Annals of Arid Zone 51(2): 91-98, 2012

Soil Biota Build-up under Organic and Inorganic Fertilization in Semi-arid Central India

S. Roy*[1], P. Saxena and R. Bano[2]

Indian Grassland and Fodder Research Institute, Jhansi 284 003, India

Received: April 2012

Abstract: A study was conducted in semi-arid central India, to investigate the response of organic and inorganic nutrient sources on soil biota in an intensive forage production system (cowpea intercropped with maize in rainy season followed by lucerne in winter). Field treatments included unfertilized control, NPK at recommended doses and FYM as per the recommended N requirement of crops. Both the inorganic and organic nutrients had increased the population of various soil biota. But change in abundance from initial was significant under organic nutrient source (collembolan = 26.0%, oribatida mites = 8.3%, other mites = 8.1%, nematodes = 2.4%, actinomycetyes = 3.9%, bacteria = -14.0% and fungi = 6.9%). Green fodder yield (GFY) was significantly higher under the organic plots (35.78 t ha^{-1}) compared to the inorganic fertilizer (31.64 t ha^{-1}). This positive impact of manure on GFY was realized in both drought and erratic rain years. Compared to unfertilized control, application of manure increased soil moisture, soil organic carbon and nitrogen (8.85%, 56%, 65%, respectively). Available nitrogen (22%), available potassium (83%) and available phosphorus (40%) had also increased in plots receiving organic nutrient source. Therefore, we conclude that application of manure will improve quality and biological activity of the nutrient deficit Alfisol.

Key words: Forage production system, FYM, micro-flora, micro-arthropods, nematodes, NPK.

The continuous use of inorganic inputs to cropping systems is deleterious for soil health and sustenance of crop productivity (Kaur *et al*., 2005; Manna *et al*., 2005; Ramesh *et al*., 2009). The application of manure increases soil organic matter, stability of micro aggregates, moisture retention capacity (Sarkar *et al*., 2003) leading to improved availability of nutrients and soil physical and chemical properties. The mineralization of the manure also alters soil ecology (Carter, 2002).

The soil micro-flora and fauna are the essential components of rhizosphere and are known to regulate soil biological processes. Their establishment in soil ecosystem depends on their interaction with many ecological factors (Benizri *et al*., 2002; Giri *et al*., 2005). To realize the benefits of soil biota, it is necessary to have information on the impact of agriculture practices on the soil biota (NAAS, 2006). In India, a number of studies were undertaken to understand the effects of cropping systems, agriculture practices, fertilizer/manure applications on the soil quality and crop yields. However, little attention was paid on the community structure of soil biota and their role in sustainable production system. Much information on endemic soil biota species is also not available.

In view of these it was hypothesized that the nutrient sources may alter soil biota diversity and dynamics, which is linked with the crop yield. An experiment was conducted to generate information on the endemic soil biota and to evaluate the impact of nutrient sources i.e. organic and inorganic, on the abundance and diversity of soil micro flora and fauna.

Materials and Methods

Physical and environmental conditions of site

A field trial was conducted at farm of Indian Grassland and Fodder Research Institute, Jhansi, India (25°27'N latitude and 78°35'E longitude and about 275 m above mean sea level) during 2000 to 2004. The topography of the region is

*E-mail: roysharmilaigfri@gmail.com

Present address: [1] Central Arid Zone Research Institute, Jodhpur 342 003, India.

[2] Zoological Survey of India (Ministry of Environment & Forests), Western Regional Centre, Rawet Road, Sector-29, Vidyanagar, Akurdi, PCNT (PO), Pune 411 044, India.

characterized by its smooth flat lands and intermixed undulating areas of varied slope. Two major soils, red and black are encountered in the region. The mean annual rainfall is 750 mm. About 90% of the total precipitation is received between mid-June to end of September with occasional showers during winter months. May and June are the hottest months with maximum temperature of 43-46°C. Minimum temperature of 3-4°C is recorded during January. The area is defined as semi-arid with moisture index (a measure of the water balance of an area in terms of gains from precipitation and losses from potential evapotranspiration) from -40 to -60 (Ghosh, 1991).

The soil of the experimental site was red, coarse grained, upland type, classified Haplustalf. The texture was sandy clay loam to sandy clay (sand 61.2%, silt 16.63% and clay 20.86%); with 1.24 Mg m^{-3} bulk density and 48.10% porosity. The soil was almost neutral (pH 6.8, EC 0.09 dS m^{-1}) with water holding capacity in the range of 25-40%. The soil fertility was medium with 0.54% organic carbon, 264.2 kg ha^{-1} available N, 11.14 kg ha^{-1} available P and 440.0 kg ha^{-1} available K.

