

About this bulletin

Soil biology is receiving increased attention of scientist's community for understanding and addressing sustainability concerns that pertain to land. In this bulletin research work conducted at Indian Grassland & Fodder Research Institute, Jhansi on various soil biology aspects of fodder production systems is presented for the benefit of research in related fields.

About Authors



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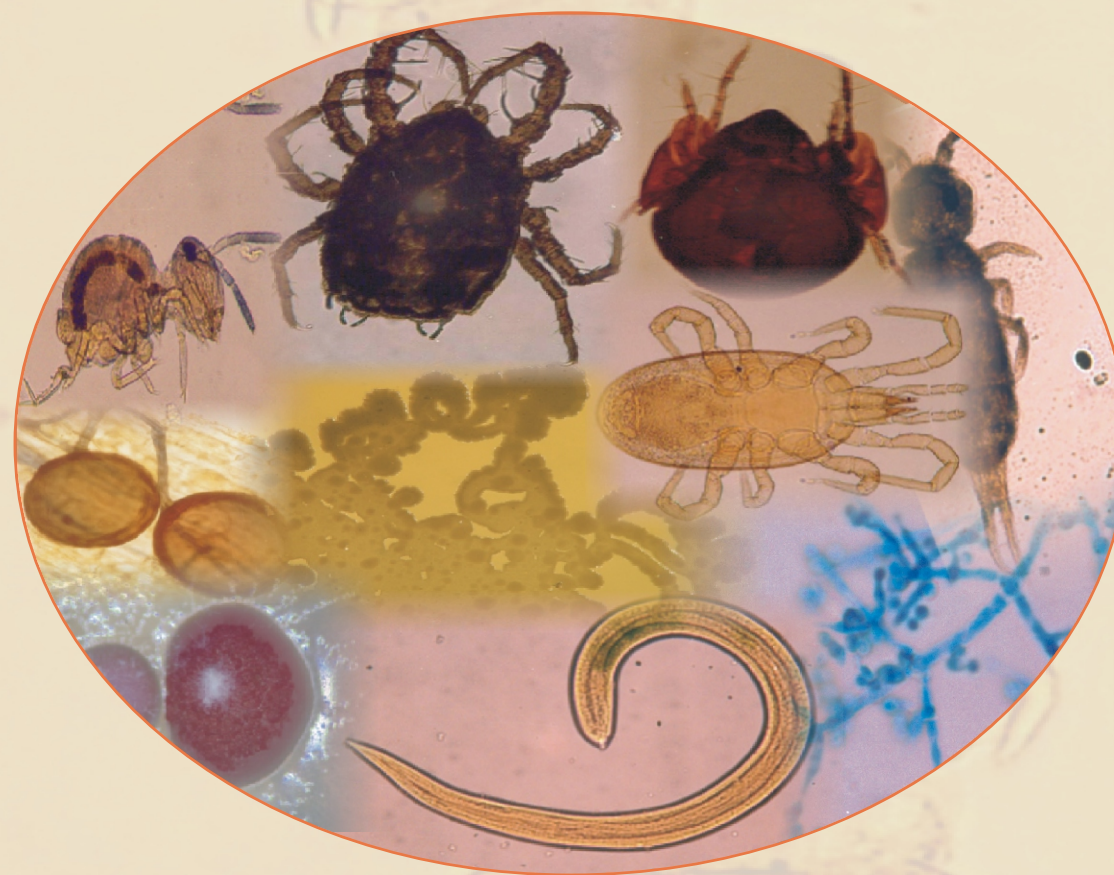
"Without soil organisms the life on this planet would come to standstill".

Waksman

"Look down at the soil to make agricultural productivity look up".

William D. Dar

Soil Biodiversity under Forage Production Systems



Indian Grassland & Fodder Research Institute

Jhansi – 284003



Soil Biodiversity Under Forage Production Systems

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Printed : April 2008

Citation : Sharmila *et al.*, 2008 Soil biodiversity under forage production systems. IGfRI, Jhansi (India)

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Cover Design : Sharmila Roy
Production : Ashok Shastri

Published by : Director
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Cover page : Microarthropods, microflora, nematode

Foreword



SOIL organisms are an integral part of agriculture and forestry ecosystem on account of their role in maintaining soil health, ecosystem functions and production. However, below ground biodiversity is less researched part of agro-ecosystems.

With increasing opportunities in the growth of livestock sector in the country, fodder production has become most important and essential. It is therefore, required to raise productivity level of cultivated fodder crops through improved production technologies and also to harness more forage from grasslands and tree based forage production systems on a sustained basis.

In order to sustain land productivity, we need to focus our attention on the rhizosphere - hot spot of below ground biodiversity. The shape and size of biological diversity is as complex as that of above ground but more resilient of anthropogenic perturbations. Holistic approaches for assessing soil quality and health are required to sustain finite soil resources for future generations.

I compliment the authors for compiling information on below ground diversity associated with major fodder production systems like fodder crop cultivation, grasslands, silvi/hortipastoral system based on the research work carried out at Indian Grassland and Fodder Research Institute, Jhansi. I am confident that this publication will not only provide good technical material for research workers but will also serve as a useful reference for planning ahead.

April, 2008

(P L Gautam)
DDG (CS) ICAR
New Delhi

Preface

THE ongoing degradation of the biological base of soil productivity in agro ecosystem has led to the realization that efforts are required for understanding below ground biodiversity - their community structure, characteristics, dynamics and functionality. In India, fodder production systems are generally practiced on marginal lands so sustainability issues become very important. The monitoring of soil biodiversity in such systems is, therefore, an important area.

At Indian Grassland and Fodder Research Institute, Jhansi various fodder production technologies have been evaluated for below ground flora and fauna in various research projects as one of the component. However, this information is in piecemeal. In this technical bulletin an effort has been made to document all such information at one place and in a logical sequence.

It is hoped that this publication will be a useful reference for the researchers in the field of soil biology.

We are extremely thankful to Dr K.A. Singh, Director, I.G.F.R.I. Jhansi and the Ex-Directors Dr P.S. Pathak and Dr Panjab Singh for providing guidance and support to soil biology studies at this institute. The research contribution of the scientists namely, M. I. Azmi, R. B. Bhaskar, K. C. Pandey, N. Hasan, S. A. Faruqui, R. K. Bhatt, M. J. Baig, R. B. Yadav, S. K. Das, M. R. Pahwa, R.K. Jain, N. K. Shah and S. B. Tripathi are also gratefully acknowledged.

We are obliged to our divisional heads who have guided us at different opportunities. We appreciate to those scientist and workers who allowed us to carry out the different aspects of soil biology works in their experiments and land use systems.

The members of Editorial Board whose careful suggestion and editing, printers and composers have stood the test of endurance in all through the production of this work for the best results, we are grateful to them.

April, 2008

Sharmila Roy
Pradeep Saxena
M. M. Roy

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Acronyms

AM	Arbuscular Mycorrhizae
a. i.	Active Ingredient
BGBD	Below Ground Bio- Diversity
CBD	Convention on Biological Diversity
C	Carbon
CABI	Commonwealth Agriculture Bureau International
CD	Critical Difference
cfu	Colony Forming Units
CO ₂	Carbon di Oxide
DMY	Dry Matter Yield
EC	Electrical Conductivity
FYM	Farm Yard Manure
g	Gram
GFY	Green Fodder Yield
GHG	Green House Gas
GSM	Grasland & Silvipasture Management Division
ha	Hectare
hr	Hour
ICAR	Indian Council of Agriculture
IGFRI	Indian Grassland and Fodder Research Institute
K	Potash
kg	Kilogram
KUE	Potash use Efficiency
m	Meter
mg	Milligram
MPTS	Multi-Purpose Tree Species
N	Nitrogen
NUE	Nitrogen Use Efficiency
NAAS	National Academy of Agricultural Sciences
OC	Organic Carbon
P	Phosphorus
pH	A number used to express acidity or alkalinity
ppm	Parts per Million
SMB	Soil Microbial Biomass
SOM	Soil Organic Matter
SM	Soil Moisture
ST	Soil Temperature
Sp.	Species
t	Tones
TPF	Tri Phenyl Formazone
TSH	Tri Specific Hybrid
μ	Micro
UK	United Kingdom
VAM	Vesicular Arbuscular Mycorrhizae

Introduction

Indian agriculture is an integration of several sub components including livestock enterprise. There is a tremendous pressure on forage production systems and grazing lands due to increased demand by exploding population, shrinking resources and declining production. While India boasts of 15 per cent total world's live stock population, the area under fodder is limited to 4.4 cent of total cultivated area. It is certain that horizontal growth is restricted while there is a scope for vertical growth by integrating the production factors in appropriate proportions.

Soil is a fragile growth medium supporting agricultural production system. In the present day high intensity agricultural production systems, more emphasis is placed on adoption of high yielding varieties coupled with application of fast reactive chemicals-fertilizers, pesticides and weedicides leading to imbalance in the sensitive soil ecosystem. In this process, manipulation of beneficial soil organisms is given the least preference.

The concept of soil health and/or quality (which are synonymously used) is the buzzword in the farming community all over the world (CBD, 2001; NAAS 2006). Soil organisms constitute an inseparable and integral part of soil health. As such organism are highly sensitive to changes they act as an indicator of soil health/quality. The fertility of soil is central to the sustainability of both natural and managed ecosystems.

The natural ecosystems maintain their production through well balanced above and belowground biological processes, which serve to conserve the nutrients, water and soil organic matter within the systems. In agricultural systems the attention is given on crop varieties, agronomic practices, application of fertilizers, and use of pest management strategies and there is almost no emphasis on potential manipulation of beneficial soil processes in designing of management practices. Similarly, soil degradation is seldom attributed to the decline of soil biota and reduction in their activities. Thus it is important to develop strategies and technologies to maintain and improve the soil biota.

Obviously, a challenge is thrown open on us to formulate a holistic approach for development of diagnostic tools for soil quality/health assessment for practical purposes at all levels. This bridges the gap between the realizable and realized yields in a sustainable and eco-friendly manner.

Indian Grassland and Fodder Research Institute initiated a series of tasks while pursuing research to answer the questions in soil health and quality aspects related to fodder production systems. This technical bulletin is a compilation of the works pursued to assess and monitor beneficial soil organisms to understand their contributions to varied land uses.

