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Influence of nutrient management practices and cropping systems on soil properties and total organic carbon content in a Vertisol

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Abstract
Soil properties and soil carbon sequestration potentials as influenced by nutrient management practices and cropping systems practiced over a period of five years in a Vertisol was monitored during 2017-18. The study revealed that, nutrient management practices showed greater impact on soil parameters studied than cropping systems. The 100 % organic farming practice significantly improved the soil physical properties *viz;* bulk density, porosity, aggregate stability and moisture retention compared to 100 % inorganic farming. Total organic carbon at 0-5, 5-15 and 15-30 cm was significantly higher in 100 % organic farming (14.8, 14.5 and 13.6 mg kg^{-1}, respectively) and greengram-safflower cropping system (14.4, 13.8 and 13.2 mg kg^{-1}, respectively). In general, many soil properties were significantly enhanced due to 100 % organic farming in greengram-safflower sequence cropping system.

Keywords: Nutrient management practices, cropping systems, soil properties, carbon sequestration.

Introduction
Organic carbon (OC) is the building block for all life on the earth. Soil organic matter (SOM), of which carbon is a major part, holds a greater proportion of nutrients, cations and trace elements that are of importance to plant growth. Also, it is widely accepted that the OC content of soil is a major factor in its overall health. Many tropical soils are poor in nutrients and depend on the recycling of nutrients from SOM to maintain productivity of crop. Although the amount of soil organic carbon (SOC) in Indian soils is comparatively low, ranging from 0.1 to 1 % and typically less than 0.5 %, yet its effect on soil fertility and physical condition is of great significance (Swarup *et al.*, 2000) [18]. Cause of low level of OC content in Indian soils is primarily due to high temperature prevailing throughout the year. Conversion of land from its natural state to agriculture generally leads to SOC losses.
In long-term fertility experiments in India, decline in SOM is generally implicated as one of the cause for yield stagnation, particularly where N is the only fertilizer, irrespective of cropping system and soil type. This eventually leads to deterioration of soil aggregation and net release of carbon from agriculture field to atmosphere. Losses and gain of SOM could be influenced by land management practices such as cropping frequency, tillage, fertilizer application, manure application (Manna *et al.*, 2005) [9] and also crops and cropping systems. Soil physical degradation is often associated with a decline in the OM content. Organic matter affects crop growth and yield, either directly by supplying nutrients, or indirectly by modifying soil physical properties that can improve the root environment and stimulate plant growth. Maintenance of optimum soil physical conditions is an important component of soil fertility management. With this background, the present study was undertaken to assess soil properties and total organic carbon (TOC) contents as influenced by adoption of different nutrient management practices and cropping systems in a Vertisol.

Material and methods
The "Evaluation of organic, inorganic and integrated production systems" is the on-going long-term filed experiment being conducted in Plot No. E121 at the Main Agricultural Research Station (MARS), UAS Dharwad, Karnataka under ICAR All India Network Project

on Organic Farming (AI-NPOF) involving nutrient management practices in different cropping systems in a Vertisol. This long-term field experiment was initiated during 2004-05 with different nutrient management practices and cropping systems. The soil properties evaluated during 2017-18 (after completion of five years of study with same cropping systems) are indicative of the cumulative effect of nutrient management practices and cropping systems practiced on fixed plots since 2013-14.The experiment was laid out in strip plot design with nutrient management practices as the main factor and cropping systems as the sub-factor with three replications. The nutrient management practices were: 100 % Organic farming (100 % OF), 75 % Organic farming (75 % OF) + Cow urine and Vermi-wash spray, 50:50 Integrated farming (50 % Organic + 50 % Inorganic) (INM 50:50), 75:25 Integrated farming (75 % Organic + 25 % Inorganic) (INM 75:25), 100 % Inorganic farming (100 % IF) and Recommended dose of inorganic fertilizers + Recommended dose of farm yard manure (RPP). In case of organic farming and INM treatments, the organics were applied on N basis for cereals and P basis for pulses. The cropping systems were: greengram-safflower sequence, pigeonpea (Sole cropping system), greengram-sorghum sequence, groundnut + cotton (2:1) intercropping system and maize-chickpea sequence.

