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Long-term effect of FYM and inorganic fertilizers on soil quality and sustainable productivity of soybean (*Glycine max*) and safflower (*Carthamus tinctorius*) in Vertisol

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ABSTRACT

A long-term experimental study was conducted at the research farm under All India Coordinated Research Project, Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani, Maharashtra to assess the impact of continuous cultivation of soybean [*Glycine max* (L.) Merr.] and safflower (*Carthamus tinctorius* L.) in Vertisol (Typic Haplusterts) using varying levels of chemical fertilizer and manure applications on approximately 7th cycle data on soil quality indicators (physical, chemical and biological), a sustainable yield index (SYI) and a soil quality index (SQI). Application of NPK fertilizers in combination with FYM also significantly increased in benefit cost ratio, higher average grain yield of soybean and safflower and enhanced the soil quality and sustainability of the system compared to the control and plots in receipt of fertilizers. A greater SYI and SQI in the 100% NPK+FYM@ 5 Mg/ha treatment demonstrated the importance of using a chemical fertilizer in combination with FYM. Among the different nutrient management supply system, economical and more sustainable nutrient management system (NPK+FYM) could be used to monitor soil quality and getting higher productivity of soybean and safflower in a semiarid agro-ecosystem.

Key words: Safflower, Soil quality assessment, Soybean, Sustainable productivity

Widespread yield stagnation and productivity declines in the soybean [*Glycine max* (L.) Merr.]-safflower (*Carthamus tinctorius* L.) cropping system have been reported and many of the associated issues are related to soil quality. Soil quality is defined as the capacity of a soil to function, within ecosystem and land use boundaries, to sustain biological activity, maintain environmental quality, and promote plant, animal and human health. Consequently, continuous cropping without use of any fertilizer and imbalance application of fertilizer sources lead to reduced level of soil organic matter in semiarid region of central India. Unless soil management practices are improved, yield reduction continues and long-term production is difficult. The low level of chemical fertilizer use, decline in soil organic matter and insufficient studies contribute the most to the loss of soil quality. Farmyard manure and fertilizers should be maintain soil quality at a threshold level. Hence, for an efficient management optimum amount of farmyard manure (FYM) and fertilizers should be added for maintaining soil organic matter. It is necessary to maintain soil organic carbon under intensive cropping system helps to maintain soil quality (Kharche *et al.* 2013). Understanding soil quality, assessing and managing soil so that it functions optimally now and is not degraded for future use. Therefore, understanding the whole concept of soil quality including methods of assessment, delineation of key indicators and their related soil functions, transformation of indicators into a single value soil quality index etc., assumes importance (Sharma *et al.* 2011). In recent years, soil quality research has been focused on the linkage among management practices and systems, observable soil characteristics, soil processes and performance of soil functions. To do so, several physical, chemical and biological indicators of soil quality were evaluated using data collected from a long term organic manure and inorganic fertilization management experiment. Strategies for using these indicators to develop an overall soil quality index that is meaningful to crop grown under semiarid agro-ecosystem were evaluated and which is used to gauge the level of an improving or declining soil condition.

