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# Sustaining soil health and cotton productivity with tillage and integrated nutrient management in Vertisols of Central India

**B.A. Sonune*, V.K. Kharche, V.V. Gabhane, S.D. Jadhao, D.V. Mali, R.N. Katkar, P.R. Kadu, N.M. Konde, D.P. Deshmukh and H.B. Goramnagar**

*Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola – 444 104, Maharashtra.*

*Corresponding author:
*E-mail: basonune@gmail.com (B.A. Sonune)*

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**ABSTRACT**

In order to assess soil health and cotton productivity as a means of tillage and integrated nutrient management (INM) practices, the experiment was conducted at Department of Soil Science and Agricultural Chemistry, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra) during 2010−11 to 2015−16 in split plot design with two sets of main plots namely, minimum and conventional tillage replicated thrice. The treatments (8 sub−plots) comprised of 100% recommended dose of fertilizer (RDF), 50% RDF + *in−situ* green manuring with sunhemp, 50% N through FYM + RDF compensation through chemical fertilizers, 50% N through wheat straw (WS) + RDF compensation through chemical fertilizers, 50% N through *gliricidia* green leaf manuring (GLM) + RDF compensation through chemical fertilizers, 25% N through FYM + 25% N through WS + remaining recommended dose (RD) through chemical fertilizers, 25% N through FYM + 25% N through GLM + remaining RD through chemical fertilizers and 25% N through WS + 25% N through GLM + remaining RD through chemical fertilizers. The minimum tillage included one harrowing and two hand weedings, while conventional tillage included one ploughing, one harrowing, two hoeing and two hand weedings. The results of the present study indicated that, minimum tillage practice found promising for obtaining higher seed cotton (1.25 t $ha^{-1}$) and cotton stalk (2.92 t $ha^{-1}$) yield over conventional tillage. Among various resource management practices, the application of 50% N through FYM + RDF compensation through chemical fertilizers significantly ($p$<0.05) increased the seed cotton (1.35 t $ha^{-1}$) and cotton stalk (3.18 t $ha^{-1}$) yield. The sustainable yield index (0.71) and soil quality index (SQI) (2.29) was higher with combined use of manures and fertilizers than 100% RDF. The adoption of minimum tillage improved hydraulic conductivity (0.72 cm $hr^{-1}$), mean weight diameter (0.70 mm), organic carbon (OC) (5.86 g $kg^{-1}$), available N status (225 kg $ha^{-1}$), soil microbial biomass nitrogen (SMBN) (43.77 mg $kg^{-1}$), SMBC (248 mg $kg^{-1}$) and dehydrogenase activity (DHA) (50.83 μg $g^{-1}$ 24 $hr^{-1}$). The improvement in soil physical [bulk density (BD), hydraulic conductivity and mean weight diameter], chemical [pH, electrical conductivity (EC), OC], soil fertility status [available N, P and K] and biological properties (SMBC, SMBN and DHA) was noticed in 50% N through FYM + RDF compensation through chemical fertilizers, the same treatment was exhibited in obtaining higher SOC stock (16.13 Mg $ha^{-1}$). There exists a significant relationship among soil organic carbon (SOC) stock ($R^2 = 0.637^{**}$) and SQI ($R^2$ = 0.915**) with SYI. Thus, it can concluded that, adoption of minimum tillage practice in conjunction with resource management practices (50% N through FYM + RDF compensation through chemical fertilizers) helps in sustaining cotton productivity and soil quality. Adoption of minimum tillage with 50% N through *gliricidia* GLM and compensation of RDF through chemical fertilizers helps in getting higher net returns and B:C ratio.

## 1. INTRODUCTION

Cotton is one of the important cash crops and plays vital role in the economy of the farmer as well as country. Vidarbha region of Maharashtra is a major cotton and cotton−based cropping system growing region in central India where it is grown predominantly as rainfed crop on medium to deep Vertisols (Mandal *et al.,* 2005). The major production constraints of Vertisols are poor physical properties like high bulk density (BD) (1.29−1.52 Mg $m^{-3}$), low hydraulic conductivity (0.41−0.75 cm $h^{-1}$), formation of wide and deep cracks and narrow range of moisture for field operation (Murthy, 1988). The low content of SOC in Vertisols in addition to low availability of N, P and Zn resulted in unsustainable productivity of cotton and cotton–based cropping system and thereby deteriorating soil health (Blaise, 2011). The soil biological properties are sensitive indicators of soil to evaluate the land configuration and other agricultural management practices. The greater (quantify) amount of crop residue remaining with conservation tillage can provide available substrate for maintenance of larger soil microbial biomass pool and higher C and N mineralization (Pawar *et al.,* 2019).

The systematic study of soil physical, chemical and biological properties of soil under different resource conservation practices and integrated nutrient management (INM) system is necessary to create an evidence for evaluating the impact of these management measures on soil quality (Sharma *et al.,* 2014). For enhancement in soil quality, restoration of SOC is of paramount importance and therefore it becomes necessary to identify the management practices causing preservation of SOC in soil. In view of significant role of SOC in evaluating soil quality, it is essential to utilize all available organic resources like involving use of balanced fertilization, conservation tillage practices, crop residue management, use of organic manures and various soil conservation practices for sustainable cotton production as well as maintenance of soil health and soil quality. The organic matter built up in semi–arid region is not feasible (Mali *et al.,* 2015) but its maintenance at a desirable level is essential. Use of these technologies alleviates soil health by changing rhizosphere environment.

Conservation tillage allows crop residues as surface mulch, is effective in conserving soil and water and maintains good soil structure, organic matter contents and maintains desirably high and economic level of productivity (Sharma *et al.,* 2008). Development of technologies that conserve soil, protect environment and provide adequate profit to farmers is needed to ensure food security (Choudhary and Behera, 2019).

Now a days, the fertilizer requirements are increasing due to adoption of new high yielding hybrids in intensive cultivation. Therefore, to maintain crop productivity, the use of chemical fertilizers in balanced quantity is important (Singh and Ahlawat, 2011; Singh *et al.,* 2013). But looking into the continuous increasing prices of fertilizers, it becomes necessary to minimize the expenses on fertilizers by using alternative sources like farmyard manure, crop residues, green manuring along with reduced tillage practices for sustaining the crop yields and soil fertility. These practices not only increase the crop yield but also improve the physical, chemical and biological properties of soil. However, the farmyard manure has become unavailable day by day due to shortage of animals. Therefore, farmers are applying FYM once in two or three years. Thus, due to meager availability of FYM the trend is changed and farmers are using only chemical fertilizers as a result soil health is deteriorated. Utilization of organic residues / locally available resources holds considerable promise for innovation in nutrient recycling and found one of the best alternative to FYM.

There has been very scare database on the long−term experimentation of intensity of tillage practices alongwith utilization of various locally available organic resources for nutrient management as a alternative to FYM at fixed site on Vertisols. This will be the database of first of its kind to identify appropriate tillage management options in black soils under dryland areas. However, such information is limited on rainfed cotton on Vertisol under semi−arid climatic conditions of Maharashtra and elsewhere in the world. Therefore, the present study was carried out to assess the effect the integrated plant nutrient strategies through green leaf manuring (GLM), crop residues, FYM and chemical fertilizers on soil health and cotton productivity under resource conservation practices on Vertisol in Vidrabha region of Maharashtra.

