Global Theme on Agroecosystems

Report no. 25

Microbial Status of Different Carbon Sequestering Systems in the Semi-Arid Tropics

International Crops Research Institute for the Semi-Arid Tropics

Indian Council of Agricultural Research

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Abstract

Microorganisms perform a key role in nutrient cycling for sustaining the productivity of soils. Microbial status was studied in soil samples from nine long-term experiments at different locations, with different carbon sequestering systems in the semi-arid tropics of India. Microbial population counts were analyzed using spread plate method and were in turn compared with different parameters such as soil treatments, soil type, soil microbial biomass C, soil organic C (SOC), soil respiration rainfall and soil pH. The counts were high in the soil with different treatments. The counts were also high in treatments where a combination of organic and inorganic fertilizers was applied. Vertisols (28 10^4 CFU g^{-1} soil) recorded four times more counts of microbial populations than Alfisols (7 10^4 CFU g^{-1} soil). In few locations, significant correlation was observed with the values of soil microbial biomass C, SOC, soil respiration and microbial populations.

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Contents

Introduction

Microorganisms perform a key role in nutrient cycling for sustaining the productivity of the soils, because they are the source and sink for mineral nutrition and can carry out biochemical transformations (Jenkinson and Ladd 1981). The decomposition of plant and animal residues in the soil constitutes a basic biological process owing to ional population of microorganisms. In this process, carbon is recycled as carbon dioxide (CO_2), nitrogen is converted to ammonium, and other associated elements appear in forms required by higher plants (McGill and Cole 1981). A part of nutrients is assimilated by microorganisms and incorporated into microbial tissues (biomass). Microorganisms regulate the nutrient flow in the soil by assimilating nutrients and producing soil biomass (immobilization) and converting C, N, P and S to mineral forms (mineralization) (Jenkinson and Ladd 1981; Wani and Lee 1995). In the absence of a soil life, all biochemical transformations cease and agricultural production suffers (McGill and Cole 1981; Wani and Lee 1995).

Nutrient depletion due to traditional low input farming systems has adverse impact on soil organic carbon (SOC). Management of soil fertility through judicious use of fertilizers, and organic manure, maintained SOC at higher levels than in systems based on low input strategy. The changes in the SOC contents are also directly associated with changes in microbial biomass carbon and biological activity in the soil. Besides living plant roots and organisms, the soil microbial biomass is a living portion of soil organic matter. Maintenance of microbial community through residue management is a means for retaining organic matter and improving nutrient availability in the rainfed farming system. The response to changes in inputs of organic material is quicker in soil microbial biomass than in soil organic matter (Powlson and Jenkinson 1981). Microbial biomass contains labile fraction of organic C and N, which are mineralized rapidly after the death of microbial cells.

The soil carbon pool composed of soil organic and inorganic C plays an important role in carbon cycle. The SOC equilibrium is governed by a number of interacting factors such as temperature, moisture, texture, quantity, and quality of organic matter; methods of organic matter application; soil tillage and cropping system. C sequestration can be augmented by increasing the quantity of organic matter returned or added to the soil, or by reducing the SOC lost by oxidation or erosion or by a combination of both.

Environmental issues have stimulated development of strategies to control the emissions of greenhouse gases from various sources. Soil acts as both source and sink for CO_2. Storing or sequestering C in soils is an important strategy to decrease atmospheric CO_2, and at the same time improves the organic matter status and fertility of soils.

Atmospheric concentration of CO_2 – one of the principal greenhouse gases – has increased from 280 to 365 ppm over the past 60 years (Keeling and Whorf 1998). The concentrations of CO_2 and other greenhouse gases can be lowered by reducing emissions or by absorbing CO_2 from the atmosphere via photosynthesis and sequestering it in different compounds of terrestrial, oceanic and freshwater aquatic ecosystems. The carbon sequestration potential of world cropland over the next 20 to 100 years may be in the order of 20 to 30% (Cole 1996), which is 7 to 11% of the emission from fossil fuel combustion at 1990 levels, over past 50 years. By making modest changes to existing farming practices, plant and soils can effectively reduce atmospheric concentration of CO_2.

Organic carbon levels increased with continuous cropping, particularly when legumes were included in the improved systems (Wani et al. 1994). Singh et al. (1996) showed that over a period of five years the change in the SOC was negative under cereal-cereal sequences, whereas the SOC had increased in

other cropping sequences with legume component. Continuous application of farmyard manure (FYM) and green manure substantially improved the organic carbon under different soils and cropping systems (Manna et al. 1997; Singh et al. 1996; Swarup 1998; Wani et al. 2003).

Soil aggregation or formation of organic products governs soil quality and facilitates C sequestration in soil. Formation of stable secondary particles or aggregates influences C sequestration by physically protecting the organic matter from microbial enzymes. Soil aggregation is affected by many factors such as climate, textural composition, method of deforestation and land development, tillage methods, and cropping system (Wani et al. 2000).

Background

The project on "Microbial Status of Different Carbon Sequestering Systems in the Semi-Arid Tropics" deals with the influence of the cropping system and management practices on microbial activity and its role in carbon sequestration in soils. The tropical soils are low in organic carbon content and in principle have a large potential to sequester C through appropriate land and crop management options.

Under the National Agricultural Technology Project (NATP), a project on "Identifying systems for carbon sequestration and increased productivity in semi-arid tropical environments (RNPS 25)," number of benchmark sites were studied to understand the relationship between C sequestration and management options. At some benchmark sites, the All India Coordinated Research Project on Dryland Agriculture (AICRPDA) coordinated by Central Research Institute for Dryland Agriculture (CRIDA) with long-term experiments evaluating management practices for improving soil quality and sustaining agricultural productivity are ongoing. The experiments provided an excellent opportunity to study the effects of different agroclimatic conditions and crop soil management practices on C sequestration and study the microbial status in selected soil and crop management practices over a long period. The specific objectives of this investigation were as follows:

1. Study the relationship between soil microorganisms and management practices and their role in the SAT systems
2. Understand the link between microbial activity and C sequestration in the SAT soils with an aim to identify the C sequestration systems in the SAT.

The results will be looked at in a holistic C sequestration context along with the physical and chemical, and agroclimatic conditions in the region at benchmark sites in the SAT.

Long-Term Experiment Sites

Under the AICRPDA, long-term fertility experiments at different centers are being conducted since 1970. The experiments are related to predominant cropping systems and various fertility management treatments involving combination of inorganic and organic sources (alone or together). Nine long-term experimental sites selected for this study along with rainfall and soil characteristics are given in Table 1 and depicted in Figure 1.

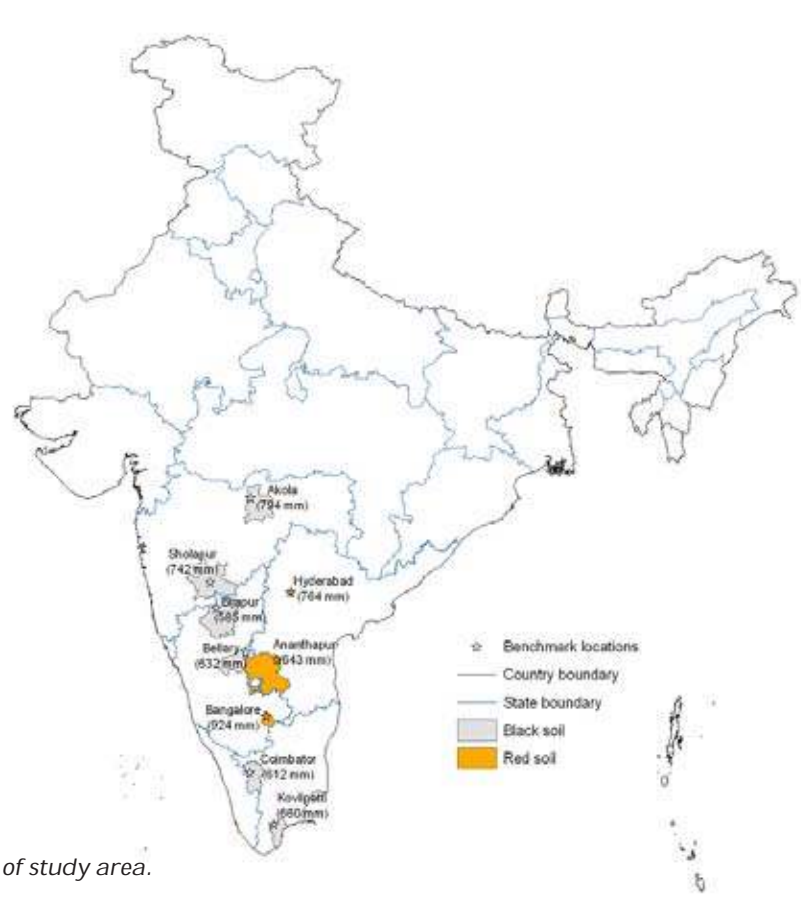


Figure 1. Location map of study area.

Table 1. Location, climate and site characterization at benchmark sites.

Sl No.	Benchmark site	State	Location			Rainfall soil samples aridity index		
			Latitude (N)	Longitude (E)	Altitude (m)	Climate	Mean annual rainfall (mm)	Soil type
1	Akola	Maharashtra	20.7	77.0	282	Semi-arid (AWC 18–40 cm)	794	Vertisols
2	Anantapur	Andhra Pradesh	14.68	77.62	350	Arid (AWC 5–6 cm)	643	Alfisols
3	Bangalore	Karnataka	12.97	77.58	930	Semi-arid (AWC 5–13 cm)	924	Alfisols
4	Bellary	Karnataka	16.5	76.85	448	Semi-arid	632	Vertisols
5	Bijapur	Karnataka	16.82	75.72	594	Semi-arid (AWC 18–40 cm)	585	Vertisols
6	Coimbatore	Tamil Nadu	11.0	77.0	426	Semi-arid	612	Vertisols
7	Hyderabad	Andhra Pradesh	17.33	78.5	516	Semi-arid (AWC 5–13 cm)	764	Alfisols
8	Kovilpatti	Tamil Nadu	9.17	77.87	90	Semi-arid (AWC 10–12 cm)	660	Vertic inceptisols
9	Solapur	Maharashtra	17.68	75.93	484	Semi-arid (AWC 18–40 cm)	742	Vertisols

Source: CRIDA. Annual Report 1999–2000, All India Coordinated Research Project for Dryland Agriculture, CRIDA.

For this study, selective contrasting fertility management treatments with a differentiating potential for C sequestration were selected. The details of the experiment and the treatments sampled for this study are described in Table 2.

