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Soil Macronutrient Availability and Microbial Population Dynamics of Organic and Conventional Agroecosystems

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Abstract: The influence of cultivation practices on rates of development of soil fungi and bacteria as well as on soil macronutrients were studied over a two years period (2007-2009). Soil organic carbon (SOC), available nitrogen (AN), available phosphorus (AP) and available potassium (AK) varied significantly over the season and showed a gradient of change with depth. Significantly higher microbial populations were observed in organically managed agroecosystems than of a conventional one. In both the farming systems top soil layer contained higher amount of SOC and available macronutrients than of inner layers. However, in summer months the microbial counts were more in inner soil layer than on the surface soil though such trend of SOC and soil macronutrients was observed. The microbial health and nutrient level of the organic fields were significantly higher than of conventional one.

Key words: Bacteria · Fungi · Soil macronutrient · Organic · Conventional farming

INTRODUCTION

Soil is a complex ecosystem, delimited by physicochemical parameters that hold enormous living organisms. Many soil organisms offer benefits to the crops by facilitating nutrient availability to the rhizosphere, but all interactions have not yet been fully studied. The soil microbes decompose the plant and animal residues in the soil which in turn influence the soil physical, chemical and biological properties. Nevertheless, enhanced site specific diversity results in higher levels of below ground microbial diversity and productivity [1]. Agriculture practices affect the soil environment and are likely to disturb soil microbial communities and their composition, subsequently affecting soil processes [2-4]. Conventional agriculture has an important role in improving food productivity. However, this system has been largely dependent on intensive chemical inputs. On the other hand, organic agriculture does not use synthetic fertilizers and pesticides, attempt to protect environmental quality and enhance beneficial interactions and processes [5]. Farming practices are likely to influence soil microbial community and nutrient level which in turn affect the crop production. One of such practice is the use of organic amendments as an alternative conventional chemical input that is in common use in the developing countries like India. Therefore, it's essential to evaluate the significance of organic farm practice before recommending it for use in the tropical conditions, whereas soil moisture availability is a problem. Again, the numbers of studies comparing organic and conventional systems in India are limited still the adoption of organic farming practices by the farmers. Hence the present experiment was designed to make a comparative study of some important soil nutrients and microbial population of organic and conventional agro ecosystems in the state of Orissa, India.

MATERIALS AND METHODS

Sampling: The study was conducted during March 2007 to January 2009 in three different seasons i.e. summer (March-May), rainy (July-September) and winter (November-January). Soil samples were collected from rice fields under both organic and conventional farming systems located in Khurda district of Orissa state and maintained by the Orissa University of Agriculture and Technology, Bhubaneswar. Sampling was done at an

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interval of 15 days during the entire period of study. The sites were characterized by a climate with most rainfall occurring during rainy months (July-September). The ambient temperature average ranged from a minimum of 11.1°C to a maximum of 44.6°C and annual normal rainfall of 1449.1 mm. Soil samples were collected from top 20 cm of soil and were segregated into five depth classes at 4 cm intervals. Collection was made in sterilized polythene bags using a steel corer and each sample was divided into three replicates. The replicates were labeled and left for isolation and enumeration of bacteria and fungi within 24 hours after collection. The remaining soil samples were air dried ground and sieved for the determination of SOC, AP, AK and AN.

Isolation of Bacterial and Fungal Population: The isolation of bacteria and fungi was done by spread plate method using Nutrient Agar and Potato Dextrose Agar, respectively. Soil microbial population was estimated by dilution plate method [6]. The inoculated plates were incubated at 37°C for 24 hours for bacteria and 25°C for 72 hours for fungi after which colonies were counted with the help of a digital colony counter and expressed as number of colony forming units (cfu/g) of dry soil [7].

Major Soil Macro Nutrients Studies: Soil organic carbon (OC) was estimated titrometrically [8], mineralisable nitrogen (MN) was quantified by the method described by Subbaiah and Asija [9]. Available Phosphorus (AP) and Potassium (AK) were carried out by Olson method [10] and Ammonium acetate flamephotometry method [11] respectively.

Statistical Analysis: The samples were collected in triplicates from 5 plots each of fifteen zones. The replicates of one sample zone were averaged as one replicate. The statistical analysis of all the data has been done using M Stat C Software (Michigan State University, USA). The data were analyzed through ANOVA (at P = 0.05 levels) among the seasons and the depths. Correlation among bacterial and fungal populations as well as the activity of the enzymes was made following standard statistical procedures [12].