## 2. MATERIALS AND METHODS

The experiment was conducted at Research Farm, Department of Soil Science and Agricultural Chemistry, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra during 2010−11 to 2015−16, in split plot design with two sets of conditions (main−plots) namely, minimum and conventional tillage replicated thrice. The eight treatments (sub−plots) consists of 100% recommended dose of fertilizer (RDF) ($T_1$), 50% RDF + *in−situ* green manuirng with sunhemp (*Crotalaria juncea* L.) ($T_2$), 50% N through FYM + RDF compensation through chemical fertilizers ($T_3$), 50% N through WS + RDF compensation through chemical fertilizers ($T_4$), 50% N through *gliricidia* GLM + RDF compensation through chemical fertilizers ($T_5$), 25% N through FYM + 25% N through WS + remaining recommended dose (RD) through chemical fertilizers ($T_6$), 25% N through FYM + 25% N through GLM + remaining RD through chemical fertilizers ($T_7$) and 25% N through WS + 25% N through GLM + remaining RD through chemical fertilizers ($T_8$).

The minimum tillage included one harrowing and two hand weeding, while conventional tillage included one ploughing, one harrowing, two hoeing and 2 hand weeding. The farmyard manure was applied 15 days before sowing. Sunhemp was sown @ 25 kg $ha^{-1}$ in between two rows of cotton and buried (with mechanical mean) 40 days after sowing (DAS) (6.75 t $ha^{-1}$ on green weight basis). The RDF (50: 25:00 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$) was applied to rainfed cotton (rainfed Bt cotton). Full quantity of the phosphorus was applied as a basal dose through single super phosphate. Nitrogen was applied through urea in two split applications, half at the time of sowing and half at 30 DAS to cotton. The soil of experimental site was deep, clayey black soil taxonomically classified as fine, smectite, calcareous, hyperthermic family of *Typic Haplusterts*, moderately alkaline in reaction (pH 8.1), low in available N (212.5 kg $ha^{-1}$) and P (14.34 kg $ha^{-1}$) and high in available potassium (335.8 kg $ha^{-1}$).

Soil samples were collected at harvest of cotton, air dried, ground to pass through <2 mm sieve for all soil chemical properties except OC (<0.5 mm sieve) and analysed for various soil properties. The pH (1:2.5) and electrical conductivity (EC) (1:2.5) of soils were measured using standard procedures as described by Jackson (1967). OC was determined using the Walkley–Black method (Nelson and Sommer, 1982). The available N in soil was determined by modified alkaline potassium permanganate method as described by Subbiah and Asija (1956). Available phosphorus (Olsen P) was measured using sodium bicarbonate ($NaHCO_3$) as an extractant (Watanabe and Olsen, 1965). Soil available K was extracted by shaking with neutral normal ammonium acetate for 5 min (Hanway and Heidel, 1952) and potassium in the extract was estimated by flame photometer. Soil physical properties, *viz.,* BD, hydraulic conductivity and mean weight diameter were determined as per the standard procedure given by Blake and Hartge (1986), Klute and Dirksen (1986) and Kemper and Rosenau (1986), respectively.

In order to assess the biological properties, soil samples were collected during flowering stage of cotton. Microbial biomass carbon was determined by chloroform fumigation extraction method as described by Jenkinson and Powlson (1976) and SMBN was determined by modified direct extraction method (Jenkinson and Ladd, 1981). Soil dehydrogenase assay was estimated by incubation with triphenyl tetrazolium chloride (TTC) and calcium carbonate method (Casida *et al.,* 1964).

For calculating the sustainability yield index (SYI) (Sharma *et al.,* 2005) the following equation was used:

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

Where, $\check{Y}$ = Average yield of the treatment; σ = Treatment standard deviation; $Y_{max}$ = Maximum yield in the experiment over the years.

Soil quality index (SQI) was determined by linear scoring method from principal component analysis of variables described by Doran and Parkin (1994).

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

Where, S = Score for the subscript variable; W = Weighing factor derived from PCA.

The data generated was subjected to statistical analysis. The data was tested for their level of significance at $p < 0.05$ as per Panse and Sukhatme (1971).

**Two way ANOVA Table**

| Source of variation | DF | Sum of squares | Mean squares | F |
|---|---|---|---|---|
| Main Plots | | | | |
| A | k−1 | SSA | $MSA = \frac{SSA}{k-1}$ | $FA = \frac{MSA}{MSE}$ |
| B | l−1 | SSB | $MSB = \frac{SSB}{l-1}$ | $FB = \frac{MSB}{MSE}$ |
| Interaction AB | (k−1) (l−1) | SSAB | $MSAB = \frac{SSAB}{(k-1)(l-1)}$ | $FAB = \frac{MSAB}{MSE}$ |
| Error | k (m−1) | SSE | $MSE = \frac{SSE}{kl(m-1)}$ | |
| Total | klm−1 | SSTo | | |

## 3. RESULTS AND DISCUSSION

### Seed Cotton and Stalk Yield

The data in respect of seed cotton yield as influenced by tillage was found to be non–significant during 2010–11, 2013–14 and 2015–16. The significant response of seed cotton yield to tillage was observed during 2011–12, 2012–13 and in pooled mean (Table 1). The pooled mean of seed cotton yield and stalk yield indicated that, significantly higher yield was recorded in minimum tillage as compared to conventional tillage. The increase in the seed cotton and stalk yield was recorded to the extent of 6.48% and 10.97% higher as compared to conventional tillage. This is attributed to the fact that, minimum tillage helps in conserving soil moisture due to less disturbance to soil. Better performance of winter sorghum was observed in conservation tillage compared to reduced tillage due to better soil moisture in soil profile under conventional tillage conditions by Patil, 2013. Blaise and Ravindran (2003) also observed significantly higher yields of seed cotton over conventional tillage in a five year study. Significant enhancement in seed cotton yield under minimum tillage on irrigated Vertisols in Australia were also reported by Hulugalle *et al.* (1997).