Table 2. Different treatments in the long-term fertility management experiment at different locations.

Sl No.	Location and year of experiment	Cropping system	Treatments
1	Akola (1987)	Cotton + green gram	(1) Control (T1) (2) 50:25 kg NP ha^{-1} (100% recommended dose) (T2) (3) 25:12.5 kg NP ha^{-1} (50% recommended dose) (T3) (4) 25 kg N ha^{-1} through *Leucaena* loppings (T4) (5) 25 kg N ha^{-1} through FYM (T5) (6) 25 kg N ha^{-1} through *Leucaena* loppings + 25:25 kg NP ha^{-1} through fertilizer (T6) (7) 25 kg N ha^{-1} through FYM + 25:25 kg NP ha^{-1} (T7) (8) 50 kg N ha^{-1} through *Leucaena* loppings + 25 kg P ha^{-1} through fertilizer (T8)
2	Anantapur (1985)	Groundnut	(1) Control (T1) (2) 20:40:40 kg N, P_2O_5, K_2O ha^{-1} (T2) (3) 10:20:20 kg N, P_2O_5, K_2O ha^{-1} (T3) (4) Groundnut shells @ 4 t ha^{-1} (T5) (5) FYM @ 4 t ha^{-1} (T5) (6) 10:20:20 kg N, P_2O_5, K_2O ha^{-1} + Groundnut shells @ 4 t ha^{-1} (T6) (7) 10:20:20 kg N, P_2O_5, K_2O ha^{-1} + FYM @ 4 t ha^{-1} (T7)
3	Bangalore (1999)	Finger millet	(1) Control (T1) (2) Recommended NPK (50:50:25 kg ha^{-1}) (T2) (3) Recommended N (1/3 green leaf manure + 1/3 FYM + 1/3 crop residues) (T3) (4) Recommended 50% N (1/3 green leaf manure + 1/3 FYM + 1/3 crop residues) + 50% NPK (T4)
4	Bellary (1978)	Maize–chickpea	(1) Control (T1) (2) NPK application on soil test based (T2) (3) FYM @ 5 t ha^{-1} $year^{-1}$ (T3) (4) FYM @ 15 t ha^{-1} $year^{-1}$ once in three years (T4) (5) NPK application on STB + FYM @ 5 t ha^{-1} $year^{-1}$ (T5)
5	Bijapur (1995)	Pigeonpea–sunhemp–sorghum + chickpea	Main treatments: (1) Control (No residue incorporation) (S0) (2) Residue incorporation (S1) Sub plots: (1) 0% Recommended N (Sunhemp incorporation @ 5 t/ha) (T1)

... Continued

Table 2. *Continued...*

Sl No.	Location and year of experiment	Cropping system	Treatments
			(2) 50% Recommended N [Sunhemp incorporation @ 2.5 t/ha + 50% recommended fertilizer (inorganic)] (T2) (3) 100% Recommended N [100% recommended fertilizer (inorganic)] (T3)
6	Coimbatore (1972)	Finger millet–maize–cowpea fodder	(1) Control (T1) (2) 50% optimal NPK (T2) (3) 100% optimal NPK (T3) (4) 100% optimal NPK+FYM (T4)
7	Hyderabad (CRIDA) (1995)	Sorghum–castor	Control Main treatments: (1) Zero tillage (Z) (2) Conventional tillage (C) Sub-treatments: *(1) Gliricidia* loppings @ 2 t ha^{-1} (surface application) (G) (2) No residue (N) Sub-treatments: (1) 60 kg N ha^{-1} (60)
8	Kovilpatti (1982)	Pearl millet–sorghum	(1) Control (T1) (2) Recommended dose of N and P_2O_5 (40:20 kg ha^{-1}) (T2) (3) 50% recommended dose (20 kg N + 10 kg P_2O_5 ha^{-1}) (T3) (4) On-farm residue to meet 20 kg N ha^{-1} (T4) (5) FYM to meet 20 kg N ha^{-1} (T5) (6) 20 kg N as on-farm residue + 20 kg N as urea + 10 kg P_2O_5 ha^{-1} (T5) (7) 20 kg N as FYM + 20 kg N as urea + 10 kg P_2O_5 ha^{-1} (T7)
9	Solapur (1984)	Fallow–sorghum	(1) Control (T1) (2) 25 kg N ha^{-1} urea (T2) (3) 50 kg N ha^{-1} urea (T3) (4) 25 kg N ha^{-1} CR (T4) (5) 25 kg N ha^{-1} FYM (T5) (6) 25 kg N ha^{-1} CR+ 25 kg N ha^{-1} urea (T6) (7) 25 kg N ha^{-1} FYM + 25 kg N ha^{-1} urea (T7) (8) 25 kg N ha^{-1} CR + 25 kg N ha^{-1} Leucaena (T8) (9) 25 kg N ha^{-1} Leucaena (T9) (10) 25 kg N ha^{-1} *Leucaena* + 25 kg N ha^{-1} urea (T10)

Materials and Methods

Soil Sample Collection

Soil samples were collected from seven consecutive depths (0–15 cm, 15–30 cm, 30–45 cm, 45–60 cm, 60–75 cm, 75–90 cm and 90–120 cm) in the soil profile, from each of the long-term experiments selected for the study during May–June 2001 using 5-cm diameter soil core. In each plot, the cores were collected and pooled together to form homogenous sample for each depth. However, for the microbiological analysis of soil, only the surface layers were collected and these samples were pooled together to form one sample from each plot. The samples were air dried and processed by passing it through 2-mm sieve. Thus mixed and processed soil samples were used for the microbial analysis.

Biomass C

Microbial biomass has been shown to be a sensitive indicator of differences in sustainable cropping systems (Anderson and Domsch 1989). Microbial biomass was estimated by ninhydrin-reactive nitrogen extracted from soil fumigated for 5 days.

Biomass C was estimated by multiplying the ninhydrin N with the factor given by Amato and Ladd (1988), which is given as under:

Biomass C = 21 ninhydrin reactive-N (g C g^{-1} soil)

These values obtained were in turn correlated with the microbial population counts in the soil samples collected.

Organic Carbon

Organic carbon is determined by subtracting inorganic carbon from total carbon.

Total organic carbon = Total carbon – Inorganic carbon.

The total carbon content of the soil samples was determined by dry combustion method using Primacs TOC analyzer. A second analysis of the sample (inorganic carbon) is performed in the low temperature IC reactor chamber (20–150°C).

Soil Respiration

This was estimated according to the method of Anderson (1982). The quantity of carbon respired was calculated as follows:

Milligrams C respired = (B – V) NE

Where B = volume of acid (mL) to titrate blank alkali

V = volume of acid (mL) to titrate the alkali in the CO_2 collectors from the treatments

N = normality of acid and

E = Equivalent weight (if it is in terms of carbon, E = 6; if expressed as CO_2, E = 22)

Enumeration of Microorganisms

The soil samples were enumerated for different groups of microorganisms using different growth media indicated in Table 3.

All the media used were prepared according to the composition given and were sterilized in an autoclave at 121°C and 15 lbs pressure. After sterilization, media was dispersed into petri plates (100 mm diameter 15 mm height), and after solidification these plates were used for the enumeration of microorganisms.

Table 3. Media used, temperature, and incubation period for different microorganisms.

Organism	Media	Temperature of incubation	Period of incubation
Bacteria	Nutrient Agar (NA) (HI-Media laboratory chemicals)	25°C	3 days
Fungi	Potato Dextrose Agar (PDA) (HI-Media laboratory chemicals)	25°C	5 days
Actinomycetes	Actinomycetes Isolation Agar (HI-Media laboratory chemicals)	30°C	14 days

Method

- Ten grams of the soil samples were weighed and were added to the sterile 90 mL water blanks. They were then placed in the shaker for 45 minutes, which resulted in 10^{-1} dilution.
- The 90 mL blanks were removed after 45 minutes and further serial dilutions up to 10^{-6} were made and used for enumeration of microorganism using pour plate method.
- Microorganisms were enumerated using dilution and plate method by spreading 0.1 mL of desired dilution on the media surface using sterilized glass triangle.
- Inoculated plates were incubated in an inverted position and specified temperature and duration as mentioned in the Table 3 were followed.

After the incubation period, the colony forming units were counted and were expressed as CFU g^{-1} of soil. The counts so obtained were compared with different parameters such as biomass C, soil type, and different treatments in the long-term fertility management experiment.

Statistical Analyses

Soil microbial counts and biomass C were analyzed using analysis of variance by Genstat sixth edition.

Results

Vertisols

Akola

Eight treatments using chemical fertilizers with nitrogen and phosphorus, *Leucaena* loppings and FYM were applied. The microbial status of the soil samples collected from this location was compared with other parameters as affected by the nutrient management practices after 14 years under cotton + green gram system (Table 4).

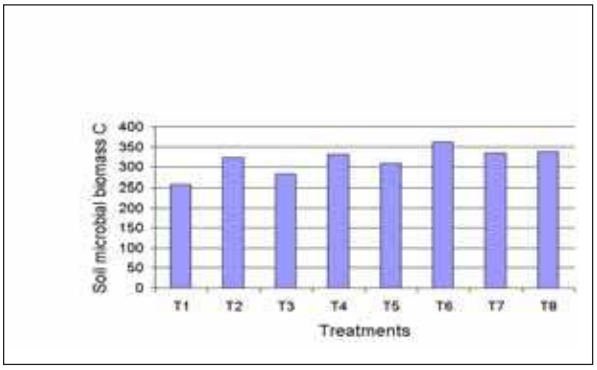
Table 4. Different parameters of surface Vertisol soil samples as affected by long-term (14 years under cotton + green gram) fertility management experiments at Akola.

Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (T1)	258	9.9	205	78	10^4	42	10^3	26	10^3	28	10^4
50:25 NP kg ha^{-1} (100% recommended dose) (T2)	324	11.8	172	84	10^4	24	10^2	33	10^3	29	10^4
25:12.5 NP kg ha^{-1} (50% recommended dose) (T3)	283	11.9	205	39	10^4	9	10^2	23	10^3	14	10^4
25 kg N ha^{-1} through *Leucaena* loppings (T4)	331	9.4	252	63	10^4	10	10^3	4	10^2	21	10^4
25 kg N ha^{-1} through FYM (T5)	308	12.8	171	65	10^4	20	10^2	28	10^3	23	10^4
25 kg N ha^{-1} through *Leucaena* loppings + 25:25 kg NP ha^{-1} through fertilizer (T6)	363	12.7	217	66	10^5	15	10^2	50	10^2	22	10^5
25 kg N ha^{-1} through FYM + 25:25 kg NP ha^{-1} (T7)	334	15.8	294	10	10^5	33	10^2	50	10^3	35	10^4
50 kg N ha^{-1} through *Leucaena* loppings + 25 kg P ha^{-1} through fertilizer (T8)	338	14.3	198	93	10^3	21	10^2	33	10^2	33	10^3
LSD (5%)	42.6	1.17	28	19	10^5	10	10^3	17	10^3		

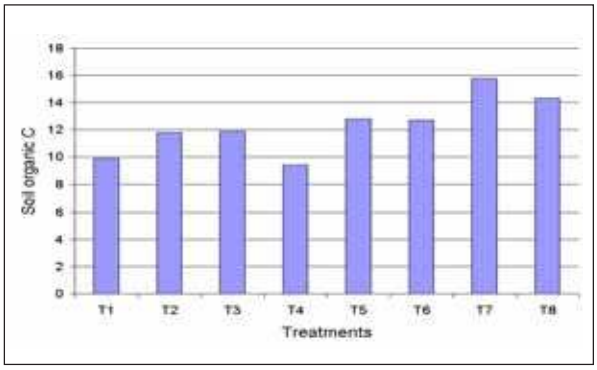
Higher values of soil microbial biomass C (363 g C g^{-1} soil) and microbial populations (22 10^5 CFU g^{-1} soil) were recorded in T6 where a combination of organic (25 kg N ha^{-1} through *Leucaena*) and inorganic (25:25 kg NP ha^{-1}) fertilizers was applied. The SOC (15.8 g C kg^{-1} soil) and soil respiration (294 g C g^{-1} soil $10d^{-1}$) were high in T7 where the soil received FYM and NP. A low value of soil microbial biomass C (283 g C g^{-1} soil) was recorded in T3 where the soil received chemical fertilizers. Low value of the SOC (9.4 g C kg^{-1} soil) was recorded in T4 where *Leucaena* loppings were applied. Low value of soil respiration (171 g C g^{-1} soil $10d^{-1}$) was observed in T5

where the soil received FYM. Microbial populations (33 10^3 CFU g^{-1} soil) were minimum in T8 when compared with other treatments (Figure 2).

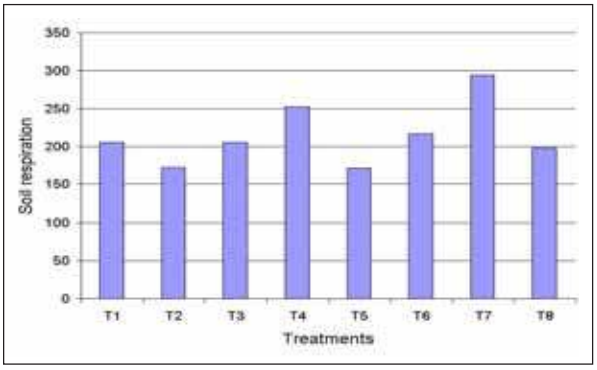
Akola recorded relatively high counts of fungi, which may be due to the cropping system and farming practices. The mean count of microbial populations was also high in Akola when compared with Vertisols of other locations.



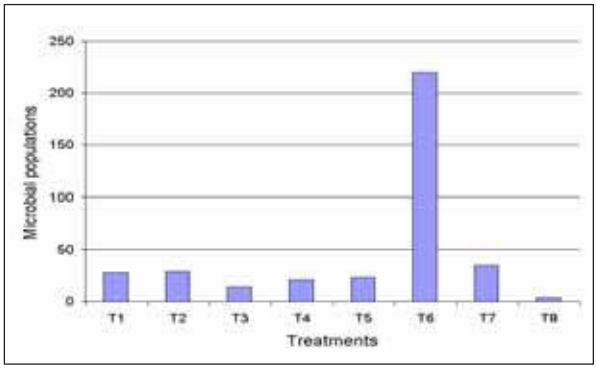
a. Soil microbial biomass C (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (10^4 CFU g^{-1} soil).

Figure 2. Different soil parameters under different treatments at Akola.

Mean annual rainfall in Akola (794 mm) is relatively high. This may be the reason for the high count of microbial populations in this location.

Bellary

At Bellary, four different treatments were applied where NPK was used on soil test based along with FYM at 5 to 15 t ha^{-1} once in three years. The microbial status of the soil samples collected from this location was compared with other parameters as affected by the nutrient management practices after 23 years under maize-chickpea system (Table 5).

Table 5. Different parameters of surface Vertisol soil samples as affected by long-term (23 years under maize-chickpea) fertility management at Bellary.

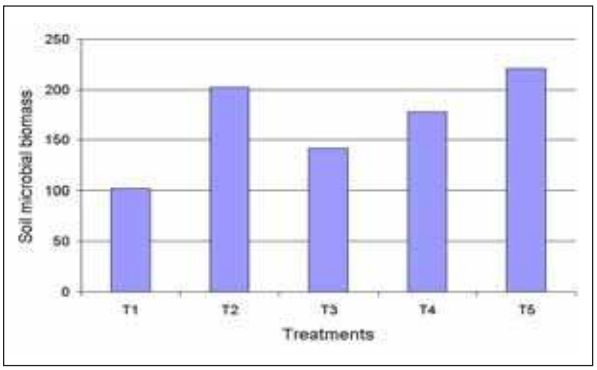
Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (T1)	102	6.5	69	54	10^3	74	10^2	28	10^3	30	10^3
NPK application on soil test based (T2)	202	6.9	160	29	10^4	4	10^2	15	10^3	10	10^4
FYM @ 5 t ha^{-1} $year^{-1}$ (T3)	142	6.7	114	59	10^3	34	10^2	20	10^3	28	10^3
FYM @ 15 t ha^{-1} $year^{-1}$ once in three years (T4)	178	6.8	110	23	10^4	3	10^2	31	10^3	87	10^3
NPK application on STB + FYM @ 5 t ha^{-1} $year^{-1}$ (T5)	221	8.1	171	81	10^5	6	10^2	26	10^3	27	10^5
LSD (5%)	36.0	0.98	33.1	56	10^4	11	10^2	11	10^3		

High values of soil microbial biomass C (221 g C g^{-1} soil), soil respiration (171 g C g^{-1} soil $10d^{-1}$), SOC (8.1 g C kg^{-1} soil), and microbial populations (27 10^5 CFU g^{-1} soil) were recorded in T5 (NPK application on STB + FYM @ 5 t ha^{-1} $year^{-1}$). All the parameters were high in T5, which may be because of the combination of organic with inorganic fertilizers.

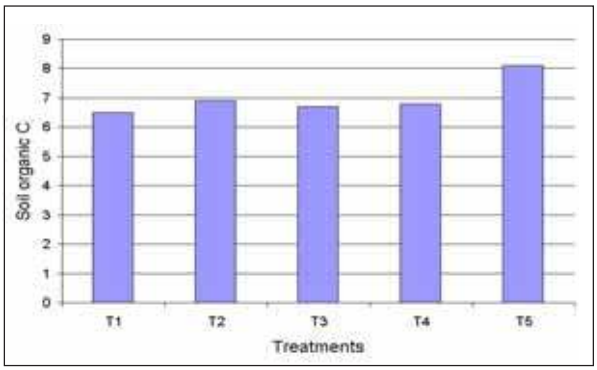
Low values of soil microbial biomass C (142 g C g^{-1} soil), SOC (6.7 g C kg^{-1} soil), and microbial populations (28 10^3 CFU g^{-1} soil) were recorded in T3 (FYM @ 5 t ha^{-1} $year^{-1}$) where organic manure was used alone. Soil respiration (110 g C g^{-1} soil $10d^{-1}$) was low in T4 (FYM @ 15 t ha^{-1} $year^{-1}$ once in three years) (Figure 3). Bellary recorded relatively high counts of bacteria, which may be due to the high application of organic fertilizers and then inorganic fertilizers. Mean annual rainfall in Bellary is 632 mm.

Bijapur

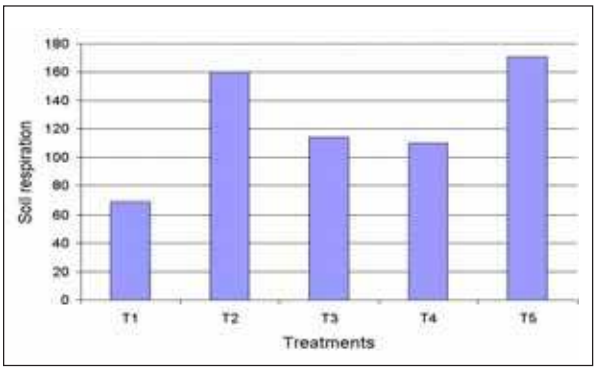
In Bijapur, two main treatments, one without residue incorporation (S0) and the other with residue incorporation (S1). These main treatments were treated with 0% recommended N (T1), 50% recommended N (T2), and 100% recommended N (T3). The microbial status analyzed in the soil samples collected from this location were compared with other parameters as affected by nutrient management practices after 4 years under pigeonpea–soybean–rabi sorghum–chickpea (Table 6).



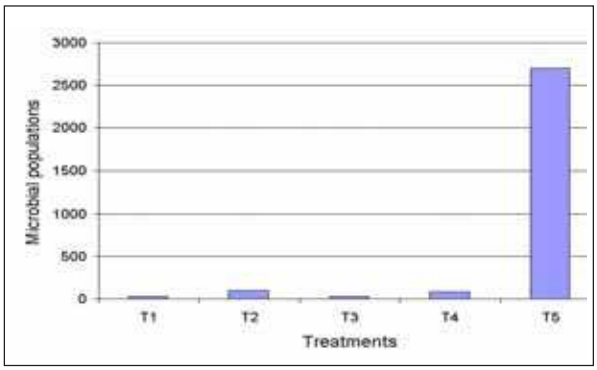
a. Soil microbial biomass (g C g^{-1} soil).



b. Soil organic C (g C kg^{-1} soil).



c. Soil respiration (g C g^{-1} soil $10d^{-1}$).



d. Mean count of microbial population (10^3 CFU g^{-1} soil).

Figure 3. Different soil parameters under different treatments at Bellary.

Table 6. Different parameters of surface Vertisol soil samples as affected by long-term (4 years under pigeonpea–soybean–postrainy sorghum–chickpea) fertility management at Bijapur.

