



Long-term effect of fertilization on soil chemical and biological characteristics and productivity under sorghum (*Sorghum bicolor*)–wheat (*Triticum aestivum*) system in Vertisol

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ABSTRACT

An experiment was undertaken during 2007–08 to study the effect of long-term fertilization and manuring on soil chemical and biological properties in Vertisol. The dynamics of soil characteristics was studied in the on-going long-term fertilizer experiment initiated in rainy (*khari*) season 1988 at Akola, Maharashtra comprised 12 treatments including NPK levels with and without FYM, sulphur and zinc replicated four times in randomised block design. The manure and mineral fertilizers were given to sorghum [*Sorghum bicolor* (L.) Moench] crop every year and only mineral fertilizers were applied to succeeding wheat (*Triticum aestivum* L. emend Fiori & Paol). Soil samples from all the treatments were collected from 0–20 cm depth. The chemical and biological soil characteristics were studied. Significantly highest increase in soil organic carbon and total nitrogen were recorded with 100% NPK + FYM @ 10 tonnes/ha. The availability of N, P, K, S, soil microbial biomass carbon and nitrogen, dehydrogenase assay and productivity of sorghum and wheat were significantly increased with the integrated application of organic manure (FYM @ 10 tonnes/ha) and mineral fertilizer (100% NPK) over control and other fertilizer treatments after 20 years of experimentation. Highly significant positive correlation of total productivity was observed with available K, N, and P, whereas moderately positive significant correlation was observed with organic carbon, total nitrogen and biological parameters.

Key words: Dehydrogenase activity, Long-term, Soil fertility, Soil microbial biomass carbon and nitrogen

Sorghum [*Sorghum bicolor* (L.) Moench] and wheat (*Triticum aestivum* L. emend Fiori & Paol) are the premier foodgrain crops of the peninsular central India and in particular of Maharashtra. There has been a phenomenal increase in their production after mid-sixties with the introduction of high-yielding varieties. The heavy removal of nutrients from the soil by high-yielding varieties for higher use of fertilizer made it imperative to examine the sustainability of modern intensive cropping systems based on high external inputs of fertilizers and high-yielding varieties under irrigated conditions. Significance of soil fertility maintenance in sustaining crop productivity has been realized worldwide. Sustaining soil quality is the most appropriate method to ensure sufficient food to support life. Maintaining and improving the level of soil organic matter is prerequisite for ensuring soil quality, future productivity and sustainability as it influences soil physical, chemical,

biological properties and processes (Singh 2008). In addition, being a direct source of plant nutrients, soil organic matter also indirectly influences the availability of plant nutrients in soil from native pools. The balanced fertilization through integrated use of manures and fertilizers has been found useful in various crop sequences.

Organic matter in soil is critical for better soil health and higher soil productivity. However, maintaining or improving soil organic carbon is difficult in arid and semi-arid regions in view of rapid oxidation of organic matter due to high temperature. Continuous application of organic manure is the only way to increase soil organic matter status (Katyal *et al.* 2001). A part of nutrient is assimilated by micro-organisms and incorporated into microbial biomass. Micro-organisms regulate the nutrient flow in the soil by assimilating nutrients and producing soil biomass. The changes in soil organic carbon contents are also directly associated with changes in microbial biomass carbon and biological activity in the soil.

Many long-term experiments conducted in India showed increasing yield trends and accumulation of soil organic carbon and biological properties due to combined application

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of fertilizer and manures (Manna *et al.* 2005, 2007, Mandal *et al.* 2007, Bhattacharyya *et al.* 2008, 2010, Vineela *et al.* 2008). However, most studies were restricted under irrigated conditions to rice–wheat and soybean–wheat systems. Relatively limited information is available on Vertisol under in semi-arid conditions on sorghum–wheat system. The hypothesis of the investigation was that the long-term application of balanced and imbalanced fertilization with or without manures under intensive cropping system may influence the soil chemical and biological properties and ultimately the productivity. Therefore, the objectives of the present study were: (i) to evaluate the effect of long-term fertilization on organic carbon, total nitrogen, residual soil fertility and biological properties, and (ii) to assess the effect of fertilization on crop productivity of sorghum–wheat system in Vertisol under semi-arid climatic condition of central India.