Soil Biota and Ecosystem Functioning

Soil-Habitat

Biological activity in soils is mainly concentrated in the top soils. The biological component occupy a small fraction ($< 0.5\%$) of the total soil volume and make less than 10 percent of total organic matter in soil. This living component of the soil organic matter consists of 5-15 percent of plant roots, 85-90 percent soil organisms. The variation in soil profile, resource availability, microclimate, chemical and physical structure influence the soil biota size, composition and distribution (Buscot and Verma, 2005). The profile of an undisturbed mature soil is divisible into a number of strata, which also includes surface organic layers (hemiedaphon) and the underlying mineral soils (enedaphon). The vegetation layer above the soil surface is termed as epigeon. The Hemiedaphon may be further divided into hydrophile, mesophile and xerophile based on the moisture content.

In an attempt to better conceptualize soil systems into biologically relevant regions on the basis of their spatial and temporal heterogeneity; the activity of soil organisms in different layers of soil profile has been conceptualizes as "sphere of influence". The soil profile may be divided into five major layers viz., (i) Detritosphere - above soil surface, comprise of litter fermentation, humification, which have considerable root mycorrhizal and saprophytic activity and grazing by the soil fauna. (ii) The drilosphere - The soil layer influenced by the activities of earthworm and other insects; (iii) The porosphere - Which is the region of water films occupied by bacteria, protozoa, nematodes and of channels between aggregates occupied by microarthropods and the aerial hyphae of fungi; (iv) the aggregatosphere - the region where the activity of microbes and fauna is concentrated in the voids between microaggregates and macroaggregates and (v) the rhizosphere - the zone of soil influenced by roots associated by mychorrhizal hyphae and other products. The spores are formed and maintained by biological influence that operates at different spatial and temporal scales. Moreover, each sphere has distinct properties that regulate interactions among organisms and biological properties that they mediate.

Diversity

The life on planet earth has originated about 4 billion years ago, just after the earth surface became cool enough to have water in liquid state. These organisms were like today's prokaryotes - bacteria. The modern studies have shown the living organisms can be broadly classified into two radically different kinds; prokaryotes (less complex cell structure) and eukaryotes (organisms with true nucleus), which further divided into many other forms. Over the times the living things have occupied different ecological niche. These niches are determined by competition between species determined by the availability of nutrients,

Soil Biota and Ecosystem Functioning

water availability and soil environment such as temperature, pH, and salt concentration. The microorganisms employed different strategies to survive and prosper in different environments. That may be combative strategies (c - selected) which maximizes occupation and exploitation of resources under non stressed conditions; stress strategies (s - selected) which have involved the development of adoption which allow survival and endurance of continuous stress environment and ruderal strategies (r- selected) characterized by a short span with a high reproductive potential which often enables success in severely disturbed but favorable for a short period. These three strategies can merge to give secondary strategies (C-R, S-R, C-S and CSR) which form part of a continuum with transition zone between them. The free-living components of soil biota are bacteria, fungi, algae and the fauna.

They may be grouped either on the basis of body width viz., micro, meso and macro-organisms (Table 1) or on the basis of functional groups viz., mycophagous/herbivores, omnivores and predators, period of soil inhabitation, habitat preference or biological activity.

Table 1. Groups of soil biota based on body size

Organism	Size(mm)	Examples
Microflora	< 1	Bacteria, algae, fungi, actinomycetes
Microfauna	< 2	Protozoa, nematode
Mesofauna	2-10	Collembola, acarina
Macrofauna	>10	Earthworms, termites, snails, arachnids

Feeding and locomotion are the other two main activities that divide the organisms in different groups. Based on locomotion the soil animals can be distinguished as burrowing ones from the others that move on the soil surface or through the pore spaces/channels/cavities in soils. In terms of feeding activity the soil animals can be classified in five major groups (Table 2).

Table 2. Classification of soil fauna based on their activity

Organism	Activity
Carnivores	Predator Animal Parasites
Phytophagus	Above ground green plant material Root systems Wood material
Saprophagus	Caprophagus Xylophagus Necrophagus Detrivores
Symbionts	VAM and Endophytes
Microphytic feeder	Fungal hyphae, spores, algae, lichens, bacteria feeder
Miscellaneous feeders	Omnivores (food varies from site to site)

Soil Biodiversity Under Forage Production Systems

The temporary and permanent members of soil fauna can be distinguished based on their period /stages of life cycle spent in soil. The permanent inhabitants of soil are termed as 'geobionts'. The temporary category belongs to the insects that enter in soil as adults and escape during unfavorable conditions or insects that undergo part of their development, as eggs or larvae, in the soil, termed as 'geophiles' e.g. Coleoptera, Thysanoptera, Heteroptera, Diptera etc. The geophiles are further distinguished as inactive and active geophiles. Inactive geophiles include adult insects which seeks the shelter afforded by loose or decaying leaf litter/wood and in surface soil. The temporary geophiles have little or no contribution in soil structure. The active geophiles pass different stages of development in soil and are closely associated with soil. The inactive geophiles are also termed as transients and the active geophiles as periodic and temporary based on their period of presence in soil (Singh and Lal, 2001).

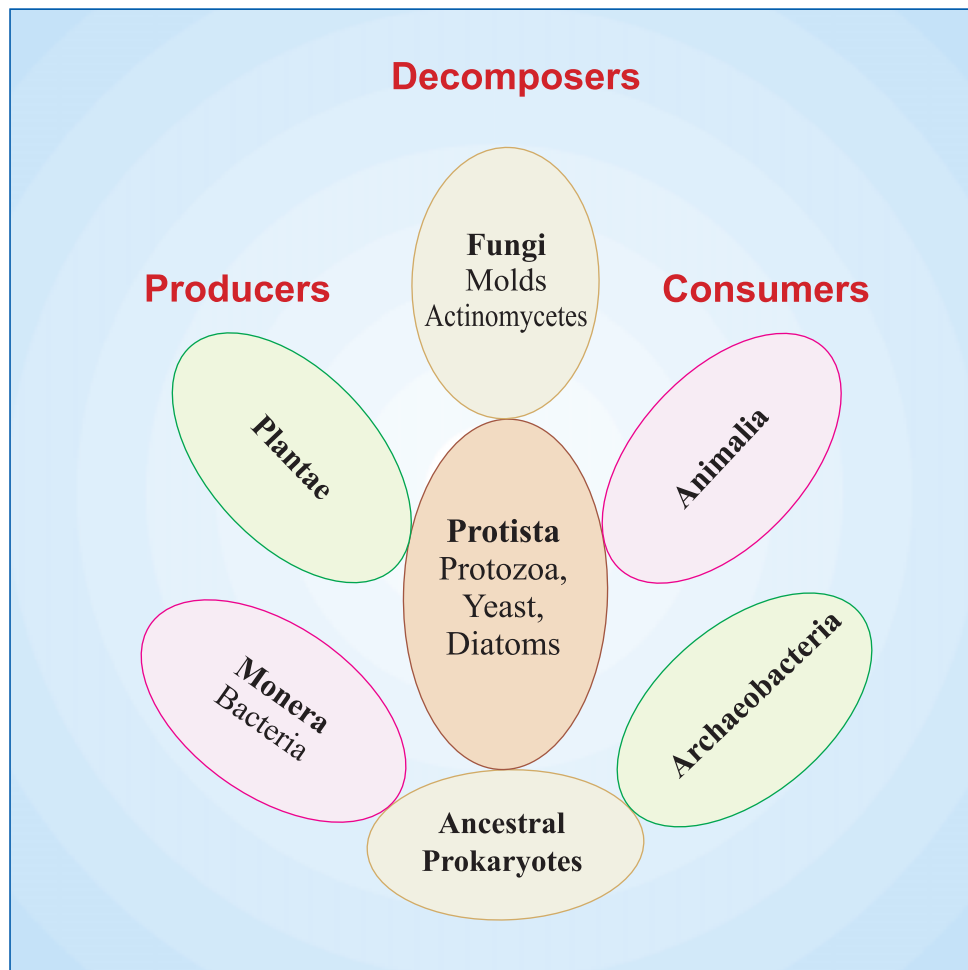


Fig.1. Schematic diagram showing five kingdoms of living organisms

Soil Biota and Ecosystem Functioning

Classification of Soil Biota

All living things can be classified into one of the five fundamental kingdoms of life namely, Monera, Protista, Fungi, Plantae, Animalia (Fig. 1) and are well represented in soil ecosystem.

1. Kingdom Monera: includes prokaryotes-single cell organisms that do not possess nucleus e.g. bacteria, actinomycetes and the blue green algae
2. Kingdom Protista: includes single cell organisms that do possess nucleus e.g. nucleated algae and slime moulds
3. Kingdom Fungi: These non motile eukaryotes lack flagella and developed spores like yeast, moulds and mushrooms
4. Kingdom Plantae: these eukaryotes develops from embryos and use chlorophyll like mosses and vascular plants
5. Kingdom Animalia: the multicellular eukaryotes develops from a blastula (a halo ball of cells).

Ecosystem Processes

Soil organisms are an integral part of agricultural and forestry ecosystems. They play a significant role in maintaining soil health, ecosystem functions and production. Each organism has a specific role in the complex web of life in the soil. The sustained use of the agriculture and water resources is dependent upon maintaining the health of the living biota and their key role in the primary productivity of the ecosystem they inhabit.

