Journal of the Indian Society of Soil Science, Vol. 67, No. 1, pp 55-64 (2019)
DOI: 10.5958/0974-0228.2019.00006.9

# Impact of Continuous Manuring and Fertilization on Changes in Soil Quality under Sorghum-Wheat Sequence on a Vertisols

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A permanent long-term fertilizer experiment is continuing since 1988-89 at Research Farm, Department of Soil Science and Agricultural Chemistry, Akola, Maharashtra with a view to investigate the effect of integrated nutrient management on soil fertility, crop productivity and sustainability under sorghum (*Sorghum bicolor* L.) - wheat (*Triticum aestivum* L.) cropping sequence. The treatments comprised of different levels of recommended dose of fertilizers (RDF) *viz*., 50, 75, 100 and 150% NPK and 100% NPK in combination with farmyard manure (FYM), FYM alone (5 t ha$^{-1}$), 100% NPK devoid of S, 100% NPK along with S @ 37.5 kg ha$^{-1}$ and Zn @ 2.5 kg ha$^{-1}$, NP, N alone and control. The results indicated that application of 100% NPK + FYM @ 5 t ha$^{-1}$ significantly increased the grain (4.61 t ha$^{-1}$) and straw (11.05 t ha$^{-1}$) yield of sorghum as well as grain (3.55 t ha$^{-1}$) and straw (5.37 t ha$^{-1}$) yield of wheat. The organic carbon status (7.91 g kg$^{-1}$) and availability of N (317 kg ha$^{-1}$), P (19.98 kg ha$^{-1}$), K (473.2 kg ha$^{-1}$) and Zn (0.96 mg kg$^{-1}$) was improved with the conjoint use of organics and fertilizers. However, continuous use of 100% NPK along with S @ 37.5 kg ha$^{-1}$ resulted in substantial improvement in S status of soil. Apparent nutrient balance implied build-up of N and P, whereas considerable mining of K was observed in the intensive sorghum-wheat cropping sequence. The nutrient uptake increased with P fertilization and showed further increase in the presence of K. The sustainable yield index (SYI) was relatively higher in 100% NPK + FYM @ 5 t ha$^{-1}$ (0.471) followed by 150% NPK (0.465). The yield of sorghum and wheat was highlly correlated with soil organic carbon content.

**Key words:** Soil quality, sorghum-wheat cropping sequence, sustainable yield index, organic carbon, nutrient status

Substantial increase in food production in India over the past 60 years is the result of modern agricultural technologies, and fertilizers are one of the most important components of these improved technologies. Inputs of nutrients, particularly N and P, are a major factor in the realization of production potential of high yielding varieties (Randhawa and Tandon 1982). It is well proven that long-term experiments generate extensive and valuable information which is used for studying the sustainability of intensive agriculture on long-term basis. Perceptible changes in soil quality as a result of imbalanced fertilizer use and unscientific management practices may take several years to appear. The climatic factors also alter the physical, chemical and biological properties of soils. It is anticipated that in India during 2025, total food grain demand will reach 291 million tonnes (Mt) comprising 109 Mt of rice, 91 Mt of wheat, 73 Mt of coarse grains and 15 Mt 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 increase the crop productivity through improved varieties and matching production technology to sustain soil fertility and crop productivity in near future. Integrated use of organic manures and fertilizers showed promise not only for maintaining higher productivity, but also for greater yield stability (Nambiar and Abrol 1989). Higher crop yields associated with greater nutrient removal resulted in the depletion of major nutrients particularly K reserves in soils. Among cereals, sorghum and wheat are the most important food crops in the plateau

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region of India. The sorghum-wheat, being the exhaustive cropping system, depletes nutrients heavily and causes negative nutrient balance when practiced with non-judicious fertilization. In order to study the effect of manures and fertilizers on soil fertility, crop productivity and sustainability, the present experiment was initiated in the year 1988-89 with sorghum (*Sorghum bicolor* L.)–wheat (*Triticum aestivum* L.) sequence on a Vertisol.