MATERIALS AND METHODS

The long-term fertilizer experiment was initiated in rainy (*khari*) season of 1988 on the Research Farm, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The experimental site is located 22°42' N and 77°02' E, 307.42 m above mean sea level in a semi-arid tropical zone. The rainfall received 779 mm during study year against 843.3 mm average annual rainfall. The average daily maximum and minimum temperature were 12.5°C and 42.2°C respectively, as against normal value of 18.2°C and 33.9°C. The soil is deep black with clay texture, Typic Haplustert of Vertisol. The initial soil properties during 1988 were alkaline pH (8.1), high cation exchange capacity (48 c mol (p⁺)/kg), medium soil organic carbon (4.6 g/kg), total nitrogen (0.044%), low available phosphorus (8.4 kg/ha), high available potassium (358 kg/ha) and marginal in available sulphur (11.4 mg/kg) and available zinc (0.62 mg/kg). The present investigation was undertaken during 2007–08 after 19th cycle.

Experiment consisted of 12 treatments, viz T₁ 50% NPK; T₂ 100% NPK; T₃ 150% NPK; T₄ 100% NPK (S free); T₅ 100% NPK + 2.5 kg Zn/ha; T₆ 100 NP; T₇ 100% N; T₈ 100% NPK+ farmyard manure @10 tonnes/ha (INM); T₉ 100% NPK (S free) + 37.5 kg S/ha; T₁₀ farmyard manure 10 tonnes/ha; T₁₁ 75% NPK and T₁₂ Control. It was laid out in randomized block design replicated four times at the same site without disturbing the layout since 1988. The nutrients were applied through the mineral fertilizers like urea, single super phosphate, muriate of potash, diammonium phosphate (T₄ and T₉). Sulphur was applied through gypsum (T₉) to sorghum every year and zinc applied through zinc sulphate once in two years for wheat only (T₅).

The farmyard manure was applied every year one month before sowing of the sorghum. The recommended fertilizer doses applied to sorghum and wheat were 100:50:40 and 120:60:60 kg N, P₂O₅ and K₂O/ha, respectively. Sorghum

(cultivar-CSH 9) was sown during first week of July and harvested in second week of November and wheat (cultivar AKW 1071) was sown during the second fortnight of November and harvested in first week of April.

The grain and straw yield of each crop were recorded and plot-wise soil samples (0–20 cm) were collected after harvest of wheat. These samples were analyzed for pH (1:2.5 soil: water suspension), electrical conductivity by conductivity meter, organic carbon by rapid titration method (Walkley and Black 1936), total N by Kjeldahl method (Jackson 1967) and available K by ammonium acetate extraction method (Jackson 1967). Available N was estimated by alkaline permanganate method (Subbiah and Asija 1956) and available P by Olsen's method (Olsen *et al.* 1954). The available S was estimated by turbidimetric method (Chesnin and Yien 1950). The fresh soil samples collected during grand growth stage of wheat were immediately used for estimating biological properties. Soil microbial biomass carbon was estimated following Jenkinson and Powlson (1976) and soil microbial biomass nitrogen was measured by modified direct extraction method (Jenkinson and Ladd 1981). Soil dehydrogenase assay was estimated by incubation with triphenyle tetrazolium chloride (TTC) and calcium carbonate method (Casida *et al.* 1964).