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MATERIALS AND METHODS

The field experiment was started in 2006-07 at Long-

Term Fertilizer Experiment Research Farm (76°46' E longitude and 19°16' N latitude and an elevation of 408.46 m above the mean sea level), Department of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Agricultural University, Parbhani, Maharashtra, India. The farm represented semiarid tropic region with the hot summers and mild winters and the annual maximum temperature during study areas ranged from 29.1 to 42 °C and minimum temperature ranged from 9.2°C to 27.8°C in the month of December and May in the year 2012-13. A total annual precipitation was 720.5 mm. The soil of the experimental site (Table 1) was Vertisol, particularly montmorillonitic, hyperthermic family of *Typic Haplustert*. The present experiment was framed in randomized block design (RBD) with twelve treatments and four replications in soybean-safflower cropping system. The treatment comprises, viz. T_1–50% NPK, T_2–100% NPK, T_3–150% NPK, T_4–100 % NPK+Hand weeding, T_5–100% NPK+ $ZnSO_4$@ 25 kg/ha, T_6–100% NP, T–100% N, T_8–100% NPK+FYM@ 5 Mg/ha, T_9–100% NPK-Sulphur, T_{10}–Only FYM@ 10 Mg/ha, T_{11}–Absolute control and T_{12}-Fallow. The crops soybean (cv. JS-335) and safflower (cv. PBNS-12) were raised during rainy and post rainy season respectively with recommended package of practices. Soybean and safflower crops were sown with 45 to 5 cm and 45 to 10 cm spacing between row to row and plant to plant respectively. The 100% NPK was 30:60:30 kg/ha for soybean and 60:40:00 kg/ha for safflower respectively. The fertilizers used were urea, single super phosphate (SSP) and muriate of potash. FYM was applied before 15 days of sowing only for rainy season crop and NPK applied through straight fertilizers such as urea, single super phosphate and muriate of potash as per treatments. Whereas, in T_9 treatment diammonium phosphate was used in place of SSP to avoid sulphur application. In T_4 treatment only two hand weedings were taken for weed control, without use of any weedicide. Inorganic fertilizers were applied as per recommended dose of fertilizer and micronutrients through chemical fertilizer $ZnSO_4.5H_2O$ and FYM was incorporated @ 5 Mg/ha at sowing time in rainy season only. The present investigation was carried out to study the long term effect of manure and fertilizers on soil quality parameters under this long term experiment after 7th crop cycle. A representative portion of each soil samples was collected from the 0-15 cm depth and it was air dried, powdered and passed through < 2 mm sieve for determination of physico-chemical properties. Organic carbon was determined by Walkley and Black's wet oxidation method (Jackson 1973). EC, pH, Ca, Mg, Na, N, P and K were determined by Jackson (1973). Available K was determined by using neutral normal ammonium acetate as an extractant and measured on flame photometer (Jackson 1973). Available sulphur in soil was extracted using 0.15% $CaCl_2$ as an extractant and determined spectrophotometrically using the method described by Chesnin and Yein (1950). Available micronutrients (Zn, Fe, Mn and Cu) and heavy metals (Ni and Pb) were determined using DTPA (Diethylene Triamine Penta Acetic Acid) extraction method developed by Lindsay and Narvell (1978). Available B in soil was measured by hot water soluble B method using Azomethine-H reagent (Berger and Troug 1944). Microbial populations (Bacteria,

Table 1 Physico-chemical composition of experimental soil based on composite sample (2006-07)

Particular	Unit	Status
Physical indicators		
Bulk density	Mg/m^3	3.36
Porosity	Per cent	48.22
Maximum water holding capacity	Per cent	52.18
Infiltration rate	cm/ha	1.75
Hydraulic conductivity	cm/ha	0.89
Chemical indicators		
pH		8.18
EC	d/Sm	0.243
Organic carbon	g/kg	5.50
Calcium carbonate	Per cent	6.12
Cation exchange capacity	cmol (p^+)/kg soil	54.72
Exchangeable calcium	cmol (p^+)/kg soil	32.53
Exchangeable magnesium	cmol (p^+)/kg soil	11.86
Exchangeable sodium	cmol (p^+)/kg soil	0.23
Exchangeable potassium	cmol (p^+)/kg soil	0.56
Base saturation	%	82.56
Available nitrogen	kg/ha	216
Available phosphorus	kg/ha	18.32
Available potassium	kg/ha	766.15
Available sulphur	kg/ha	30.50
DTPA-Extractable zinc	mg/kg	0.98
DTPA-Extractable ferrous	mg/kg	5.12
DTPA-Extractable manganese	mg/kg	9.74
DTPA-Extractable copper	mg/kg	2.86
Hot water soluble boron	mg/kg	0.85
DTPA- Extractable nickel	mg/kg	0.32
DTPA- Extractable lead	mg/kg	0.81
Biological indicators		
Bacteria	CFU × 10^7/g soil	156.23
Fungi	CFU × 10^4/g soil	7.69
Aactinomycetes	CFU × 10^6/g soil	41.36
Soil microbial biomass carbon	µg/g	235.71
Soil microbial biomass nitrogen	µg/g	42.53
CO_2 evolution	(mg/100g soil/24 hr)	51.18
Dehydrogenase activity	(µg TPF/g soil/24 hr)	42.51
Acid phosphatase activity	(µg p-NP/g soil/r)	65.10
Alkaline phosphatase activity	(µg p-NP/g soil/hr)	132.76