The effect of nutrient management on seed cotton and stalk yield was significant during 2010–11 to 2015–16 and pooled mean. In the initial year of experimentation, the application of RDF significantly increased seed cotton (1.37 t $ha^{-1}$) and stalk yield (3.51 t $ha^{-1}$), however with years of experimentation, the application of 50% N through FYM

**Table: 1**
**Effect of various tillage and nutrient management practices on seed cotton and stalk yield**

| Treatments | Yield (q ha−1) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Seed Cotton | | | | | | Cotton Stalk | | | | | |
| (a) Tillage | 2010−11 | 2011−12 | 2012−13 | 2013−14 | 2015−16 | Pooled Mean | 2010−11 | 2011−12 | 2012−13 | 2013−14 | 2015−16 | Pooled Mean |
| Minimum tillage | 12.13 | 14.31 | 15.10 | 10.80 | 10.12 | 12.49 | 28.82 | 33.16 | 36.72 | 25.51 | 21.90 | 29.22 |
| Conventional tillage | 11.77 | 12.34 | 13.20 | 11.59 | 9.76 | 11.73 | 28.27 | 27.81 | 29.48 | 25.84 | 20.24 | 26.33 |
| SE (m) ± | 0.28 | 0.21 | 0.32 | 0.30 | 0.18 | 0.13 | 0.31 | 0.45 | 0.62 | 0.66 | 0.55 | 0.22 |
| CD at 5% | NS | 0.61 | 0.92 | NS | NS | 0.39 | NS | 1.30 | 1.79 | NS | 1.59 | 0.65 |
| (b) Nutrient management | | | | | | | | | | | | |
| T1−100% RDF | 13.72 | 11.77 | 11.93 | 9.84 | 8.69 | 11.19 | 35.13 | 27.28 | 27.59 | 22.91 | 16.84 | 25.95 |
| T2−50% RDF + *in−situ* GM | 12.63 | 12.09 | 12.69 | 11.15 | 9.86 | 11.68 | 31.25 | 28.83 | 31.14 | 25.35 | 20.64 | 27.44 |
| T3−50% N through FYM | 13.20 | 14.93 | 15.58 | 12.84 | 11.15 | 13.54 | 31.06 | 34.44 | 37.56 | 30.69 | 25.22 | 31.79 |
| T4−50% N through WS | 11.35 | 13.06 | 14.05 | 10.54 | 10.46 | 11.89 | 27.04 | 29.37 | 32.78 | 22.21 | 22.23 | 26.73 |
| T5−50% N through GLM | 12.10 | 13.82 | 15.15 | 12.54 | 11.10 | 12.94 | 27.44 | 31.16 | 34.77 | 27.37 | 22.41 | 28.63 |
| T6−25% N through FYM + 25% N through WS | 10.05 | 13.74 | 14.84 | 11.38 | 9.68 | 11.94 | 24.31 | 30.72 | 34.51 | 26.63 | 20.91 | 27.42 |
| T7−25% N through FYM + 25% N through GLM | 11.22 | 13.65 | 14.36 | 10.93 | 9.58 | 11.95 | 26.14 | 30.96 | 31.92 | 25.19 | 21.96 | 27.23 |
| T8−25% N through WS + 25% N through GLM | 11.34 | 13.55 | 14.58 | 10.32 | 8.99 | 11.76 | 26.00 | 31.11 | 34.52 | 25.10 | 18.38 | 27.02 |
| SE (m) ± | 0.55 | 0.43 | 0.63 | 0.61 | 0.36 | 0.27 | 0.61 | 0.90 | 1.24 | 1.31 | 1.10 | 0.44 |
| CD at 5% | 1.60 | 1.23 | 1.83 | 1.75 | 1.03 | 0.78 | 1.76 | 2.60 | 3.58 | 3.79 | 3.18 | 1.28 |
| (c) Interaction effect | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: In $T_3$ to $T_8$, remaining recommended dose of fertilizer was compensated through chemical fertilizers,* **,** *in $T_2$ in−situ green manuring was done through sunhemp*

+ remaining RD through chemical fertilizers were found promising in obtaining higher seed cotton (1.35 t $ha^{-1}$) and stalk yield (3.18 t $ha^{-1}$). The application of 50% N through GLM + remaining RD through chemical fertilizers also found equally beneficial for obtaining higher seed cotton and stalk yield. The higher yield in subsequent year under these treatments attributed to the improvement in soil physical conditions due to organic inputs like FYM and GLM which helps in steady supply of all nutrients including the micro–nutrients.

This clearly indicated that the balanced nutrition through only chemical fertilizers did not sustain the cotton yield on long run compared with conjunctive use of organic and inorganic fertilizers. Similar significant increase in seed cotton yield due to application of 100 kg N (RD of N to cotton) only through mineral fertilizers during first year of experimentation was also recorded by Blaise (2011) and Singh and Ahlawat, 2011. Choudhary *et al.* (2018) also reported that balanced use of inorganic fertilizer initially produced higher grain yield of wheat compared to INM treatments, but subsequently with the passage of time, INM showed higher yield over inorganic fertilizer treatment. The interaction effect of tillage and nutrient management on seed cotton and stalk yield was non–significant.

**Sustainable Yield Index**

The highest SYI (0.71) was noticed with the application of 50% N through FYM and remaining RD applied through chemical fertilizers followed by 50% N through *gliricidia* GLM and remaining RD applied through chemical fertilizers indicating combined application of organic sources and chemical fertilizers is essential for sustainability in cotton yield as evidenced from higher sustainable yield index (SYI). Sharma *et al.* (2005) reported that application of *gliricidia* GLM to sorghum and castor crops resulted in higher SYI compared with other residues treatments. In our earlier studies, application of FYM @ 10 t $ha^{-1}$ alongwith 50% RDF from chemical fertilizers also increased the SYI of seed cotton on Vertisols of semi–arid tropics (Gabhane *et al.,* 2014; Gabhane *et al.,* 2017). In previous studies positive effects of substitution of N through FYM, GLM on SYI under semi–arid conditions of Central India was also reported by Mali *et al.,* 2015.

**Physical Properties**

The effect of tillage on BD of soil was found to be non–significant, however, hydraulic conductivity and mean weight diameter was influenced significantly with tillage practices (Table 2). The significant improvement in hydraulic conductivity (0.72 cm $hr^{-1}$) and mean weight diameter (0.70) was observed in minimum tillage compared to conventional tillage indicating that minimum tillage did not have any significant change in BD in Vertisols of semi–arid region even upto five years. This can be attributed to the fact that the Vertisols of semi–arid region have lower potential for SOC accumulation due to low precipitation and high temperature. Relatively no change in BD due to minimum and conventional tillage practices were also reported by Sonune *et al.* (2012) on Vertisols under semi–arid region. However, after 5 years of experimentation, significant differences were noticed in hydraulic conductivity and mean weight diameter which may have been caused by greater pores continuity, better aggregation and less tortuosity in the soil (Jabro *et al.,* 2009). Similarly, plant root growth and other biological activity in the soil created a better pore connectivity, improving the hydraulic conductivity (Garg *et al.,* 2009).

The BD was influenced significantly with different nutrient management practices. The significantly lowest BD (1.31 Mg $m^{-3}$) was observed with the application of 50% N through FYM + remaining RDF through chemical fertilizers. The management option involving conjoint use of manures and fertilizers decreased the BD of soil over balanced use of chemical fertilizer. This could be ascribed to the higher level of OC as a result of INM. Addition of organic matter through different organics increased the microbial activity of soils which helped micro aggregates to bind together to form water stable aggregates might have decreased BD of soil. The reduction in BD by improving soil aggregation and total porosity due to soil particle binding agents derived from organics were also reported by Hugar and Soraganvi (2014). The interaction effect of tillage and nutrient management practices was non–significant.