RESULTS AND DISCUSSION

Organic carbon and total nitrogen

The soil organic carbon and total nitrogen of soil varied significantly with long-term application of man and mineral fertilization (Table 1). The significantly highest soil organic carbon (6.77 g/kg) and total N (0.059%) were recorded in

Table 1 Long-term effect of various treatments on chemical properties of soil in sorghum–wheat system

Treatment	OC (g/kg)	Total N (%)	pH	EC (dS/m)
T ₁ , 50% NPK	4.32	0.0428	7.94	0.281
T ₂ , 100% NPK	5.11	0.0483	7.85	0.314
T ₃ , 150% NPK	5.93	0.0516	7.78	0.341
T ₄ , 100% NPK (S free)	5.10	0.0479	7.85	0.293
T ₅ , 100% NPK + 2.5 kg Zn/ha	5.15	0.0492	7.83	0.324
T ₆ , 100% NP	4.90	0.0461	7.87	0.311
T ₇ , 100% N	4.29	0.0432	7.88	0.307
T ₈ , 100% NPK + FYM @ 10 tonnes/ha	6.77	0.0594	7.75	0.336
T ₉ , 100% NPK + 37.5 kg S/ha	5.21	0.0504	7.82	0.331
T ₁₀ , FYM alone 10 tonnes/ha	6.01	0.0512	7.82	0.284
T ₁₁ , 75% NPK	4.64	0.0433	7.86	0.289
T ₁₂ , control	2.81	0.0331	7.98	0.270
SEm (±)	0.13	0.002	0.07	0.014
CD (P=0.05)	0.38	0.005		0.042

the treatment of application of farmyard manure at 10 tonnes/ha +100% NPK (T_8). The soil organic carbon and total N were enhanced due to long-term application of farmyard manure at 10 tonnes/ha + 100% NPK by nearly 14.1 and 15.1% compared to supra optimal dose of fertilizers (150% NPK). The 31.3 and 23.0% increase in organic carbon and total nitrogen were observed under NPK+ farmyard manure over NPK alone (T_2) through mineral fertilizers (Table 1). The increase in organic carbon over a period of 19 years under integrated nutrient management (T_8) over the initial can be attributed to addition of farmyard manure which stimulated the growth and activity of micro-organism and better root biomass. Vineela *et al.* (2008) also observed that soil organic carbon levels increased considerably due to long-term fertilization and/or manuring applied for 16–29 years in Vertisol and Alfisol under semi-arid climatic condition.

Application of sulphur at 37.5 kg/ha along with 100% NPK also recorded increase in organic carbon (5.21 g/kg) compared to 100% NPK (S free) (5.10 g/kg). This was probably due to higher biomass production with balanced supply of NPK and S. Application of 100% NPK also showed significant increase in organic carbon (5.11 g/kg) over initial content (4.6 g/kg). Similar trend was also noticed in total nitrogen content. Soil type could be one of the importances of the inorganic part of the soil as substrate to bind the organic carbon (Manna *et al.* 2005). Furthermore, total below ground biomass C in sorghum –wheat system was as good as triple cropping system, which directly reflected on better SOC storage. At the end of 30 years, application of balanced fertilization of NPK showed significantly higher organic carbon (7.51 g/kg) compared to unfertilized control (6.01 g/kg) in 0–45 cm soil layer (Kundu *et al.* 2007). This has clearly indicated that INM followed over a long-term was beneficial in maintenance of organic carbon levels in Vertisols of semi-arid regions of central India. Total soil nitrogen was also found to enhance in the treatment of INM, which is useful for nitrogen management under intensified cropping in the subsequent years for better supply of nitrogen to the crops after its mineralization.

Soil pH and electrical conductivity

The soil pH was not significantly influenced due to long-term fertilization and manuring (Table 1) ranged from 7.75 to 7.98 in different treatments in the 0–20 cm soil depth. Continuous application of mineral fertilizers and manures had significant effect on soil electrical conductivity. Application of inorganic fertilizers slightly increased EC of soil. The highest value of EC (0.341 dS/m) was recorded in 150% NPK, followed by 100% NPK + farmyard manure at 10 tonnes/ha (0.336 dS/m) while lowest EC (0.270 dS/m) was recorded in control.