Their diverse role can be categories into (a) Facilitating nutrient acquisition by the vegetation through the mycorrhiza and N- fixing organisms, (b) Regulating the flow of nutrients

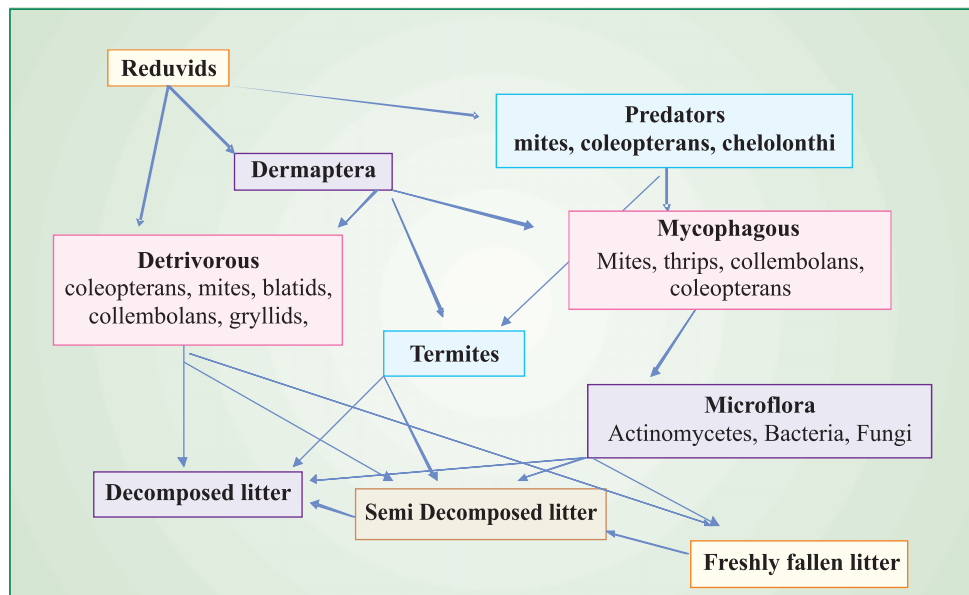


Fig. 2. A typical food chain of forest soil ecosystem (Ananthakrishnan and Thomas, 1993)

Soil Biodiversity Under Forage Production Systems

through decomposition, mineralization and immobilization, (c) mediating and breakdown of organic matter, (d) modification of soil structure which influence water availability to the plants, (e) Modifying the health of the plant by parasitism and pathogenesis.

Soil micro flora is the primary consumer in the detritus food web. They act on the organic wastes and convert them either into useful or into innocuous and less harmful substance. In nature fungi, bacteria and invertebrates interact and influence decomposition and functioning of rhizosphere. Soil fauna governs the distribution, abundance and activity of soil fungi and bacteria (Fig 2). In saprophytic succession, six mechanisms of interaction are important. Two control fungal distribution and abundance (I) selective grazing of fungi, (II) dispersal of fungal inoculums. Four mechanisms stimulate microbial activity; (I) direct supply of mineral nutrients in urine and faeces, (II) stimulation of bacterial activity by faunal activity, (III) compensatory fungal growth due to periodic grazing and (IV) release of fungi from competitive stasis. In rhizosphere, the mechanisms of interactions are dispersal and selective grazing of flora. Micro and meso fauna carry fungal propagules including root pathogens, to root surface. They also graze on root surface, and they selectively graze saprophytic fungi. It has been shown that dispersal of pathogens to the rhizosphere is less important than preferential grazing on pathogens.

Soil organisms can also be used to reduce or eliminate environmental hazards resulting from accumulations of toxic chemicals or other hazardous wastes. This action is known as bioremediation. A number of soil organisms can be detrimental to plant growth, for example, the build up of nematodes under certain cropping systems. However, they can also protect crops from pest and disease outbreaks through biological control and reduced susceptibility.

Soil Health Indicator

Soil health defined as 'continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant. Soil health animal and human health' is a term that is used synonymously with soil quality.

Soil organisms contribute to maintenance of soil health by regulating decomposition, mineralization, formation and maintenance of soil structure. These functions and their regulatory role make them potential bioindicators of soil health. The organisms respond to the soil management in time scale (months/years) and are highly sensitive to any change, whereas the chemical and physical parameters of soil are largely fixed by geographic constraints and changes can be perceived or measured after the damage was already done to the system (Pankhurst et al., 1998). Soil properties which have desirable properties to develop or used as bioindicators are listed by Doran and Safley (1998) in Table 3.

Soil Biota and Ecosystem Functioning

Table 3. Soil properties of relevance as indicators of soil quality and soil health

Indicators	Relevance to	
	Soil Quality	Soil Health
Physical Indicators		
Mineral composition	+	-
Texture	+	-
Depth	+	-
Bulk density	+	+
Water holding capacity	+	+
Porosity	+	+
Chemical Indicators		
pH	+	+
Electrical conductivity	+	+
Cation exchange capacity	+	+
Organic matter	+	+
Major elements	+	+
Heavy metals	+	+
Biological Indicators		
Microbial biomass	+	+
Soil respiration	+	+
Mineralizable N	+	+
Enzyme activity	+	+
Abundance of microflora	+	+
Abundance of soil fauna	+	+
Root disease	+	+
Soil biodiversity	-	+
Food web structure	-	+
Plant growth	+	+
Plant biodiversity	-	+

+ = relevant; - = no or little relevance

□

Major Fodder Production Systems

IGFRI has developed a number of improved fodder production systems for a variety of situations (Table 4). The animal husbandry in Central Indian region is primarily grazing based. The traditional forage production systems are low in productivity and under great strain, due to both land and input constraints. Extensive studies in low productive systems showed that fodder production could be increased by several folds.

The cultivated fodder especially sorghum in kharif and berseem in rabi are popular in this region. The other cultivated fodders are lucerne, cowpea, oat, maize and bajra. Amongst the perennial cultivated forages napier-pearl millet hybrid, guinea grass and para grass are popular with the farmers. A number of varieties and intensive fodder production systems have been developed and promoted by the organization for different regions and clienteles. Since the region is semiarid and wherever the prospects of fodder crop cultivation is limited, perennial species based systems like grassland and silvipasture are recommended for degraded forests and other wastelands. These systems are popular with the farmers and with the developmental agencies such as wasteland and forest departments.

Table 4. Fodder production systems developed at the IGFRI

	Cultivated fodder		Grassland/pasture		Tree based fodder	
Systems	Intensive fodder production systems	Food Fodder System	Cultivated grasslands	Improved pastures	Silvipasture systems	Horti-pasture Systems
Purpose	Round the year availability of green, nutritious fodder	Availability of green fodder between the major food crops	For quality grass as fodder	To improve the fodder quality, soil restoration	Fodder availability in lean period, conserve soil and moisture	Additional fodder income from orchards
Potential Application	Intensive Dairy Units	House hold livestock	Grazing based animal husbandry		Wasteland and degraded forest development projects and farmers interested in developing their degraded lands or utilisation of under storey of orchards	

Major Fodder Production Systems

Fodder Production Systems

Plate-1



Silvipasture



Hortipasture



Natural Grassland



Improved Pasture



Fodder Production under elevated CO₂



Intensive Fodder Cultivation

Soil Biodiversity Characterisation

Species Diversity

Soils contain enormous numbers of diverse living organisms, ranging from the myriad of invisible microbes, bacteria and fungi to the more familiar macro-fauna such as earthworms, termites and plant roots. It is almost impossible to take into account the absolute diversity of soil flora and fauna due to its complexity. However, the observed diversity and the mathematical theories guide in exploring the below ground diversity to some extent. These organisms interact with one another and with the various plants and animals in the ecosystem forming a complex web of biological activity. Environmental factors and anthropogenic actions, in particular, agricultural and forestry management practices, affect soil biological communities and their functions.

The works related to soil biodiversity in this region have revealed rich community diversity associated with different fodder production systems. Among the arthropods 148 species were encountered in different systems studied. They belonged to four classes viz., Insecta (17 orders), Arachnida (3 orders), Crustacea (1 order) and Myriapoda (4 orders). Out of all encountered species, 81 per cent were identified - 45 per cent at genus level and 36 per cent at family level. The frequently occurred species constituted 28 per cent of the total soil biodiversity while 18 per cent were in the rare category. Remaining 54 per cent were of medium order. The absolute species occurring in all the seasons and in all the systems, including bare land, were 4 Formica 3 Isoptera and 2 cryptostigmata (Scheloribatidae, Epilohmanniidae) species (Annexure I).

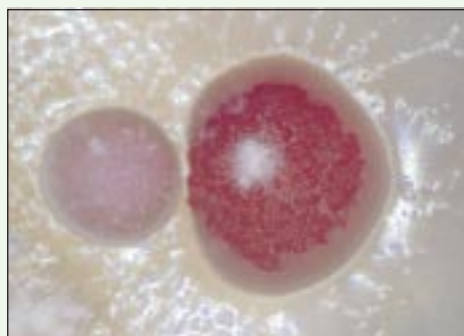
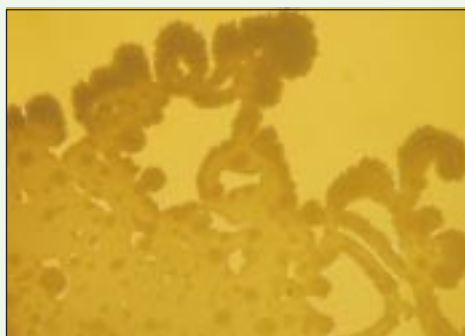
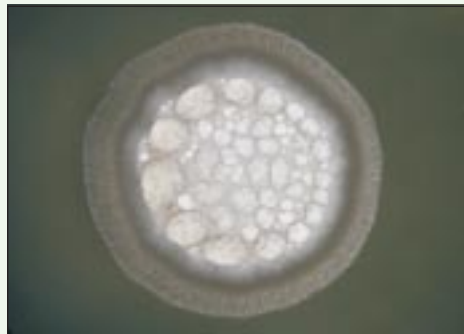
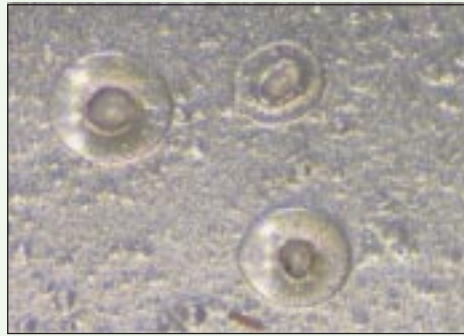
Among the micro-flora ten actinomycetes genera (11 species), seven bacterial strains, thirty eight fungal genera (79 species) and VAM were isolated and identified from different fodder systems (Annexure II). A number of nematodes and Protozoa have also been identified from the soils of different fodder crops and systems (Annexure III). Some annelids (earthworms and enchytraeids) and terrestrial snails and slugs have also encountered in various studies, but identification and further research work was not been carried out on these organisms.