RESULTS

The average bacterial and fungal population variation in organic and conventional farming systems over the seasons has been depicted in figs. 1 and 2, respectively for three crops. In both organic and conventional farming system the bacterial count (1x 10^4 cfu/g of soil) as well as

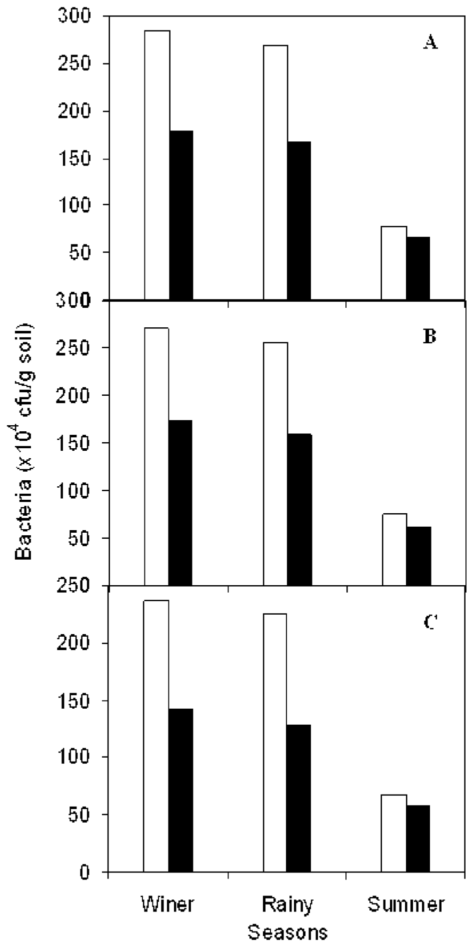

Fig. 1: Season wise variation in bacterial population (x 10^4 cfu/g soil) in (A) rice, (B) - pulses and (C) - vegetable farming system. Histograms: *full*- organic; *empty*- conventional.

fungal count (1x 10^3 cfu/g of soil) showed the highest value in winter followed by rainy and lowest in summer irrespective of depth for all the three crops. The bacterial load in summer season was observed to be 27, 27 and 28% (organic) and 37, 36 and 40% (conventional) rice, pulses and vegetable fields, respectively. Similarly, the fungal count was calculated to be 77, 77 and 73% (organic) and 90, 92 and 71% (conventional) rice, pulses and vegetable fields, respectively. The depth wise variations in average bacterial and fungal population in both the farming systems have been depicted in figs. 3 and 4, irrespective of seasons, respectively. In organic farming systems irrespective of seasons D1 layer indicated the highest bacterial population and fungal count whereas minimum values were found in D5 for rice and vegetable. But, in case of pulses D2 layer exhibited maximum bacterial population whereas maximum fungal population was

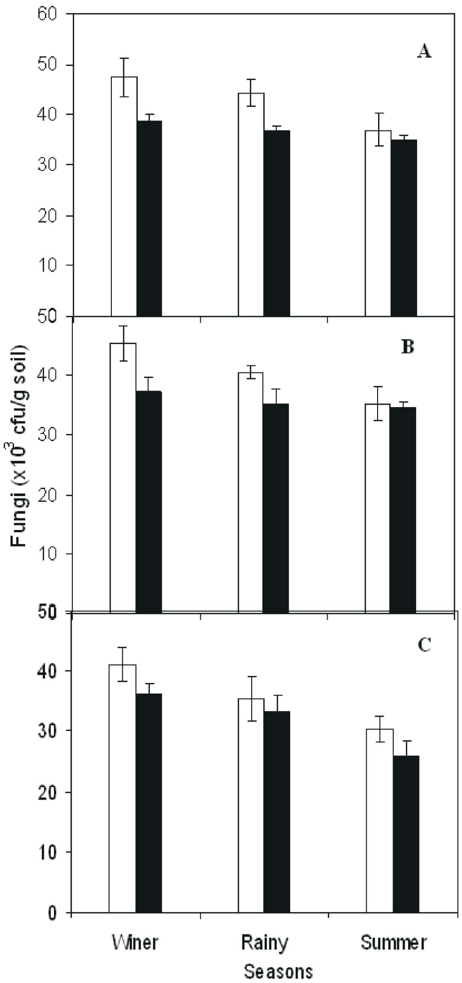

Fig. 2: Season wise variation in fungal population (x10^3 cfu/g soil) in (A) rice, (B) - pulses, and (C) - vegetable farming system. Histograms: *full*- organic; *empty*- conventional.