## Materials and Methods

A long-term field experiment was initiated during 1988-89 under the aegis of All India Coordinated Research Project on Long-term Fertilizer Experiments (AICRP-LTFE) at Research Farm, Department of Soil Science and Agricultural Chemistry, Akola, Maharashtra with a view to study the effect of integrated nutrient management on changes in soil quality, crop productivity and sustainability under sorghum-wheat crop sequence. The treatments consists of 12 treatments *viz*., 50% recommended dose of fertilizer (RDF), 100% RDF, 150% RDF, 100% RDF (-S), 100% RDF + Zn @ 2.5 kg $ha^{-1}$ once in two years to wheat crop only, 100% RD of NP, 100% RD of N, 100% RDF + farmyard manure (FYM) @ 5 t $ha^{-1}$ to sorghum only, 100% RDF + S @ 37.5 kg $ha^{-1}$, FYM @ 10 t $ha^{-1}$ to sorghum and wheat, 75% RDF + 25% N through FYM and Control. The 25$^{th}$ cycle of the experiment during 2012-13 was studied in the present investigation. The 100% RDF was 100:50:40 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$ for sorghum while 120:60:60 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$ for wheat. The FYM (0.57% N, 0.18% P and 0.59% K) was added on oven dry basis before sowing of sorghum whereas, half dose of N and full dose of P and K were applied at the time of sowing to sorghum and remaining half dose of N was applied 30 days after sowing. For wheat, the half dose of N and full dose of P and K were applied at the time of sowing and remaining half dose of N was applied 21 days after sowing. The soil of experimental site was deep, clayey black, taxonomically classified as fine, smectitic, calcareous, hyperthermic family of Typic Haplusterts. The soil had low hydraulic conductivity and high water holding capacity. The initial analysis indicated that the soil was low in organic carbon (OC) (4.60 g $kg^{-1}$) and available N (120 kg $ha^{-1}$), very low in available P (8.40 kg $ha^{-1}$) and high in available K (358 kg $ha^{-1}$). The soil was marginal in S (11.8 mg $kg^{-1}$) and Zn (0.62 mg $kg^{-1}$) status. Soil samples were collected at harvest of *rabi* crop and analyzed for various soil properties following standard prescribed method.

## Results and Discussion

### *Crop Productivity*

The data on grain yield (25$^{th}$ cropping cycle) of sorghum and wheat are presented in table 1. The data indicated that various fertilizer treatments recorded significant increase in the grain yield of sorghum and wheat over control. Application of 100% NPK + 5 t FYM $ha^{-1}$ significantly increased the grain yield of sorghum and wheat *viz*., 4.61 and 3.55 t $ha^{-1}$,

**Table 1.** Long-term effect of fertilization on yield of sorghum and wheat (25$^{th}$ cropping cycle)

| Treatments (*Kharif* and *Rabi*) | Yield (t $ha^{-1}$) | | | |
|---|---|---|---|---|
| | Sorghum | | Wheat | |
| | Grain | Fodder | Grain | Straw |
| 50% NPK | 2.39 | 5.63 | 1.80 | 2.97 |
| 100% NPK | 3.14 | 7.53 | 2.79 | 4.21 |
| 150% NPK | 4.22 | 10.14 | 3.15 | 4.79 |
| 100% NPK S free | 2.78 | 6.64 | 2.45 | 3.79 |
| 100% NPK + Zn @ 2.5 kg $ha^{-1}$ | 3.62 | 8.62 | 3.07 | 4.59 |
| 100% NP | 2.54 | 5.89 | 1.32 | 2.13 |
| 100% N | 1.76 | 4.18 | 0.75 | 1.29 |
| 100% NPK + FYM @ 5 t $ha^{-1}$ (to sorghum only) | 4.60 | 11.05 | 3.55 | 5.37 |
| 100% NPK + S @ 37.5 kg $ha^{-1}$ | 3.70 | 9.06 | 4.00 | 4.67 |
| FYM only 10 t $ha^{-1}$ (to sorghum and wheat ) | 2.41 | 5.82 | 1.29 | 2.16 |
| 75% NPK + 25% N through FYM | 3.61 | 8.48 | 2.20 | 3.52 |
| Control | 0.38 | 0.73 | 0.07 | 0.14 |
| *CD (P=0.05)* | 0.39 | 0.83 | 0.35 | 0.46 |
| CV% | 0.92 | 0.83 | 1.13 | 0.97 |

*Note:* Zinc application once in two years to wheat; FYM @ 5 t $ha^{-1}$ instead of 10 t $ha^{-1}$ was applied from 2011-12; FYM @ 10 t $ha^{-1}$ to wheat instead of no application from 2011-12; 25% N through FYM to both *kharif* and *rabi* from 2011-12.

respectively. Exclusion of S and Zn from fertilizer schedule has deleterious effect on crop yield due to long absence of these nutrients in the sequence. The reduction was noted to the extent of 25.0 and 13.1 per cent of sorghum and 20.6 and 8.9 per cent in wheat with the application of 100% NPK devoid of S and Zn, respectively. The crop response to S was more as compared to Zn which may be due to secondary nutrients that contribute towards more yield. Sulphur plays an important role in growth, development and chlorophyll formation, resulting in its higher utilization. Among the crop, beneficial effect of S and Zn application was noted with sorghum than wheat. Suresh *et al.* (1999) also reported that application of Zn along with recommended dose of fertilizer is highly essential for sustaining the yield of sorghum. However, the yield of sorghum and wheat in presence of S and Zn, was quite low as compared to NPK + FYM, since sufficient Zn is added through FYM which takes care of Zn requirement as well other micronutrients (Singh *et al.* 2014). Continuous use of N alone cannot be relied upon to produce sustained yield and therefore, application of nitrogenous fertilizer alone continuously to sorghum-wheat sequence adversely affects the soil fertility resulting in drastic reduction in yield. The P and perhaps K also had yield limiting factor in the sequence. The depletion of available P due to the exclusion of P from fertilizer schedule might have led to improper root development, leading to deleterious effect on crop growth and yield (Selvi *et al*. 2005). Continuous application of FYM reduced the yield of sorghum and wheat to the tune of 23.2 and 53.8 per cent, respectively as compared to 100% NPK and it was proved that only FYM could not sustained the crop productivity.

