

Original Research Article

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## Effect of Different Nutrient Management Practices on Soil Microbial Properties in the Sub Humid Agro-Ecological Zone

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### ABSTRACT

The present study was conducted at Hill Agricultural Research and Extension centre, Kullu, in mid-hill sub-humid zone of Himachal Pradesh in order to investigate the effect of organic, inorganic and integrated nutrient management practices on soil microbial properties. The microbial count was found maximum ( $6.5 \times 10^5$  cfu/ml) in organic plot and minimum ( $2.6 \times 10^5$  cfu/ml) in inorganic. The maximum ( $50.8 \times 10^4$  cell/g) actinomycetes count was also recorded in soil under organic nutrient management practice where as it was minimum ( $26.00 \times 10^4$  cell/g) under inorganic treatment. The fungal count was maximum ( $4.6 \times 10^3$  cfu/ml) soil treated with organic manure and minimum ( $3.6 \times 10^3$  cfu/ml) in soil treated with inorganic fertilizers. The maximum ( $4.2 \mu\text{g g}^{-1}\text{hr}^{-1}$ ) dehydrogenase activity was also observed in the organic treatment. The phosphatase activity of the soil in organic treatment was recorded maximum ( $3.5 \mu\text{g TPF g}^{-1}\text{hr}^{-1}$ ) in integrated treatment and minimum ( $1.7 \mu\text{g TPF g}^{-1}\text{hr}^{-1}$ ) in inorganic treatment. The microbial respiration and microbial biomass carbon was observed maximum in organic application, followed by integrated and then inorganic.

### Keywords

Organic, Inorganic, Integrated, Farming systems, Microbial.

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### Introduction

Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. The main idea behind organic farming is 'zero impact' on the environment. It is a holistic food production system, which promotes and enhances agro ecosystem health, including biodiversity, biological cycles and soil activity sustaining the production system. The organic agriculture increases the capacity of soil to maintain

some key ecological functions, such as decomposition and formation of organic matter. This is a farming system in which the soil bounded organisms often benefit because of increased bacteria populations due to natural fertilizer spread such as manure (Hole *et al.*, 2005). Organic farming has re-emerged as the outcome of consumer reaction against harmful toxins and the desire for more health and environmental safeguards. This type of farming is a re-implementation of the primitive process followed by our ancestors before they discovered chemicals. In organic

agriculture an increased biodiversity, especially from soil microbes such as mycorrhizae, have been proposed as an explanation for the high yields experienced by some organic plots. The microbial respiration of soil in organic farming has received considerable attention because it can be used as a soil quality indicator and it is one important variable to quantify soil microbial activity. The soil microbial biomass carbon is considered the most dynamic and labile component of soil organic carbon. The level of biodiversity that can be yielded from organic farming provides a natural capital to humans. Species found in most organic farms provides a means of agricultural sustainability by reducing amount of human inputs. Studying the response of the microbial community to agricultural disturbances is vital to our understanding on how management practices contribute to sustaining fertility and productivity to improve soil management systems. This paper describes the effect of the three different farming practices on soil microbial properties, enzymatic activity, microbial respiration and microbial biomass carbon.

## **Materials and Methods**

The research trial was conducted in the experimental plots of ongoing network project on organic farming at CSKHPKV, Hill Agricultural Research and Extension Centre, Bajaura, Kullu H.P. in three cropping sequences, A1:Tomato- Cauliflower- Pea, A2: French bean- French bean- Cauliflower and A3: Cauliflower- Cauliflower-Pea. The study area is located in the mid-hills sub-humid zone II near Kullu Manali in Himachal Pradesh. The Research Station is situated at 32.2<sup>0</sup> N latitude and 77<sup>0</sup> E longitude and 1090 m altitude above mean sea level on the National Highway No. 21. It receives mild annual precipitation of 1500 mm. The soil is neutral to acidic in reaction; sandy loam and clay loam.

The field experiment was conducted on a pre-established experiment which comprised of three treatments. The treatments were, T<sub>1</sub> (100% organic; 50% NPK substituted by Vermicompost + 50% by NPK), T<sub>2</sub> (100% inorganic; NPK – 20:40:60) and T<sub>3</sub> (Integrated; 50% inorganic + 50 % NPK). The recommended dose of chemical fertilizer NPK for French bean was 45:100:30 for Cauliflower was 125:75:65, for Tomato 100:75:55 and for Pea it was 25:65:65. The fertilizer Source was Urea, Single Super Phosphate (SSP) and Murate of Potash (MOP). The plot size was 4.5 X 4.0 m<sup>2</sup>. Factorial Randomized Block Design was used as statistical tool.