Field experiment

Maize (*Zea mays*; cv. African Tall) and cowpea (*Vigna unguiculata*; cv. Bundel Lobia 1) were sown in 2:2 row ratio with 25 cm row to row and 15 cm plant to plant spacing in the first week of July (kharif crop). Lucerne (*Medicago sativa*, cv. 99-1) was sown in the last week of October (rabi crop) at 25 cm row spacing. The experiment was laid out in a randomized block design with twelve replications (total 36 plots). The plots were of 4 × 3 m in size arranged in four blocks. Plot to plot distance was 1 m, whereas the blocks were 2 m apart. Interculture operations were done manually after 15 and 40 days of sowing. Supplemental irrigation of 60 mm to each treatment was applied to kharif crop as and when required during the study period. The check basin irrigation at 15-day interval and after each cut was applied to lucerne crop in rabi season. The kharif crop was harvested 90 days after sowing or at the silking stage of maize. Lucerne was harvested three times (1st cut at 45 days after sowing, 2nd and subsequent cuts at 30-day interval) and the cumulative yield of three cuts was taken for total forage yield.

The treatments selected for the study included 100% inorganic fertilizer (NPK), 100% organic fertilizer (FYM) and unfertilized (NF) control. Inorganic fertilizer was applied @ 60 kg N ha^{-1} + 50 kg P ha^{-1} + 30 kg K ha^{-1} in kharif crops and 20 kg N ha^{-1} and 80 kg P ha^{-1} in lucerne crop (recommended package of practice) as basal. Urea, SSP (single super phosphate) and Muriate of Potash were used as inorganic nutrient source. Organic manure was applied in soil fifteen days before sowing during every season and doses were defined as per the nitrogen requirement of each crop (4.4 t ha^{-1} for kharif and 1.5 t ha^{-1} for rabi). Organic manure (N = 1.35%, P = 0.34%, K = 1.32%) used in this experiment was a mixture of cattle dung, excreta of goat/sheep, and plant residues.

Soil chemical and biological analysis

Soil samples (0-15 cm) were taken at the beginning (in 2000) and at the end (in 2004) of the experiment to estimate physical and chemical parameters. Soil electrical conductivity (EC) and pH (1:2 w/v) were determined using digital EC meter and pH meter, respectively. Organic carbon was estimated by Walkley and Black's rapid titration method (Walkley and Black, 1934), total nitrogen by Kjeldahl method, available nitrogen by alkaline permanganate method (Bremner and Mulvaney, 1982), available phosphorus by Olsen method (Olsen *et al*., 1954) and available potash by ammonium acetate extract method (Hanway and Heidal, 1952). Soil moisture was estimated gravimetrically.

The observations on soil biota and soil moisture were recorded from the second year (July 2001) of experiment and continued for three consecutive years. The soil samples were drawn at three intervals and were collected, 7th day, 15th day and 21st day after seeding, with the help of cylindrical core sampler (5 × 15 cm) and were drawn from the center of the plot i.e. 108 cores at every sampling occasion. The micro-arthropods were extracted by modified Berlese-Tullgren Funnel, while Cobb Sieving Technique was used to extract nematode followed by enumeration and identification by traditional microscopy method. Soil micro-flora was estimated by traditional plate count method (10^5 dilution), using Martin Rose Bengal media for fungi

Table 1. Soil parameters (0-15 cm) in different fertilizer treatments after four years (n = 4)

Soil parameters	Control	NPK	FYM
pH	6.77 ± 0.02	6.90 ± 0.03	6.85 ± 0.03
Electrical conductivity (dS m^{-1})	0.09 ± 0.006	0.10 ± 0.009	0.08 ± 0.008
Bulk density	1.24 ± 0.03	1.28 ± 0.04	1.23 ± 0.04
Organic carbon (%)	0.52 ± 0.09^{a}	0.54 ± 0.04^{a}	0.82 ± 0.04^{b}
Available nitrogen (kg ha^{-1})	249.33 ± 8.14^{a}	261.80 ± 10.12^{a}	304.15 ± 12.62^{b}
Available K (kg ha^{-1})	438.20 ± 23.24^{a}	446.30 ± 64.24^{b}	611.80 ± 41.68^{b}
Available P (kg ha^{-1})	8.30 ± 0.69^{a}	13.50 ± 1.74^{a}	15.22 ± 1.59^{b}
Total N (%)	0.07 ± 0.01^{a}	0.08 ± 0.01^{ab}	0.11 ± 0.01^{b}

± SE; Row wise superscripts $^{a\ b\ c}$ indicate Duncan's homogenous sub sets; alpha 0.05.

counting, Nutrient Agar media for bacteria counting and Kennight Munniar's media to count actinomycetes (Subbarao, 1977).