Available nutrients

Long-term manuring and fertilization registered

Table 2 Long-term effects of various treatments on availability of macro and secondary nutrients in soil in sorghum–wheat system

	Available nutrients			
	(kg/ha)			mg/kg
	N	P	K	S
T_1 , 50% NPK	186	16.21	309	36.06
T_2 , 100% NPK	280	30.96	388	44.13
T_3 , 150% NPK	305	32.98	431	58.08
T_4 , 100% NPK 267 (S free)	29.11	371	33.38	
T_5 , 100% NPK + 2.5 kg Zn/ha	282	29.07	386	48.61
T_6 , 100% NP	260	29.83	339	40.54
T_7 , 100% N	248	24.70	299	34.05
T_8 , 100% NPK+FYM @ 10 tonnes/ha	313	37.08	460	63.39
T_9 , 100% NPK + 37.5 kg S/ha	283	31.16	391	65.18
T_{10} , FYM alone 10 tonnes/ha	253	28.81	338	31.58
T_{11} , 75% NPK	214	19.92	348	43.01
T_{12} , control	175	12.17	230	28.67
SEm (\pm)	4.24	0.26	3.25	0.42
CD ($P=0.05$)	12	0.75	9	1.16

significant increase in available P, K and S in the plots under 100% NPK + farmyard manure at 10 tonnes/ha (T_8). The application of farmyard manure at 10 tonnes/ha + 100% NPK increased the availability of N, P, K and S by 2.6, 12.4, 6.7 and 9.1% compared to supra optimal dose of fertilizers (150% NPK) without any organic addition. Annual applications of farmyard manure at 10 tonnes/ha in *kharif* season to sorghum decreased soil NPK status (Table 2).

Availability of P increased to the extent of 91% in the plots under NPK (T_2) compared to 50% NPK treated plots (T_1). It was found higher by 6.5% in the plots under 150% NPK (T_3) compared to NPK treated plots (T_2). The maximum build-up of soil P was observed under NPK+ farmyard manure (T_8). This might be attributed to build-up of P in soil by its addition every year and solubilization of native P in the soil through release of organic acids from farmyard manure (Tolanur and Badanur 2003). The finding corroborates with the results reported by Verma *et al.* (2005).

The highest available K was observed in the plots under NPK +farmyard manure and the lowest under control. Soils under NPK+ farmyard manure-treated plots recorded higher available K by 18.6% compared to NPK treated plots. Continuous cropping without addition of K and imbalanced fertilization (N and NP) reduced the availability of K compared to initial soil K status. This might be due to continuous omission of K and/or imbalanced fertilization in crop nutrition caused mining of its native pools that also

caused reduction in crop yields (Subehia *et al.* 2005). The available S found highest (65.18 mg/kg) in the plot under 100% NPK+ S, followed by the treatment of INM (T₈).

The increase in available N was observed in NPK + farmyard manure may be through direct addition of organic matter from farmyard manure in combination with 100% NPK which might have helped in multiplication of soil microbes, ultimately enhancing the conversion of organically bound N to mineral form (Tolanur and Badanur 2003). Increase in available K might be due to the direct addition to the available K pool of the soil, besides reduced K fixation and release of K due to the interaction of organic matter with clay (Sharma *et al.* 2001). This has been further reflected in sustained crop productivity over a long-term cropping period of 19 years justified by adequate and balanced supply of plant nutrients to the intensive cropping sequence.

Biological properties

Application of NPK+ farmyard manure at 10 tonnes/ha recorded significant increase in biological parameters, viz soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN) and dehydrogenase activity (DHA) to the extent of 8.8, 9.3, and 9.0% compared to 150% NPK through chemical fertilizers without organics (Table 3). This can be ascribed to direct addition of organic matter through farmyard manure and increase in root biomass which helped in growth and development of soil micro-organisms causing beneficial effect on SMBC, SMBN and DHA. Application of farmyard manure at 10 tonnes/ha (only to sorghum) significantly increased SMBC, SMBN and DHA over control which might be due to a steady source of organic carbon to support the microbial community (Bhattacharyya

et al. 2008). The lowest value of SMBC was observed in the control obviously due to unfavourable environment arising out of depletion of nutrients due to continuous cropping without any fertilization or manuring. The highest SMBC in the INM treatments was due to additional mineralizable and readily hydrolysable carbon from farmyard manure (Verma and Mathur 2009).