The significantly highest hydraulic conductivity (0.77 cm $hr^{-1}$) and mean weight diameter (0.73) was noticed with the application of 50% N through FYM and remaining RD applied through chemical fertilizers. The increase in hydraulic conductivity and mean weight diameter under integrated use of organic manures and inorganic fertilizer was mainly attributed due to build up in SOC, decrease in BD and improvement in aggregation. Better aggregation and increased porosity as a consequence of the addition of organic have favorable effect on hydraulic conductivity, which influences soil water dynamics has been reported by Saha *et al.* (2010) in maize–mustard cropping sequence. Similar increase in hydraulic conductivity was also reported by Bandyopadhyay *et al.* (2010). The interaction effect between tillage and nutrient management on hydraulic conductivity and mean weight diameter was non– significant.

**Soil Fertility Status and SOC Stock**

The soil pH was differed significantly due to tillage and nutrient management practices. However, a slight variation in soil pH was attributed to suppression of diffused double layer (Bhargava and Sharma, 1982) and high buffereing capacity of soil owing to high clay content and smectitic mineralogy (Sharma and Gupta, 1986).

**Table: 2**
**Effect of various tillage and nutrient management practices on soil properties after harvest of cotton (5th cycle)**

| Treatments | BD ($Mg\ m^{-3}$) | HC ($cm\ hr^{-1}$) | MWD (mm) | pH (1:2.5) | EC ($dS\ m^{-1}$) | Org. C ($g\ kg^{-1}$) | Av. N ($kg\ ha^{-1}$) | Av. P ($kg\ ha^{-1}$) | Av. K ($kg\ ha^{-1}$) | SMBC ($mg\ kg^{-1}$) | SMBN ($mg\ kg^{-1}$) | DHA ($\mu g\ g^{-1}\ 24\ hr^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) Tillage | | | | | | | | | | | | |
| Minimum tillage | 1.35 | 0.72 | 0.70 | 8.17 | 0.30 | 5.86 | 225 | 14.27 | 365 | 248 | 43.77 | 50.83 |
| Conventional tillage | 1.35 | 0.70 | 0.66 | 8.11 | 0.29 | 5.74 | 217 | 14.19 | 357 | 238 | 38.46 | 44.65 |
| SE (m) ± | 0.01 | 0.006 | 0.007 | 0.014 | 0.01 | 0.04 | 2.42 | 0.23 | 3.55 | 3.07 | 1.12 | 2.09 |
| CD at 5% | NS | 0.017 | 0.021 | 0.041 | NS | 0.11 | 6.98 | NS | NS | 8.86 | 3.23 | 6.04 |
| (b) Nutrient management | | | | | | | | | | | | |
| T1−100% RDF | 1.37 | 0.65 | 0.64 | 8.19 | 0.30 | 5.53 | 206 | 13.07 | 323 | 219 | 26.88 | 38.37 |
| T2−50% RDF + in situ GM | 1.36 | 0.69 | 0.69 | 8.12 | 0.27 | 5.93 | 223 | 14.03 | 347 | 235 | 40.67 | 44.86 |
| T3−50% N through FYM | 1.31 | 0.77 | 0.73 | 8.04 | 0.27 | 6.17 | 236 | 15.50 | 391 | 264 | 51.00 | 63.94 |
| T4−50% N through WS | 1.36 | 0.74 | 0.68 | 8.17 | 0.28 | 5.84 | 220 | 14.99 | 367 | 239 | 42.02 | 47.69 |
| T5−50% N through GLM | 1.34 | 0.74 | 0.70 | 8.12 | 0.31 | 5.95 | 230 | 14.45 | 381 | 247 | 45.18 | 51.95 |
| T6−25% N through FYM + 25% N through WS | 1.36 | 0.70 | 0.67 | 8.15 | 0.33 | 5.68 | 220 | 13.66 | 361 | 246 | 41.52 | 45.68 |
| T7−25% N through FYM + 25% N through GLM | 1.34 | 0.70 | 0.68 | 8.18 | 0.30 | 5.68 | 218 | 14.05 | 361 | 251 | 44.62 | 45.58 |
| T8−25% N through WS + 25% N through GLM | 1.36 | 0.69 | 0.64 | 8.15 | 0.33 | 5.63 | 214 | 14.09 | 359 | 243 | 37.00 | 43.84 |
| SE (m) ± | 0.01 | 0.01 | 0.014 | 0.03 | 0.01 | 0.08 | 4.83 | 0.46 | 7.10 | 6.1 | 2.23 | 4.18 |
| CD at 5% | 0.04 | 0.03 | 0.042 | 0.08 | 0.03 | 0.22 | 13.96 | 1.32 | 20.49 | 17.7 | 6.45 | 12.07 |
| (c) Interaction effect | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Initial Status | | | | | | | 212.5 | 14.34 | 335.8 | | | |

*Note: In $T_3$ to $T_8$, remaining recommended dose of fertilizer was compensated through chemical fertilizers, in $T_2$ in−situ green manuring was done through sunhemp*

EC was varied insignificantly among tillage practices after five years of experimentation (Table 2). The nutrient management practices significantly affect the EC of soil although the effect was inconsistent among the treatments. The application of 50% N through *gliricidia* GLM + remaining RD through chemical fertilizers recorded higher value of EC, the lowest being observed in 50% RDF + *in–situ* green manuring (sunhemp) and 50% N through FYM + remaining RD through chemical fertilizers.

A significant increase in SOC was observed in minimum tillage as compared to conventional tillage. The SOC in minimum tillage was slightly higher (2.1%) over conventional tillage. The increase in SOC in minimum tillage is attributed to a combination of addition of surface residues, reduced in rapid decomposition and utilization and less soil disturbance under conservation tillage (Hulugalle and Entwistle, 1997). The application of 50% N through FYM and remaining RD through chemical fertilizers significantly improved SOC status over rest of the treatments. Except, treatment of chemical fertilizer alone, the addition of organic matter through FYM, crop residues and green manuring helps to maintain relatively higher levels of SOC. The superiority of various organics for higher SOC status in general, FYM in particular has been reported by Sonune *et al.* (2012) and Jadhao *et al.* (2019). The maximum increase in SOC due to application of FYM could mainly be attributed to direct addition of organic matter into the soil. The study demonstrate the higher proportion of SOC was observed with reduced fertilizer dose where 50% of RDF compensated with different organics indicating ability of these organics to maintain higher levels of SOC. This clearly demonstrated that use of various organics with reduced fertilizer dose was equally effective in enhancing SOC in Vertisols under rainfed conditions. In view of declining SOC in semi–arid climatic conditions application of *gliricidia* GLM initially could act as a mulching to the soil and then after decomposing acts as a good source of OC and nutrients ultimately improving soil health.