Land use vs. Community Structure

The land management practices alter soil conditions which in turn regulate the soil community of micro, meso and macro-organisms. However, the relationship between specific practices and soil functions is less clear. In general, the structure of soil communities is largely determined by ecosystem characteristics and land use systems. The activity of different species depends on specific management practices as these affect the micro-environment conditions, including temperature, moisture, aeration, pH, pore size, and type of food sources.

Some microflora isolates from study sites

Plate-2

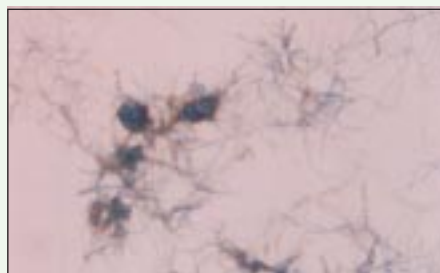


Bacteria colonies

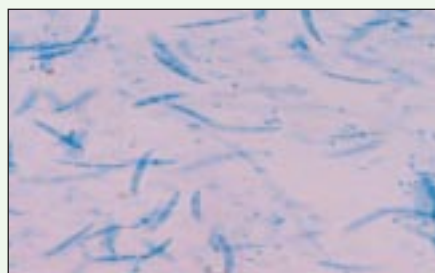
Actinomycetes colonies

Soil Fungi isolated from the study sites

Plate-3



Rhizoctonia



Fusarium



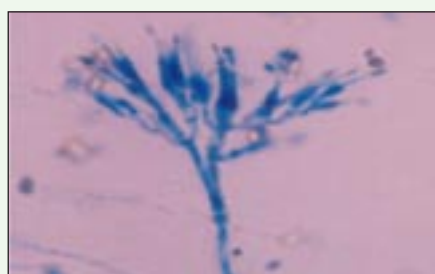
Aspergillus



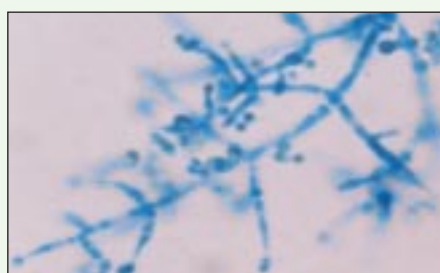
Helminthosporium



Dreschlera



Paecilomyces



Trichoderma



Penicillium

Nematodes and VAM observed in different studies

Plate-4

Nematodes



Plant parasitic

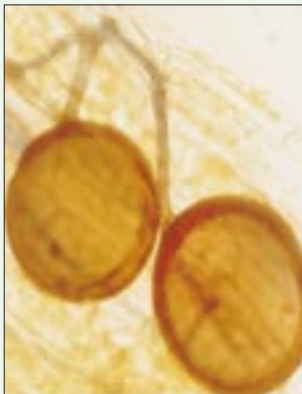


Bacteriophagus

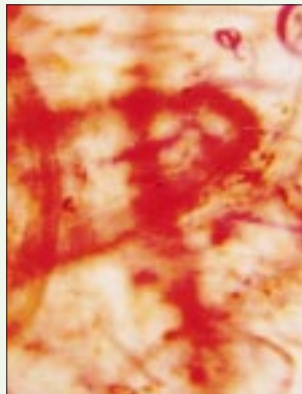


Predator

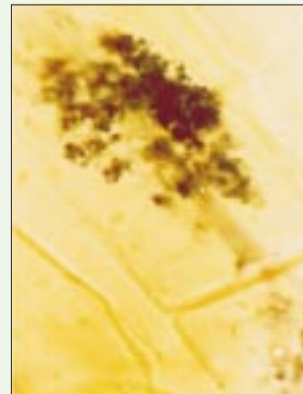
Vesicular Arbuscular Mycorrhizae



Spores of Glomus sp.



2nd Juvenile nematode
inside root



VAM inside root cell

Soil Mesofauna observed in different studies

Plate-5



Collembolans



Prostigmata



Mesostigmata



Cryptostigmata



Astigmata

Soil Macro fauna observed at the study sites

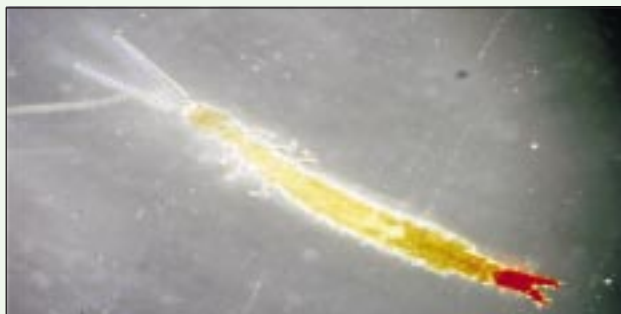
Plate-6



Pauropus



Symphylan



Japygidae



Protura



Campodeidae

Soil Macro fauna observed at the study sites

Plate-7



Pseudoscorpion



Silver fish



Chilopods



Isopteran



Araneids

Soil Biodiversity Characterisation

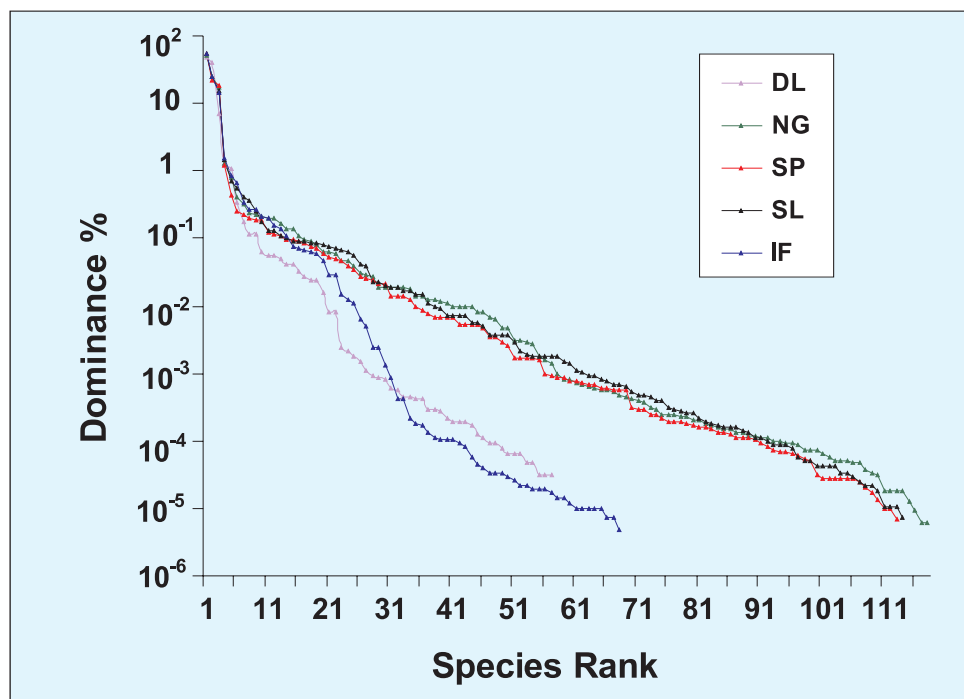


Fig. 3. Species Diversity of soil biota in different land use systems (DL = Degraded Lands; SP = Sown Pasture; NG = Natural Grassland; SL = Silviculture; IF = Intensive fodder crop cultivation)

Since soil biota community changes in response to various land management practices, an attempt was made to study the soil biota associated with various forage production systems (Roy *et al.*, 2006a). The studies indicated that the perennial systems, especially natural grassland, supported higher species biodiversity compared to the intensive forage cultivation. The forage cropping system that characterized high dominance of only a few species matched with the degraded land situation. The superiority of perennial systems in terms of high species richness and medium abundance is a reflection of the high level of maturity attained, allowing other species to flourish and thus leading towards a sound ecosystem (Fig. 3 & 4).

The silvipasture systems, being popular fodder production systems are promoted for lean period and conservation of degraded lands. A study has been conducted to evaluate the four silvipasture systems (three were single tree species based while fourth was multiple tree species based) for various soil fertility aspects. It has been found that they supported high biodiversity and density of the soil biota besides the good fodder yield. It has also been observed that the higher the above ground plant diversity higher the belowground diversity of soil biota (Table 5).

The abundance and diversity of VAM associated with fodder crops, fodder trees and five silvopastoral systems viz., *Acacia tortilis* + *Cenchrus ciliaris*, *Leucaena leucocephala*