fungi and actinomycets) were determined by serial dilution plate technique as given by Dhingra and Sinclair (1993). Soil microbial biomass carbon (SMBC) and nitrogen (SMBN) were determined by using chloroform fumigation technique as described by Brookes *et al.* (1985). CO_2 evolution of soil was determined by alkali trap method as given by Anderson (1982). Phosphomonoesterases (Acid and alkaline phosphatase) activity in soil determines the enzymatic hydrolysis of p-nitrophenyl phosphate to p-nitrophenol which was extracted by $CaCl_2$–NaOH solution (Tabatabai and Bremner 1969). Dehydrogenase enzyme activity in soil (Klein *et al.* 1971) was determined by triphenyl formazan (TPF) produced by the reduction of 2,3,5-triphenyl tetrazolium chloride (TTC). In addition, bulk density of soil was determined by dry clod coating technique as described by Blake and Hartge (1986). Maximum water holding capacity (MWHC) of soil was determined by using Keen-Rocrko-Waske-Box at wet and dry basis of water content as described by Sankaram (1966). Infiltration rate and hydraulic conductivity of soil were determined by using double ring infiltrometer and constant head method as described by Michael (1987). The experimental data was subjected to analysis of variances (ANOVA) and treatment means were compared, significant differences were tested at P=0.05 using randomized block design (RBD) as given by Panse and Sukhatme (1985) using computer design MAUSTAT. To determine a soil quality index, four main steps were followed: (i) define the goal, (ii) select a minimum data set (MDS) of indicators that best represent soil function, (iii) score the MDS indicators based on their performance of soil function and (iv) integrate the indicator scores into a comparative index of soil quality. In general, soil organic carbon (or organic matter) is considered to be the universal indicator of soil quality (Rasmussen and Collins 1991). However, the ultimate outcome of good soil quality is yield or economic produce because it serves as a plant bioassay of the interacting soil characteristics. In the present study, the average yield of soybean and safflower crops individually and sustainability yield index (after 7^{th} cycle considering average and equivalent soybean and safflower grain yield) for each treatment were defined as the goals because the farmers like to get more productivity from each unit land using following equation (Sharma *et al.* 2005).

$$SYI = \frac{Y-\sigma}{Y_{max}}$$

where, Y was average yield of the treatment, σ was treatment standard deviation and Y_{max} was maximum yield in the experiment over the year.

To select a representative minimum data set (Doran and Parkin 1994) only those soil properties (34 soil indicators) that showed significant treatment differences were selected. The total weighted MDS variables scores for each observation was obtained using the following equation to determined soil quality index:

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

where, S_i is the score for the subscripted variable and W_i is the weighing factor derived from the PCA. Here the assumption is that higher index scores meant better soil quality or greater performance of soil function. Further, the percent contribution of each final key indicator was also calculated. The SQI values so obtained were tested for their level of significance at P = 0.05.