Treatment	Soil microbial biomass C (g C g^{-1} of soil)	Soil organic carbon (g C kg^{-1} of soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (no residue incorporation) with 0% recommended N (Sunhemp incorporation @ 5 t/ha) (S0T1)	131	9.2	63	45	10^4	18	10^2	18	10^3	16	10^4
Control (no residue incorporation) with 50% recommended N [Sunhemp incorporation @ 2.5 t/ha + 50% recommended fertilizer (inorganic)] (S0T2)	141	7.4	63	31	10^4	7	10^2	14	10^3	11	10^4

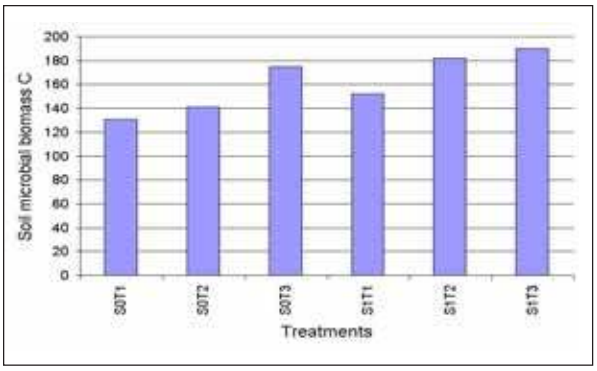
... Continued

Table 6. *Continued...*

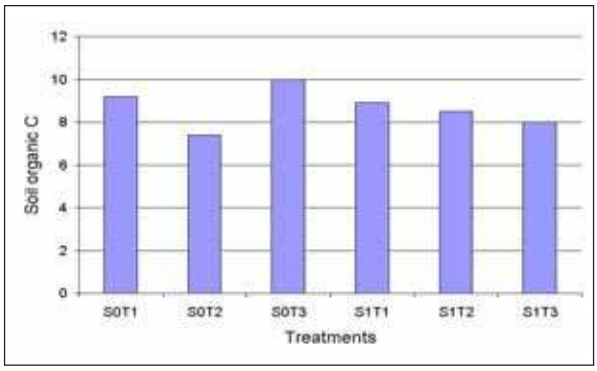
Treatment	Soil microbial biomass C (g C g^{-1} of soil)	Soil organic carbon (g C kg^{-1} of soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (no residue incorporation) with 100% recommended N [100% recommended fertilizer (inorganic)] (S0T3)	175	10.0	67	62	10^4	9	10^2	20	10^3	21	10^4
Residue incorporation with 0% recommended N (Sunhemp incorporation @ 5 t/ha) (S1T1)	152	8.9	62	30	10^4	6	10^2	21	10^3	11	10^4
Residue incorporation with 50% recommended N [Sunhemp incorporation @ 2.5 t/ha + 50% recommended fertilizer (inorganic)] (S1T2)	182	8.5	70	37	10^5	5	10^2	10	10^4	13	10^5
Residue incorporation with 100% recommended N [100% recommended fertilizer (inorganic)] (S1T3)	190	8.0	55	47	10^4	20	10^2	86	10^2	16	10^4
LSD (5%)	NS	NS		143	10^4	8	10^2	3	10^4		

High values of soil microbial biomass C (175 g C g^{-1} soil), SOC (10 g C kg^{-1} soil), soil respiration (67 g C g^{-1} soil $10d^{-1}$) and microbial populations (21 10^4 CFU g^{-1} soil) were recorded in S0T3 (no residue incorporation) with 100% recommended N. With no residue incorporation, low values of soil microbial biomass C (141 g C g^{-1} soil), SOC (7.4 g C kg^{-1} soil), soil respiration (63 g C g^{-1} soil $10d^{-1}$), and microbial populations (11 10^4 CFU g^{-1} soil) were recorded in S0T2 with 50% recommended N.

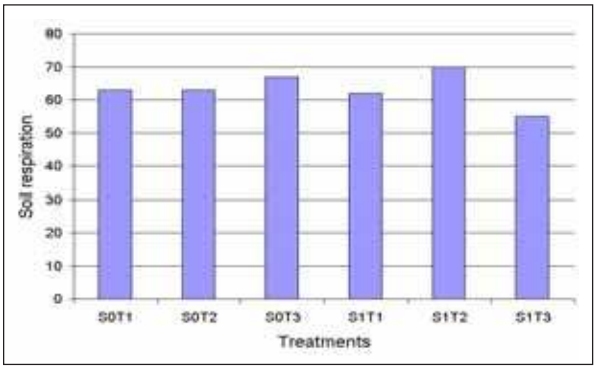
In main treatment (S1) where residue was incorporated, high value of soil microbial biomass C (190 g C g^{-1} soil) was recorded (100% recommended N). Other parameters such as soil respiration (70 g C g^{-1} soil $10d^{-1}$), SOC (8.5 g C kg^{-1} soil), and microbial counts (13 10^5 CFU g^{-1} soil) were high in S1T2 (50% recommended N). Low values of soil respiration (55 g C g^{-1} soil $10d^{-1}$), SOC (8.0 g C kg^{-1} soil), and microbial counts (16 10^4 CFU g^{-1} soil) were recorded with S1T3 (100% recommended nitrogen). Soil microbial biomass C (182 g C g^{-1} soil) was low in S1T2 (50% recommended nitrogen). When compared with the values of the control, all the treatments recorded high values (Figure 4).



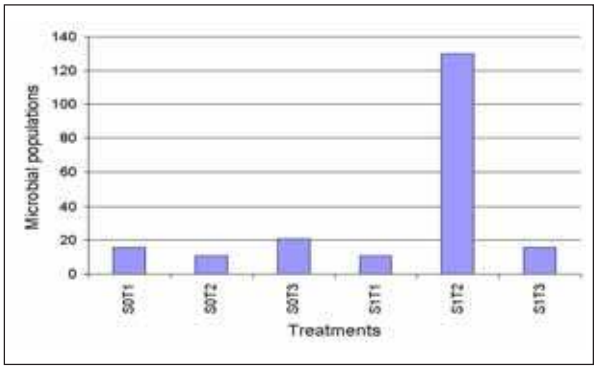
a. Soil microbial biomass (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (10^4 CFU g^{-1} soil)

Figure 4. Different soil parameters under different treatments at Bijapur.

Bijapur recorded microbial populations lower than in the other Vertisols, which may be because of the soil pH (8.0–8.5) and low rainfall (585 mm).

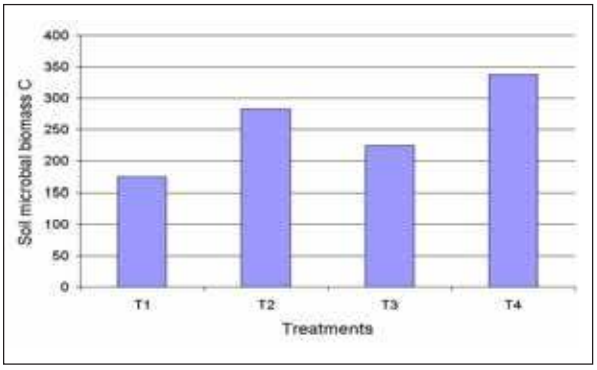
Coimbatore

Four treatments using chemical fertilizers with nitrogen, phosphorus and potassium, and FYM in different doses were applied. The status of microbial populations of the soil samples collected from this location was compared with other parameters as affected by the nutrient management practices after 29 years under finger millet–maize–cowpea fodder cropping system (Table 7).

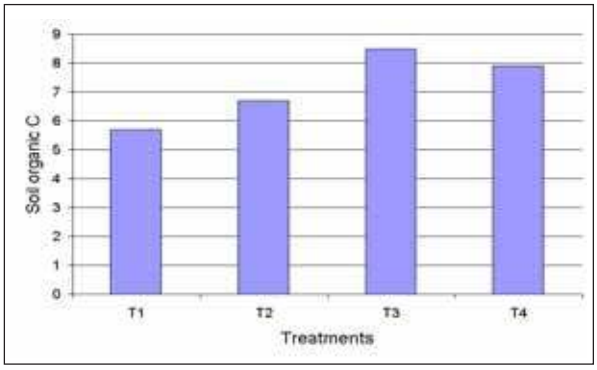
Table 7. Different parameters of surface Vertisol soil samples as affected by long-term (29 years under finger millet–maize–cowpea fodder) fertility management at Coimbatore.

Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)	Fungi (CFU g^{-1} of soil)	Actino-mycetes (CFU g^{-1} of soil)	Mean of microbial population (CFU g^{-1} of soil)
Control (T1)	175	5.7	155	59 10^3	21 10^2	83 10^2	23 10^3
50% optimal NPK (T2)	283	6.7	165	36 10^3	3 10^2	13 10^2	13 10^3
100% optimal NPK (T3)	224	8.5	146	15 10^4	16 10^2	20 10^3	57 10^3
100% optimal NPK+ FYM (T4)	338	7.9	192	52 10^4	2 10^2	66 10^3	20 10^4
LSD (5%)	43.7	1.22	32.6	7 10^4	5 10^2	5 10^3	

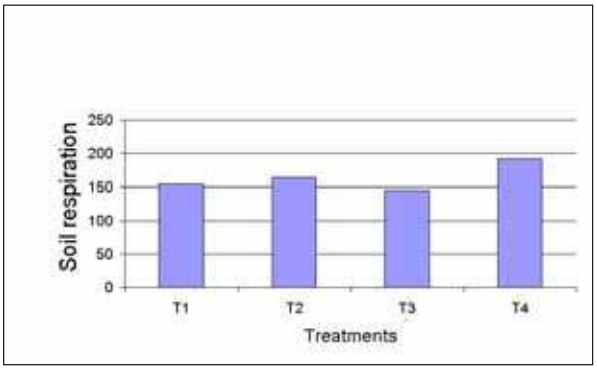
High values of soil microbial biomass C (338 g C g^{-1} soil), soil respiration (192 g C g^{-1} soil $10d^{-1}$), and microbial counts (20 10^4 CFU g^{-1} soil) were recorded in T4 (100% optimal NPK + FYM). High values of SOC (8.5 g C kg^{-1} soil) was recorded in T3 (100% optimal NPK) where the soil was treated with chemical fertilizers.