A composite soil sample was collected from the experimental site during 2004-05 (Initial) and analyzed for physico-chemical properties. The soil was clay loam with 58.78 % clay. The $pH_{2.5}$ was slightly alkaline (7.50) and very normal in respect of $EC_{2.5}$ (0.13 dS m^{-1}). The bulk density, per cent aggregate stability (>0.25mm) and maximum water holding capacity values were 1.28 Mg m^{-3}, 61.21 % and 62.5 %, respectively. The soil was low in available N (255 kg ha^{-1}), medium in available P_2O_5 (28.4 kg ha^{-1}), high in available K_2O (380 kg ha^{-1}) and medium in available sulphur (20.1 kg ha^{-1}). The soil was non-deficient in available micronutrients *viz*; iron, manganese, zinc and copper.

Soil samples were collected treatment-wise at 4 soil depths (0-5, 5-15, 15-30 and 30-50 cm) after the harvest of *rabi* crops during 2017-18. The soil samples were processed and analysed for soil physico-chemical properties. The soil pH and electrical conductivity (EC) were measured by using soil water suspension ratio of 1:2.5 (Sparks, 1996). The bulk density (BD)of soil was determined by clod method (Black, 1965) [4]. Porosity was calculated using the values of bulk density and particle density (Black, 1965) [4]. Aggregate stability was determined by Yoder's wet sieving method (Black, 1965) [4]. Maximum water holding capacity (MWHC) was determined by using Keen Raczkowaski brass cup (Black, 1965) [4]. The soil moisture content at field capacity (-33 kPa) was determined by pressure plate apparatus (Richards and Fireman, 1943) [15] and permanent wilting point (-1500 kPa) by pressure membrane apparatus (Richards, 1941) [14]. The TOC was determined by loss on ignition method using muffle furnace at 550-650 °C for 6-8 hours (Tiessen *et al*., 1981) [19]. The total organic matter and total carbon contents were calculated by using following formulas:

$$\text{Total organic matter (\%)} = \frac{\text{(Pre-ignition weight} - \text{Post-ignition weight)} \times 100}{\text{Weight of sample taken}}$$

$$\text{Total carbon (\%)} = \frac{\text{Total organic matter}}{1.724}$$

Inorganic carbon content was determined by rapid acid titration method. The total organic carbon in soil was estimated by subtracting the inorganic carbon content from total carbon.

Results and discussion

Soil physical and chemical properties

The soil pH ranged from 7.47 to 8.20 among nutrient management practices (Table 1) and was significantly lower (7.47) in 100 % organic farming. The lower soil pH under organic farming practices might have resulted from the release of organic acids and formation of carbonic acid during the decomposition of organic (Meena *et al.*, 2018) [11]. Recommended dose of NPK + recommended dose of FYM (RPP) resulted in relatively higher soil pH (8.20) which corroborated with low level of total organic carbon of the soil. Bhatt *et al*. (2019) [3] also reported higher pH due to continuous cropping with inorganics. The pH values among the cropping systems ranged from 7.70 to 7.84, though the differences between them were statistically non-significant.

The EC values among nutrient management practices and cropping systems varied between 0.117 to 0.128 dS m^{-1} and 0.121 to 0.126 dS m^{-1}, respectively (Table 1). Neither nutrient management practices nor cropping systems individually influenced the EC. Pothare *et al*. (2007) [12] also observed non-significant changes in EC of soil due to various fertilization combinations.

The soil BD values under nutrient management practices and cropping systems ranged from 1.24 to 1.38 Mg m^{-3} and 1.31 to 1.33 Mg m^{-3}, respectively (Table 2). The BD in 100 % organic farming was significantly lower (1.24 Mg m^{-3}) as compared to other treatments. The decrease in BD was due to higher build-up of TOC in the treatment (Table 5) which resulted in crumb soil structure leading to decreased bulk density. Similar result and reasoning was given by Sharma *et al*. (2014) [16]. The plot which was inorganically fertilized (100 % IF) showed higher value of bulk density. This could be attributed to the lower TOC of the soil with continuous application of inorganic fertilizers. No consistent trend was observed among cropping systems in respect of BD.