The yield of both sorghum and wheat was invariably decreased with years of cropping due to application of FYM alone as indicated by least $r^2$ value as compared to 100% NPK + FYM and 100% NPK (Fig. 1 and 2). Contrarily, the balanced application of nutrients sustained the productivity, which further improved with the combined application of organic and inorganic fertilizers. Yaduvanshi *et al.* (2013) reported that yield of rice could be sustained with 50% recommended dose of NPK with green manure (GM) or FYM.

*Soil Properties*

*Organic Carbon*

Soil OC is the key soil property for evaluating the soil health. The OC content of soil increased with various fertilizer and manure treatments over the initial status (4.6 g $kg^{-1}$) after continuous cropping for 25 years in all the treatments except control, 100% N and 50% NPK (Fig. 3a). Slight increase in the OC content was observed under 100% NPK and 100% NPK(-S), whereas, substantial build-up in the OC content was noted under 100% NPK + 5 t FYM, FYM

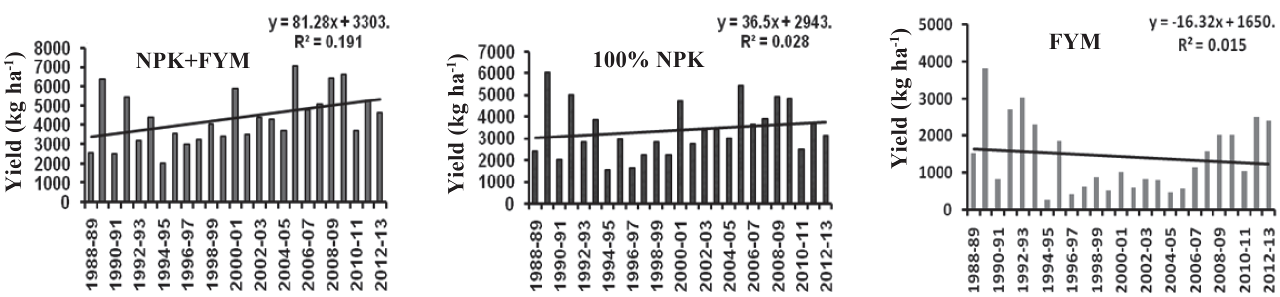


**Fig. 1.** Trends in yield of sorghum grain under sorghum-wheat sequence

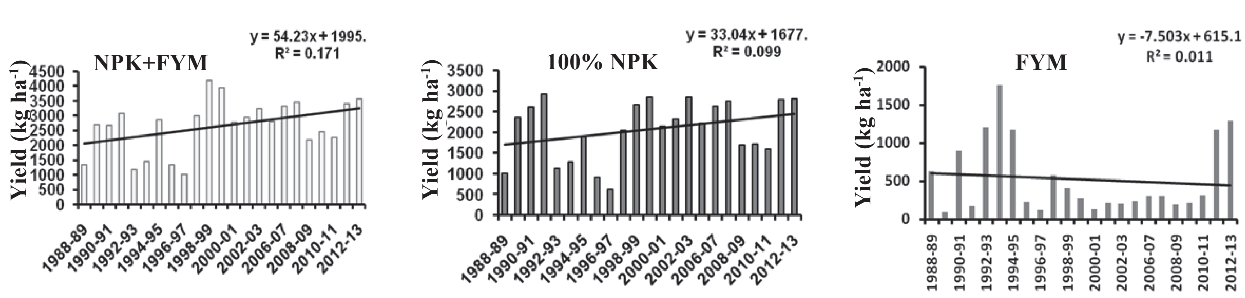


**Fig. 2.** Trends in yield of wheat grain under sorghum-wheat sequence

alone, 150% NPK, 100% NPK + S and 100% NPK + Zn. However, negligible change was reported under 100% NP. The application of 100% NPK + FYM @ 5 t $ha^{-1}$ recorded significantly highest OC (7.91 g $kg^{-1}$) followed by FYM @ 5 t $ha^{-1}$ (7.80 g $kg^{-1}$). The application of 150% NPK found effective in improving the OC status of soil (6.64 g $kg^{-1}$) as compared to initial status and other treatments as well. Imbalanced application of fertilizers *viz.*, 100% N (4.43 g $kg^{-1}$) or NP (4.91 g $kg^{-1}$) or 50% NPK (4.54 g $kg^{-1}$) caused significant decline in the OC content of soil. However, addition of S and Zn along with 100% NPK resulted in higher OC during the period of experimentation. The increase in OC content under integrated use of fertilizers and organic manure treatments might have been due to direct incorporation of organic matter, better root growth and more plant residues addition. The application of fertilizers alone or along with S and Zn also recorded higher OC content in soil as compared to unfertilized control, which might be due to the use of fertilizer contributed for higher biomass to soil through crop stubbles and residues. The subsequent decomposition of these materials might have resulted in enhanced OC content of the soil. Ravankar *et al.* (2005) reported that, the maximum amount of OC was found in the plot receiving inorganic fertilizers in combination with organics. Similar results were reported by Mishra *et al.* (2008). In spite of regular application of organics in the Vertisols of semi-arid areas the OC increase is gradual, therefore offers a great challenge for the sustenance of soil quality (Singh and Wanjari 2007).