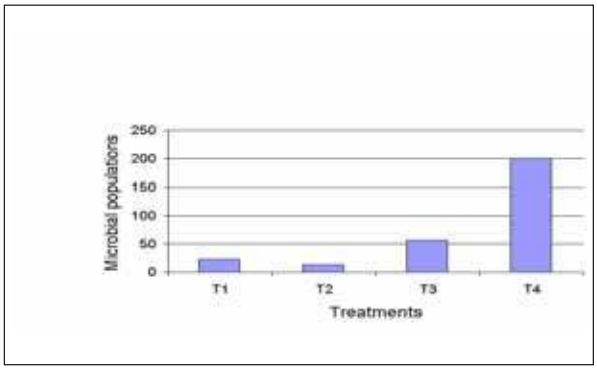
a. Soil microbial biomass (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (10^3 CFU g^{-1} soil)

Figure 5. Different soil parameters under different treatments at Coimbatore.

Low values of soil biomass C (224 g C g^{-1} soil) and soil respiration (146 g C g^{-1} soil $10d^{-1}$) were recorded in T3. Whereas low values of the SOC (6.7 g C kg^{-1} soil) and microbial populations (13 10^3 CFU g^{-1} soil) were recorded in T2 (50% optimal NPK) (Figure 5).

The microbial population in Coimbatore was relatively low as compared to other sites which may be because of the soil pH (8.0–8.5) and rainfall (612 mm).

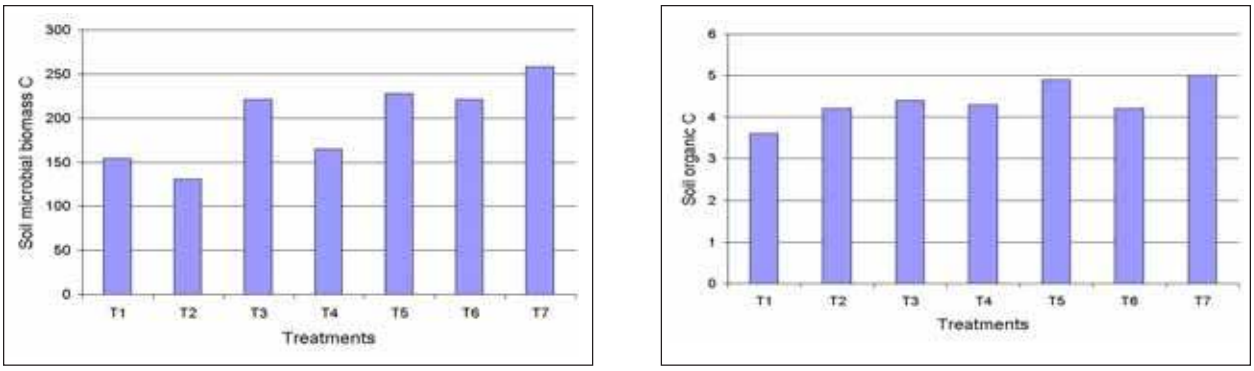
Kovilpatti

In Kovilpatti, seven different treatments were followed where N, P_2O_5, FYM, and farm residue were applied. The microbial counts obtained from this location were compared with other parameters as affected by the nutrient management practices after 19 years under pearl millet–sorghum system (Table 8).

Table 8. Different parameters of surface Vertisol soil samples as affected by long-term (19 years under pearl millet-sorghum) fertility management at Kovilpatti.

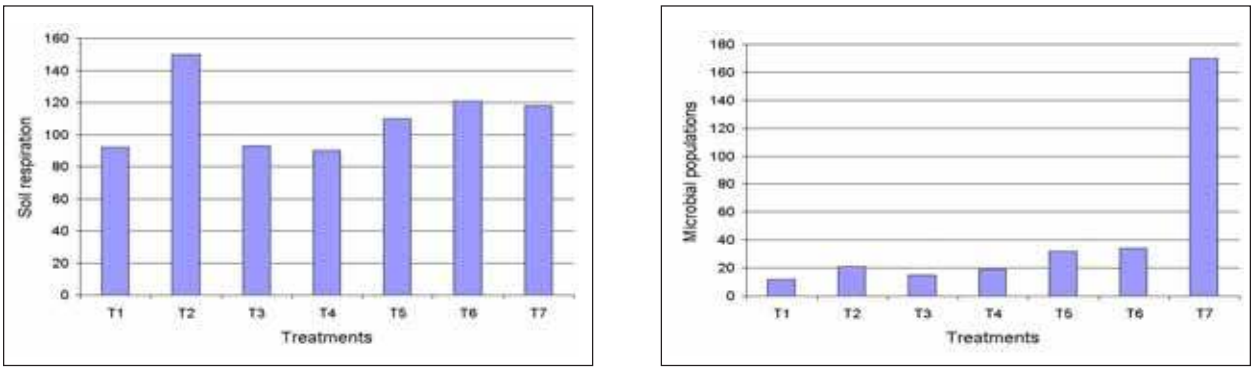
Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi CFU (g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (T1)	154	3.6	92	24	10^3	85	10^2	34	10^2	12	10^3
Recommended dose of N and P_2O_5 (40:20 kg ha^{-1}) (T2)	131	4.2	150	37	10^3	7	10^2	66	10^2	15	10^3
50% recommended dose (20 kg N : 10 kg P_2O_5 ha^{-1}) (T3)	221	4.4	93	46	10^3	7	10^2	16	10^3	21	10^3
On-farm residue to meet 20 kg N ha^{-1} (T4)	165	4.3	90	45	10^3	6	10^2	10	10^3	19	10^3
FYM to meet 20 kg N ha^{-1} (T5)	228	4.9	110	83	10^3	5	10^2	13	10^3	32	10^3
20 kg N as on-farm residue + 20 kg N as urea + 10 kg P_2O_5 ha^{-1} (T6)	221	4.2	121	85	10^3	9	10^2	16	10^3	34	10^3
20 kg N as FYM + 20 kg N as urea + 10 kg P_2O_5 ha^{-1} (T7)	258*	5.0	118	49	10^4	6	10^2	16	10^3	17	10^4
LSD (5%)	NS	NS	27.7	11	10^4	5	10^2	8	10^3		

High values of soil microbial biomass C (258 g C g^{-1} soil), SOC (5.0 g C kg^{-1} soil), and microbial counts (17 10^4 CFU g^{-1} soil) were recorded in T7 (20 kg N as FYM + 20 kg N as urea + 10 kg P_2O_5 ha^{-1}). In this treatment, a combination of inorganic and organic fertilizers was used. High value of soil respiration (150 g C g^{-1} soil $10d^{-1}$) was recorded in T2 (Recommended dose of N and P_2O_5– 40:20 kg ha^{-1}).



a. Soil microbial biomass (g C g^{-1} soil)

b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)

d. Mean count of microbial population (10^3 CFU g^{-1} soil)

Figure 6. Different soil parameters under different treatments at Kovilpatti.

Low value of soil microbial biomass C (131 g C g^{-1} soil), SOC (4.2 g C kg^{-1} soil), and microbial counts (15 10^3 CFU g^{-1} soil) were recorded in T2. Soil respiration (90 g C g^{-1} soil $10d^{-1}$) was low in T4 (on-farm residue to meet 20 kg N ha^{-1}) (Figure 6). The microbial population in this location was low, when compared with Vertisols of other locations.

Solapur

In Solapur, ten different treatments were applied where N through urea, FYM, CR, *Leucaena* were added to the soils in different doses. The microbial counts obtained from these soil samples were compared with other parameters as affected by the nutrient management practices after 17 years under fallow-sorghum (Table 9).

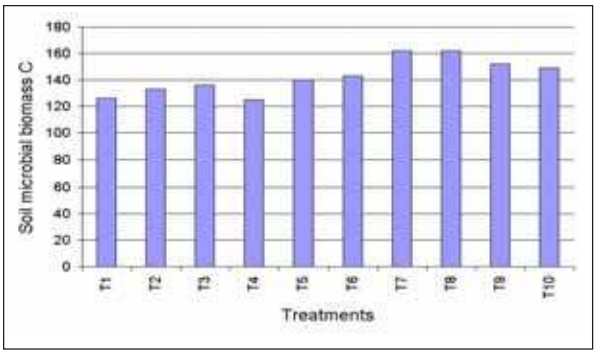
Table 9. Different parameters of surface Vertisol soil samples as affected by long term (17 years under fallow-sorghum) fertility management at Solapur.

Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (T1)	126	5.7	89	15	10^4	3	10^2	67	10^2	52	10^3
25 kg N ha^{-1}- urea (T2)	133	7.8	84	14	10^4	27	10^2	26	10^3	56	10^3
50 kg N ha^{-1}- urea (T3)	136	8.0	123	27	10^4	10	10^2	26	10^3	99	10^3
25 kg N ha^{-1}- CR (T4)	125	8.3	119	12	10^4	4	10^2	23	10^3	48	10^3
25 kg N ha^{-1}- FYM (T5)	140	9.2	137	29	10^4	15	10^2	10	10^3	10	10^4
25 kg N ha^{-1}- CR+25 kg N ha^{-1}-urea (T6)	143	9.7	115	15	10^4	15	10	15	10^3	55	10^3
25 kg N ha^{-1}-FYM + 25 kg N ha^{-1}-urea (T7)	162	11.0	117	48	10^4	33	10^2	25	10	17	10^4
25 kg N ha^{-1}-CR +25 kg N ha^{-1}- *Leucaena* (T8)	162	8.2	107	17	10^5	11	10^2	13	10^3	57	10^4
25 kg N ha^{-1} – *Leucaena* (T9)	152	8.1	89	19	10^4	9	10^2	15	10^3	69	10^3
25 kg N ha^{-1}- *Leucaena* + 25 kg N ha^{-1} – urea (T10)	149	8.0	95	22	10^4	20	10^2	31	10^3	84	10^3
LSD (5%)	40.52	1.43	17.1	11	10^4	7	10^2	5	10^3		

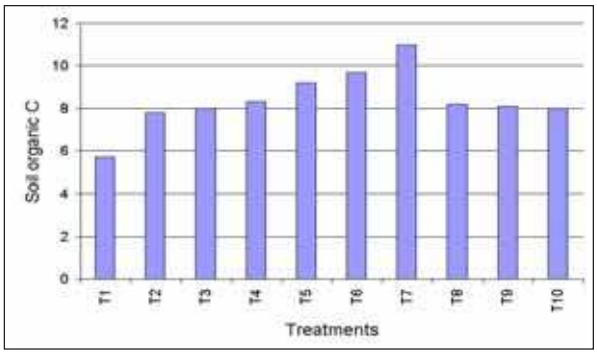
High values of soil microbial biomass C (162 g C g^{-1} soil) and microbial populations (57 10^4 CFU g^{-1} soil) were recorded in T8 (25 kg N ha^{-1} CR +25 kg N ha^{-1} *Leucaena*) where the soil was treated with organic fertilizers. High value of soil respiration (137 g C g^{-1} soil $10d^{-1}$) was recorded in T5 (25 kg N ha^{-1} FYM). The SOC (11.0 g C kg^{-1} soil) was high in T7 (25 kg N ha^{-1} FYM + 25 kg N ha^{-1} urea) where a combination of FYM and urea was used.