The nutrient management practices exhibited a positive impact on soil porosity. The total porosity varied between 48.1 to 53.0 % among nutrient management practices and 50.0 to 50.4 % among cropping systems. The higher porosity was registered in 100 % organic farming (53.0 %) across cropping systems but remained on par with other nutrient management practices where organic manures were applied except in 100 % inorganic farming (Table 2). Higher soil porosity with 100 % organic farming could be attributed to higher TOC (Table 5), better aggregation and change in pore size distribution of the soil (Aggelides and Londra, 2000) [1].

The nutrient management practices significantly influenced maximum water holding capacity (MWHC), field capacity (FC) and permanent wilting point (PWP) soil moisture constants. However, these parameters were not significantly influenced by cropping systems and the interactions. The MWHC values for nutrient management practices and cropping systems ranged from 62.1 to 67.3 % and 64.1 to 65.7 %, respectively (Table 4). The MWHC was significantly higher in 100 % organic farming (67.3 %) than in 100 % inorganic farming (62.1 %), while variations among other treatments were non-significant. The higher value of MWHC due to addition of organic manure may be attributed to promotion of microbial activity, release of products such as bacterial gums, gels and polysaccharides which act as soil binding agents, increase aggregation and porosity and thereby increase water holding capacity. Barzegar *et al.* (2002) [2] also reported that the soil water holding capacity increased as the amount of added organic materials increased. The FC values ranged from 31.0 to 33.8 % and 32.2 to 32.7 % among nutrient management practices and cropping systems, respectively. The PWP values ranged from 16.4 to 18.2 and 16.8 to 17.6 % among nutrient management practices and cropping systems, respectively (Table 3). The FC and PWP values were significantly higher in 100 % organic farming (33.8 and 18.2 %, respectively) than in 100 % inorganic farming (31.0 % and 16.4 %, respectively), while variations among other treatments were non-significant. Application of bulky organic manure is known to improve soil organic carbon and other structural indices. Organic carbon contributes to bonding or adhesion of soil particles (*i.e.*, aggregation) and stability of soil aggregates. The crumb soil structure is favoured by enhanced organic carbon content which accommodates both macro and micro pores. An increased water holding capacity at low tensions such as at FC (0.033 Mpa) is primarily caused by increased number of these micropores. At higher tensions close to wilting point (1.5 Mpa), nearly all pores are filled with air and water retention is mainly determined by the surface area and thickness of water films at these surfaces. Addition of organic matter increases specific surface area, which results in increased water holding capacity at higher tensions (Gupta *et al*., 1977) [7].

The 100 % organic farming (70.1 %) and 75 % organic farming + cow urine and vermi-wash spray (69.1 %) increased the aggregate stability of soils when compared to other nutrient management practices (Table 4). This could be due to addition of large quantity of organic matter, which stabilizes the aggregates by strengthening the bonding between soil particles as reported by Premi *et al.* (2005) [13]. The aggregate stability values for nutrient management practices and cropping systems varied from 65.9 to 70.1 %and 67.3 to 68.0 %, respectively. Difference between cropping systems was found non-significant, but their interaction with nutrient management practices was found significant. The practice of 100 % organic farming in greengram-sorghum sequence recorded higher aggregate stability (70.6 %). Water stable aggregates were reported to be more under legume based cropping systems (Jadhav, 1990) [8].

Table 1: Effect of nutrient management practices and cropping systems on soil pH and EC (after harvest of *rabi* crops 2017-18)

CS / NM	pH						EC (dS m^{-1})					
	Greengram –Safflower	**Pigeonpea**	**Greengram - Sorghum**	**Groundnut +Cotton**	**Maize - Chickpea**	**Mean**	**Greengram - Safflower**	**Pigeonpea**	**Greengram - Sorghum**	**Groundnut +Cotton**	**Maize – Chickpea**	**Mean**
100 % OF	7.61	7.58	7.52	7.33	7.29	7.47	0.139	0.118	0.116	0.119	0.132	0.125
75 % OF	7.75	7.68	7.44	7.57	7.89	7.67	0.131	0.122	0.127	0.127	0.124	0.126
INM (50:50)	7.62	7.95	7.75	7.70	7.81	7.77	0.112	0.125	0.115	0.113	0.129	0.119
INM (75:25)	7.82	7.65	7.65	7.74	7.64	7.70	0.127	0.126	0.122	0.124	0.116	0.123
100 % IF	8.06	7.95	7.76	7.77	7.97	7.90	0.112	0.111	0.113	0.118	0.131	0.117
RPP	8.20	8.16	8.19	8.10	8.35	8.20	0.118	0.127	0.143	0.124	0.127	0.128
Mean	7.84	7.83	7.72	7.70	7.83	7.78	0.123	0.122	0.122	0.121	0.126	0.123
	NM		CS		NM × CS		NM		CS		NM × CS	
S.Em. ±	0.13		0.14		0.36		0.01		0.01		0.01	
CD (P=0.05)	0.40		NS		NS		NS		NS		NS	
CV (%)	12.85						13.32					