*Available N*

Continuous use of nitrogenous fertilizer over a period of time increased the available N status gradually under all the treatments than the control, and the maximum increase was observed with NPK + 5 t FYM followed by 150% NPK under sorghum-wheat cropping sequence. The available N varied from 135 to 317 kg $ha^{-1}$ (Fig. 3b). In general, conjoint use of chemical fertilizer along with FYM increased the soil available N status (317 kg $ha^{-1}$). The favourable soil conditions provided by FYM addition might have helped in mineralization of additional soil N leading to build-up of higher available N (Santhy *et al.* 1998). Sarin *et al*. (1991) also reported that mineralization of N was higher with the addition of FYM. The substantial increase in available N from 120 (initially) to 311 kg $ha^{-1}$ (after 25 years) was observed with the application of 150% NPK, this might be due to continuous application which is associated with better crop growth and biomass production. The plant biomass produced, is a source of C and N, in due course of time can be converted into plant available forms through the process of mineralization. Increase in soil available N due to the application of nitrogenous fertilizers is a well-documented phenomenon (Glendining and Powlson 1995). The application of 100% NPK along with S and Zn also favours the crop growth by improving the net regime of N in soil. Similarly, the application of 100% NPK alone and suboptimal dose of fertilizers (75% RDF) along with FYM was equally beneficial in improving the available N status of soil. Sharma and Gupta (1998), also reported that supplementing organics (FYM) with inorganic N-fertilizers enhanced the available N content of the soil due to hastened mineralization, once the requirement of N by microbes is met through inorganic N.

*Available P*

To sustain the productivity over the year's regular supply of P to plant is essential. The status of Olsen's extractable P in experimental soil increased with the continuous application of fertilizer and manure over the control treatment (Fig. 3c). Integrated use of NPK along with FYM (19.98 kg $ha^{-1}$) and super optimal *i.e.* 150% NPK (18.05 $ha^{-1}$) or optimal doses of NPK alone (15.05 $ha^{-1}$) resulted in the build-up of available P. The application of NPK along with FYM maintained P reserve fairly at high level which was 77.8 per cent more over that of control and 24.5 per cent more over optimal NPK. The FYM could have solubilized the native P in the soil through the release of various organic acids. The carbon dioxide ($CO_2$) released during the decomposition of organic matter forms carbonic acids, solubilizing certain primary minerals. It has been notice that in calcareous soils $CO_2$ production plays a dominant role in enhancing the P availability (Singh and Wanjari 2007). Organic matter forms a protective covers on sesquioxides and this facilitates reduction in the P-fixing capacity of soil (Tandon 1987). The P build-up under 100% NPK + 5 t FYM was higher which may be due to the influence of organic manure in increasing the labile P in soil through complexation of cations like $Ca^{2+}$ and $Mg^{2+}$ which are mainly responsible for the fixation of P in calcareous soil (Yashpal *et al.* 1993). Thus, the build-up of P was observed where 100% NPK + 5 t FYM and 150% NPK alone was applied continuously to the sequence. This emphasizes the need for rethinking in recommending the regular application of P to every crop. Hence, suitable management strategies need to be tested to skip P application. This findings is also substantiated with decreasing crop response to the application of P over a period of cropping in above treatments. The data on balance sheet of P shown in table 2 also support these observations.