The 2003 collection was sorted to family level for collembola, mites (into groups) and micro flora (genera level). Collembola were classified as per the keys of Christiansen (1990). The mites were grouped following Krantz (1978). The actinomycetes were tentatively identified with the key based on colony structure and microscopic features of growth (Williams and Wellington, 1982). The fungi were classified following the keys provided in the manual of soil fungi (Gilman, 1956). The bacteria were grouped based on gram stain and colony characters.

Statistical analysis

Statistical analysis was performed by SPSS (version 13.0), while Bio-tool (version 2.0) software was used to calculate diversity indices. Population data were log (n+1) transformed before analysis. To compare biota analysis of variance (multivariate), with the variables being treatments, crops, date of sampling and the year of sampling was performed. The crop yield, soil moisture and fertility parameters were analyzed by univariate method. Duncan's post Hoc test was used for multiple comparisons of observed means.

Results and Discussion

Soil fertility, moisture and crop yield

The increase in organic carbon (56%) and nitrogen (65%) was considerably high in FYM treatment compared to control. Correspondingly, the available nitrogen (22%), available potassium (83%) and available phosphorus (40%) had also increased under FYM (Table 1). Though, no change was found in soil pH, EC and bulk density.

The organic amendment had improved moisture retention capacity of the soil. It was significantly higher in manure plots (8.9%) than inorganic fertilizer (7.8%) and control plots (7.9%) in cowpea-maize intercropping (Fig. 1). Similar trend of moisture availability was found in lucerne crop (FYM -7.4%; NPK -6.5%; control -6.2%) also.

The soil moisture was highest in July 2001, and the lowest in July 2002 samples. This temporal variation in moisture content may be attributed to the erratic rainfall received during the experiment. Year 2000 received below average rainfall (712.1 mm) but the year 2001 was a normal rain fall year (1147.7 mm). While 2002 was a drought (545.7 mm) year and the year 2003 was erratic rain fall year (1194.7 mm) with an unusual high rain (493.8 mm) in the 37th week.

Sarkar *et al*. (2003) in a nine-year study, conducted on the rice-lentil cropping sequence in northern India, reported a decline in the soil structure moisture retention due to the sole application of NPK. They also reported that the un-decomposed organic source of nutrient lowered the bulk density of the soil to a greater extent than the decomposed organic material. Another study (Manna *et al*., 2005), on long term effect of fertilizer and manure also indicated that 100% NPK along with FYM decreased soil bulk density in the 0-15 cm surface layer of soil, but the soil C and N levels were maintained or improved over the initial soil status in the treatment.

Unlike the above mentioned studies, we did not observe any change in the bulk density, pH

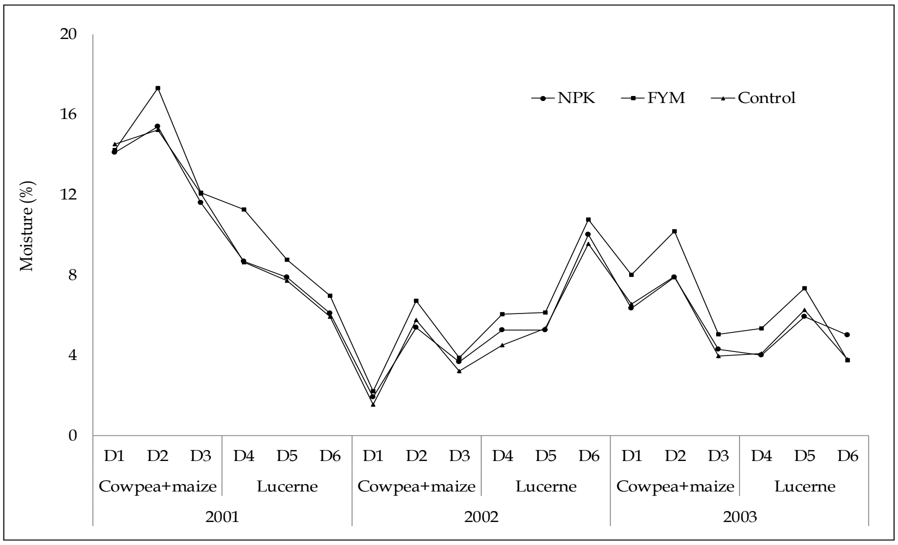

Fig. 1. Soil moisture recorded in different treatments during the study period (D1, D2, D3 = 7th day, 15th day and 21st day after seeding, respectively).

and EC of the soil though; the moisture and available nutrients were increased significantly in the FYM treated plots compared to plots that received mineral fertilizer.