Surface and subsurface soil samples (0-15cm) and (15-30cm) were collected before sowing and after the harvest of the three cropping sequences. The processed soil samples were analysed for microbial properties (total microbial count, biomass carbon, enzyme activity *i.e.* phosphatase, dehydrogenase and urease) by following the standard methods. The enumeration of microbial population was done by plate count technique of (Wollum, 1982) through serial dilution using a variety of media. Microbial biomass carbon was determined by fumigation-extraction method of Vance *et al.*, (1987). The dehydrogenase activity was determined by the method as described by Casida *et al.*, (1964). For phosphatase activity method as described by Tabatabai and Bremmer (1969) was used. The urease activity was determined by the method as described by Tabatabai and Bremmer (1972).

## **Results and Discussion**

### **Microbial population**

The microbial population was counted at different dilutions, the bacterial count was done at 10<sup>5</sup> dilution, actinomycetes at 10<sup>4</sup> and fungal count at 10<sup>3</sup> dilution, as at these

dilutions proper trends were observed. The data revealed a significant difference in the microbial count of three different farming systems *i.e.* organic, inorganic and integrated and a common trend was seen for bacterial, actinomycetes and fungal count. The maximum ( $6.5 \times 10^5$  cfu/ml) bacterial count was found in organic treatment followed by integrated and it was minimum ( $2.6 \times 10^5$  cfu/ml) in inorganic treatment (Table 1). The actinomycetes population was found to be maximum ( $50.8 \times 10^4$  cell/g) again in the organic treatment minimum ( $26.00 \times 10^4$  cells/g) in inorganic treatment. The fungal population was observed maximum ( $4.6 \times 10^3$  cfu/ml) in organic treatment and minimum ( $3.6 \times 10^3$  cfu/ml) in inorganic treatment (Table 2). The microbial count was also found decreased with the depth, the value was highest for 0-15cms as compared to the sub surface *i.e.* 15-30cms. The microbial count increased in after harvesting samples. The bacterial count in the surface layer before sowing was  $5.5 \times 10^5$  cfu/ml and in sub surface layer it was found to be  $5.1 \times 10^5$  cfu/ml and in the after harvesting samples in surface layer it was  $6.2 \times 10^5$  cfu/ml and  $5.3 \times 10^5$  cfu/ml in the sub surface layer (Table 3).

### **Enzymatic activity**

#### **Dehydrogenase activity**

The dehydrogenase activity varied from 1.4 to  $4.2 \mu\text{g hr}^{-1}$  (Table 4). The maximum ( $4.2 \mu\text{g g}^{-1}\text{hr}^{-1}$ ) dehydrogenase activity was observed in the organic treatment and minimum ( $3.5 \mu\text{g g}^{-1}\text{hr}^{-1}$ ) in the inorganic treatment. Dehydrogenase activity was higher in the surface soil in all the three treatments as compared to the sub surface soil.

#### **Phosphatase activity**

Phosphatase is the group of enzymes that catalyze the hydrolysis of both esters and

anhydrides of orthophosphate anions. Major part of the phosphorous is organically bound and its fractions also vary from soil to soil. The phosphatase activity in the three farming systems and in surface and sub-surface soil ranged from 0.91 to  $3.50 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  (Table 5). The data revealed that the treatment which received the combined application of organics and in-organics gave highest phosphates activity, followed by organic treatment and then integrated. The activity decreased with depth due to the reduction in the sources and the value also decreased in the after harvesting samples. The phosphatase activity of the soil in organic treatment was found to be  $2.8 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  and that of the integrated treatment was  $3.5 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  and that of the inorganic treatment  $1.7 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$ . The value of phosphatase activity in the surface and sub-surface soil in before sowing samples were  $3.5 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  and  $3.2 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  respectively and that in after harvesting samples were  $2.4 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  and  $2.0 \mu\text{g TPF g}^{-1} \text{hr}^{-1}$  respectively (Table 6).

#### **Urease activity**

The urease activity in the three farming systems varied from 4 to  $5 \mu\text{g g}^{-1} \text{hr}^{-1}$  (Table 6). The maximum value was observed in the integrated treatment followed by organic and inorganic treatment. The value decreased with depth and also in the after harvesting samples.

#### **Microbial biomass carbon**

The values of microbial biomass carbon ranged from 174 to  $254 \mu\text{g kg}^{-1}$  (Table 7). The microbial biomass carbon was found to be significantly highest in the organic treatment followed by integrated and then the inorganic treatment. The microbial biomass carbon was found to be higher in surface soil than in subsurface soil and the value decreased in the before sowing samples.