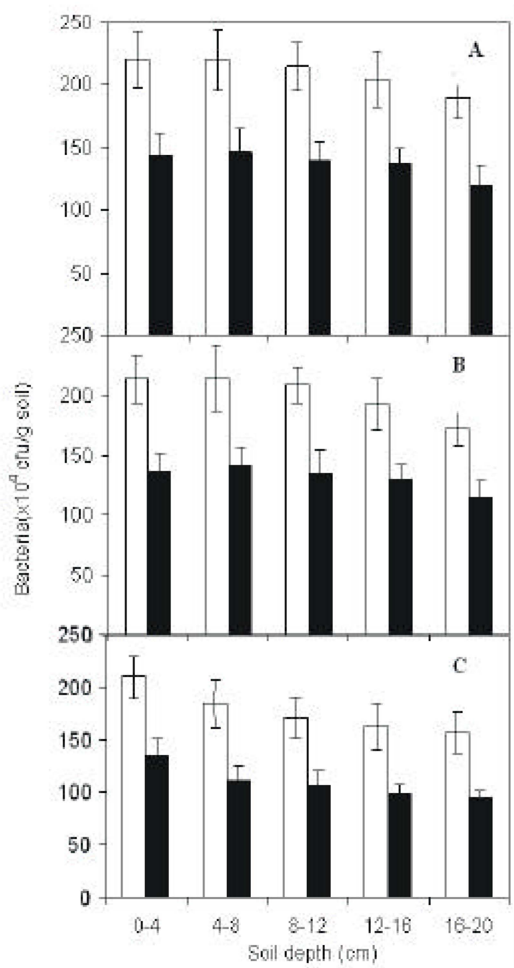

Fig. 3: Depth wise variation in bacterial population (x 10^4 cfu/g soil) in (A) rice, (B) - pulses, and (C) - vegetable farming system. Histograms: *full*- organic; *empty*- conventional.

found in D1. Both the population showed minimum value in D5 for pulses. In conventional farming systems, D2 showed highest bacterial count for rice and pulses whereas for vegetable D1 showed maximum and D5 the minimum value. Also, in both organic and conventional farming system the seasonal as well as depth wise variation for average bacterial and fungal population was found to be highest in winter and rainy seasons in D1 depth, while the lowest counts were obtained in D5 for all the crops.. For both systems a reverse trend in summer was noticed where the minimum count was found in D1 and the D5 exhibited highest count. Besides, summer season higher microbial load in terms of bacteria and fungi was noticed in the deeper soil layer than surface layer. The bacterial load in last soil layer (16-20 cm) was found to be 86, 80 and 79% (organic) and 86, 83 and 81% (conventional) than the surface soil layer in rice, pulses and vegetable farm systems, respectively. The fungal count in the inner soil layer was calculated to be 77, 77 and 73% (organic) and 90, 92 and 71% (conventional) rice, pulses and vegetable fields, respectively. However, in almost all cases organic farming systems showed more bacterial and fungal population irrespective of season and depth. The bacterial count in conventional field was found to be 62, 63 and 60% (winter), 62, 62 and 56% (rainy) and 84, 83 and 85% (summer) than of the organic rice, pulses and vegetable farming system. Similarly, the corresponding percentage of fungal count in conventional farming system was calculate to be 81, 82 and 87% (winter), 82, 86 and 93% (rainy) and 95, 97 and 85% (summer) than the conventional one. From the annual average values it was observed that the difference of

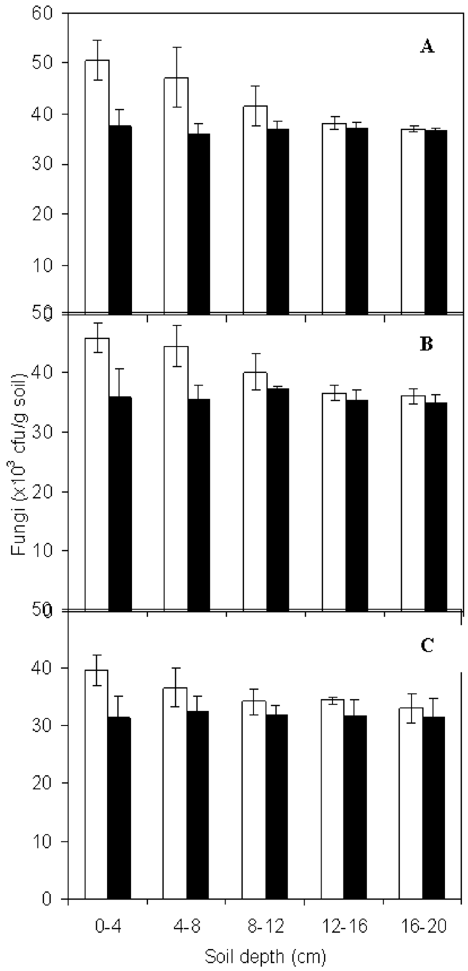

Fig. 4: Depth wise variation in fungal population ($x10^3$ cfu/g soil) in (A) rice, (B) - pulses, and (C) - vegetable farming system. Histograms: *full*- organic; *empty*- conventional.