OF, organic farming; INM, integrated nutrient management; IF, inorganic farming; NS- Non significant; RPP, recommended package of practice

Table 2: Effect of nutrient management practices and cropping systems on soil bulk density and porosity (after harvest of *rabi* crops 2017-18)

CS / NM	Bulk density (Mg m^{-3})						Porosity (%)					
	Greengram – Safflower	**Pigeon pea**	**Greengram - Sorghum**	**Groundnut +Cotton**	**Maize - Chickpea**	**Mean**	**Greengram - Safflower**	**Pigeonpea**	**Greengram - Sorghum**	**Groundnut +Cotton**	**Maize - Chickpea**	**Mean**
100 % OF	1.24	1.23	1.24	1.26	1.25	1.24	53.3	53.5	53.2	52.3	52.8	53.0
75 % OF	1.28	1.30	1.31	1.27	1.28	1.29	51.7	50.8	50.7	52.1	51.8	51.4
INM (50:50)	1.35	1.33	1.33	1.34	1.35	1.34	49.1	49.7	49.8	49.6	49.1	49.4
INM (75:25)	1.32	1.33	1.32	1.33	1.31	1.32	50.1	49.8	50.2	49.7	50.4	50.0
100 % IF	1.37	1.38	1.37	1.39	1.38	1.38	48.4	47.9	48.2	47.7	48.1	48.1
RPP	1.33	1.36	1.33	1.36	1.36	1.35	49.9	48.6	49.9	48.6	48.7	49.1
Mean	1.31	1.32	1.32	1.33	1.32	1.32	50.4	50.0	50.3	50.0	50.1	50.2
	NM		CS		NM × CS		NM		CS		NM × CS	
S.Em. ±	0.02		0.03		0.06		1.30		0.61		1.95	
CD (P=0.05)	0.06		NS		NS		4.01		NS		NS	
CV (%)	13.91						13.75					

OF, organic farming; INM, integrated nutrient management; IF, inorganic farming; NS- Non significant; RPP, recommended package of practice

Table 3: Effect of nutrient management practices and cropping systems on soil FC and PWP (after harvest of *rabi* crops 2017-18)

CS / NM	FC (%)						PWP (%)					
	Greengram –Safflower	**Pigeonpea**	**Greengram - Sorghum**	**Groundnut +Cotton**	**Maize - Chickpea**	**Mean**	**Greengram - Safflower**	**Pigeonpea**	**Greengram - Sorghum**	**Groundnut +Cotton**	**Maize - Chickpea**	**Mean**
100 % OF	34.2	35.0	33.8	32.9	32.8	33.8	18.6	19.3	18.3	17.4	17.5	18.2
75 % OF	33.1	32.5	33.1	32.5	33.0	32.9	17.8	17.8	16.8	16.6	17.3	17.3
INM (50:50)	32.2	32.2	33.0	32.1	32.6	32.4	17.8	17.1	17.6	16.9	16.4	17.1
INM (75:25)	32.8	33.0	32.1	32.3	33.1	32.7	16.5	17.3	17.6	17.2	17.4	17.2
100 % IF	31.5	31.2	30.7	30.5	31.2	31.0	17.0	17.1	15.8	15.9	16.1	16.4
RPP	32.1	32.4	32.0	32.7	32.7	32.4	17.1	17.2	16.7	16.9	17.5	17.1
Mean	32.7	32.7	32.5	32.2	32.6	32.5	17.4	17.6	17.1	16.8	17.0	17.2

	NM	CS	NM × CS	NM	CS	NM × CS
S.Em. ±	0.72	0.77	1.51	0.57	0.52	1.17
CD (P=0.05)	2.26	NS	NS	1.78	NS	NS
CV (%)	10.53			13.25		

OF, organic farming; INM, integrated nutrient management; IF, inorganic farming; NS- Non significant; RPP, recommended package of practice