Low values of soil microbial biomass C (125 g C g^{-1} soil) and microbial population (48 10^3 CFU g^{-1} soil) were recorded in T4 (25 kg N ha^{-1} CR). Soil respiration (84 g C g^{-1} soil $10d^{-1}$) and the SOC (7.8 g C kg^{-1} soil) were low in T2 (25 kg N ha^{-1} urea) where the soil was treated with urea (Figure 7).

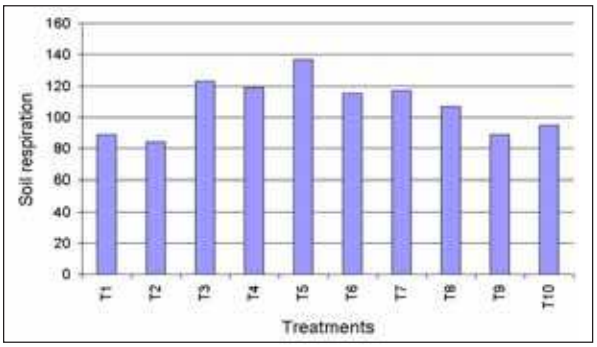
Though the mean annual rainfall in Solapur (742 mm) is next to that of Akola (794 mm), microbial population counts were relatively moderate. This may be because of the fertility management practices and cropping system. Though the soil pH (7.0–8.0) was favorable for the growth of microorganisms, low microbial populations were recorded in the location.



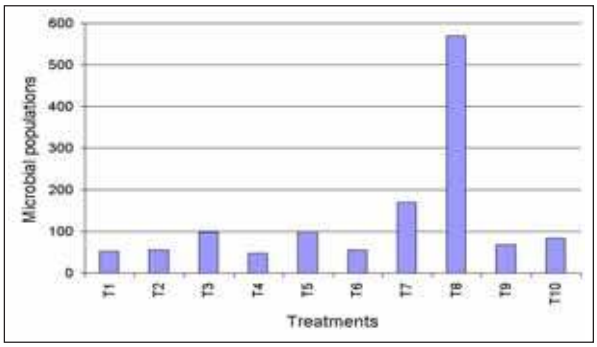
a. Soil microbial biomass (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (10^3 CFU g^{-1} soil)

Figure 7. Different soil parameters under different treatments at Solapur.

Alfisols

Anantapur

The soil samples collected from Anantapur include seven treatments with different doses of NPK in the form of chemical fertilizers, groundnut shells and FYM. The microbial counts obtained from this location were compared with other parameters as affected by nutrient management practices after 16 years or groundnut (Table 10).

Table 10. Different parameters of surface Alfisol soil samples as affected by long-term (16 years under groundnut) fertility management at Anantapur.

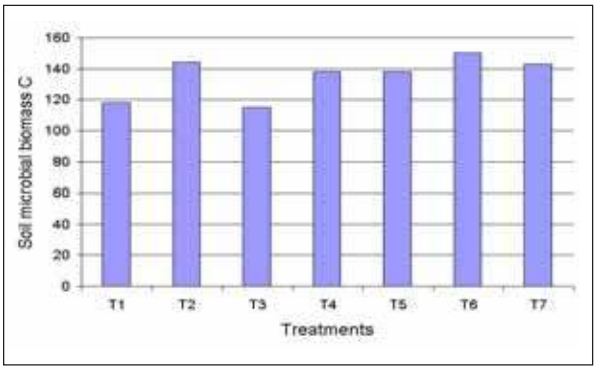
Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (T1)	118	3.9	110	13	10^4	28	10^2	13	10^2	45	10^3
20:40:40 kg N, P2O5, K_2O ha^{-1} (T2)	144	3.9	122	60	10^3	50	10^2	54	10^2	23	10^3
10:20:20 kg N, P2O5, K_2O ha^{-1} (T3)	115	3.4	119	13	10^4	25	10^3	9	10^2	52	10^3

... Continued

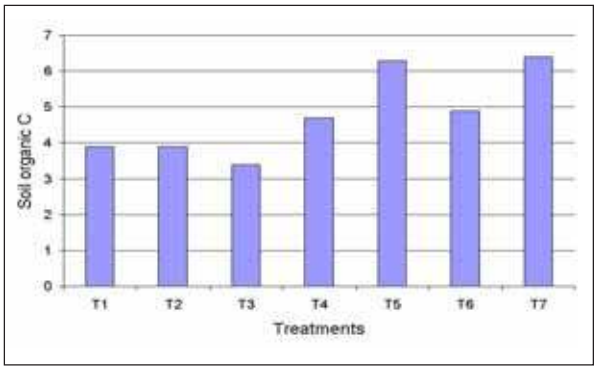
Table 10. *Continued...*

Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Groundnut shells @ 4 t ha^{-1} (T4)	138	4.7	115	19	10^4	32	10^3	17	10^2	75	10^3
FYM @ 4 t ha^{-1} (T5)	138	6.3	118	51	10^3	10	10^3	14	10^2	21	10^3
10:20:20 kg N, P_2O5, K_2O ha^{-1} + Groundnut shells @ 4 t ha^{-1} (T6)	150	4.9	113	27	10^4	35	10^3	29	10^2	10	10^4
10:20:20 kg N, P_2O_5, K_2O ha^{-1} + FYM @ 4 t ha^{-1} (T7)	143	6.4	122	18	10^4	21	10^3	22	10^3	74	10^3
LSD (5%)	NS	1.27	4.50	77	10^3	7	10^3	14	10^2		

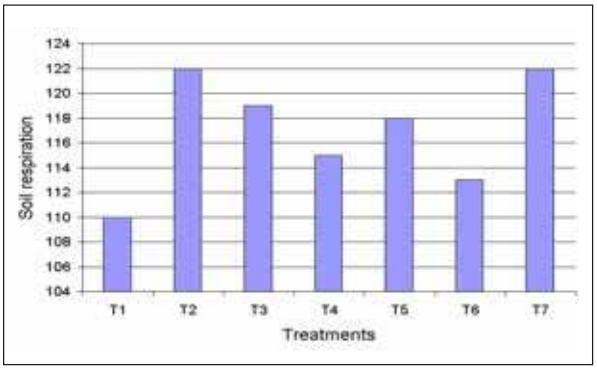
High values of soil microbial biomass C (150 g C g^{-1} soil) and microbial counts (10 10^4 CFU g^{-1} soil) were recorded in T6 (10:20:20 kg N, P_2O_5, K_2O ha^{-1} + Groundnut shells @ 4 t ha^{-1}). Soil respiration (122 g C g^{-1} soil $10d^{-1}$) and SOC (6.4 g C kg^{-1} soil) were high in T7 (10:20:20 kg N, P_2O_5, K_2O ha^{-1} + FYM @ 4 t ha^{-1}).



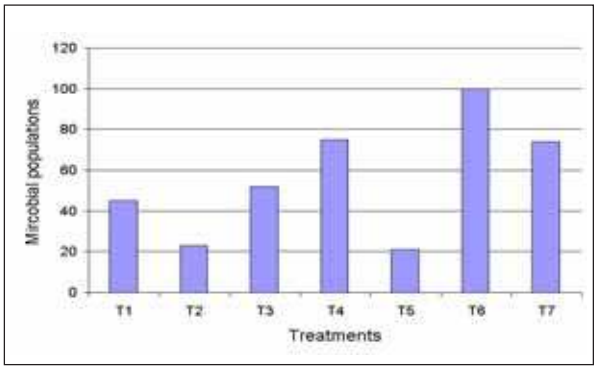
a. Soil microbial biomass (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (10^3 CFU g^{-1} soil)

Figure 8. Different soil parameters under different treatments at Anantapur.

Low values of microbial biomass C (115 g C g^{-1} soil) and the SOC (3.4 g C kg^{-1} soil) were recorded in T3 (10:20:20 kg N, P_2O_5, K_2O ha^{-1}). Soil respiration (115 g C g^{-1} soil $10d^{-1}$) value is low in T6 (10:20:20 kg N, P_2O_5, K_2O ha^{-1} + Groundnut shells @ 4 t ha^{-1}) whereas microbial counts were low in T5 (FYM @ 4 t ha^{-1}) (Figure 8).

The bacterial and fungi counts in Anantapur were higher than that of Bangalore and Hyderabad (CRIDA) where the soil type is Alfisol. Mean counts of microbial population in Anantapur is next to Bangalore which may be due to favorable soil pH (6.0–7.0) as well as the cropping system. Mean annual rainfall (643 mm) in Anantapur is lower than that of other two locations.

Bangalore

Four treatments were studied in Bangalore, where the supply of NPK is through chemical fertilizers and supply of nitrogen is through GLM, FYM and CR. The microbial counts analyzed in this location were compared with other parameters as affected by the nutrient management practices under finger millet (Table 11).

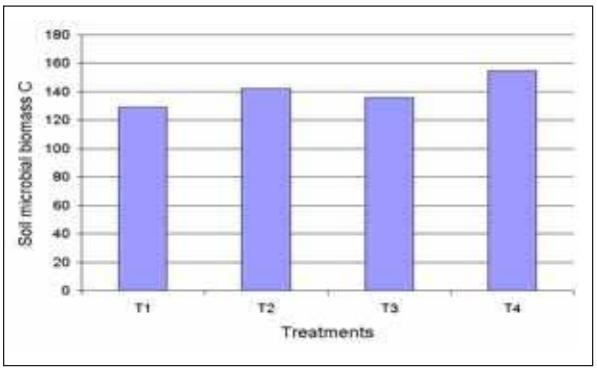
Table 11. Different parameters of surface Alfisol soil samples as affected by long-term (under finger millet) fertility management at Bangalore.

Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil $10d^{-1}$)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Control (T1)	129	4.3	110	27	10^3	6	10^2	40	10^2	11	10^3
Recommended NPK (50:50:25 kg/ha) (T2)	142	4.0	132	13	10^4	28	10^2	91	10^2	47	10^3
Recommended N (1/3 green leaf manure + 1/3 FYM + 1/3 crop residues) (T3)	136	4.2	126	33	10^3	20	10^2	16	10^3	17	10^3
Recommended 50% N (1/3 green leaf manure + 1/3 FYM + 1/3 crop residues) (T3) +50% NPK (T4)	155	4.6	137	53	10^4	15	10^2	18	10^3	18	10^4
LSD (5%)	NS	NS	NS	10	10^4	8	10^2	30	10^3		

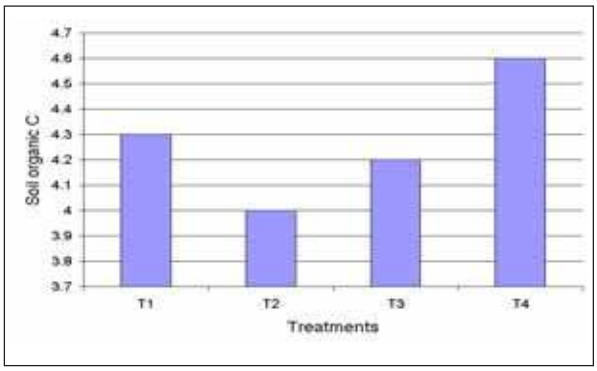
High values of soil microbial biomass C (155 g C g^{-1} soil), soil respiration (137 g C g^{-1} soil $10d^{-1}$), SOC (4.6 g C kg^{-1} soil), and microbial counts (18 10^4 CFU g^{-1} soil) were recorded in T4 [Recommended 50% N through (GLM + FYM + CR) + 50% NPK].

Low values of soil microbial biomass C (136 g C g^{-1} soil), soil respiration (126 g C g^{-1} soil $10d^{-1}$), and microbial counts (17 10^3 CFU g^{-1} soil) were recorded in T3 [Recommended N through (GLM + FYM + CR)]. Whereas the SOC (4.0 g C kg^{-1} soil) is low in T2 [Recommended NPK (50:50:25 kg ha^{-1})] (Figure 9).

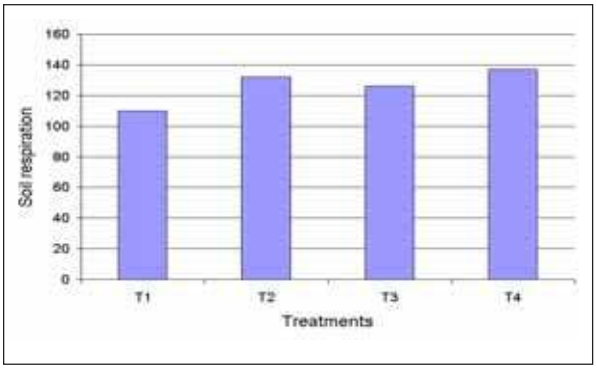
Microbial populations in Bangalore were much lower than that of Anantapur and Hyderabad (CRIDA), which may be due to the soil pH (5.5–6.5).



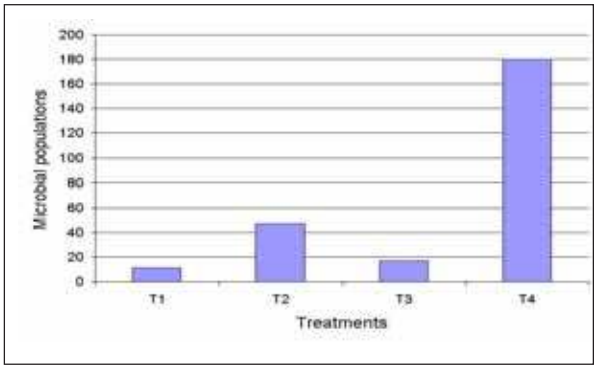
a. Soil microbial biomass (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (10^3 CFU g^{-1} soil)

Figure 9. Different soil parameters under different treatments at Bangalore.

Hyderabad (CRIDA)

Two main treatments with zero tillage (Z) and conventional tillage (C) were observed at CRIDA, Hyderabad. These treatments were subtreated with *Gliricidia* loppings @ 2 t ha^{-1} and 60 kg N ha^{-1} (G60) and no residue with 60 kg N ha^{-1} (N60). The microbial counts analyzed from the soil samples were compared with other parameters as affected by tillage and manure application after 5 years under castor-sorghum system with different fertility management options (Table 12).

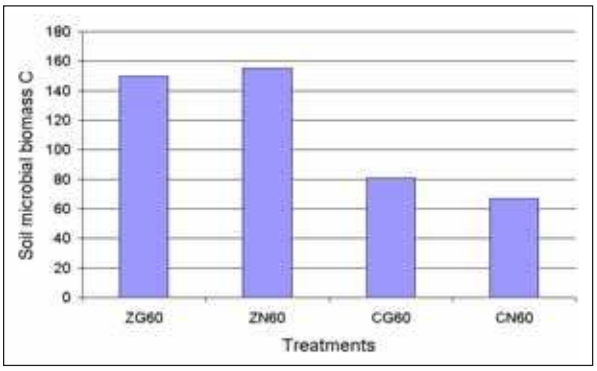
Table 12. Different parameters of surface Alfisol soil samples as affected by long-term (5 years under castor-sorghum) fertility management at Hyderabad (CRIDA).

Treatment	Soil microbial biomass C (g C g^{-1} soil)	Soil organic carbon (g C kg^{-1} soil)	Soil respiration (g C g^{-1} soil 10 d^{-1}) of soil)	Bacteria (CFU g^{-1} of soil)		Fungi (CFU g^{-1} of soil)		Actino-mycetes (CFU g^{-1} of soil)		Mean of microbial population (CFU g^{-1} of soil)	
Zero tillage with *Gliricidia* loppings @ 2 t ha^{-1} (surface application) and 60 kg N ha^{-1} (ZG60)	150	7.0	42	40	10^3	10	10^2	13	10^3	18	10^3
Zero tillage with No residue and 60 kg N ha^{-1} (ZN60)	155	7.4	50	44	10^3	7	10^2	16	10^3	20	10^3
Conventional tillage with *Gliricidia* loppings @ 2 t ha^{-1} (surface application) and 60 kg N ha^{-1} (CG60)	81	6.0	56	63	10^4	5	10^2	10	10^4	24	10^4
Conventional tillage with No residue and 60 kg N ha^{-1} (CN60)	67	5.7	45	53	10^4	6	10^2	83	10^2	18	10^4
LSD (5%)	NS	0.81	NS	33	10^4	3	10^2	50	10^3		

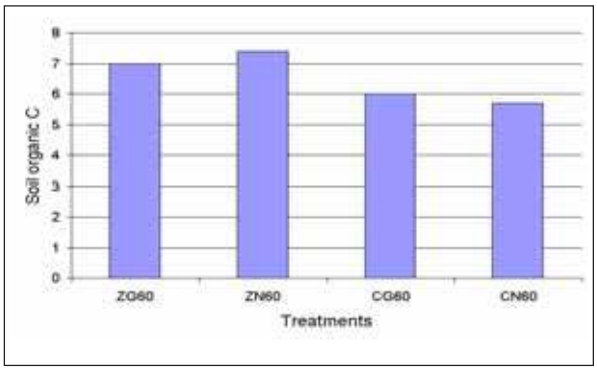
In sub-treatment with zero tillage high values of soil microbial biomass C (155 g C g^{-1} soil), soil respiration (50 g C g^{-1} soil 10d^{-1}), SOC (7.4 g C kg^{-1} soil) and microbial populations (20 10^3 CFU g^{-1} soil) were recorded in ZN 60 (Zero tillage with No residue and 60 kg N ha^{-1}). Low values of soil microbial biomass C (150 g C g^{-1} soil), soil respiration (42 g C g^{-1} soil 10d^{-1}), SOC (7 g C kg^{-1} soil) and microbial populations (18 10^3 CFU g^{-1} soil) in zero tillage were recorded in ZG 60 [zero tillage with *Gliricidia* loppings @ 2 t ha^{-1} (surface application) and 60 kg N ha^{-1}].

In sub-treatment with conventional tillage high values of soil microbial biomass C (81 g C g^{-1} soil), soil respiration (56 g C g^{-1} soil 10d^{-1}), SOC (6 g C kg^{-1} soil) and microbial populations (24 10^4 CFU g^{-1} soil) were recorded in CG60 (conventional tillage with *Gliricidia* loppings @ 2 t ha^{-1} (surface application) and 60 kg N ha^{-1}). Low values of soil microbial biomass C (67 g C g^{-1} soil), soil respiration (45 g C g^{-1} soil 10d^{-1}), SOC (5.7 g C kg^{-1} soil) and microbial populations (18 10^3 CFU g^{-1} soil) were recorded in CN60 (conventional tillage with no residue and 60 kg N ha^{-1}) (Figure 10).

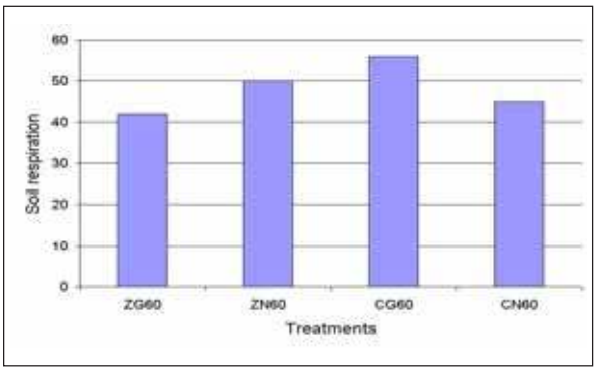
Actinomycetes population counts were higher in Hyderabad than in other Alfisols location, which may be due to the fertility management practices and cropping system in this location. The mean annual rainfall (764 mm) of Hyderabad is next to that of Bangalore.



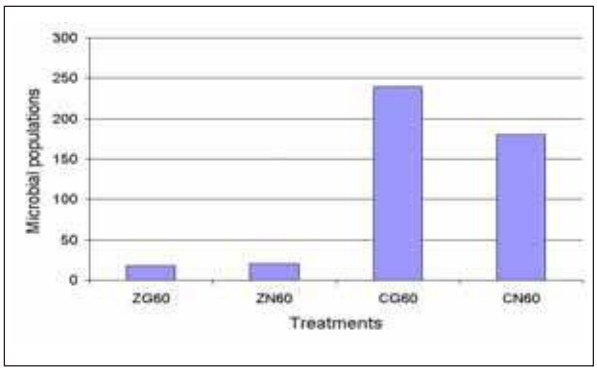
a. Soil microbial biomass (g C g^{-1} soil)



b. Soil organic C (g C kg^{-1} soil)



c. Soil respiration (g C g^{-1} soil $10d^{-1}$)



d. Mean count of microbial population (g C g^{-1} soil $10d^{-1}$)

Figure 10. Different soil parameters under different treatments at Hyderabad (CRIDA).