Soil Biodiversity Under Forage Production Systems

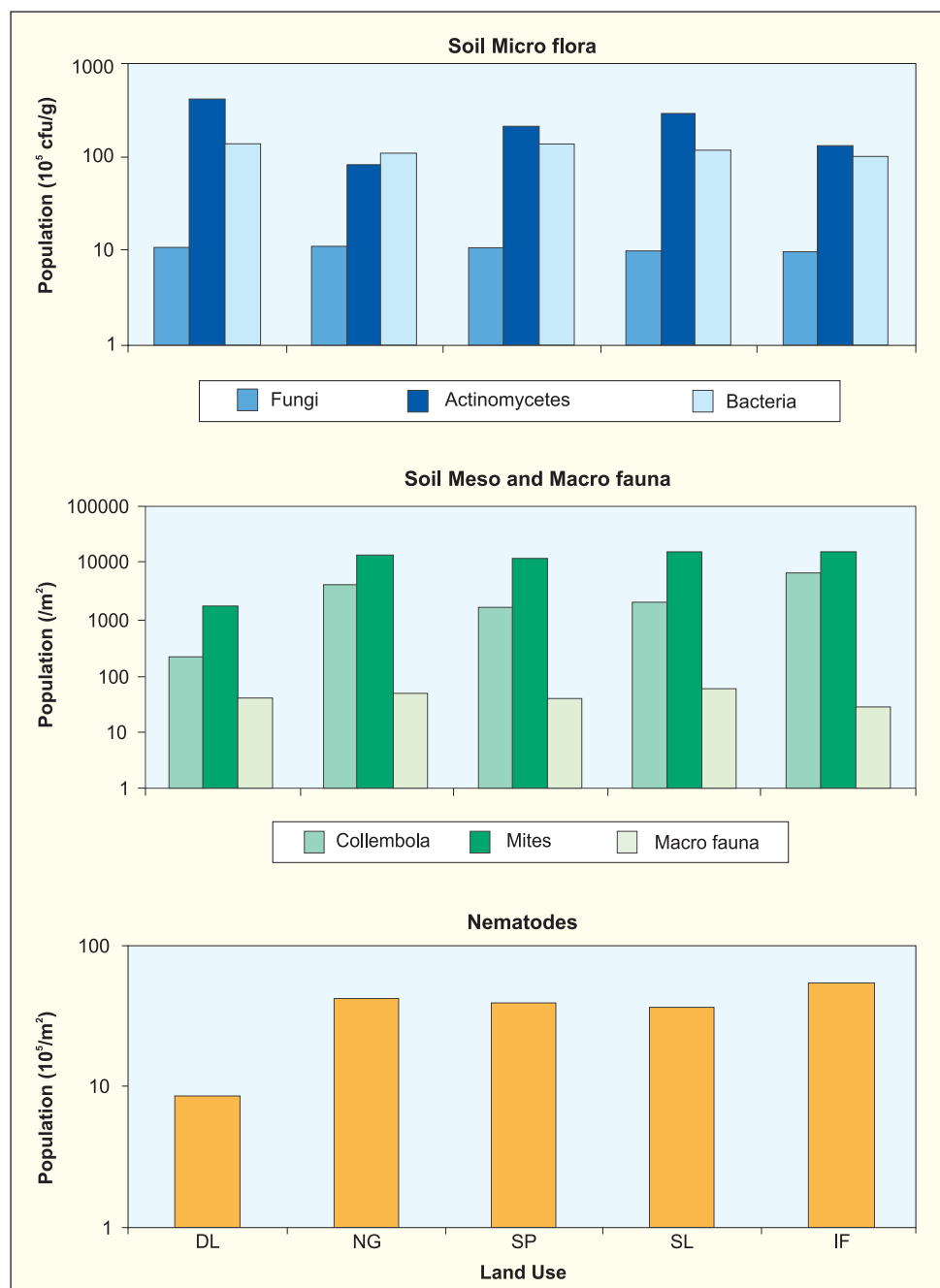


Fig. 4. Population density of Soil Biota in different land use (DL = Degraded land; NG = Natural Grassland; SP = Sown Pasture; SL = Silvopasture system; IF= Intensive Forage Cultivation)

Soil Biodiversity Characterisation

Table 5. Species Diversity of soil biota in different silvipasture systems

Soil Biota	Silvipasture Systems			
	SL-1	SL-2	SL-3	SL-4
Collembola	10	9	7	13
Cryptostigmata	20	13	19	27
Prostigmata	5	5	3	7
Mesostigmata	5	9	9	12
Astigmata	1	1	-	3
Other arthropods	20	22	20	48
Micro-flora	20	19	20	22

(SL 1= *Accacia tortilis*; SL 2= *Albizia amara*; SL 3= *Hardwickia binata*; SL 4= Multispecies Silvipasture)

Table 6. Species diversity of VAM/AM fungi associated with fodder trees crops

Plant Species	Spore Density (/100g soil)	Mycorrhizal	Colonization (%)
<i>Leucaena leucocephala</i>	200		79
<i>Albizia amara</i>	170		40
<i>A. lebbek</i>	197		52
<i>Hardwickia binata</i>	118		35
<i>Acacia tortilis</i>	167		43
<i>Cassia occidentalis</i>	156		40
<i>Trianthema portulacastrum</i>	244		90
<i>Parthenium hysterophorus</i>	66		20
<i>Corchorus olitorius</i>	23		15
<i>Chenopodium album</i>	64		18
<i>Cyperus iria</i>	53		15
<i>Euphorbia hirta</i>	23		10
<i>Cleome viscosa</i>	29		15
<i>Tridax procumbans</i>	18		10
<i>Boerhavia diffusa</i>	45		25
<i>Spergula arvensis</i>	51		35
<i>Stellaria media</i>	57		52
<i>Anagalis arvensis</i>	69		45
<i>Melilotus app.</i>	18		20
<i>Sida spinosa</i>	17		30
<i>Trifolium alexandrinum</i>	69		61
<i>Medicago sativa</i>	47		49
<i>Vigna unguiculata</i>	88		61
<i>Lablab purpureus</i>	24		35
<i>Sorghum bicolor</i>	84		50
<i>Stylosanthes sp.</i>	57		42
<i>Zea mays</i>	107		63
<i>Avena sativa</i>	40		40
<i>Cicer arietinum</i>	134		71
<i>Cajanus cajan</i>	140		37
<i>Panicum antidole</i>	-		67
<i>Cenchrus ciliaris</i>	51		52
<i>Pennisetum pedicilatum</i>	-		72
<i>Sehima nervosum</i>	-		33
<i>Bothrichloa intermedia</i>	-		59
<i>Chrysopogan fulvus</i>	-		62
<i>Pennisetum trispetic hybrid</i>	-		68
<i>Dicanthium annulatum</i>	48		51

Soil Biodiversity Under Forage Production Systems

+ *Panicum maximum*, *Hardwickia binata* + *Sehima nervosum*, *Albizia amara* + *Cenchrus ciliaris*, *Albizia lebbeck* + *Sehima nervosum* was studied at IGRI (Table 6). Eight species, belonging to four genera of VAM/ AM were found to be associated with five species of fodder trees. *Glomus* appeared to be most dominant genus followed by *Gigaspora*, *Auiculospora* and *Sclerocystis* (Hasan *et al.* 2004; Jain and Hasan, 1988; Jain *et al.*, 1998)

Different land use systems changes the soil environment and thus influence the habitat of soil biota and their dynamics (Roy *et al.*, 2006b). The Whittaker's β diversity and Index of dissimilarity were used to quantify such impacts. The decreasing index value of Whittaker (β_w) represented the increasing similarity, while the dissimilarity value is directly reflecting the result (Table 7). The complex and mature habitats like natural grassland, sown pastures and silvipasture system are closely related than the simplified systems (crop cultivation and degraded lands).

Table 7. Comparison of land uses based on soil fauna

	DL	NG	SP	SL	IF
DL		0.59	0.60	0.56	0.29
NG	0.11		0.07	0.08	0.44
SP	0.05	0.06		0.06	0.47
SL	0.14	0.03	0.09		0.42
IF	0.11	0.12	0.18	0.15	

Values above the diagonal are for fauna and below the diagonal are for flora (where, 0 = Completely similar and, 1= Completely dissimilar) (DL = Degraded lands; SP = Sown pasture; NG = Natural grassland; SL = Silvipasture; IF = Intensive fodder crop cultivation)

Seasonal Dynamics

The observation at specific time of year provide information on the population structure in an ecosystem which enables evaluation of the importance of particular functional group during the crop growth and hence provide an understanding of effects of management practices.

The population density and activity patterns of various soil biota were strongly governed by the seasons in this region (Fig 5). The maximum population was recorded in monsoon season. The low population was recorded in peak winters and summers. This indicated that the population built up of different soil biota was influenced by a number of factors climate/microclimate, physical and chemical properties of soil (Table 8). The most influencing parameters were soil moisture, soil temperature, rainfall. The different organisms have been found related with the soil nutrients parameters, but to understand their role in nutrient dynamics intensive research programmes are required (Roy *et al.*, 2007).

Litter Decomposition

The decay/decomposition can be broadly defined as the decrease in the mass of litter. The reduction in mass results from (a) leaching of soluble minerals (b) catabolism or oxidation of organic matter (c) physical breakdown (i.e. comminuting) of the substrate. As a result of

Soil Biodiversity Characterisation

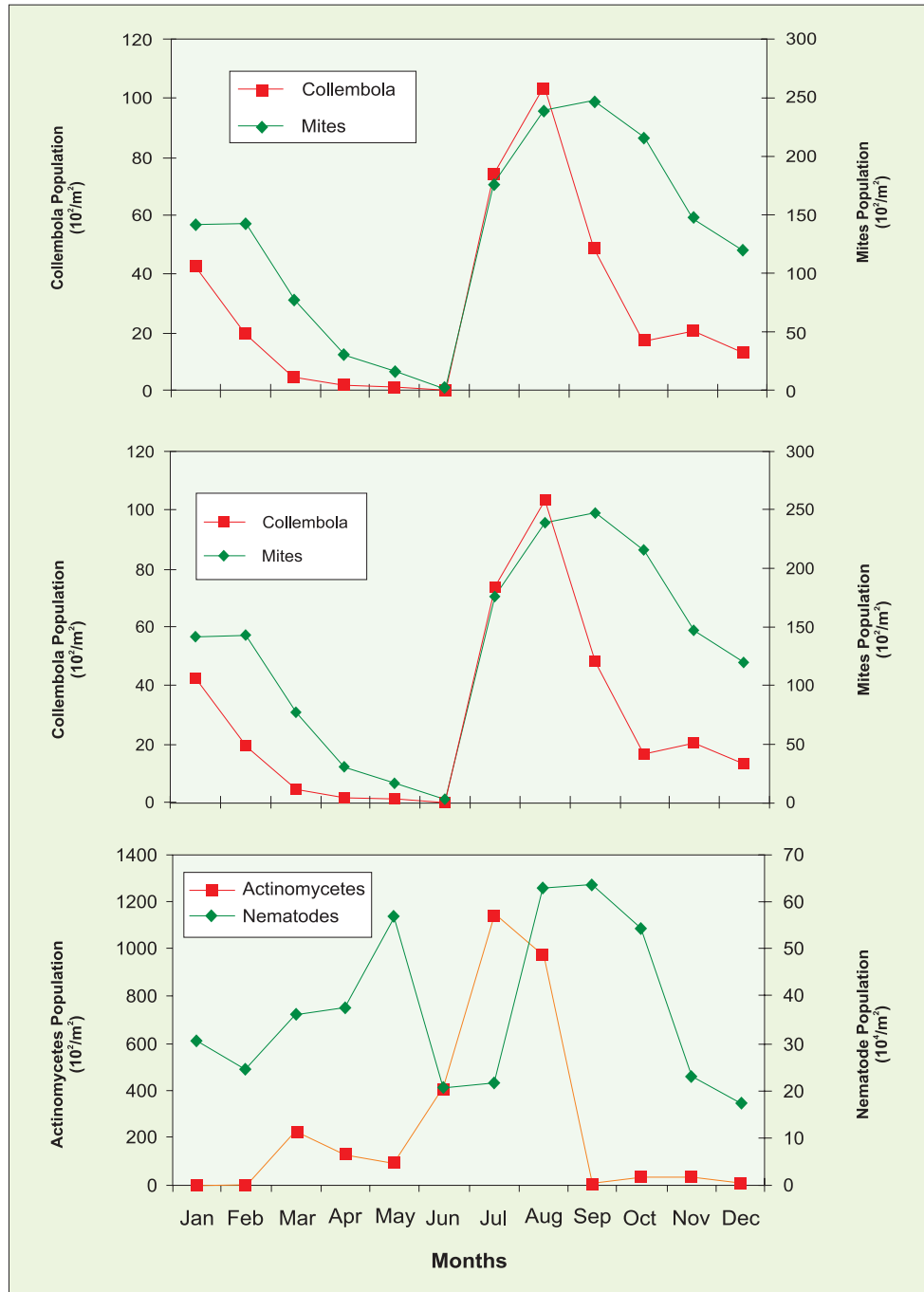


Fig.5. Seasonal abundance of various soil biota (mean monthly population)