The higher net mean annual productivity (35.8 t ha^{-1} in FYM>31.6 t ha^{-1} in NPK>21.7 t ha^{-1} in control) of the cropping system can be attributed to enhanced fertility and moisture of the soil under organic manure input. The increase in green fodder yield under FYM was 31% in cowpea + maize, and 142% in lucerne over the control. Whereas about 25% increase in yield of maize + cowpea and 93% increase in yield of lucerne crop was recorded under NPK treatment over the control. A significant ($P<0.01$) yearly variation in green fodder yield was also observed in this study (Table 2). Highest yield of maize + cowpea intercropping was recorded in year 2001 (57.4 t ha^{-1}), whereas the maximum yield of lucerne was realized in year 2000 (32.7 t ha^{-1}). In this study yield reduction was recorded in all the treatments in the third and fourth year of experiment possibly due to the drought and erratic rainfall (Fig. 1) in these years.

Table 2. Green fodder yield (t ha^{-1}) during the study period

Year	Control	NPK	FYM	Average
Cowpea + Maize				
2000	34.8	36.3	35.8	35.6
2001	44.0	64.2	64.0	57.4
2002	26.5	29.6	35.0	30.4
2003	15.0	20.4	22.3	19.2
Average	30.1^{a}	37.6^{c}	39.3^{b}	35.6
Lucerne				
2000	19.8	32.3	46.0	32.7
2001	16.2	28.1	33.9	26.1
2002	6.2	16.9	16.0	13.1
2003	10.9	25.3	33.2	23.2
Average	13.3^{a}	25. 7^{c}	32.3^{b}	23.8

	Treatment (df = 2)	Year (df = 3)	Crop (df = 1)	Treatment × Year (df = 6)	Treatment × Crop (df = 2)	Year × Crop (df = 3)	Treatment × Year × Crop (df = 6)
F	78.68**	112.40**	158.62**	2.41*	8.95**	68.84**	4.81**

($^{a\ b\ c}$Superscripts indicate Duncan's sub sets; * F value significant at 0.05; ** F value significant at 0.01).

Table 3. Soil biota diversity under different nutrient treatments observed in year 2003

	Cowpea + Maize			Lucerne			Total		
	Control	NPK	FYM	Control	NPK	FYM	Control	NPK	FYM
Micro-arthropod diversity									
Shannon-Wiener	1.27	1.28	1.45	0.92	0.88	1.06	1.19	1.18	1.45
Evenness	0.58	0.58	0.66	0.42	0.40	0.48	0.54	0.54	0.66
Simpson's Index (1/D)	2.47	2.51	3.59	1.68	1.61	1.93	2.15	2.11	3.32
Micro-flora diversity									
Shannon-Wiener	1.57	1.77	1.84	1.68	1.61	1.70	1.77	1.77	1.93
Evenness	0.50	0.56	0.59	0.61	0.56	0.59	0.56	0.56	0.61
Simpson's Index (1/D)	3.35	3.96	4.62	4.31	3.92	3.83	4.37	4.34	4.93

NPK= Inorganic nutrient source, FYM = Organic nutrient source.

Application of manure in soil increased the soil organic matter which had possibly increased the available nutrients (Table 1). Hence higher yield was recorded in FYM plots in this study. An 18% and 9% higher yield from manure plots compared to NPK was realized even in 2002 (drought year) and in 2003 (erratic rainfall year), respectively, in kharif crops.

Saxena *et al*. (1997) in their study on effect of tillage and cropping system on soil moisture balance found that application of FYM had greater favorable influence on soil moisture storage and consequently resulted in higher water-use efficiency and grain yield. The increase in yield under NPK and NPK + FYM was also reported by Manna *et al*. (2005) in their study on long term effect of fertilizer and manure application. Chaturvedi and Chandel (2005) concluded in their study that steady and slow release of the nutrients in manure treatment, improves the nutrient uptake by plants resulting to higher crop yields.