Table 4: Effect of nutrient management practices and cropping systems on soil MWHC and per cent water stable aggregates (after harvest of *rabi* crops 2017-18)

NM \ CS	MWHC (%)						Per cent water stable aggregates (%)					
	Greengram –Safflower	Pigeonpea	Greengram – Sorghum	Groundnut +Cotton	Maize - Chickpea	Mean	Greengram - Safflower	Pigeonpea	Greengram - Sorghum	Groundnut +Cotton	Maize - Chickpea	Mean
100 % OF	68.5	68.1	66.7	66.3	66.8	67.3	70.5	70.3	70.6	69.2	69.8	70.1
75 % OF	66.4	66.0	67.5	64.9	66.8	66.3	69.5	68.1	69.9	69.0	68.9	69.1
INM (50:50)	64.9	64.8	63.9	64.3	65.8	64.7	67.3	66.2	68.0	66.6	67.5	67.1
INM (75:25)	67.0	64.6	65.5	65.6	64.6	65.4	69.2	67.0	66.1	68.3	66.7	67.5
100 % IF	62.8	63.5	61.5	60.5	61.8	62.1	65.8	65.3	66.4	65.3	66.6	65.9
RPP	64.6	64.7	64.8	62.8	65.7	64.5	65.8	66.8	66.3	66.0	67.0	66.4
Mean	65.7	65.3	65.0	64.1	65.2	65.1	68.0	67.3	67.9	67.4	67.8	67.7
	NM		CS		NM × CS		NM		CS		NM × CS	
S.Em. ±	1.71		1.33		3.02		0.46		0.39		0.83	
CD (P=0.05)	5.13		NS		NS		1.44		NS		2.51	
CV (%)	10.65						9.24					

OF, organic farming; INM, integrated nutrient management; IF, inorganic farming; NS- Non significant; RPP, recommended package of practice

Table 5: Effect of nutrient management practices and cropping systems on total organic carbon (g kg^{-1}) (after harvest of *rabi* crops 2017-18)

NM \ CS	Total organic carbon (0-5 cm)						Total organic carbon (5-15 cm)					
	Greengram –Safflower	Pigeonpea	Greengram – Sorghum	Groundnut +Cotton	Maize - Chickpea	Mean	Greengram - Safflower	Pigeonpea	Greengram - Sorghum	Groundnut +Cotton	Maize - Chickpea	Mean
100 % OF	15.3	14.5	15.0	14.1	15.0	14.8	15.0	14.2	14.7	13.7	14.6	14.5
75 % OF	14.9	14.0	14.7	13.4	14.9	14.4	14.6	13.7	14.1	13.2	14.4	14.0
INM (50:50)	14.6	13.2	13.8	12.9	14.0	13.7	13.8	12.9	13.4	12.4	13.6	13.2
INM (75:25)	14.8	13.5	14.5	13.0	14.3	14.0	14.3	13.3	13.9	12.6	14.1	13.6
100 % IF	13.1	11.9	12.4	11.5	12.3	12.2	12.5	11.6	11.9	11.1	12.0	11.8
RPP	13.5	12.6	13.3	12.3	13.1	13.0	12.8	12.5	12.7	12.2	12.7	12.6
Mean	14.4	13.3	14.0	12.9	13.9	13.7	13.8	13.0	13.4	12.5	13.6	13.3
	NM		CS		NM × CS		NM		CS		NM × CS	
S.Em. ±	0.42		0.32		0.77		0.46		0.25		0.79	
CD (P=0.05)	1.33		0.98		2.30		1.40		0.78		2.36	
CV (%)	15.11						14.04					

OF, organic farming; INM, integrated nutrient management; IF, inorganic farming; NS- Non significant; RPP, recommended package of practice