## SOC Stocks

The SOC stock is associated with the SOC status and BD. The impact of tillage practices on BD was non–significant; hence the SOC stock followed a similar trend as SOC concentration among various tillage practices. The improvement in SOC status and physical quality of soil ultimately resulted improvement in the SOC stock of soil. As a result, the application of 50% N through FYM + RDF compensation through chemical fertilizers registered higher SOC stock (16.13 Mg $ha^{-1}$) (Fig. 1). The compensation of 50% RD of chemical fertilizer through various organic resulted improvement in the SOC stock over RDF alone, however, the differences were slightly varied among these treatments. The higher SOC stock irrespective of various treatments combinations possibly due to the addition of

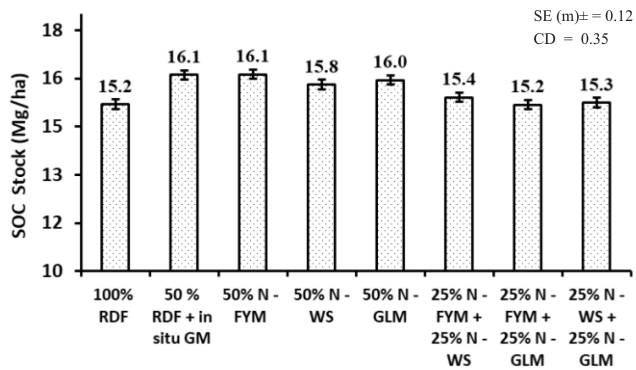


**Fig. 1. Effect of various tillage and nutrient management practices on SOC stock**

higher carbon inputs compared to RDF alone which ultimately favour SOC build–up in soil. The results are in close conformity with the earlier finding of Babu *et al.* (2016).

The available N was significantly increased in minimum tillage as compared to conventional tillage practice. The increase in available N has often been associated with soil organic matter. The higher available N was associated with the higher SOC in minimum tillage. Higher the soil organic matter, higher will be the decomposition and mineralization rate, which modify the availability of N in soils.

The highest available N (235.7 kg $ha^{-1}$) was recorded in treatment 50% N through FYM and remaining RD through chemical fertilizers followed by 50% N through *gliricidia* GLM and remaining RD through chemical fertilizers. The increase was due to addition of N through FYM, fast decomposition of *gliricidia* lopping and higher nitrogen fixation capacity by nodules of green manuring crop into the soil as compared to the other treatments. Beside this, soils under FYM, *gliricidia* lopping along with NPK fertilizer treated plots produced more plant biomass and therefore, possibly had more extensive root system that might have contributed to increased N availability in soil (Choudhary *et al.,* 2018). 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 dynamic nature of nitrogen forms in soil in the form of its losses through volatilization and leaching. In this view, the results of present study 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, which has been documented by Mali *et al.* (2015).

The available P and K did not influenced significantly due to tillage practices, since the lower concentration of P in most of the organic matter, which affect the availability of P in soil and K is not a constituent of cell wall which did not take part in the mineralization process, which ultimately affect the availability of K in soils. The highest available P (15.50 kg $ha^{-1}$) was recorded with the application of 50% N through FYM and remaining RD through chemical fertilizers followed by 50% N through WS and remaining RD through chemical fertilizers (14.99 kg $ha^{-1}$) and 50% N through *gliricidia* GLM and remaining RD through chemical fertilizers (14.45 kg $ha^{-1}$), the increase in Olsen P was reported to the extent of 18.6%, 14.7% and 10.6% higher over 100% NPK. The application FYM / *gliricidia* loppings with fertilizer P resulted in appreciable enhancement in Olsen P. This enhancement in Olsen P seems to be partly due to additional supply of P through organic manures and partly due to reduction of applied P in soil (Singh *et al.,* 2007). Moreover, organic matter decomposition produces organic acids, which help in solubilization of soil fixed P. Similar enhancement in Olsen P due to FYM and *gliricidia* lopping with reduction in fertilizer dose in Vertisol of semi–arid region was also reported by Sonune *et al.,* 2012. The effect of interaction among tillage and INM was found to be non–significant.

Significantly highest available K (391 kg $ha^{-1}$) was recorded with the application of 50% N through FYM and remaining RD through chemical fertilizers followed by50% N through *gliricidia* GLM and remaining RD through chemical fertilizers (381 kg $ha^{-1}$) this resulted 16.6% and 13.5% higher available K over initial status whereas, 21% and 17.5% higher over 100% NPK. Highest enhancement in available K in organic amalgamated treatments could be attributed to the fact that more release of non–exchangeable K from soil as FYM increased soil cation exchange capacity (Choudhary *et al.*, 2018), besides, direct addition of available K from FYM. Similarly, higher availability of K in *gliricidia* loppings was due to high K content of *gliricidia* besides its faster decomposition than other green manuring and WS. The reduction in available K under 100% NPK fertilizers could be attributed to the fact that, the rate at which K applied was insufficient to sustain soil K status in Vertisols under semi–arid conditions of Maharashtra. *Gliricidia* is a rich source of nitrogen and potassium as compared to other green manuring crops. In addition to this it was easily decomposed in soil compared to other green manuring thereby increase mineralization of nutrients in soil which was helpful to crops and to improve soil fertility. The improvement in soil fertility status as results of application of organics in combination with fertilizers were also reported by Ramachandrappa *et al.* (2017) in semi–arid Alfisols. The interaction effect between tillage and INM was found to be non–significant.

## Biological Properties of Soil

The effect of tillage on soil biological properties was found to be significant (Table 2). The significantly higher SMBC (248 mg $kg^{-1}$), SMBN (43.77 mg $kg^{-1}$) and DHA (50.83 μg $g^{-1}$ 24 $hr^{-1}$) was recorded in minimum tillage as compared to conventional tillage. The soil biological properties decreased with increased intensity of tillage associated with decrease in organic matter content in soil.

In general, substitution of 50% N through various organic sources and remaining RD through chemical fertilizers ($T_2$ to $T_8$) significantly improved SMBC, SMBN and DHA over 100% RDF through mineral fertilizers. Substitution of 50% N through FYM significantly increased SMBC (264 mg $kg^{-1}$), SMBN (51 mg $kg^{-1}$) and DHA (63.94 μg $g^{-1}$ 24 $hr^{-1}$). The improvement in SMBC, SMBN and DHA was noted where substitution of 50% N through FYM, 50% N through *gliricidia* GLM and 25% N each from FYM and *gliricidia* GLM alongwith RD compensation through chemical fertilizers indicating augmented effect of organics. It might be due to the supply of readily available and mineralizable carbon by the addition of organic matter resulted in higher microbial activity and it turns in the increase of microbial biomass carbon. This indicated that, systems with high organic matter inputs and easily available soil organic matter compounds tend to have higher microbial biomass contents and activities because they are preferred energy sources for micro–organisms. High SOC, more root proliferation and additional supply of N by various organics to micro–organisms might be responsible for increasing the level of soil biological properties (Verma and Mathur, 2009). The superiority of FYM in improvement in DHA over other organic sources was due to the more easily decomposable components of crop residues on the metabolism of soil micro–organism and due to the increase in microbial growth with addition of carbon substrate was also reported by Mali *et al.* (2014).