*Available K*

Although K is not a constituent of plant but required in large quantity almost equal to N. The available K status was higher in all the treatments than the control (Fig. 3d) and significantly increased with the application of 100% NPK + FYM @ 5 t $ha^{-1}$ (473 kg $ha^{-1}$) and 150% NPK (453 kg $ha^{-1}$). The omission of K in crop nutrition (control, 100% N and 100% NP) led to higher mining of its native reserve. There is a clear evidence of K mining after 25 years in all the treatments than the initial status of 358 kg $ha^{-1}$, except that of 150% NPK, 100% NPK along with FYM and 100% NPK alone. The uptake of K was more than the amount of K added, the slight increase in $NH_4OAc$-K in K treated plots may be due to shift in the equilibrium from non-exchangeable form to exchangeable-N and solution forms. The depletion of K was higher under NP or N treatments. Apparent balance of K indicated that the soils are mined for K heavily because of its higher uptake by both sorghum and wheat crops grown in sequence. This signifies the importance of inclusion of K in the fertilizer recommendations for different crops in order to avoid exploitation of native lattice K in such swell-shrink soils. The increase in the status of available K with the combined use of organics and inorganic fertilizers as compared to even optimal or super optimal dose of NPK may be due to the addition of organic materials which supply nutrients to the soil (Verma and Ram 1994). Also higher amount of available K in the FYM treated plots may be due to the fact that FYM addition could increase the CEC of soil, which is responsible for holding more amount of exchangeable K and helped in the release of exchangeable K from non-exchangeable pool (Kher and Minhas 1991). This may also ascribed to the reduction in the K-fixation and release of K from non-exchange site of the reserves held in the clay interlayer's or due to the interaction of organic matter with clay besides the direct addition of K to available pool of the soil. The higher status of available K in 150% NPK over rest of the treatments may be due to higher application rate (Sood *et al.* 2008). In view of the mining of native soil K and decline in available K in the sequence, it can be concluded that present K recommendations are not sufficient and needs to be revised. In order to avoid decline in native K fertility, it is essential to monitor the K status in the soil, otherwise an abrupt decline in production could be encountered in the near future.

*Available S*

The available S varied from 8.63 to 32.50 mg $kg^{-1}$ (Fig. 3e). The various fertilizer treatments significantly increased the S status of soil. The initial status of available S was 11.8 mg $kg^{-1}$, which was increased with time due to various fertilizer treatments excepts control and 100% NPK treatment where DAP was used as a source of P. This increase in available S was due to use of single superphosphate (SSP) as a source of P, which contains appreciable amount of S. The improvement in the status of available S with the application of NPK (where SSP was used) + 5 t FYM is obvious apparently due to the supply of S through chemical fertilizers and organic sources. Similar results were reported by the Ravankar *et al.* (2005). Continuous cropping with 100% NPK (-S) resulted in drastic reduction in available S (10.86 mg S $kg^{-1}$) which may be attributed to continuous use of diammonium phosphate (DAP) as P source which resulted in S deficiency in 100% NPK (-S) treatment causing reduction in crop yields (Santhy *et al.* 1998).

*Available Zn*

The available Zn varied from 0.34 to 0.96 mg $kg^{-1}$ (Fig. 3f) and improved with the application of 100% NPK + FYM @ 5 t $ha^{-1}$ (0.96 mg $kg^{-1}$) followed by 100% NPK + Zn @ 2.5 kg $ha^{-1}$ (0.93 mg $kg^{-1}$). Continuous cropping with 100% NPK + Zn resulted in the build-up of DTPA-Zn which is obvious, however, the increase in available Zn status with the application of NPK + 5 t FYM and FYM alone may be due to mineralization of organically bound forms of Zn with organics. Zinc is known to form relatively stable chelates with organic legands which decrease their susceptibility to adsorption, fixation and precipitation (Subehia *et al.* 2011). Amount of nutrients added, reaction time in soil, rate of extraction by roots, nature and amount of clay minerals, organic matter content are the governing factors affecting the transformation of Zn in soils (Jat *et al.* 2014). The deficiency of micronutrients in general and that of Zn in particular is emerging in swell-shrink soil due to intensive agriculture, use of high analysis NPK fertilizers and lack of addition of organic manures. In the present experiment, under intensive sorghum-wheat sequence, it has been well established that