Soil Biodiversity Under Forage Production Systems

Table 8. Correlation of different climatic and soil nutrient parameters with the soil biota

Soil Parameters	Organisms								
	COL	DEM	PRM	OTM	TOM	NEM	ACT	BAC	FUN
ST	-0.08	-0.24	-0.26	-0.31	-0.32	0.18	0.29	0.02	-0.02
SM	0.60	0.58	0.58	0.07	0.54	0.42	0.06	0.09	0.39
RH	0.31	0.45	0.49	0.25	0.48	0.20	-0.05	0.15	0.46
CO ₂	0.50	0.66	0.73	0.42	0.73	0.61	0.18	0.17	0.68
Rain	0.37	0.41	0.41	0.33	0.47	0.34	0.31	0.36	0.72
Av. N	0.07	0.04	0.08	-0.16	-0.01	0.32	0.07	0.12	0.08
Av. P	0.18	0.31	0.36	0.01	0.28	0.42	-0.20	-0.20	-0.13
Av. K	-0.17	-0.27	-0.26	-0.39	-0.36	0.03	0.36	0.11	-0.01
OC	-0.05	-0.01	0.11	-0.20	-0.06	0.13	0.12	0.16	0.01
pH	0.07	0.01	-0.02	-0.27	-0.07	0.11	0.08	0.05	0.19
EC	-0.05	0.12	-0.10	-0.24	0.00	-0.15	0.29	-0.10	0.11

r (5%) = 0.23; r (1%) = 0.30

(ST = Soil Temperature; SM = Soil Moisture; RH = Relative Humidity; Rain = Rain fall; Av. N,P,K = Available Nitrogen, Phosphorus, Potash; OC = Organic Carbon; COL = Collembola; DEM = Fungivorous/ Detritivorous Mites; PRM = Predator Mites; OTM = Other Mites; TOM = Total Mites; NEM = Nematodes; AC = Actinomycetes; BAC = bacteria; FUN = Fungi)

comminuting, leaching and oxidation rates are often greatly enhanced. The decay of plant litter, in nature occurs with the active involvement of soil microarthropods and microorganisms besides various abiotic environmental factors.

The litter mass loss of respective systems in different periods of year showed a positive trend with the population built up of soil biota, suggesting their potential role in soil nutrient dynamics (Fig. 6). In all the systems of study, increase in litter mass loss was accompanied by a significant increase in the number of collembolans and acarines. The Collembola were the early colonizers and their population was very high at the initial three months of decomposition in all the litter types. Among the microflora the fungi population was positively and significantly correlated with the litter mass loss.

Soil Enzymes

Soil enzymes are important mediators and catalysts of important soil functions that regulate decomposition, transformation and release of inorganic nutrients for plants growth, help in nitrogen fixation etc. The cropping systems, crops and fertilizer doses affect not only soil biota also influence soil enzyme activities (Das *et al*, unpublished data). The Table 9 indicating the variation in enzyme activity along with the soil fauna.

Under Elevated CO₂

The activities of some soil organisms determine the carbon cycle - the rates of carbon sequestration and gaseous emissions and soil organic matter transformation. The carbon sequestration is three times more in soil in comparison to the above ground biomass. The mycorrhizal fungi function as main carbon sink in soil. In view of the alarming scenario of

Soil Biodiversity Characterisation

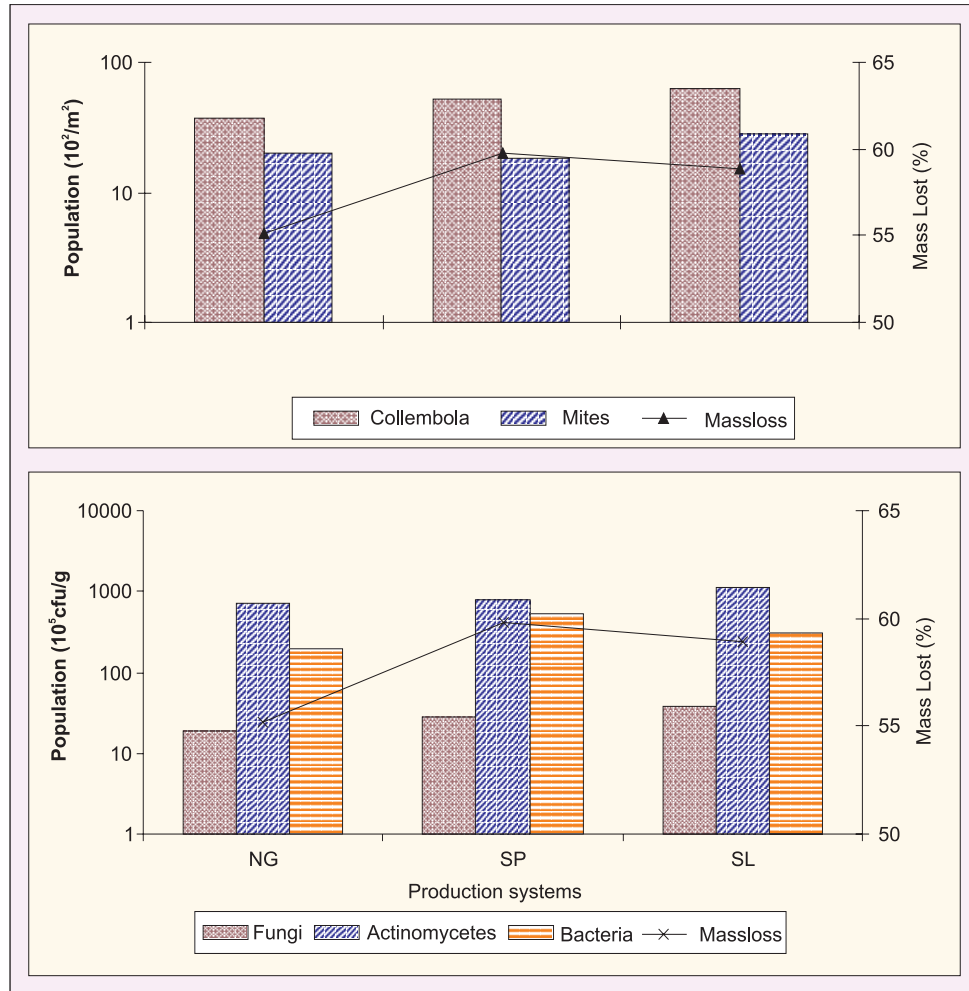


Fig. 6. Litter mass loss and soil micro flora and fauna in different systems (NG = Natural grassland; SP = Sown pasture; SL = Silviculture)

global warming via a greenhouse gas emission (GHG), the soil biota contribution towards carbon sequestration in soil should receive active consideration. The impact of GHG and atmospheric warming nexus on soil biota ecosystem functionality needs precise understanding. The agriculture production systems need attention on these aspects (NAAS, 2006).

To assess the carbon sequestration and microbial population dynamics in soil under elevated CO_2 and silviculture systems in semi arid tropics a programme was launched in the IGRI. The results indicated that the fungi population has significantly reduced in elevated level of CO_2 ($600ppm \pm 50$), whereas actinomycetes and the bacteria population have shown

Soil Biodiversity Under Forage Production Systems

Table 9. Soil enzyme activities under different land uses and management practices

Treatments	UA	PA	DA	C	M	N
	$\mu\text{g TPF/g/24hr}$			$10^3/\text{m}^2$		
Control	0.36	0.003	154.1	0.3	3.2	66.6
Fertilizer						
25% organic + 75% inorganic	0.54	0.02	221.0	0.8	11.2	180.9
50% organic + 50% inorganic	0.50	0.03	182.6	1.4	14.6	184.7
75% organic + 25% inorganic	0.51	0.02	242.1	0.6	11.0	219.4
CD (5%)	-	-	-	0.5	3.3	22.0
Food & Fodder Cropping systems						
Sorghum (fodder) + Pigeon pea (grain)	0.49	0.01	230.1	1.1	13.0	212.1
Cowpea (fodder)-Gram+Linseed (grain)	0.51	0.02	0.5.5	0.6	11.3	213.4
Maize (grain) + Cowpea (fodder)	0.56	0.01	219.3	0.8	11.2	159.5
CD (5%)	-	-	-	0.6	3.3	21.0
Perennial Systems						
Subabool + Tri specific Hybrid	0.49	0.02	203.1	0.4	10.2	184.4
Subabool + Guinea grass	0.55	0.01	233.5	1.3	13.0	205.5
CD (5%)	-	-	-	0.4	2.6	17.0

UA = Urease activity; PA = Phosphatase activity; DA = Dehydrogenase activity; C = collembola; M = Mites; N = Nematodes

a significant increase in this treatment with both the crop combinations (Table 10). However, the acari, collembolan and nematodes population have increased in the elevated CO_2 level under both the crop systems. This increase was significant in case of acari and nematodes in the *Panicum maximum* + *Stylosanthes hamata* crop (Bhatt *et al.*, 2005).