## Soil Quality Index (SQI)

The SQI was improved with the application of 50% N through FYM and remaining RD through chemical fertilizers (2.29) (Fig. 2). The SQI was comparatively lower in 100% RDF indicating application of RDF alone could not maintain soil quality and as a result seed cotton and cotton stalk yield

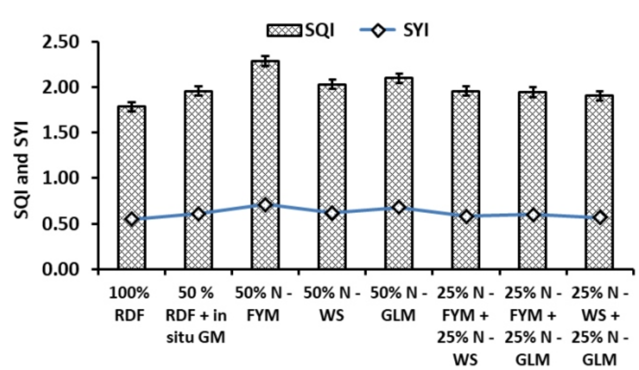


**Fig. 2. Effect of various tillage and nutrient management practices on sustainable yield index (SYI) and soil quality index (SQI)**

was drastically reduced in Vertisols. The compensation of chemical fertilizers through various organic sources *viz., gliricidia* GLM, green manuirng with sunhemp and WS were found equally effective in maintaining higher SQI. The higher SQI with the adoption of INM practice was reported by Meshram *et al.* (2020) under soybean−safflower system after 7th cycle of crops and Mali *et al.* (2015) under sorghum-wheat sequence in inceptisol.

**Relationships of SYI with SOC Stock and SQI**

The SYI was significantly and positively correlated with SOC stock as indicated by correlation coefficient among SYI and SOC stock ($R^2 = 0.637^*$) indicating higher SOC stock influenced the yield of cotton, which ultimately reflected in higher SYI. The improvement in soil properties resulted in increment in the yield of cotton, as result the, SYI was significantly and positively correlated with SQI ($R^2 = 0.92^{**}$) (Fig's 3 and 4).

**Economic Analysis**

**Net monetary returns**

The data in respect of net returns (Table 3) revealed that significantly higher net monetary returns (₹ 19105) were obtained with minimum tillage compared to conventional tillage. The significant higher net returns in minimum tillage was due to reduced cost of production mainly non−requirement of tillage operations. According to Gathala *et al.* (2011), 79−95% reduction in tillage and crop establishment cost under zero tillage than conventional tillage. However, in the present study, though the results were significant, the differences were not much higher because instead of zero tillage we have adopted minimum tillage.

The pooled results revealed that, significantly highest NMR (₹ 23656 $ha^{-1}$) was obtained with the application of 50% N through GLM + compensation of RDF through chemical fertilizers. Though the seed cotton yield was higher in FYM treatment, the cost of FYM and its application was increased the cost of production and reduced the net returns. *Gliricidia* can serve as the most potential alternative to FYM. The practice of *gliricidia* GLM is simple for adoption by the farmers and it can be very well grown on the field bunds successfully since it is quick growing crop. It produces significant amount of green biomass which can be easily used for partially substituting costly chemical fertilizers. Its application on farmers field minimizes the expenses on chemical fertilizers besides improvement in soil quality in respect of physical, chemical and biological properties of soil.

**B:C ratio**

The positive effect of tillage on seed cotton yield and reduction in production cost reflected in higher B:C ratio of cotton. The higher B:C ratio was found in minimum tillage as compared conventional tillage indicating minimum tillage

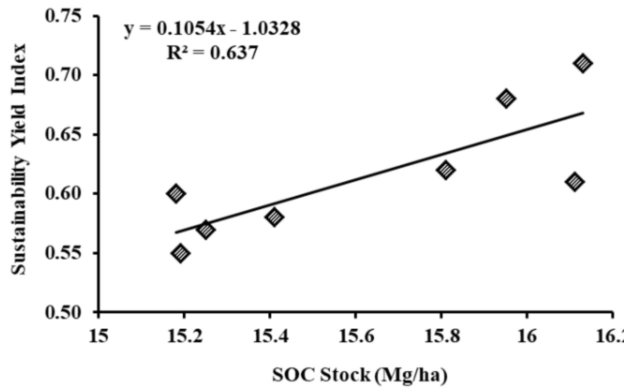


**Fig. 3. Relationships among SYI and SOC Stock ($R^2 = 0.637^*$, significant at 5% probability level)**

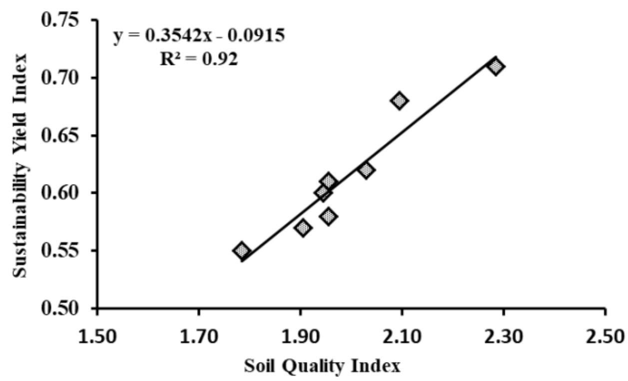


**Fig. 4. Relationships among SYI and SQI ($R^2 = 0.92^{**}$, significant at 1% probability level)**

**Table: 3**
**Net monetary returns and B:C ratio of cotton as influenced by tillage and nutrient management (pooled mean of 2010−11 to 2015−16)**

| Treatments | NMR | B:C Ratio |
|---|---|---|
| (a) Tillage | | |
| Minimum tillage | 19105 | 1.82 |
| Conventional tillage | 14185 | 1.56 |
| SE (m) ± | 393 | − |
| CD at 5% | 1152 | − |
| (b) Nutrient management | | |
| T1−100% RDF | 19429 | 2.02 |
| T2−50% RDF + *in−situ* GM | 19917 | 1.96 |
| T3−50% N through FYM | 15694 | 1.49 |
| T4−50% N through WS | 11604 | 1.38 |
| T5−50% N through GLM | 23656 | 2.09 |
| T6−25% N through FYM + 25% N through WS | 11604 | 1.37 |
| T7−25% N through FYM + 25% N through GLM | 15709 | 1.60 |
| T8−25% N through WS + 25% N through GLM | 15545 | 1.60 |
| SE (m) ± | 785 | − |
| CD at 5% | 2304 | − |
| (c) Interaction effect | NS | − |

*Note: The economic analysis was done by considering the variable production costs only; The variable costs included human labour, use of machinery, the input cost, irrigation, harvesting, threshing, loading / unloading and transport to market; The production cost did not include the value of the land; NMR = Gross returns – Total cost.*

was found beneficial economically mainly due to reduced tractor costs associated with conventional practice of tilling the soil. (Chaudhary and Behera, 2019). The highest B:C ratio (2.09) was obtained with the application of 50% N through GLM + compensation of RDF through chemical fertilizers. The profound influence of organic source of nutrients resulting in better crop growth and yield might be the reason for increasing the B:C ratio under FYM + bio−fertilizer over no organic nutrient application (Senthil and Santha, 2008).

Hence, it can be concluded that minimum tillage recorded higher seed cotton yield and monetary returns and application of 50% N through *gliricidia* GLM and compensation of RDF through chemical fertilizers found beneficial in sustaining the cotton productivity and economic returns on Vertisol besides improvement in soil properties under rainfed condition.