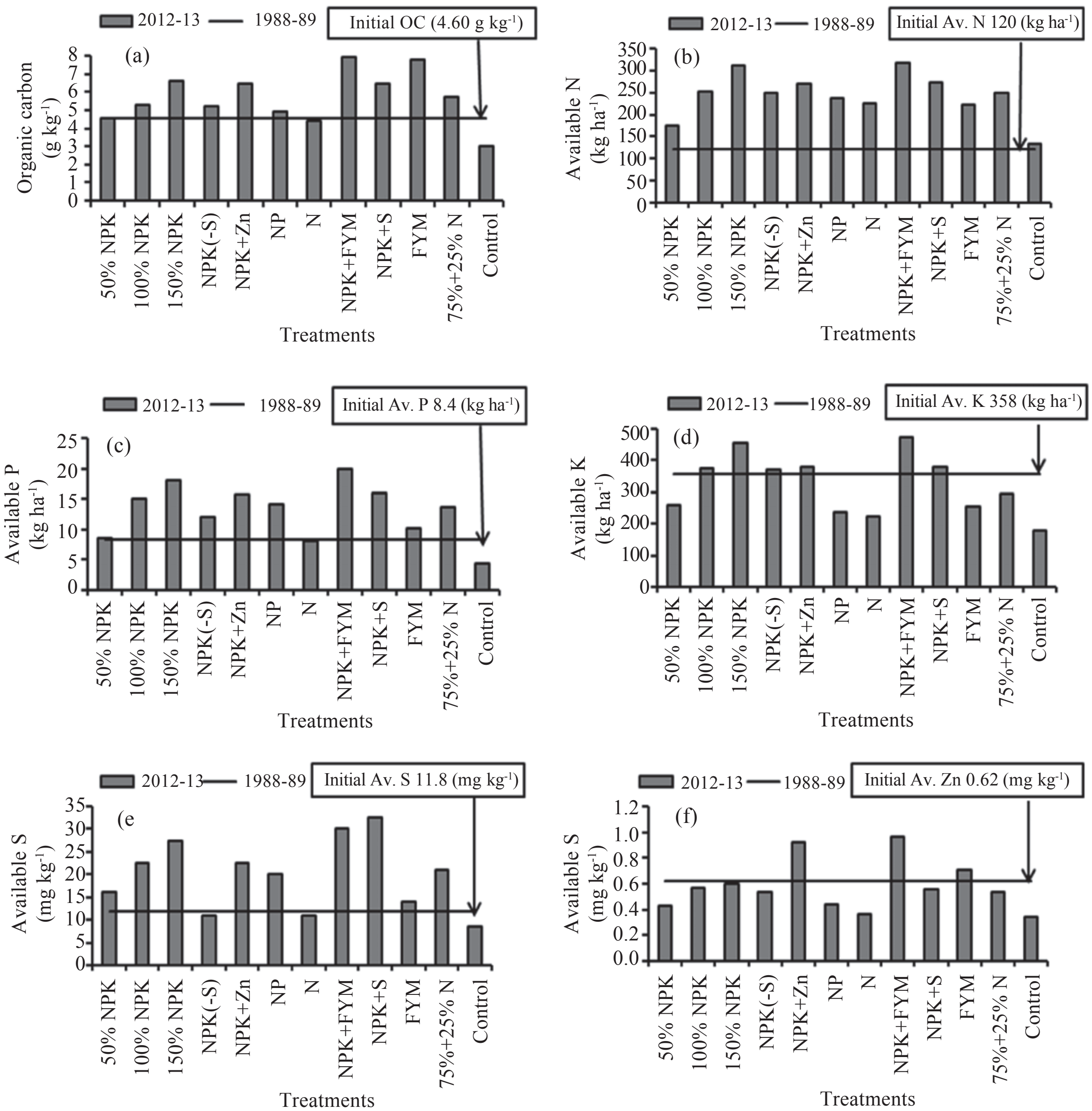


**Fig. 3.** Change in soil fertility under sorghum-wheat sequence

application of higher quantity of major nutrient fertilizers (100% NPK and 150% NPK) could not maintain the level of available Zn.

*Apparent nutrient balance*

In order to calculate the nutrient balance, it is essential to assess the amount of nutrients needed to attain the desired level of production without depleting the native reserves predominantly to ensure maintenance of soil fertility.

A total of 5160 kg N has been added through chemical fertilizers as recommended levels of N to the sequence (Table 2 and 3). The removal of 5121 kg N $ha^{-1}$ was maximum with the use of 100% NPK + 5 t FYM and 5007 kg N $ha^{-1}$ with the use of 150% NPK, which might be the effect of FYM in adsorbing $NH_4^+$ ions on fertilizer application and the combination also sustained the yields. The highest positive balance of 3227 kg N $ha^{-1}$ was observed in 100% N treatment and declined with integration of P, K, S, Zn and FYM. This may be ascribed to reduced N removal because of poor crop growth in the absence of P and K. There was a positive balance of N in all the treatments except control and FYM. The negative balance in control is obviously due to long absence of N in fertilizer schedule over the period of cropping.

**Table 2.** Apparent nutrient balance (kg $ha^{-1}$) under sorghum-wheat sequence

| Treatments | Nitrogen | | Phosphorus | | Potassium | |
|---|---|---|---|---|---|---|
| | Removal | Balance | Removal | Balance | Removal | Balance |
| 50% NPK | 2034 | 546 | 486 | 724 | 2879 | -1779 |
| 100% NPK | 3662 | 1498 | 917 | 1503 | 4755 | -2555 |
| 150% NPK | 5007 | 2733 | 1286 | 2344 | 6138 | -2838 |
| 100% NPK (-S) | 3223 | 1937 | 819 | 1601 | 4255 | -2055 |
| 100% NPK + Zn @ 2.5 kg $ha^{-1}$ | 3767 | 1393 | 972 | 1448 | 4960 | -2760 |
| 100% NP | 2607 | 2553 | 625 | 1795 | 3513 | -3513 |
| 100% N | 1933 | 3227 | 421 | -421 | 2604 | -2604 |
| 100% NPK + 10 t FYM $ha^{-1}$ | 5121 | 889 | 1412 | 1338 | 6415 | -3498 |
| 100% NPK + 37.5 kg S $ha^{-1}$ | 3416 | 1744 | 904 | 1516 | 4322 | -2122 |
| FYM only 10 t $ha^{-1}$ | 1333 | -133 | 322 | 68 | 1865 | -665 |
| 75% NPK | 2543 | 1402 | 655 | 1170 | 3621 | -1921 |
| Control | 614 | -614 | 164 | -164 | 824 | -824 |

