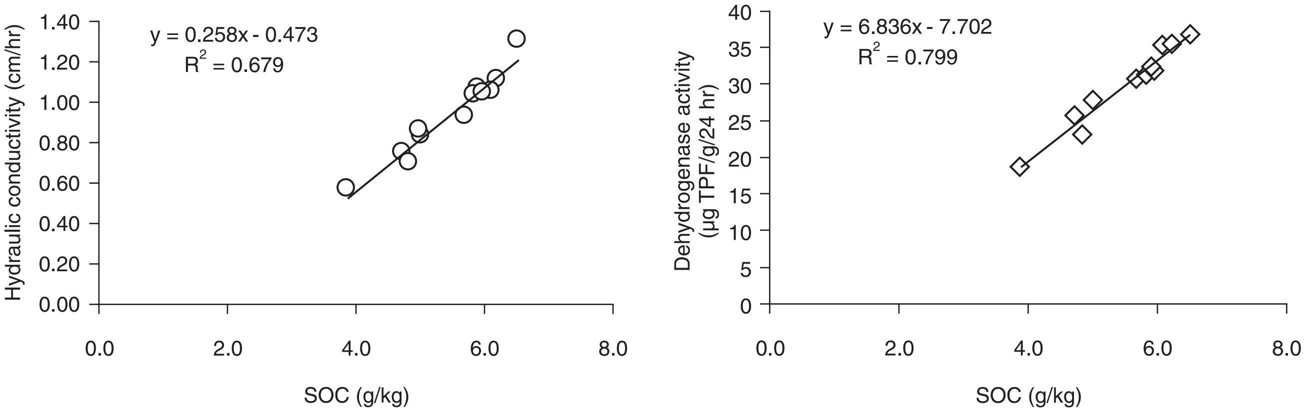

Fig 3 Relationship between soil organic carbon and soil quality attributes

importance of INM for soil sustainability.

Contribution of key soil quality indicators in grain yield and soil quality index

The key indicators which contributed considerably towards soil quality index were hydraulic conductivity, organic carbon and de-hydrogenase activity (DHA). On an average, the order of relative contribution of these indicators towards soil quality index were hydraulic conductivity (94.79%), organic carbon (5.14%) and de-hydrogenase activity (0.07%) (Fig 2).

This suggests further that the crop yield in the long run in black soils of semi arid regions is determined and controlled by the soil quality attributes like hydraulic conductivity, organic carbon and dehydrogenase activity owing to their improvement under use of organics resulting into enhancement in soil quality. This has been further evidenced from the highly significant positive relationship (n=48) between organic carbon and soil quality attributes like hydraulic conductivity (r=0.679**) and de-hydrogenase (r=0.799**) (Fig 3).This justify the significance of organics addition to the soil for improving physical and biological properties as against application of only chemical fertilizers. The chemical fertilizers use over a long term although recorded at par crop yields with INM, the soil quality was observed to be deteriorated especially in terms of physical and biological properties which can only be improved by addition of organics.

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