the microbial density of two farming systems was more prominent in the top 4 cm of soil than in other soil depths though there was consistently higher density of microbes in organic systems than of conventional systems irrespective of the soil depth.

Among the seasons (Table 1), irrespective of crops and farming systems, winter showed the highest average values of for SOC, MN, AP and AK, rainy season the second highest and the lowest was recorded for summer. However, the rate of reduction in the level of mineralisable nitrogen with increase in the depth of soil was found to be more in the organic fields than in the conventional one. Soil organic carbon content in summer were found to be 82, 78 and 80% than winter, respectively for rice, pulses and vegetable fields under conventional farm practice. The soil organic carbon content at the deeper soil layer (16-20 cm) in organic rice, pulses and vegetable fields were found to be 84, 78 and 80%, respectively of the surface. The corresponding values for conventional farming system were found to be 89, 85 and 92%, respectively for rice, pulses and vegetable fields. The values of nitrogen content of conventional rice, pulses and vegetable fields were calculated to be 89, 91 and 91%, respectively compared to that of organic fields. The level of phosphorus in organic rice, pulses and vegetable was found to be 70, 77 and 83% in summer than winter and the respective percentage for conventional fields were 79, 84 and 83%. The available potassium in summer was found to be 74% than that of winter for all the crops with organic farming, but the corresponding values for conventional rice, pulses and vegetable fields was found to be 77, 79 and 80%, respectively showing the variation in the latter farming system. But the amount decreased with increasing soil depth as were recorded in D5 in all the three seasons

Table 1: Seasonal variation of soil organic carbon organic (SOC: g/Kg), mineralizable nitrogen N (AN: Kg/ ha) available phosphorus (AP: Kg/ ha) and available potassium (AK: Kg/ha) in organic (O) and conventional (C) farming systems for three crop fields

	SOC		MN		AP		AK	
Season	O	C	O	C	O	C	O	C
RICE								
Winter	9.02±0.73	4.83±0.24	148.8±10.61	135.4±6.32	29.73±3.19	19.81±2.84	157.2±14.76	131.1±15.78
Summer	7.66±0.29	3.98±0.18	139.2±6.98	125.5±4.34	20.93±2.49	15.64±1.52	116.1±9.59	100.4±6.56
Rainy	8.12±0.69	4.66±0.19	146.7±5.51	128.5±4.34	26.87±3.83	18.32±2.61	131.4±12.45	113.9±11.71
PULSES								
Winter	8.43±1.04	4.82±0.17	144.2±12.06	135.2±2.32	30.34±3.76	19.81±2.15	149.9±14.87	127.1±16.47
Summer	7.12±0.46	3.74±0.28	136.2±7.35	125.5±5.34	27.78±2.29	16.67±1.81	110.6±12.05	101.2±10.58
Rainy	7.88±0.99	4.48±0.14	147.3±4.01	128.5±2.34	24.24±2.15	18.87±2.94	131.7±8.83	116.5±8.09
VEGETABLE								
Winter	8.28±1.05	4.61±0.24	145.3±5.87	131.9±6.85	21.81±2.29	18.21±3.52	138.4±11.42	121.3±8.66
Summer	6.92±0.35	3.69±0.17	130.5±2.05	122.9±2.47	18.07±1.84	15.06±2.74	103.7±11.24	96.7±12.95
Rainy	7.94±0.65	4.19±0.09	142.4±3.46	123.8±6.47	20.12±2.28	17.54±2.71	118.9±7.89	107.5±9.55

Table 2: Depth wise variation of soil organic carbon organic SOC: (g/Kg), mineralizable nitrogen N (AN: Kg/ ha) available phosphorus (AP: Kg/ ha) and available potassium (AK: Kg/ha) in organic (O) and conventional (C) farming systems for three crop fields