**Table 3.** Uptake response and addition of nutrients under sorghum-wheat sequence

| Treatments | Nitrogen | | Phosphorus | | Potassium | |
|---|---|---|---|---|---|---|
| | Addition (kg $ha^{-1}$) | Response (%) | Addition (kg $ha^{-1}$) | Response (%) | Addition (kg $ha^{-1}$) | Response (%) |
| 50% NPK | 2580 | 78.82 | 1210 | 40.18 | 1100 | 262 |
| 100% NPK | 5160 | 70.96 | 2420 | 37.91 | 2200 | 216 |
| 150% NPK | 7740 | 64.69 | 3630 | 35.43 | 3300 | 186 |
| 100% NPK (-S) | 5160 | 62.47 | 2420 | 33.86 | 2200 | 193 |
| 100% NPK + 2.5 kg Zn $ha^{-1}$ | 5160 | 73.01 | 2420 | 40.18 | 2200 | 225 |
| 100% NP | 5160 | 50.53 | 2420 | 25.84 | 0 | - |
| 100% N | 5160 | 37.45 | 0 | | 0 | - |
| 100% NPK + 10 t FYM $ha^{-1}$ | 6010 | 85.20 | 2750 | 51.34 | 2917 | 222 |
| 100% NPK + 37.5 kg S $ha^{-1}$ | 5160 | 66.20 | 2420 | 37.34 | 2200 | 196 |
| FYM only 10 t $ha^{-1}$ | 1200 | 111.11 | 390 | 82.45 | 1200 | 155 |
| 75% NPK | 3945 | 64.45 | 1825 | 35.88 | 1700 | 213 |
| Control | 0 | - | 0 | - | 0 | - |

Out of total 2420 kg of P $ha^{-1}$ added under 100% P application rates, the removal ranged from 164 to 1412 kg P $ha^{-1}$. Further, it was observed that soils are depleted to the extent of 421 kg P $ha^{-1}$ over a period of cropping when N alone was applied continuously over a period of time. The depletion of P due to exclusion of P from fertilizer schedule might have led to the improper root development, leading to deleterious effect on crop growth and yield. Treatment combinations involving P fertilization have shown a positive balance and the magnitude of P balance was found to be dependent on the amount of P applied and utilization by crops. The highest positive balance of about 2344 kg $ha^{-1}$ was noted under 150% NPK followed by 100% NP (1795 kg $ha^{-1}$).

Unlike N and P, K removal was much higher than the added K rates through fertilizers. The maximum K removal of 6415 kg $ha^{-1}$ against the addition of 2917 kg K $ha^{-1}$ was recorded under 100% NPK + 5 t FYM. The highest negative balance of 3513 kg $ha^{-1}$ was noted with the use of 100% NP, which is ascribed to the imbalanced use of fertilizer application. Similarly, such negative balance is obviously due to larger uptake by the crops than K addition (Singh *et al*. 2014).

It may be observed that N uptake increases with P fertilization and showed further increase in presence of K (Table 3). Similarly, P uptake was also increased in the presence of K. In general, the uptake of N, P and K was lower when the rate is increased to 150%. The N, P and K uptake response was improved when 100% NPK was supplemented with 5 t FYM. Swarup and Yaduvanshi (2004) reported that magnitude of response to applied P was increased under rice-wheat system studied over a period of more than ten years.

*Sustainable Yield Index (SYI)*

The SYI of system productivity was relatively higher in 100% NPK + 5 t FYM (0.471) followed by 150% NPK (0.465, Fig. 4). Application of FYM alone