Discussion

Of the nine benchmark sites, three sites [Anantapur, Bangalore and Hyderabad (CRIDA)] represented Alfisols and the other six (Akola, Bellary, Bijapur, Coimbatore, Kovilapatti and Solapur) represented Vertisols. Vertisols recorded higher microbial populations than the Alfisols (Figure 11).

Significant correlation between microbial populations and rainfall was not observed in Vertisols. Akola, which recorded the highest rainfall, could not record high counts of microbial population. Three sites with Alfisols recorded significant relation between the rainfall and the microbial populations. In Bangalore, where the mean annual rainfall is high, counts of microbial populations were also high. Anantapur, which recorded low rainfall, recorded low counts of microbial populations. Absence of direct relationship between rainfall and microbial populations in Vertisols as against in Alfisols could be due to high water holding capacity and clay content of Vertisols which support plant growth better during non-rainy periods. In addition with excess rainfall these soils are prone to waterlogging which would also affect the population of aerobic microorganisms adversely.

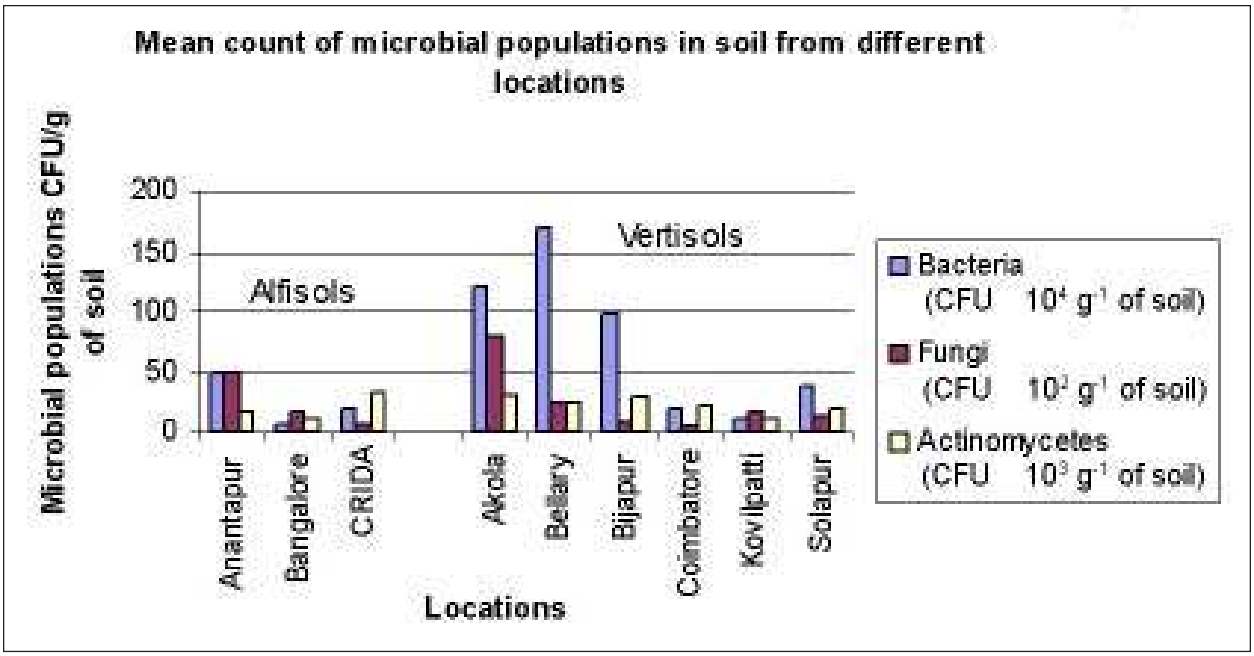


Figure 11. Mean counts of microbial populations in soil from different locations.

High counts of bacterial population were recorded with soil pH ranging between 6 and 8.5. Acidic soil pH recorded more counts of fungi than bacteria and actinomycetes. Alkaline soil pH recorded high counts of actinomycetes than bacteria and fungi. In treatments with the application of inorganic fertilizers, more counts of fungi were recorded, which may be because of the change in rhizosphere soil pH. Soil treated with organic fertilizers only recorded more counts of actinomycetes. A combination of both organic and inorganic fertilizers recorded more counts of bacteria.

In Vertisols, cropping system with maize and chickpea in Bellary recorded high microbial population followed by cotton + green gram in Akola, and pigeonpea-sunhemp-sorghum + chickpea in Bijapur. In these locations, the percentage of soil treatments with a combination of organic and inorganic fertilizers was more than that with the individual application. In Alfisols, cropping system with finger millet in Bangalore recorded high counts of microbial populations followed by sorghum-castor in Hyderabad (CRIDA). In these two locations, soil treatments with a combination of organic and inorganic fertilizers were more than that with the individual application in terms of nutrients/organic matter applied.

In Vertisol soil type, Bellary and Bijapur recorded high values of soil microbial biomass C, SOC, soil respiration and microbial populations in the same treatment. In Alfisols, Bangalore and Hyderabad (CRIDA) recorded high values of soil microbial biomass C, SOC, soil respiration and microbial populations in the same treatments. In all the nine locations, treatments, which recorded high soil microbial biomass C, recorded high counts of microbial populations. Some variation is recorded with the values of SOC and soil respiration in relation with microbial populations counts.

Conclusions

- Elevated counts of microbial populations were recorded with the treatments where both organic and inorganic sources of NPK were applied. Individual addition of organic or inorganic fertilizers did not record high counts of microbial populations as in the combination of organic plus inorganic fertilizers.
- Microbial population counts were more in Vertisols than in Alfisols.
- High counts of microbial population were in the pH range 6.5–8.0.
- Highly acidic conditions were tolerated by fungi. Consequently, in soils where the population of fungi was more, the counts of bacteria and actinomycetes were low.
- The counts of actinomycetes were more in the treatments with FYM, CR, GLM than with chemical fertilizers.
- Significant correlation was observed in all the locations between biomass C and microbial populations.
- More carbon could be sequestrated in soil by selecting treatments, which enhance microbial activity, microbial biomass C, SOC and soil respiration. Long-term experiments have provided opportunity to study the relation between various soil treatments and their impact on soil microbial activity and link between microbial populations, SOC, soil respiration and soil microbial biomass C.

References

Amato M and **Ladd JN.** 1988. Assay for microbial biomass based on ninhydrain reactive nitrogen in extracts of fumigated soil. Soil Biology and Biochemistry 20 (1):107–114.

Anderson JPE. 1982. Soil respiration. Pages 831–872 *in* Methods of soil analysis. Part 2. Chemical and Microbiological Properties. Madison, Wisconsin, USA: ASA, SSSA.

Anderson TH and **Domsch KH.** 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil Biol. Biochem. 21:417–479.

Cole CVK. 1996. "Agricultural Options for mitigation of greenhouse gas emissions". Climate Change 1995. Impacts, Adaptations and Mitigation of climate change: Inter governmental panel on climate change (Watson SRT, Zinyoure MC and Moss RH, eds.). Cambridge, UK: Cambridge University Press.

CRIDA. 2001. Annual Report 1999–2000. All India Coordinated Research Project for Dryland Agriculture. Hyderabad 500059, Andhra Pradesh, India: Central Research Intitute for Dryland Agriculture.

Genstat Manual. 2002. Genstat, a general statistical program. Released 6.1. Laws Agricultural Trust (Rothamsted Experimental Station).

Jenkinson DS and **Ladd JN.** 1981. Microbial Biomass in Soil Measurement and Turnover. Pages 415–471 *in* Soil Biochemistry (Paul EA and Ladd JN, eds.). New York, USA: Marcel Dekker.

Keeling CD and **Whorf TP.** 1998. Atmospheric CO_2 concentrations — Mauna Loa Observatory, Hawaii, 1958–1997. Technical Report NDP-001. Oak Ridge, Tennessee, USA: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

Manna MC, Hajra JN, Sinha NB and **Ganguly TK.** 1997. Enrichment of compost by bio inoculants and mineral amendments. Journal of Indian Society Soil Science. 45:831–833.

Mc Gill WB and **Cole CV.** 1981. Comparative aspects of organic C,N,S and P cycling through organic matter during pedogenesis, Geoderma (in press).

Powlson DS and **Jenkinson DS.** 1981. A comparison of organic matter, biomass, adenosine triphosphate and mineralisable nitrogen contents of plowed and direct drilled soils. Journal of Agricultural Science 97:713–721.

Singh Y, Choudhary DC, Singh SP, Bharadwaj AK and **Singh D.** 1996. Sustainability of rice (*Oriza sativa*) - wheat (*Triticum aestivum*) sequential cropping through introduction of legume crops and green manure crops in the systems. Indian Journal. of Agronomy. 41:510–514.

Swarup A. 1998. Emerging soil fertility management issues for sustainable crop productivity in irrigated systems. Proc. National Workshop on Long-term Soil Fertility Management through Integrated Plant Nutrient Supply System, April 2–4, Indian Institute of Soil Science, Bhopal, India.

Wani SP and **Lee KK.** 1995. Microorganisms as biological inputs for sustainiable agriculture. Pages 39–76 *in* Organic Agriculture (Thampan PK ed.). Cochin, India: Peekay Tree Crops Development Foundation.

Wani SP, Mc Gill WB, Haugen-Koyzra KL, Robertson JA and **Thurstson JJ.** 1994. Improved soil quality and barley yields with faba beans, manure, forages, and crop rotation on a gray luvisol. Canadian Journal of Soil Science 74:75–84.

Wani SP, Jangawad LS, Eswaran H and **Singh P.** 2003. Improved mangement of Vertisols in the semi-arid tropics for increased productivity and soil carbon sequestration. Soil Use and Management 19:217–222.

Wani SP, Singh P, Pathak P and **Rego TJ.** 2000. Sustainable Management of Land Resources for Achieving Food Security in the Semi-Arid Tropics. *In* Advances in Land Resource Management for 21st century, lead papers of the International Conference on Land Resource Management for food, employment and environmental security (ICLRM), 9–13 November 2000, Soil Conservation Society of India, New Delhi, India. New Delhi, India: Soil Conservation Society of India.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR).

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