The soil microbial biomass nitrogen decreased at 100% NP and 100% N to the tune of 17.6 and 24.8% compared to 100% NPK (T₂) indicating necessity of balanced fertilizer application for enhancing soil microbial activity. It was further observed that combined use of farmyard manure at 10 tonnes/ha with 100% NPK increased microbial biomass nitrogen by 17.3% compared to NPK indicating augmented effect of organics in microbial activities. High soil organic carbon, more root proliferation and additional supply of N by farmyard manure to micro-organisms might be responsible for increasing the level of SMBN (Verma and Mathur 2009). Selvi *et al.* (2004) reported that farmyard manure is not only rich in carbon but also in nitrogen and other macro and micronutrients.

The dehydrogenase assay (DHA) increased with graded levels of mineral fertilizer doses from 50 to 150% NPK. Applications of farmyard manure at 10 tonnes/ha +100% NPK recorded significantly higher dehydrogenase activity (49.78 µg/g/24 hr) compared to all other treatments. The increase in DHA was 18.6% due to INM over 100% NPK through mineral fertilizers. The results are in line with the findings reported by Bhattacharyya *et al.* (2008) wherein observed 4–5 folds increase in dehydrogenase activity due to farmyard manure application along with NPK. The addition of farmyard manure coupled with mineral

Table 3 Long-term effect of various treatments on soil biological properties in sorghum–wheat cropping system

Treatment	SMBC (mg/kg)	SMBN (mg/kg)	DHA (µg/g/24 hr)
T ₁ , 50% NPK	187	12.36	37.32
T ₂ , 100% NPK	214	14.95	41.95
T ₃ , 150% NPK	227	16.03	45.69
T ₄ , 100% NPK (S free)	208	13.86	41.06
T ₅ , 100% NPK + 2.5 kg Zn/ha	217	14.30	43.14
T ₆ , 100% NP	196	12.74	40.11
T ₇ , 100% N	179	11.98	36.97
T ₈ , 100% NPK + FYM @ 10 tonnes/ha	247	17.53	49.78
T ₉ , 100% NPK + 37.5 kg S/ha	220	14.80	44.19
T ₁₀ , FYM alone 10 tonnes/ha	222	15.18	45.08
T ₁₁ , 75% NPK	192	13.34	38.81
T ₁₂ , control	139	8.86	32.51
SEm (±)	10	0.70	0.61
CD (P=0.05)	29	1.95	2.23

SMBC, Soil microbial biological carbon; SMBN, soil microbial biological nitrogen; DHA, dehydrogenase activity

Table 4 Grain yield of sorghum and wheat under long-term fertilization in sorghum–wheat system

Treatment	Sorghum	Wheat	Total productivity
	(tonnes/ha)		
T ₁ , 50% NPK	2.62	1.44	4.06
T ₂ , 100% NPK	3.87	2.73	6.60
T ₃ , 150% NPK	4.61	3.22	7.83
T ₄ , 100% NPK (S free)	3.47	2.40	5.87
T ₅ , 100% NPK + 2.5 kg Zn/ha	3.99	2.81	6.81
T ₆ , 100% NP	2.76	1.43	4.20
T ₇ , 100% N	2.17	1.03	3.19
T ₈ , 100% NPK + FYM @ 10 tonnes/ha	5.08	3.44	8.52
T ₉ , 100% NPK + 37.5 kg S/ha	3.94	2.57	6.51
T ₁₀ , FYM alone 10 tonnes/ha	1.58	0.30	1.88
T ₁₁ , 75% NPK	3.10	1.89	4.19
T ₁₂ , control	0.20	0.06	0.25
SEm (±)	0.76	0.71	
CD (P=0.05)	0.22	0.20	