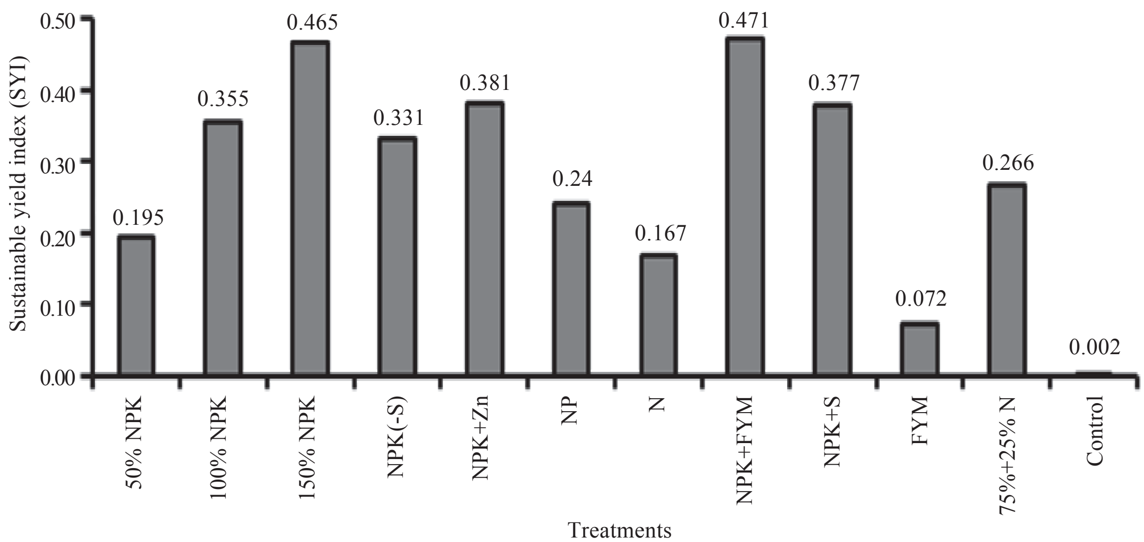


**Fig. 4.** Sustainable yield index of system productivity (sorghum+wheat) during 25th cropping cycle

recorded lower SYI of system productivity (0.072) as compared to the use of inorganic fertilizers alone or in combination with FYM. Lowest SYI *i.e.* 0.002 was noticed in control treatment which might be attributed to the fact that FYM alone could not sustain the yields of sorghum and wheat. The sustainability of the system could be achieved by integrated approach of nutrient management. Hence, application of 100% NPK + FYM @ 5 t $ha^{-1}$ could serve as an alternative for sustainable higher yield in the sorghum-wheat cropping system. Singh (2010) concluded that the increase in SYI on application of 150% NPK suggests that the amounts of nutrient applied at 100% NPK are not sufficient to realize the potential crop yields. Of course increase in SYI due to FYM application over and above NPK indicates that in addition to nutrients supply, physical and biological conditions of soils are also important components playing a key role in sustaining crop productivity.

*Relationship between crop productivity and soil organic carbon*

The relationship between crop productivity and soil OC was determined by drawing regression line with yield as dependant and OC as independent variable (Fig. 5 a,b). There exists a strong relationship between yield of sorghum and the OC (r = 0.613) than yield of wheat and OC (r = 0.465). This could be ascribed to the contribution of OC from FYM, which is mainly applied in *kharif* and relatively higher biomass addition through sorghum roots and stubbles subsequently. Increasing levels of fertilizer application has helped in increasing OC content, which is due to increased contribution from the biomass, as it is observed with increasing levels of fertilizers application also increased the crop yield. Lal (2010) reported that an optimal level of SOC stock is an essential determinant of soil quality to support relatively high crop yield and a strong relationship between agronomic production and the SOC stock,

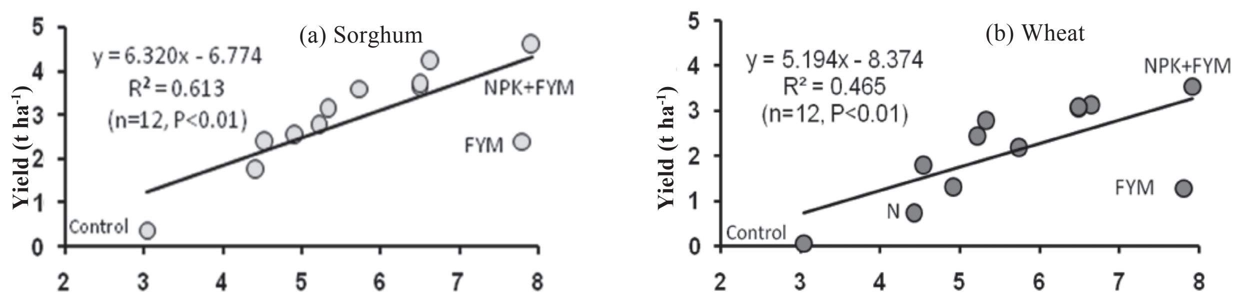


**Fig. 5.** Regression equations of crop productivity response to increase in organic carbon

especially in low-input agriculture (none or low rate of fertilizer input).

## Conclusions

On the basis of 25 years of continuous cropping of sorghum-wheat sequence on a Vertisol, it can be concluded that application of 100% NPK+ 5 t FYM $ha^{-1}$ sustained higher yield of both sorghum and wheat with improvement in soil fertility status. Balanced use of fertilizers alone or in combination with FYM maintained soil organic carbon status. The nutrient uptake increased in the presence of P, which was further improved with K fertilization. The sustainable yield index was almost similar with 100% NPK + 5 t FYM $ha^{-1}$ and 150% NPK, indicating that balanced fertilization alone or in combination with FYM is necessary for sustaining soil fertility and crop productivity.

## Acknowledgement

The authors express thanks to the Hon'ble Vice Chancellor, Dr. Panjarao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra for providing all required facilities for the study. Authors also gratefully acknowledge the financial support received from the Indian Council of Agricultural Research, New Delhi.

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Revised received 12 December 2018; Accepted 23 March 2019