**Table.1** Effect of organic, inorganic and integrated treatments on fungal population, 10<sup>3</sup> cfu/mL

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	4.7	4.3	3.7	4.2	4.6	4.3	3.5	4.1	4.8	4.9	4.3	4.7	4.8	4.8	3.8	4.5
Inorganic	4.5	3.7	2.3	3.7	4.4	3.6	2.8	3.6	4.7	3.9	3.5	4.0	4.6	3.7	3.2	3.9
Integrated	4.6	4.0	3.1	3.9	4.6	4.0	3.0	3.8	4.8	4.2	3.7	4.2	4.7	4.1	3.4	4.1
MEAN	4.6	4.0	3.3		4.6	4.0	3.1		4.8	4.3	3.8		4.7	4.2	3.5	
CD(P≤0.05)	0.03				0.02				0.09				0.02			

**Table.2** Effect of organic, inorganic and integrated treatments on actinomycetes population, 10<sup>4</sup> cells g<sup>-1</sup>

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	41.3	39.0	43.3	41.2	35.3	33.4	38.7	35.8	48.3	54.7	49.3	50.8	43.3	41.3	43.0	42.6
Inorganic	34.0	43.3	30.7	30.2	26.0	25.3	27.0	26.1	35.0	37.3	36.3	36.2	30.0	31.0	31.0	30.7
Integrated	33.0	34.7	34.0	33.9	28.3	30.0	29.7	29.3	39.0	45.0	41.0	41.3	34.0	32.7	33.7	33.4
MEAN	34.4	34.9	36.0		29.9	29.6	31.8		40.8	45.7	41.9		35.8	35.0	35.9	
CD(P≤.05)	1.9				1.7				1.16				1.17			

**Table.3** Effect of organic, inorganic and integrated treatments on bacterial population, 10<sup>5</sup> cfu/mL

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	6.3	4.9	5.2	5.5	5.8	4.4	5.0	5.1	6.7	6.5	5.4	6.2	4.7	5.9	5.2	5.3
Inorganic	3.4	2.9	2.5	2.9	2.9	2.7	2.4	2.6	3.9	3.5	3.9	3.4	4.6	2.9	2.6	3.4
Integrated	5.9	4.8	4.9	5.2	5.7	4.4	4.3	4.8	6.2	6.3	5.2	5.9	4.8	5.7	5.0	5.2
MEAN	5.2	4.2	4.2		4.8	3.8	3.9		5.6	5.4	4.5		4.7	4.8	4.3	
CD (p≤0.05)	.15				.14				.13				.10			

**Table.4** Effect of organic, inorganic and integrated treatments on dehydrogenase activity,  $\mu\text{g g}^{-1}\text{hr}^{-1}$

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	4.4	4.0	4.6	4.2	4.0	3.5	3.5	3.7	2.8	1.7	1.9	2.2	2.4	1.6	1.9	2.0
Inorganic	3.7	3.7	3.0	3.5	2.8	2.9	3.0	2.9	1.7	1.2	1.4	1.4	1.5	1.6	1.3	1.7
Integrated	3.9	3.8	3.9	3.9	3.7	3.0	3.0	3.2	2.2	1.6	1.6	1.8	2.1	1.4	1.5	1.7
MEAN	4.0	3.9	3.7		3.5	3.1	3.2		2.2	1.5	1.7		2.0	1.5	1.6	
CD ( $P\leq 0.05$ )	0.09				0.05				0.46				0.44			

**Table.5** Effect of organic, inorganic and integrated treatments on phosphatase activity,  $\mu\text{g TPF g}^{-1}\text{hr}^{-1}$

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	2.7	2.8	2.9	2.8	2.6	2.5	2.7	2.6	1.1	1.3	1.5	1.3	1.0	1.2	1.9	1.4
Inorganic	2.1	1.3	1.8	1.7	1.9	1.2	1.7	1.6	1.0	1.0	1.1	1.0	0.6	0.9	1.0	0.9
Integrated	3.7	3.1	3.5	3.4	3.4	2.9	3.3	3.2	2.6	2.1	2.5	2.4	1.9	2.0	2.1	2.0
MEAN	2.9	2.4	2.7		2.6	2.2	2.6		1.6	1.5	1.7		1.2	1.4	1.7	
CD ( $p\leq 0.05$ )	0.08				0.04				0.07				0.03			