Depth range (cm)	SOC O	SOC C	MN O	MN C	AP O	AP C	AK O	AK C
RICE								
0-4	9.12±1.04	4.70±0.48	156.6±7.34	131.8±5.09	30.11±4.78	21.12±2.42	168.2±7.66	137.6±11.21
4-8	8.39±0.81	4.66±0.35	150.1±7.12	130.7±4.51	27.56±2.91	18.14±2.27	144.4±9.46	124.2±13.38
8-12	8.28±0.74	4.52±0.41	146.3±4.04	132.3±6.11	25.56±2.01	18.02±2.01	133.1±11.51	114.4±5.50
12-16	7.84±0.51	4.38±0.31	138.2±6.01	128.1±4.98	24.11±2.40	16.23±2.52	119.3±12.89	101.2±9.01
16-20	7.69±0.48	4.21±0.43	136.4±5.70	126.2±4.97	21.89±1.50	16.17±1.02	109.7±6.72	98.5±8.35
PULSES								
0-4	8.97±1.07	4.61±0.53	153.9±7.37	131.8±5.09	30.2±4.35	21.56±1.92	156.4±9.32	136.3±13.80
4-8	8.23±0.76	4.55±0.42	146.8±7.72	130.7±4.50	27.78±2.59	20.07±2.30	132.5±14.86	122.7±14.85
8-12	7.76±0.60	4.47±0.37	143.4±4.91	132.4±6.11	24.45±3.97	17.67±1.45	135.9±12.98	114.2±11.55
12-16	7.12±0.32	4.17±0.49	135.9±7.97	128.2±4.98	23.56±2.52	16.78±1.57	119.3±12.89	105.7±8.62
16-20	6.98±0.44	3.92±0.234	133.3±5.17	126.3±5.17	22.48±1.12	16.27±1.35	109.6±7.70	95.8±3.29
VEGETABLE								
0-4	8.71±1.05	4.37±0.53	144.7±12.37	129.1±3.41	23.22±2.34	20.56±1.95	144.1±19.04	131.6±16.23
4-8	8.09±1.17	4.27±0.57	138.2±9.32	126.6±4.71	20.05±2.90	19.33±1.85	126.4±9.69	117.8±9.01
8-12	7.57±0.62	4.16±0.602	139.1±6.24	126.3±6.65	18.67±2.19	16.47±2.21	118.6±14.53	114.2±9.31
12-16	7.18±0.43	3.98±0.47	138.4±5.59	125.2±6.37	19.24±2.12	14.36±1.67	111.4±12.11	102.8±7.15
16-20	6.99±0.44	4.04±0.19	136.5±5.88	123.7±3.55	18.78±0.77	14.06±1.19	101.7±6.79	95.9±5.53

Table 3: Analysis of variance of parameters of rice, pulses and vegetable field soil

Variables	S and F C.D	S and F F	D and F C.D	D and F F	S, D and F C.D	S, D and F F	C.V (%)
RICE							
Bacteria	1.04	10355	1.34	38.64	2.32	40.53	0.82
Fungi	1.85	16.10	2.39	24.07	4.15	3.92	6.36
SOC	0.12	39.58	0.16	24.29	0.27	3.42	2.62
MN	1.14	47.33	1.47	73.33	2.55	6.56	1.13
AP	0.89	28.00	1.15	6.20	1.99	1.74	5.58
AK	1.54	51.27	1.99	47.33	3.44	39.46	1.69
PULSES							
Bacteria	2.53	1523	3.27	26.65	5.66	8.41	2.09
Fungi	1.43	26.72	1.85	20.96	3.21	3.66	5.15
SOC	0.11	4.65	0.14	59.44	0.25	10.54	2.59
MN	1.16	82.25	1.49	73.73	2.59	11.46	1.16
AP	0.78	31.24	1.00	4.30	1.75	1.88	4.85
AK	2.25	35.51	2.89	11.67	5.02	11.41	2.51
VEGETABLE							
Bacteria	4.05	606	5.22	7.08	9.05	2.58	3.88
Fungi	1.89	3.18	2.45	4.41	4.24	6.06	7.17
SOC	0.09	40.83	0.12	89.76	0.19	12.44	2.06
MN	1.08	104.91	1.39	4.53	2.42	10.33	1.12
AP	0.73	2.15	0.94	14.51	1.63	4.47	5.41
AK	1.72	34.79	2.22	7.56	3.84	14.00	2.05

Note: F values were found significant at p = 0.01. Abbreviations: SOC-soil organic carbon; MN- mineralizable nitrogen; AP- available phosphorus; AK- available potassium; S – season; D – depth; F – farming system.