RESULTS AND DISCUSSION

Productivity of soybean and safflower

Analysis of data over a period of 2007-2013, the increased production of soybean and safflower due to the integration of FYM with inorganic fertilizers was due to the addition of nutrients from the FYM, which indicates the full rate of NPK is not enough for soybean and safflower production and additional fertilizers are required (Fig 1 and 2). Application of inorganic fertilizers (NPK) with FYM gave a better result than application of inorganic fertilizers alone. But the best result was also obtained in inorganic one when applied super optimal dose of fertilizer having 150% NPK rather than 50% NPK, 100% NP alone and N alone, respectively. Zn along with recommended dose of fertilizer, i.e. 100% NPK + $ZnSO_4$ @ 25 kg/ha consistently recorded almost same yield as with the treatments T_8 and T_3 which reflects to recommend this in Zn deficient soil. Nevertheless, application of half rate of NPK, NP alone, only N and absolute control (no fertilizer) gave significantly lower results than other applications. Similar trend was also recorded for safflower crop in sequential cropping. Moreover, residual effect of FYM in combination with NPK was also recorded significantly maximum yield than only FYM (residual). The continuous application of 100% N alone and 50% NPK showed an increase in yield over control but response exhibited declining yield with time due to imbalanced use of nutrients. The grain equivalent yield was recorded highest in integrated application receiving optimal dose of fertilizer along with organic manure (FYM), whereas that much yield was recorded with super optimal dose of fertilizer (150% NPK). The higher yield due to NPK+FYM application could be attributed to enhanced population of stimulated nitrogen fixing and phosphate solubilizing microorganisms and thus might have increased availability of nutrients in steady manner. The stimulated soil microbes are valuable not because they supply nutrients but also they enhance the synchrony of plant nutrients demand with soil (Murthy 2011, Arbad and Syed Ismail 2011, Naik *et al.* 2012). According to pooled data of 2006-2013, the higher grain equivalent yield and benefit cost ratio under soybean-safflower system was obtained with 150 % NPK and 100% NPK + FYM @ 5 Mg/ha. Both the treatments are beneficial over rest of the treatments (Fig 3). An experiment conducted on soybean and safflower indicated that application of organic manure alone supplied some nutrients and gave higher yields than the non-fertilized ones although it was not sufficient to support a high yield.

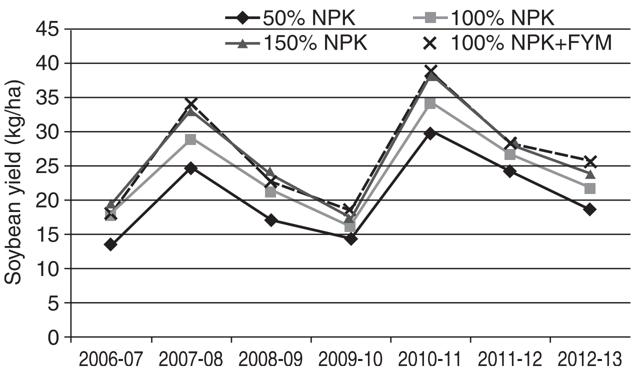

Fig 1 Productivity trend of soybean under long-term experiment

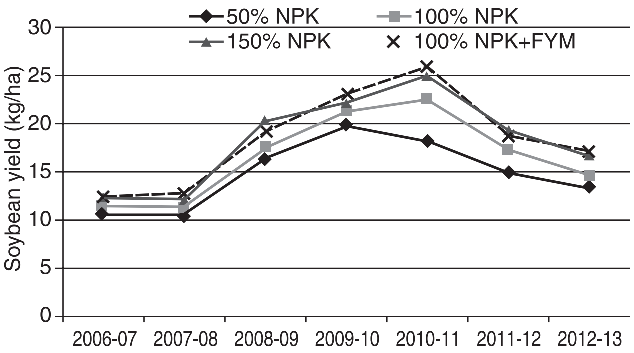

Fig 2 Productivity trend of safflower under long-term experiment

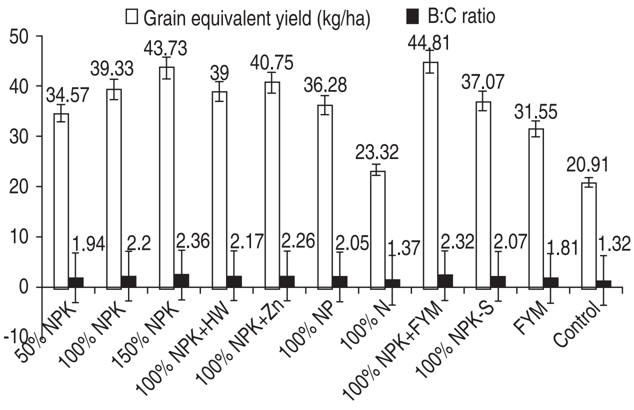

Fig 3 Economical measurement under long-term experiment.