Table10. Effect of elevated CO_2 (600ppm $\pm$ 50) on microflora population (10^5cfu/g), soil micro fauna ($10^2/\text{m}^2$) and carbon sequestration (mg C/ha) in pastures

	<i>Panicum maximum</i> + <i>Stylosanthes hamata</i>				<i>Cenchrus ciliaris</i> + <i>Stylosanthes hamata</i>			
	Open	OTC	OTC+ CO_2	CD (5%)	Open	OTC	OTC+ CO_2	CD (5%)
Am	40.07	67.00	93.20	12.39	35.07	60.73	83.67	14.61
Ba	57.73	67.67	82.33	18.59	47.13	62.4	81.8	21.01
Fu	3.13	5.80	2.20	1.14	3.53	5.40	3.73	1.87
Cl	24.43	26.81	32.92	13.07	22.06	30.20	37.33	11.26
Mt	49.20	51.58	68.88	12.47	62.10	72.62	79.40	17.69
Nm	1350	1423	1561	102.5	1492	1676	1778	146.0
CSV	4.01	4.92	6.63	-	3.58	4.69	6.57	-
CSS	1.82	2.35	1.89	-	2.45	2.50	2.30	-
TCS	5.83	7.27	8.52	-	6.03	7.19	8.87	-

(Am = Actinomycetes; Ba = Bacteria; Fu = Fungi; Cl = Collembola; Mt = Mites; Nm = Nematode; CSV = Carbon sequestration in vegetation; CSS = Carbon sequestration in soil; TCS = Total Carbon sequestration; OTC = Open top chamber)

□

External Inputs vs Soil Biodiversity

Management strategies including tillage, crop rotations and use of plant residues and manure, changes soil habitats and the food web and alter soil quality, or the capacity of the soil to perform its functions. For example, soil compaction, poor vegetation cover and/or lack of plant litter covering the soil surface tend to reduce the number of soil arthropods. Farming practices that minimize soil disturbance (ploughing) and return plant residues to the soil, such as no-tillage farming and crop rotation, allow slowly rebuilding and restoring soil organic matter. Reducing tillage tends to increased growth of fungi, including mycorrhizal fungi.

Fertilizer

Subterranean flora and fauna are known to play a major role in maintenance of soil fertility and their response to various agricultural practices is differential. In crop production systems, the emphasis on chemical fertilizer/pesticide application for enhancing yield overshadows the decline in soil biota population leading to loss in soil fertility. The proper management of crop production systems for manipulation of beneficial soil fauna to the advantage of soil fertility is considered very important.

A comparative study of five fodder production systems viz., Guinea grass + Cowpea - Berseem; Sorghum - Berseem; Maize + Cowpea - Wheat; Maize + Cowpea - Lucerne; Ground nut - Wheat; indicated that the population of collembola and mites was significantly higher in FYM treated plots when compared to NPK and No fertilizer plots in all the cropping systems (Table 11). The ratio of collembola population in organic/inorganic was maximum in case of sorghum - berseem system (4.54) followed by maize + cowpea-wheat (3.08). The mite population organic/inorganic was maximum in guinea grass + cowpea - berseem (3.25) followed

Table 11. Farm Yard Manure supports Soil Meso- Fauna build up

Cropping systems	Collembola			Mites		
	FYM/NPK	FYM/NF	NPK/NF	FYM/NPK	FYM/NF	NPK/NF
Sorghum - Berseem	4.54	2.19	0.48	2.65	2.65	1.00
Maize + Cowpea - Wheat	3.08	9.25	3.00	1.16	2.19	1.88
Guinea grass+Cowpea- Berseem	1.47	2.00	1.36	3.25	7.65	2.35
Ground nut - Wheat	3.33	3.85	1.15	1.61	2.96	1.84
Maize + Cowpea - Lucerne	1.90	2.90	1.53	1.32	1.25	0.95

NPK = inorganic fertilizer; FYM = Farm Yard Manure; NF = No fertilizer

Soil Biodiversity Under Forage Production Systems

Table 12. Effect of K and N levels on soil microbial biomass/respiration and soil microbial population in *Cenchrus ciliaris* + *Stylosanthus hamata* pasture

Treatment	N ₀ K ₀	N ₄₀ K ₄₀	N ₄₀ K ₈₀	N ₂₀ (U) ₂₀ (FS) + K ₄₀	N ₂₀ (U) ₂₀ (FS) + K ₈₀
SMB-C (mg/kg soil)	215.3	401.1	441.0	411.5	439.0
Microbial respiration (mg CO ₂ -C/kg soil)	96.8	180.5	198.4	185.1	197.5
Bacteria (cfu x 10 ⁶)	2.0	8.5	8.9	14.0	15.0
Actinomycetes (cfu x 10 ⁵)	5.8	10.3	16.5	15.3	11.2
Fungi (cfu x 10 ⁴)	3.4	7.6	6.8	13.0	8.0
Dry Fodder Yield	8.06	10.34	10.40	10.79	11.40
KUE (%)	-	88.5	94.1	116.0	116.0
NUE (%)	-	159	169	217	260

U = Urea; FS = Farm Yard Manure Slurry; N = Nitrogen; K = Potash

by sorghum - berseem system (2.65). The study has indicated that organic fodder production system is better for maintaining soil health and long term productivity of the systems (Roy and Bano, 2005).

Similarly, in the pasture production systems the fertiliser and manure application enhances the soil microbial abundance (Tripathi *et al.*, 2004a). In the study conducted with different doses of N and K mixed with FYM slurry, indicated that the combined doses of K @ 80kg/ha, N @ 20 kg/ha through urea along with the FYM slurry (equivalent to N @ 20 kg/ha) was advantageous in realising forage yield and nutrient uptake, organic carbon, microbial counts, microbial biomass carbon (Table 12).

Litter Addition

An experiment conducted (Roy and Faruqui unpublished data) on the affect of build up of meso fauna by soil amelioration through leaf litter and neem cake was found to enhance the population of collembola and mites (Fig. 7).

Herbicides

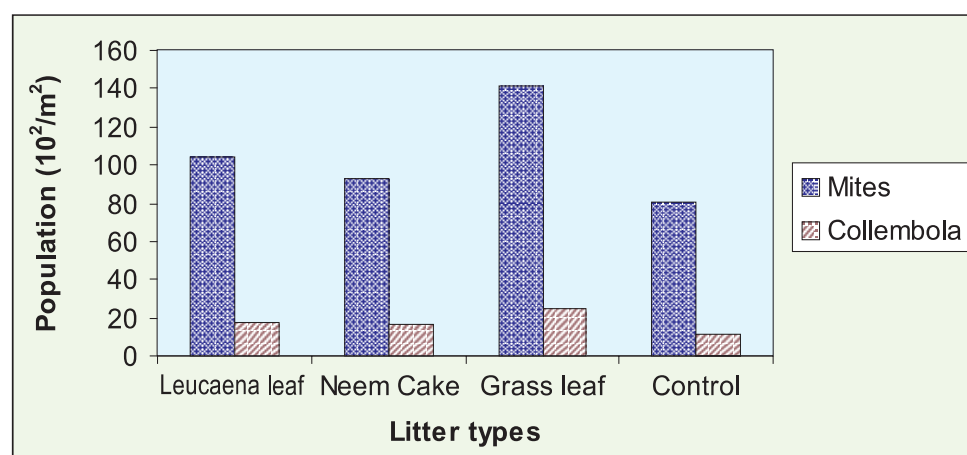


Fig 7. Impact of litter addition on soil meso fauna

External Inputs Vs Soil Biodiversity

Studies conducted on two herbicides viz., atrazine @ 0.75 a.i. kg/ha and alachlor @ 2kg a.i./ha which are popular in the Bundelkhand region to test their effect on soil biota under laboratory and field conditions. The herbicides showed a stimulated dehydrogenase activity and soil microbial population in lab experiment (Das *et al.*, 2002).

However, microarthropods population reduced under these herbicides in field condition and did not recover after 90 days of application (Roy and Faruqui unpublished data, Table 13 & 14).

Table 13. Effect of Herbicides on microbial population and soil enzyme activity

Treatments	0 day incubation				30 days incubation			
	DA µgTP F/g/hr	F 10 ⁵ cfu/g	A 10 ⁶ cfu/g	B 10 ⁶ cfu/g	DA µgTP F/g/hr	F 10 ⁵ cfu/g	A 10 ⁶ cfu/g	B 10 ⁶ cfu/g
Control	61.5	10	15	3	43	13	20	7
Alachlor	101.1	8	25	7	58	6	80	42
Atrazine	74.4	12	15	8	66	20	55	23

DA = Dehydrogenase activity; F = Fungi; A = Actinomycetes; B = Bacteria

Table 14. Effect of Herbicides on micro arthropod population

Treatments Crop		1day after application		30 days after application		90 days after application	
		COL	MIT	COL	MIT	COL	MIT
Control	Bajra	4.1	42.8	3.1	28.5	13.2	142.6
Atrazine		0	21.4	1.1	18.3	18.4	94.7
Control	Cowpea	3.1	28.5	5.1	25.5	22.4	65.2
Alachlor		5.1	10.2	4.1	21.4	32.6	72.3

COL= Collembola; MIT = Mites

Pesticides

Pesticides are integral part of today's agriculture. The chemicals contaminate soil and affect soil biota in many ways. This may be divided into two groups: effect of pesticides on target organisms and indirect effect of pesticide residues on soil organisms. This problem has been further aggravated with the advent of new molecules and their indiscriminate uses.

The response of various microorganisms differed with respect to the pesticide application has been studied by Roy *et al.*, (2003). An adverse effect of pesticides on non target soil microorganisms was observed in the crop sequence Cowpea + Maize - Lucerne leads to a reduction in the soil microorganism population (Fig.8). The soil fauna were the most adversely affected group under the pesticides.