except summer month. It can be visualized (Table 2) that D1 (0-4) has the highest nutrient values with subsequent decline up to D5 (16-20). It was also observed that all the nutrients showed a decline in their amount with subsequent increase in soil depth irrespective of season and crops. The amount of phosphorus in deeper soil layer (16-20) was calculated to be 73, 76 (rice), 74 and 75 (pulses) and 81 and 68% (vegetable), than the surface soil layer, respectively for organic and conventional farming system. The available phosphorus content of conventional rice, pulses and vegetable fields were calculated to be 69, 72 and 85% than that of organic farms, respectively indicating that only for vegetable field minimum variation was noted between the two farming systems. The amount of available potassium in soil layer of 16-20 cm depth was found to 65 and 71% (rice), 70 and 76 (pulses) and 71 and 69% (vegetable) organic and conventional fields, respectively. The available potassium in conventional rice, pulses and vegetable fields was found to be 85, 88 and 90%, respectively than that of organic one, proving that organic fields had higher values of potassium than conventional one independent of season and crop fields. A statistically significant difference ($P<0.01$) was observed in the nutrients, bacterial and fungal population among seasons, soil depths as well as for season and soil depth taken together (Table 3). The difference in microbial population was also significant between soil depths and between seasons. In both the cultivation conditions there was gradual decrease of microbial density with increase in soil depth in winter and rainy, except the summer months, where inner layers were denser in microbes than surface soil.

DISCUSSION

Independent of the farming systems, soil depths and crops, population of both the bacteria as well as fungi were found highest in winter followed by rainy and summer. In tropical climate the winter season provides the moderate temperature and soil moisture conditions. The distribution of microbial population in soil is determined by important environmental factors such as soil moisture, pH and organic matter [13]. Our observation is similar to the reports of Jha *et al.* [14] who recorded higher population of bacteria in post rainy (autumn) period [15] and higher fungal population during autumn and winter. In the present study the fungal population has been recorded to be high in winter which supports these earlier observations. Higher fungal population in post monsoon (winter) period are perhaps due to the prevailing favorable moisture, temperature settings and accumulation of humus which enhance the colonization of soil microbes. Increase in number of microbial population in summer towards deeper soil layers as seen from our results corroborates that of Classen *et al.* [16] who pointed out that during hot summer months, the sub layer of soil occasionally harbors more fungal populations caused by temperature and moisture regimes than that prevailing in topsoil layer.

Generally, topsoil contains high organic matter which in presence of adequate moisture supply is acted upon by microbes to decompose complex organic residues into simpler forms. Therefore, microbial counts are generally higher in the surface soil layer [17]. Further, overall reduction in microbial population in the lower soil depths has been attributed to lesser amounts of minerals, oxygen availability and higher carbon dioxide concentration [18]. However, the natural forest soil at 0-10 cm depth has the greatest number of fungi and bacteria count [19], which is supported by the observation of Piriyaprin ***et al.*** [20] that the number of microorganisms in the upper soil depths was higher than those of the lower. Our observation corroborates these earlier findings indicating higher bacterial and fungal colonies in the upper soil layers with respect to the deeper ones in organically and conventionally managed systems.

Higher bacterial and fungal counts in the organic management systems than conventional one has also been reported by earlier studies [21] corresponding with higher levels of organic carbon in former than in the latter one [22]. Our findings are in agreement with the proposition that organic farms are superior sources of soil organic matter which are essential for microbial growth and activity. Higher organic matter level in soil is also important for sustainability, since it influences soil physical, chemical and biological properties [23]. The retention of organic matter has also been reported to be higher in organic farms in comparison to conventional farms [3, 24]. Thus it is clear that our results are similar to these earlier findings as organic farms have shown more microbial population than conventional farms.

Population of bacteria and fungi varied from 10^5 to 10^4 respectively [25] in tomato field. Similar results were obtained by Castro ***et al.*** [26]. Bacterial counts were always high as compared to fugal population [27]. Our findings are in agreement with the above results.

In conclusion, the present study concludes that management practices have significant influence on microbial population and level of available soil nutrients. The study indicated that counts of bacteria and fungi were higher in soils from organic in comparison to conventional farming systems irrespective of seasons and soil depths and crops. The study also indicated a decline in both bacterial and fungal population with corresponding availability of soil nutrients such as OC, N, P and K at different soil depths. The variations in microbial population have been attributed to the availability of macronutrients. There was significant difference in microbial density of the two farming systems, the organic one having more than conventional.

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