**Table.6** Effect of organic, inorganic and integrated treatments on urease activity,  $\mu\text{g g}^{-1}$

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	7.5	6.8	6.8	7.0	6.4	6.2	6.5	6.4	6.7	4.7	6.3	5.9	6.3	4.1	5.9	5.4
Inorganic	6.7	6.3	6.4	6.5	5.9	5.7	5.7	5.7	6.1	4.1	5.7	5.3	5.7	3.4	5.4	4.8
Integrated	7.8	7.4	7.3	7.5	6.7	6.8	6.6	6.7	7.5	5.4	6.7	6.5	6.9	4.8	6.5	6.1
MEAN	7.3	6.8	6.8		6.3	6.2	6.3		6.8	4.7	6.2		6.3	4.1	5.9	
CD ( $p\leq 0.05$ )	0.22				0.14				0.17				0.13			

**Table.7** Effect of organic, inorganic and integrated treatments on microbial biomass carbon,  $\mu\text{g g}^{-1}$

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	224.1	204.5	215.5	214.7	214.7	196.0	207.3	205.7	238.9	318.2	238.2	265.1	222.5	309.3	228.2	253.3
Inorganic	167.0	106.9	126.7	133.5	147.7	99.1	114.5	120.4	184.9	182.3	142.5	169.9	173.4	176.2	133.7	161.1
Integrated	204.9	165.5	189.8	186.7	196.7	157.1	168.8	174.2	214.4	209.3	196.6	208.8	207.7	142.9	184.2	176.2
MEAN	198.7	159.0	177.3		186.3	150.7	163.2		212.7	236.6	192.5		199.2	209.6	189.9	
CD ( $P \leq 0.05$ )	1.6				2.8				2.4				3.6			

**Table.8** Effect of organic, inorganic and integrated treatments on microbial respiration,  $\mu\text{g C g}^{-1} \text{hr}^{-1}$

	BEFORE SOWING								AFTER HARVESTING							
	0-15 cms				15-30 cms				0-15 cms				15-30cms			
	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN	A1	A2	A3	MEAN
Organic	13.6	13.7	12.3	13.2	12.7	13.3	11.7	12.6	14.9	14.5	12.8	14.0	14.3	10.1	10.1	12.0
Inorganic	5.9	5.9	5.1	5.6	5.3	5.6	4.9	5.3	6.7	6.7	5.6	6.3	6.1	6.0	5.8	6.0
Integrated	7.9	7.5	6.9	7.4	7.3	7.2	6.6	7.0	8.6	7.8	7.6	8.0	8.3	7.3	9.5	8.3
MEAN	9.1	9.1	8.1		8.4	8.7	7.7		10.3	9.8	8.7		9.6	7.8	8.5	
CD( $P \leq 0.05$ )	0.17				0.19				0.1				0.3			

## Microbial respiration

The amount and rate of CO<sub>2</sub> released is an expression of metabolic activity of microorganisms present in the soil. The microbial respiration of the soil in organic treatment was found to be 13.2 g/kg, in integrated 7.4g/kg and in inorganic 5.6 g/kg. The value of microbial respiration in the surface and sub-surface soil in before sowing samples were recorded 13.2 g/kg and 12.2 g/kg respectively and that in after harvesting samples were found 14.0 g/kg and 11.9 g/kg respectively (Table 8). The surface soil had a higher value of CO<sub>2</sub> evolution than the sub surface soil due to higher microbial count in the latter.

The effect of three farming systems was studied on the various microbial properties of the soil. There was a common trend followed by the bacterial population, fungal count and actinomycetes. It was found to be maximum in organic treatment, followed by integrated and then inorganic. Similar findings have been recorded by Das and Mukherjee (1990) for alluvial soils of West Bengal and Jain *et al.*, (2003) for the soil of Jabalpur. This may be attributed the organic source of carbon as food and oxidation of organic substances as sources of energy. The microbial count was also found decreased with the depth, the value was highest for 0-15cms as compared to the sub surface *i.e.* 15-30cms which may be ascribed to the more accumulation of organic matter at the surface soil then the subsurface soil. An increase in microbial count in after harvest samples may be attributed to the addition of crop biomass and organic inputs. The results were corroborated with the results of Sheeba and Chellamuthu (1999).

Biological oxidation of organic matter is generally through the process of dehydrogenation. The enzyme dehydrogenase transfer hydrogen from substrate to acceptors.