## 4. CONCLUSIONS

This results of the present study indicate that, continuous application of 50% N through FYM with remaining RD from mineral fertilizers sustained the cotton productivity, SYI index with improvement in soil properties. However, substitution of 50% N through *gliricidia* GLM with remaining RD from chemical fertilizers was found equally beneficial for sustaining cotton productivity, SYI, improvement in soil health in rainfed Vertisols of semi−arid climatic conditions of Maharashtra. Ultimately adoption of minimum tillage in black soils alongwith green biomass addition with reduced dose of chemical fertilizers will enhance crop productivity and soil health besides environmental benefit which should be calculated by the researchers in the future. In view of the relatively higher cost involvement in application of FYM, the application of 50% N through *gliricidia* GLM and compensation of RDF through chemical fertilizers found beneficial in sustaining the cotton productivity and ultimately economic returns in terms of NMR and B:C ratio besides improvement in soil properties under rainfed condition on Vertisols.

## REFERENCES


Babu, V.M., Nataraja, K.C., Srihari, A., Reddy, B.S., Ravindrachary, G. and Ch. Srinivas Rao. 2016. Impact of long term integrated nutrient management on groundnut yield and soil properties in scarce rainfall Zone of Andhra Pradesh, India. *Indian J. Ecol.,* 43(Special Issue −1), 452−454.

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K. and Hati, K.M. 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil Till. Res*.,110(1): 115−125.

Bhargava, V.S. and Sharma, R.M. 1982. *Saline Environment and Plant Growth*. S.K. Sharma and T.C. Gupta (eds). Agro−botanical Publishers, India, pp 103−111.

Blaise, D. 2011. Tillage and green manure effects on Bt transgenic cotton (*Gossypium hirsutum* L.) hybrid grown on rainfed Vertisols of central India. *Soil Till. Res.,* 114 (2): 86−96.

Blaise, D. and Ravindran, C.D. 2003. Influence of tillage and residue management on growth and yield of cotton grown over 5 years in a semi−arid region of India. *Soil Till. Res.,* 70: 163–173.

Blake, G.R. and Hartge, K.H. 1986. Bulk density. *In:* Klute, A. (ed.). Methods of Soil Analysis, Part − 1 : Physical and Mineralogical Methods, 2nd Ed., Agronomy Monograph 9, American Society of Agronomy − Soil Science Society of America, Madison, pp 363−382.

Casida, L.E., Klein, D.A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.,* 98(6): 371−76.

Choudhary, S.G., Yaduvanshi, N.P.S., Chudhari, S.K., Sharma, D.R., Nayak, D.C. and Singh, S.K. 2018. Effect of nutrient management on soil organic carbon sequestration, fertility, and productivity under rice−wheat cropping system in semi−reclaimed sodic soils of North India. *Environ. Monit. Assess*., 190(3): 117.

Choudhary, R.L. and Behera, U.K. 2019. Conservation agricultural and nitrogen management practices in maize-wheat cropping system: Effect on productivity, nutrient uptake and profitability of maize. *Indian J. Soil Cons.,* 47 (3): 286−293.

Doran, J.W. and Parkin, T.B. 1994. *Defining and assessing soil quality. In:* J.W. Doran *et al.* (eds), Defining soil quality for sustainable environment. Soil Science Society America Special Pub. 35, ASA−SSSA, Madison, Wisconsin, pp 3−21.

Gabhane, V.V., Sonune, B.A. and Katkar, R.N. 2014. Long term effect of tillage and integrated nutrient management on soil quality and productivity of rainfed cotton in Vertisols under semi−arid conditions of Maharashtra. *Indian J. Dryland Agric. Res. Dev.,* 29(2): 71−77.

Gabhane,V.V., Maruthi Sankar, G.R., Nagdeve, M.B. and Ganvir, M.M. 2017. Long-term effect of fertilizer application on rainwater use efficiency, soil fertility and sustainability of yield and profitability from sorghum and pigeonpea in semi-arid Vertisols. *Indian J. Soil Cons.,* 45(3): 318−324.

Garg, R.N., Mazumdar, S.P., Chattaraj, S., Chakraborty, D., Singh, R., Kumari, M., Saha, B., Trivedi, S.M., Kaur, R., Kamble, K.H. and Singh, R.K. 2009. Assessment of soil physical conditions: evaluation of a single value index. *J. Agric. Phy.,* 9: 9−19.

Gathala, M.K., Ladha, J.K., Kumar, V., Saharawat, Y., Kumar, S., Sharma, V., Kumar, P., Sharma, S. and Pathak, H. 2011. Tillage and crop establishment affects sustainability of south asian rice−wheat system. *Agron. J.,* 103(4): 961−971.

Hanway, J.J. and Heidel, H. 1952. *Soil analysis methods, as used in Iowa state*. College Soil Testing Laboratory, Iowa, Agriculture, 57: 1−31.

Hugar, G.M. and Soraganvi, V.S. 2014. Effect of SOC in the form of amendments on hydraulic properties of arid soils. *Int. J. Civil Struc. Eng*., 4(3): 450–468.

Hulugalle, N.R. and Entwistle, P. 1997. Soil properties, nutrient uptake and crop growth in an irrigated Vertisol after nine years of minimum tillage. *Soil Till. Res*., 42(1−2): 15−32.

Hulugalle, N.R., L.A. Lobry de Bruyn and Entwistle, P. 1997. Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated Vertisol sown to cotton. *Appl. Soil Ecol.,* 7(1): 11−30.

Jabro, Jay D., Sainju, Upendra M., Stevens, William, B., Lenssen, Andrew, W. and Robert, G.E. 2009: Long−term tillage influences on soil physical properties under dryland conditions in north−eastern Montana. *Arch. Agro. Soil Sci*., 55(6): 633−640.

Jackson, M.L. 1967. *Soil Chemical Analysis*. Prentice Hall Publication Pvt. Ltd., New Delhi, India.

Jenkinson, D.S. and Ladd, J.N. 1981. *Microbial Biomass in Soil Measurement and Turnover. In:* Paul, E.A. and Ladd, J.N. (eds.), Soil Biochemistry, Marcel Dekker, New York USA, pp 415−715.

Jenkinson, D.S. and Powlson, D.S. 1976. The effects of biocidal treatments on metabolism in soil − I. Fumigation with chloroform. *Soil Biol. Biochem.* 8(3): 167−177.

Jadhao, S.D., Mali, D.V., Kharche, V.K., Singh, M., Bhoyar, S.M., Kadu, P.R., Wanjari, R.H. and Sonune, B.A. 2019. Impact of continuous manuring and fertilization on changes in soil quality under sorghum−wheat sequence on a Vertisols. *J. Indian Soc. Soil Sci.,* 67(1): 55−64.

Kemper, W.D. and Rosenau, R.C. 1986. *Aggregate stability and size distribution.* In: A. Klute (ed.), Methods of soil analysis. Part – 1 : 2nd ed. Agron. Monogr. 9. ASA, Madison, WI, pp 425−442.