Sustainability Yield Index and Soil Quality Index

Sustainability yield index (SYI) for soybean-safflower cropping system (Fig 4), with the conjunctive use of organic manures with chemical fertilizers for the substitution of 100% NPK recorded significantly more SYI (0.80) as compared to chemical fertilizers treatments T_3 and T_5, i.e.150% NPK and 100% NPK + $ZnSO_4$@ 25 kg/ha. The SYI was considerably reduced with use of chemical fertilizers devoid of organics. Although the SYI values showed comparable figures at 100% dose of only chemical fertilizers the soil quality attributes showed fairly good improvement under conjunctive use of inorganic with organics. This indicates necessity of regular addition of organics in order to sustain crop productivity of legume-oilseed cropping system without declining the soil quality further. This has been further evidenced in the soil quality index which indicates that due consideration to soil sustainability is necessary while selecting options of management rather than only consideration of yield (Billore and Joshi 2005, Sharma *et al.* 2005). Kang *et al.* (2005) additional application of FYM@ 10 t/ha before sowing of corn made the system more sustainable than application of 100% NPK under corn-wheat cropping system in *Typic Ustochrept*. The drastic reduction in yield of both the crops was noted under control plot, which lack addition of organics and balanced use of fertilizers which were also reflected in deterioration of sustainability yield index (SYI) and soil quality index (SQI), which is also evident from the data on physical, chemical and biological properties of soil which could not sustain the yields of soybean and safflower. Organic manure directly added an appreciable amount of major and micronutrients to soil which could contribute to the enhanced yield. In addition to this the improved physical properties provided a desirable soil condition for the root development, enhanced nutrient uptake, crop growth and yield. This increase in crop production due to integration of organic and inorganic nutrient sources resulted into enhancement in SQI and SYI which may be ascribed to the combined effect of nutrient supply, synergism and improvement in soil physical and biological properties. In contrast to SQI are simple values that indicate the alteration of soil characteristics under different management systems and the changing trends of soil properties. According to Karlen *et al.* (2001) SQI scores are relative and not absolute. They also emphasized the better accuracy of indices developed for specific soil quality assessment projects as these rely on analytical laboratory data. Our results showed that, after seven years residual effect on soil quality index for soybean-safflower cropping system, there were 34 soil attributes were analyzed for the determination of soil quality index. Out of these 34 attributes 23 soil attributes contributed high indicator scoring of the MDS indicators based on their performance of soil functions for soil quality index. All of these soil quality indicators were tested significantly at the level ($p < 0.05$) as considered for determination of soil quality index. The highest value of soil quality index was observed with the integrated use of NPK and FYM (0.72) and showed improvement with the applications of super optimal dose of fertilizer (150% NPK) (0.69) and micronutrient (Zn) incorporated with recommended dose of fertilizer (0.65). The super optimal dose of fertilizer (150% NPK) was significantly superior due to higher amount of root residue added in soil which contributed higher organic carbon. However, the soil quality index value was low (0.52) under T_{11} due to continuous nutrient removal by crop resulted declining soil quality (Fig 4). Moreover, the application of 100% N alone and 50% NPK could not show a prominent result on soil quality, suggesting less aggregative effect of these treatments. Therefore, these would be low priorities for remediation. On the other hand a high score means a high potential and a low score means a low potential or concern for negative impact (Mohanty *et al.* 2007, Sharma *et al.* 2008). Masto