Table 5 Correlation matrix between total grain productivity (sorghum and wheat) and soil properties under long-term fertilization

	OC	T.N	Av.N	Av.P	Av.K	Av.S	SMBC	SMBN	DHA	TP
TP	1									
OC	0.68**	1								
Total N	0.71**	0.95**	1							
Av. N	0.76**	0.83**	0.88**	1						
Av. P	0.74**	0.88**	0.88**	0.96**	1					
Av. K	0.92**	0.89**	0.89**	0.88**	0.88**	1				
Av. S	0.82**	0.63**	0.68**	0.71**	0.67**	0.82**	1			
SMBC	0.69**	0.90**	0.95**	0.86**	0.81**	0.87**	0.65**	1		
SMBN	0.72**	0.92**	0.95**	0.85**	0.82**	0.89**	0.68**	0.96**	1	
DHA	0.71**	0.95**	0.96**	0.87**	0.88**	0.91**	0.73**	0.93**	0.93**	1

** $P = 0.01$; TP, Total productivity

fertilization exerted a stimulating influence on the preponderance of bacteria (Selvi *et al.* 2004). It was significantly higher in the plots under 100% NPK (41.95 $\mu\text{g/g/24 hr}$) and 100% NP (40.11 $\mu\text{g/g/24 hr}$) compared with 100% N (36.97 $\mu\text{g/g/24 hr}$), suggesting balanced application of nutrients is necessary for this. Jain *et al.* (2003) also reported significant increase in DHA due to balanced nutrient supply.

Crop productivity

The highest productivity of sorghum and wheat (5.08 and 3.44 tonnes/ha) was recorded with the application of farmyard manure at 10 tonnes/ha +100% NPK. This was significantly higher than 150% NPK (4.61 and 3.22 tonnes/ha). Non-application of potassium (T_0) and phosphorus and potassium (T_7) through mineral fertilizer showed reduction in the total productivity over 100% NPK (T_2) to the tune of 36.4 and 51.6%, respectively (Table 4). The productivity of sorghum and wheat were significantly increased with application of 37.5 kg S/ha coupled with 100% NPK to the extent of 9.8% as compared to 100% NPK (without S). Increasing levels of NPK showed linear and significant increase in productivity of sorghum and wheat. The lowest productivity was recorded in the control. The higher biomass yield in NPK + farmyard manure amended soil may have been associated with other benefits from N, P and K supply through farmyard manure, such as improvements in microbial activity and soil physical conditions. This indicates that sustainability in productivity of sorghum and wheat could be maintained by integrated use of organic and inorganic fertilizers. This is substantiated by the results reported by Manna *et al.* (2005). However, use of only farm yard during *khari* was unable to increase crop yields to a sustainable level in the long run.

Relationship of soil properties with crop productivity

A highly significant positive correlation of total productivity (Table 5) was observed with available K ($r=0.92^{**}$), available S ($r=0.82^{**}$), available N ($r=0.76^{**}$),

available P ($r=0.74^{**}$), whereas moderately positive significant correlation was observed with organic carbon ($r=0.68^{**}$), total nitrogen ($r=0.71^{**}$) and biological parameters (soil microbial biomass carbon ($r=0.69^{**}$) and nitrogen ($r=0.72^{**}$) and dehydrogenase assay ($r=0.71^{**}$). This indicates that total productivity of sorghum and wheat grown in Typic Haplusterts was enhanced and controlled by these soil parameters.

Thus, it could be concluded that long-term application of farmyard manure at 10 tonnes/ha in combination with 100% recommended NPK to sorghum and wheat significantly improved the soil chemical and biological properties as well as productivity of sorghum and wheat. Neither organic sources alone nor mineral fertilizers can achieve sustainability in crop productivity under intensive cropping sequence, where nutrient turnover in soil plant system is much higher. Conjoint and judicious use of organics and mineral fertilizers found promising in long run.

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