Klute, A. and Dirksen, C. 1986. *Hydraulic conductivity and diffusivity.* Laboratory methods. *In:* A. Klute (ed.), Methods of soil analysis : Part − 1. Physical and mineralogical methods, pp 687−734.

Mali, D.V., Kharche, V.K., Jadhao, S.D., Jadhao, S.M., Gite, P.A. and Age, A.B. 2014. Soil biological health under long−term fertilization in sorghum−wheat sequence on swell−shrink soils of Central India. *J. Indian Soc. Soil Sci.,* 63(4): 423−428.

Mali, D.V., Kharche, V.K., Jadhao, S.D., Katkar, R.N., Konde, N.M., Jadhao, S.M. and Sonune, B.A. 2015. Effect of long term fertilization and manuring on soil quality and productivity under sorghum (*Sorghum bicolor*) − wheat (*Triticum aestivum*) sequence in Inceptisol. *Indian J. Agric. Sci.,* 85(5): 695–700.

Mandal, D.K., Mandal, C. and Venugopalan, M.V. 2005. Suitability of cotton cultivation in shrink–swell soils in Central India. *Agric. Syst.,* 84(1): 55–75.

Meshram, N.A., Ismail, S., Pinjari, S.S., More, S.S., Wahane, M.R. and Jagtap, D.N. 2020. Impact of long-term fertilization on soil quality and fertility under soybean–safflower cropping sequence in Vertisol. *Indian J. Soil Cons.,* 48(1): 27–34.

Moharana, P.C., Sharma, B.M., Biswas, D.R., Dwivedi, B. S. and Singh, R.V. 2012. Long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-year-old pearl millet -wheat cropping system in an Inceptisol of subtropical India. Field Crops Res., 136: 32 -41.

Murthy, A.S.P. 1988. Distribution, properties, and management of Vertisol of India. *Adv. Soil Sci.,* 8: 151–214.

Nelson, D.W. and Sommers, L.E. 1982. *Total carbon, organic carbon and organic matter. In:* Method of soil Analysis, Part − 11. Page, A.L., Miller, R.H. and Keeney, D.R. (eds). Soil Science Society of America Inc., Madison, Wisconsin, USA.

Panse, V.G. and Sukhatme, P.V. 1971. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi.

Patil, S.L. 2013. Winter sorghum (Sorghum bicolor) productivity as influenced by tillage practices and nitrogen management in Vertisols of SAT, India. *Soil Till. Res*., 126: 183–192.

Pawar, A., More, N.B., Amrutsagar, V.M. and Tamboli, B.D. 2019. Influence of organic residue recycling on crop yield, nutrient uptake, and microbial and nutrient status of *rabi* sorghum (*Sorghum bicolor l.*) under dryland condition. *Communi. Soil Sci. Pl. Anal.,* 50(4): 435−443.

Ramachandrappa, B.K., Sankar, G.R., Maruthi Sankar, Satish, A., Thimmegowda, M.N., Dhanapal, G.N., Kumar, N.Indra, Shankar, M.A., Rao, C.H. Srinivasa and Mishra, P.K. 2017. Efficient tillage and nitrogen practices for improving monetary returns and yield of finger millet and pigeonpea in semi−arid Alfisols. *Indian J. Soil Cons.,* 45(2): 157−167.

Saha, R., Mishra, V.K., Majumdar, B., Laxminarayana, K. and Ghosh, P.K. 2010. Effect of INM on soil physical properties and crop productivity under a Maize (*Zea mays*) − Mustards (*Brassica campestris*) cropping sequence in acidic soils of Northeast India. *Commun. Soil Sci. Pl. Anal*., 41: 2187−2200.

Senthil Kumar, N. and Santha, S. 2008. Productivity and economics of castor through integrated nutrient management practices under irrigated condition. *Madras Agric. J.,* 95 (7−12): 339−342.

Singh, M., Reddy, K.S., Singh, V.P. and Rupa, T.R. 2007. Phosphorus availability to rice (*Oriza sativa* L.) – wheat (*Triticum estivum* L.) in a Vertisol after eight years of in organic and organic fertilizer additions. *Bioresour. Technol.,* 98(7): 1474–1481.

Sharma, O.P. and Gupta, R.K. 1986. Comparative performance of gypsum and pyrites in sodic Vertisols. *Indian J. Agric. Sci.,* 56(6): 423−428.

Sharma, K.L., Grace, J. Kusuma, Mandal, U.K., Gajbhiye, P.N., Srinivas, K., Korwar, G.R., Hima, Bindu V., Ramesh, V., Ramachandran, Kausalya and Yadav, S.K. 2008. Evaluation of long−term soil management practices using key indicators and soil quality indices in a semi−arid tropical Alfisol. *Aust. J. Soil Res.,* 46(4): 368–377.

Sharma, K.L., Mandal, U.K., Srinivas, K., Vittal, K.P.R., Mandal, B., Grace, J.K. and Ramesh, V. 2005. Long−term soil management effects on crop yields and soil quality in a dryland Alfisol. *Soil Till. Res.,* 83(2): 246–259.

Sharma, K.L., Maruthi Shankar, G.R., Suma Chandrika, D., Kusuma Grace, J., Sharma, S.K., Thakur, H.S., Jain, M.P., Sharma, R.A., Ravindra Chary, G., Srinivas, K., Gajbhiye, P., Venkatravamma, K., Munnalal, T., Kumar, S., Usha Rani, K., Sammi Reddy, K., Shinde, R., Korwar, G.R., Venkateswarlu, B. 2014. Effects of conjunctive use of organic and inorganic sources of nutrients on soil quality indicators and soil quality index in sole maize, maize + soybean, and sole soybean cropping systems in hot semi−arid tropical vertisol. *Comm. Soil Sci. Plant Anal.,* 45:16: 2118−2140.

Singh, R.J. and Ahlawat, I.P.S. 2011. Productivity, competition indices and nutrients dynamics of Bt cotton (*Gossypium hirsutum* L.) − groundnut (*Arachis hypogaea* L.) intercropping system using different fertility levels. *Indian J. Agric. Sci.,* 81(7): 606−611.

Singh, R.J., Ahlawat, I.P.S. and Kumar, K. 2013. Productivity and profitability of the transgenic cotton–wheat production system through peanut intercropping and FYM addition. *Exper. Agric.,* 49(3): 321−335, doi:10.1017/S0014479713000197.

Sonune, B.A., Gabhane, V.V., Rewatkar, S.S. and Sawangikar, M.S. 2012. Productivity of rainfed cotton and soil health as influenced by tillage and integrated nutrient management in Vertisol under semi−arid agro−ecosystem of Maharashtra. *Indian J. Dryland Agric. Res. Dev.,* 27(1): 10−17.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the determination of available N in soils. *Curr. Sci.* 25: 259−65.

Verma, G. and Mathur, A.K. 2009. Effect of integrated nutrient management on active pools of soil organic matter under maize–wheat system of a *Typic Haplustept*. *J. Indian Soc. Soil Sci.,* 57(3): 317−322.

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from the soil. *Soil Sci. Soc. of Am. J.,* 29(6): 677−678.