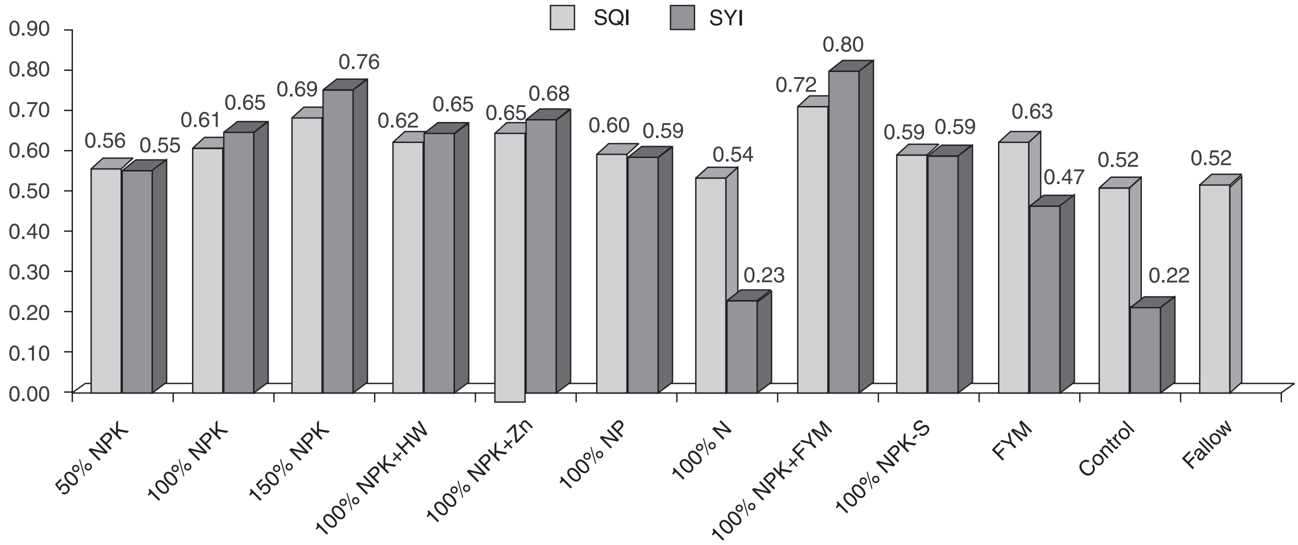

Fig 4 Soil quality index (SQI) and sustainability yield index (SYI) under long-term experiment.

et al. (2007) stated that the highest soil quality index was observed with the combined NPK fertilizer plus organic manure treatments. The soil quality index mainly depends on setting the appropriate critical limits for individual soil properties. They fixed the thresholds for each soil quality indicator based on the range of values measured in natural ecosystems or in best managed systems and on critical values available in the literature. After finalizing the thresholds, they transformed the soil property values recorded into unitless scores between (0 and 1). Kharche *et al*. (2013) identified the management inputs used in the present study such as use of organics which strongly influenced dynamic soil properties and were found beneficial for building or restoring soil quality. The decline in soil quality in Vertisol under the long term experimentation revealed the causes of soil quality degradation especially in reduction of SOC and depletion of available nutrient status was due to lack of organic matter addition in soil which was observed in chemical fertilizer treatments.

Conclusions

It can be concluded that the application of 100% NPK + FYM@ 5 Mg/ha (T_8) was found to be beneficial in respect to build up of soil fertility, higher productivity, sustainability, soil quality and economically feasible for soybean-safflower cropping sequence grown in Vertisol. Enhancing organic matter in soils of semi-arid zones in the central India is indomitable task. However, regular additions of organics without hastening their decomposition process can provide some relief. Best management practices such as application of organic manures (FYM) along with NPK and inclusion of legumes-oilseed in crop rotation can be taken up as inbuilt components of integrated nutrient management (INM) system. This suggests its importance as a resource that could be used to maintaining soil fertility and sustainability over a long period. Due to its easy availability in the region and its multiple benefits, farmyard manure is likely to remain one of the key resources for managing soil fertility in Vertisol. Among the various treatments, treatment (T_3) receiving 150% NPK was found closely at par with treatment (T_8) reflects superiority in case of only inorganic applications. This nutrient supply system can be regarded as better management option when applying only inorganic fertilizers. A sound nutrient management system should strive to make a balance between maximizing crop production and sustaining soil quality.

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