Community structure of soil biota in different treatments

Collembola and mites were the dominant micro-arthropod observed in the samples. While few individuals of Protura (5 individuals), Diplura (12 individuals), Pseudoscorpion (2 individuals) were occasionally found in the samples during the study period. Thirteen fungi, seven actinomycetes and seven types of bacteria were isolated from the samples. Among micro flora *Aspergillus* was the overriding fungal genus. The *Folsomia* (50%) was the most abundant collembola. Oribatida (82%) was the main mite group followed by mesostigmata (14%) and prostigmata (4%).

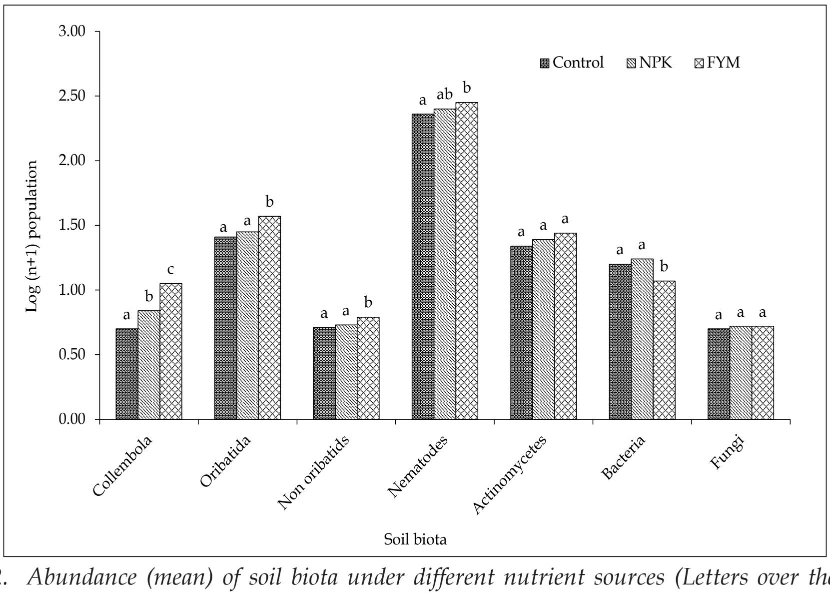

Fig. 2. Abundance (mean) of soil biota under different nutrient sources (Letters over the bars indicate significant differences).

Table 4. Comparisons (ratio) of soil biota abundance under different nutrient treatments in a fodder production system

Soil biota	Cowpea + Maize			Lucerne		
	NPK/control	FYM/control	FYM/NPK	NPK/control	FYM/control	FYM/NPK
Actinomycetes	0.90	1.14	1.28	1.39	1.78	1.28
Bacteria	1.66	1.71	1.03	0.83	0.68	0.82
Fungi	1.61	1.08	0.67	0.76	1.46	1.93
Collembola	1.23	4.08	3.32	1.14	2.51	2.21
Oribatid mites	1.27	1.73	1.36	2.19	1.23	0.56
Other Mites	1.09	1.50	1.38	0.85	1.41	1.66
Nematodes	1.10	1.42	1.30	1.08	1.14	1.06

NPK= Inorganic nutrient source, FYM = Organic nutrient source, Control = No nutrient was applied.

Compared to control and NPK the microarthropod was more diverse (Shannon Diversity Index = 1.45), and evenly distributed (evenness index = 0.66) in FYM treated plots. The likelihood of choosing two individuals belonging to different species was also higher in FYM treated plots (Simpson's Reciprocal Index = 3.32) than control or NPK treated plots. Moreover, similar trend in diversity and distribution was also observed for micro-flora (Table 3).

A number of individuals of biota was greater in manure plots (Fig. 2). The peak population of actinomycetes (363×10^5 cfu/g), bacteria (136×10^6 cfu/g), fungi (24×10^5 cfu/g), collembola ($144\times10^2/m^2$), oribatid (cryptostigmata) mites ($203\times10^2/m^2$), non-oribatid mites ($23\times10^2/m^2$) and nematodes ($1386\times10^2/m^2$) was noted in FYM treatment. This increase may be attributed to the improvement in soil nutrients and moisture under organic crop management. We observed a significant decrease in bacterial count in FYM treated plots in comparison to control and the NPK plots. The build-up of collembola was pronounced in FYM plots compared to other biota (Table 4).