Table 5: Continued

NM \ CS	Total organic carbon (15-30 cm)						Total organic carbon (30-50 cm)					
	Greengram –Safflower	Pigeonpea	Greengram – Sorghum	Groundnut +Cotton	Maize - Chickpea	Mean	Greengram - Safflower	Pigeonpea	Greengram - Sorghum	Groundnut +Cotton	Maize - Chickpea	Mean
100 % OF	14.0	13.3	13.9	13.0	13.8	13.6	12.2	11.4	11.9	11.1	11.7	11.7
75 % OF	13.9	12.9	13.5	12.6	13.4	13.3	11.8	10.8	11.5	10.6	11.3	11.2
INM (50:50)	12.9	12.1	12.8	11.9	12.7	12.5	10.9	10.4	10.7	9.7	10.3	10.4
INM (75:25)	13.7	12.6	13.2	12.2	13.2	13.0	11.2	10.6	11.2	9.9	11.1	10.8
100 % IF	12.1	10.4	12.0	10.1	11.7	11.3	10.4	9.2	9.9	9.0	9.7	9.60
RPP	12.7	11.8	12.4	11.4	12.3	12.1	10.6	10.2	10.1	9.5	9.9	10.1
Mean	13.2	12.2	13.0	11.9	12.9	12.6	11.2	10.4	10.9	10.0	10.7	10.6
	NM		CS		NM × CS		NM		CS		NM × CS	
S.Em. ±	0.49		0.32		0.82		1.05		0.59		1.69	
CD (P=0.05)	1.50		0.98		2.45		NS		NS		NS	
CV (%)	13.27						12.13					

Total organic carbon

The 100 % organic farming (14.8, 14.5and 13.6 g kg^{-1}, respectively) and 75 % organic farming + cow urine and vermi-wash spray (14.4, 14.0 and 13.3 g kg^{-1}, respectively) practices registered significantly higher TOC than in recommended dose of inorganic fertilizers + recommended dose of FYM (13.0, 12.6 and 12.1 g kg^{-1}, respectively) and 100 % inorganic farming (12.2, 11.8and 11.3 g kg^{-1}, respectively) at 0-5, 5-15 and 15- 30cm depths (Table 5). Among the cropping systems, the TOC at 0-5, 5-15 and 15-30cm depths was significantly higher in greengram-safflower sequence cropping system (14.4,13.8 and 13.2 g kg^{-1}, respectively) while, the lowest was recorded in groundnut + cotton intercropping system (12.9, 12.5 and 11.9 g kg^{-1}, respectively). The highest TOC was with 100 % organic farming under green gram-safflower sequence.

The greater TOC contents in organic farming treatments could be attributed to long-term use of organic inputs as well as to a higher crop productivity and therefore return of more crop residues in the forms of stubbles and roots. Sharma *et al*. (2014) [16] also found higher organic carbon under maize-wheat cropping system after 16 cropping cycles due to FYM application. The 100 % inorganic farming registered significantly lower TOC content. Sharma *et al*. (2014) [16]

reported that application of manures enhanced the organic carbon content of soil as compared to fertilizer alone.

Among the cropping systems, greengram-safflower sequence registered significantly higher TOC due to considerably higher biomass addition and also higher nitrogen addition to soil (greengram being legume and safflower being less N exhaustive). Similar finding was reported by Fugen *et al.* (2007) [6]. Increases in TOC under legume based cropping systems are commonly ascribed to increased plant biomass resulting from N fixed by the legumes. The application of organic nutrients increased plant carbon inputs in the soil through root residue, stubble, rhizo-deposition *etc*. The groundnut+cotton intercropping system with almost similar biomass addition recorded significantly lower TOC on account of the exhaustive nature of cotton crop in the system. Mathew *et al*. (2017) [10] reported that the C allocation to roots was less for fibre crops as compared to other field crops. The transformation of plant biomass carbon into more resistant form of carbon in soil *i.e*., humic acid requires nitrogen in the soil environment. Cotton being N exhaustive and non-N supplementing crop, the TOC build up was not favoured in groundnut+cotton intercropping system.

The TOC content at 30-50 cm depth was not influenced by either nutrient management practices or cropping systems (Table 5). A study by Chen *et al*. (2008) [5] also suggested that the impact of application of large quantity of organic manures were primarily limited to the surface layer.

Conclusion

The study indicated that organic farming practices (100 % organic farming and 75 % organic farming + cow urine and vermi-wash spray) resulted in increased total organic carbon. Increased total organic carbon was favourably associated with improvement of soil water retention characteristics, aggregate stability, porosity and reduced bulk density. In general, many soil properties were significantly enhanced due to 100 % organic farming in greengram-safflower sequence cropping system.

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