The maximum dehydrogenase activity was observed in the organic treatment because of the maximum organic matter content in this treatment. It was found to be minimum in the inorganic treatment, the substitution of organics increased the concentration of substrate which resulted in the increase in this activity in soil followed the 1<sup>st</sup> order reactions meaning thereby the activity of enzyme is proportional to the concentration of the substrate Mark (1999b). Dehydrogenase activity was higher in the surface soil in all the three treatments as compared to the sub surface soil. Firstly, it might be due to the fact that the maximum organic matter accumulation was at surface soil. Secondly, the addition of nitrogen doses solely and partially through chemical fertilizers resulted in the accumulation of nitrate in subsurface which inhibited the activity of enzyme through interfering in the process of electron acceptor. Phosphatase is the group of enzymes that catalyze the hydrolysis of both esters and anhydrides of orthophosphate anions. Major part of the phosphorous is organically bound and its fractions also vary from soil to soil. The treatment which received the combined application of organics and in-organics gave highest phosphates activity, followed by organic treatment and then integrated. This may be due to the reason that in integrated treatments two effects can be seen. Firstly, monoesters and diesters of phosphate, which act as a substrate for the phosphatase activity are available from the inorganic treatment and secondly the addition of organic sources maintained the continuity of addition of organic to inorganic form, so the substrate of phosphorous *i.e.* monoesters and diesters are continuously available and caused the phosphatase activity. The activity decreased with depth due to the reduction in the sources and the value also decreased in the after harvesting samples. The maximum urease activity in the integrated treatment might be due to the application of organic and

inorganic source together maintaining the continuity of conversion of nutrients from organic to inorganic form because it act on C-N bonds other than peptide bond in linear amides and thus belongs to a group of enzymes that include glutaminase and amidase. The microbial biomass carbon was found to be significantly highest in the organic treatment followed by integrated and then the inorganic treatment. The microbial population may be attributed to such a type of trend in the microbial biomass carbon. The similar trend was observed by Shen *et al.*, (1997). The microbial biomass carbon was found to be higher in surface soil than in subsurface soil because of high microbial population in the surface soil. The amount and rate of CO<sub>2</sub> released is an expression of metabolic activity of microorganisms present in the soil. The microbial respiration was found to be maximum in the organic treatment at both the depths of soil, followed by integrated treatment and the minimum in inorganic treatment. This may be attributed to the maximum microbial population in organic treatment. The same results have also been reported by Jonasson *et al.*, (1996). The value was found to be increased in the after harvesting samples due to more bio-fertilizers added. The surface soil had a higher value of CO<sub>2</sub> evolution than the sub surface soil due to higher microbial count in the latter.

It is only the organic agriculture which offers the practical way to restore the agricultural lands that have been degraded by conventional agronomic practices. It offers an environmentally sound and affordable way for small holders to sustainably intensify production in marginal lands. Therefore in the present study, investigations were made to study the effect of three farming systems on the soil health by studying the effect of microbial properties of soil under Sub-Humid Agro ecological Conditions. The microbial population was counted at different dilutions,

the bacterial count was done at 10<sup>5</sup> dilution, actinomycetes at 10<sup>4</sup> and fungal at 10<sup>3</sup> dilution, as at these dilutions proper trends were observed. The maximum (6.5 x 10<sup>5</sup> cfu/ml) microbial count was observed in organic treatment followed by integrated and minimum (2.6x10<sup>5</sup> cfu/ml) was in inorganic treatment (Table 4.15, 4.16, 4.17). It decreased with the soil depth and increased in the after harvesting samples. The soil enzymes were also measured, the dehydrogenase activity was found to be maximum in the organic treatment and the value was found to be better in the surface soil as compared to the sub surface soil. The dehydrogenase activity decreased in the after harvesting samples and it was maximum (4.2µg hr<sup>-1</sup>) in the cropping sequence 1 (Table 4.18). The phosphatase activity was found to be maximum (3.50 µg TPF g<sup>-1</sup> hr<sup>-1</sup>) in integrated treatment due to the combined effect of in-organics and organics. Its values were found decreased in sub surface soil and also in the after harvesting sample (Table 4.19). The urease activity was recorded maximum (7.5 µg g<sup>-1</sup> hr<sup>-1</sup>) in the integrated farming system and its value decreased with depth and also in the after harvesting samples. The maximum urease activity was seen in cropping sequence 1 (Table 4.20). Microbial biomass carbon was found to be maximum (254 µg kg<sup>-1</sup>) in the organic treatment in both the soil depths which may be ascribed to the more microbial population. Its value reduced in the sub surface soil and also in the after harvesting samples (Table 4.21). Microbial respiration, was found to be maximum (13 µgC/g/hr) in organic farming due to the highest microbial population (Table 4.22). Its value decreased with the depth and also in the after harvesting samples. The present investigation revealed the highest bacterial, actinomycetes, fungal and the total microbial population followed by the higher values of dehydrogenase, microbial biomass carbon, organic carbon and microbial respiration in

the organic farming system. Therefore, it can be concluded that the organic practice enhances the microbial properties of the soil thus improving the ecology of the soil environment and ultimately contributes to the sustainability of soil quality, fertility and productivity.

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