Several studies have shown that the impact of organic fertilizer on the abundance and diversity of soil biota. The organic amendments such as sewage sludge and manure in barley agro ecosystem at Spain increased the population of collembola and acari in contrast to plots where only inorganic fertilizers were added (Arroyo *et al.*, 2003). Lupwayi *et al.* (2005) and Mahajan *et al.* (2007) have reported incorporation of FYM, crop residues, cattle manure enhanced the soil nutrients, especially organic carbon level, influenced the soil structure, physical properties as well as moisture retention capacity along with the soil microbial diversity and biomass carbon.

This study also confirmed a strong treatment effect on soil biota build-up. The population

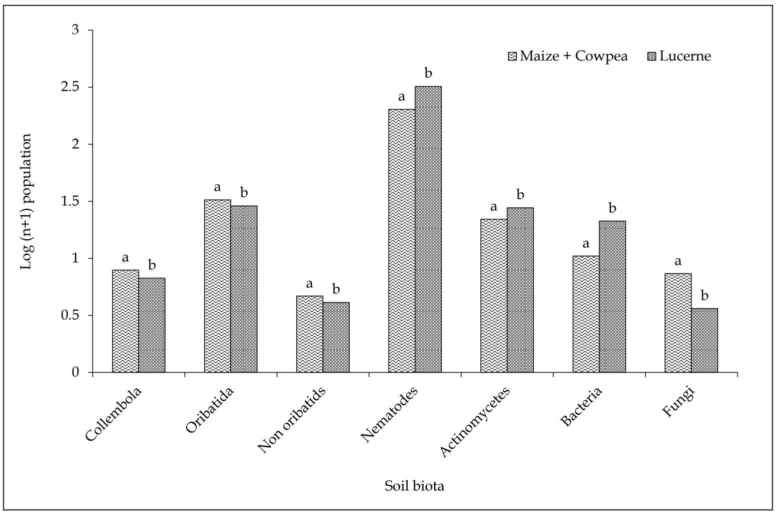

Fig. 3. Soil biota abundance (mean) under different crops (Letters over the bars indicate significant differences).

of various biota steadily increased over the study period in FYM treated plots (collembola = 26%, oribatida = 8.34%, non oribatida = 8.1%, nematodes = 2.4%, actinomycetyes = 3.89%, bacteria = -14% and fungi = 6.94%).

Relationship of biota with crops

In general greater build-up of biota was noted in maize + cowpea intercropping (67% of total micro-arthropods and 63% of micro-flora) than the lucerne crop. However, this response varied with groups of biota ($P<0.05$, Fig. 3). The collembolans, mites and fungi thrived well in rainy season crop (maize + cowpea intercropping) while, nematodes, bacteria and actinomycetes boomed in winter crop (lucerne).

Temporal build-up of biota

The soil biota build-up was considerably high in year 2003 compared to the 2001 and 2002 samples ($P<0.01$). The build-up was most pronounced in case of non oribatid mites (225%) followed by collembola (165%), actinomycetes (161%), bacteria (147%), nematodes (145%), oribatids (139%) and fungi (116%).

The soil organisms are usually sensitive to environmental vagaries and this may possibly be the reason of yearly inconsistent abundance pattern of the organisms observed in this study. Osler *et al*. (2008) had earlier reported similar observations on build-up of micro-arthropods under arable crop rotation in Alberta, Canada.

Due to the lack of any information on the soil biota build-up from the study area we had decided to collect soil samples at three intervals to find out the impact of soil disturbances and various cultivation operations on the recovery of biota under different treatments. The initial observations showed a significant difference in population build-up of biota at different dates of sampling. However, further analysis on interaction of crop and treatment with the dates of sampling revealed mixed impact of dates of sampling on the abundance of various biota. Hence, it is suggested that the samples may be collected on the 21st day after seeding to extract enough number of individuals/sample as there may be initial decline in biota due to agriculture operations. Badejo *et al*. (2004) and Twardowski *et al*. (2004) had also encountered similar initial decline of epigeic forms of micro-arthropods due to tillage and later on a better recovery under the organic management of crops.

Conclusion

The study demonstrated that in comparison to unfertilized control the abundance and diversity of different groups of biota had increased under both the organic and inorganic nutrients. But the population build-up was more pronounced in organic treatment along with the significant improvement in soil fertility and crop yield. This positive impact of manure on green fodder yield was realized even in drought and rain deficit years. Therefore we conclude that the application of manure will improve soil quality and biological activity of the nutrient deficit Alfisol of the region.

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