Soil Biodiversity Under Forage Production Systems

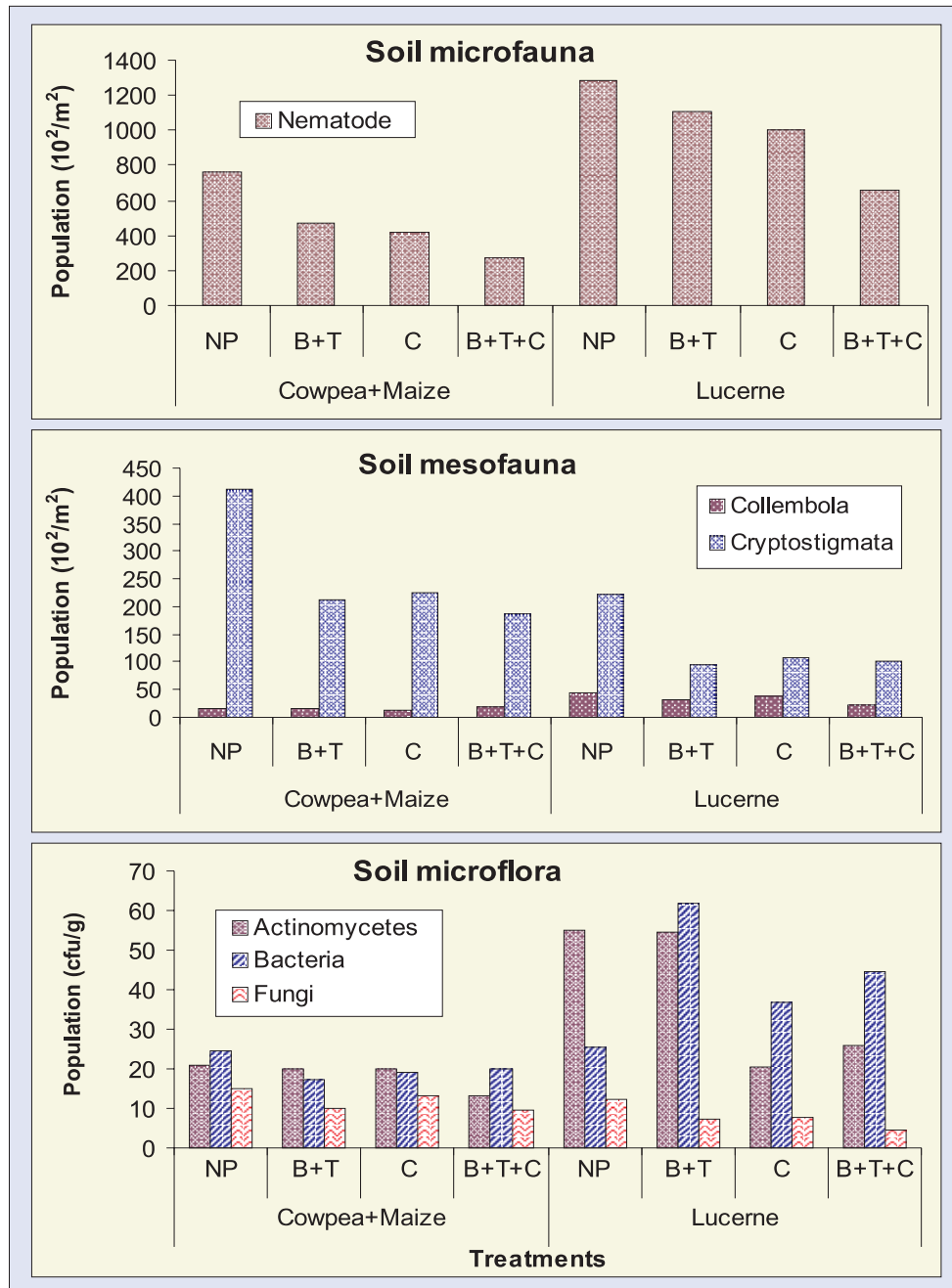


Fig. 8. Population of soil microorganisms showing affects of pesticide (NP= no pesticide; B+T = Bavistine & Thiram as soil Treatment; C = Carbofuran as seed treatment; B+T+C = Soil & seed Treatment)

External Inputs Vs Soil Biodiversity

Table 15. Effect of VAM on plant parasitic nematodes

Treatments (DE)	Nematode population ($10^3/m^2$)					
	Cowpea		Berseem		Lucerne	
	Mi	Tv	Mi	Tv	Mi	Tv
N	15.3	-	7.4	11.2	9.8	6.8
Gf + N (0)	14.4	-	6.4	12.0	8.5	5.6
Gf + N (3)	13.2	-	5.1	7.7	7.3	5.1
Gf + N (7)	13.2	-	5.4	6.7	6.3	4.8
Gf + N (15)	10.3	-	4.8	5.6	5.8	4.5
CD (5%)	1.9	-	0.6	0.5	0.6	0.4

DE = Days of establishment prior to nematode inoculation; Gf = *Glomus fusiculatum*; N = Nematode; Mi = *Meloidogyne incognita*; Tv = *Tylenchorhynchus vulgaris*

VAM

VAM are reported to control various plant parasitic nematodes. Results of some experiments conducted to find out the performance of some VAM on pathogenic nematodes were in corroboration of reported studies (Table 15). Prior establishment of VAM fungi (*Glomus fusiculatum*) by a week or two tended to mitigate the adverse effects of nematode (*Meloidogyne incognita* and *Tylenchorhynchus vulgaris*) on the plant growth of cowpea, berseem and lucerne (Hasan and Jain, 1998; Jain *et al.*, 1998).

Indigenous technical knowledge and soil Biota

There is a growing demand for green technologies that produce safer foods and fodders for human health and protect the environment. Considering fodder as a prime component of the soil-plant-live stock-human food chain, its safer production and optimum productivity are aimed at IGFR, Jhansi. Some of the experiments conducted at the research farm were evaluated for the effect of organic amendments. The study on role of farm yard manure in improving soil biology resulting in higher forage yields has shown that organics improve the total soil biology for healthy crop growth and production. The soil biology and fertility research along with *Jaivik Krishi* programme it will be possible to educate the farmers to produce, handle and use amendments that help in producing healthier foods.

A farmer using some of such preparations at the advice of Scientists of IGFR has claimed more than double grain yield of soybean (Bhaskar *et al.*, 2004). Scientific evaluation of such amendments and practices are aimed at demystifying the myths.

The 'Bhumi-sanskara' by 'Angara' and 'Amritpani' before sowing the sorghum crop helped to significantly increase the population of fungi, actinomycetes and bacteria, which facilitated improved edaphic function in terms of soil respiration, soil microbial biomass carbon and dehydrogenase activity. Soil organic matter increased 50% over the control. It has demonstrated the value of these locally available cheaper amendments for regulating soil health and soil biota that can assure sustainability of production and safeguard critical ecological functions (Pahwa *et al.*, 2004).

Soil Biodiversity Under Forage Production Systems

A field study under taken by Tripathi et al. (2004b) observed that the Vedic soil amendments (Angara, Amritpani and a combination of these two) and seed priming with Panchgavya helps in increasing the oat seed yield plant vigor and also the microbial biomass, respiration and the population of fungi, actinomycetes and bacteria (Table 16).

Table16. Periodical change in micro flora population (10^4 cfu/g soil)

Treatments	Fungi				Actinomycetes				Bacteria			
	D1 W	D2 P	D1 W	D2 P	D1 W	D2 P	D1 W	D2 P	D1 W	D2 P	D1 W	D2 P
Control	3	3	2	3	5	4	4	6	5	7	4	4
Angara	4	6	3	4	6	11	6	10	10	13	10	12
Amritpani	6	8	6	8	20	27	12	20	12	21	8	12
Angara+ Amritpani	6	9	8	10	16	18	5	27	13	18	10	15

W = water; P = panchgavya; D1 = soil sampling on Oct 2004; D2 = soil sampling on Jan 2005

□

Soil Biodiversity and Forage Production

Soil biota can increase or reduce agricultural productivity depending on its composition and the effects of its different activities. *Vice versa*, farming practices modify soil life including the total number of organisms, the diversity of species and the activity of the individual organisms and the aggregate functions of soil biota. These changes can be beneficial or detrimental to soil biota, its functions and its regenerative capacity.

The different experiments conducted at IGRI with VAM and rhizobium inoculations have been found to have enhanced fodder yield in cultivated legumes (Jain and Sethi, 1988; Hasan and Jain, 1984; Pahwa *et al.*, 2001). The uptake of nitrogen by plants increased in *Stylosanthus sp.*, *Cenchrus sp.* and in the cultivated legumes (Table 17 & 18).

The correlation between forage yield as result of FYM application and population build up of collembola, cryptostigmata and nematodes was found highly significant in an experiment conducted on farm in this institute. The results confirm potential role of FYM in crop production system for yield enhancement, a part of which could be attributed to higher population of these organisms (Roy *et al.*, 2003). The study suggests that the activities of soil fauna may be managed for augmentation of higher forage yield *viz a viz* sustainable land use (Table 19).

Table 17. Affect of Rhizobium and VAM inoculation on productivity of cultivated legumes

Treatments	Berseem		Lucerne	
	GFY	DMY	GFY	DMY
VAM	9.9	1.2	10.6	1.5
Rhizobium	8.7	1.1	9.3	1.3
V + R	9.8	1.3	11.2	1.6
Control	8.3	1.0	8.8	1.3
CD (5%)	1.02	0.1	1.3	0.1

GFY = Green fodder yield; DMY = Dry fodder Yield in g/plant; V + R = VAM + Rhizobium

Table 18. Effect of Rhizobium inoculation on productivity of range legume and grass

Treatments	<i>Cenchrus ciliaris</i>		<i>Stylosanthus hamata</i>		Grass + Legume	
	GFY	DMY	GFY	DMY	GFY	DMY
Uninoculated	20.9	8.5	34.1	9.8	52.9	19.4
Inoculated	24.5	10.3	42.0	12.0	57.5	22.5

GFY = Green fodder yield; DMY = Dry fodder Yield in g/plant

Soil Biodiversity Under Forage Production Systems

Table 19. Trend of significant correlations obtained between soil microorganism population and forage yield.

Yield		Fertilizer Treatments					
		Collembola		Cryptostigmata			
<i>harif</i>		0.99**		0.88**			
<i>Rabi</i>		0.70**		0.84**			
Pesticides Treatments							
		Collembola	Cryptostigmata	Nematode	Actinomycetes	Bacteria	Fungi
<i>Kharif</i>		-0.99**	-0.33	0.34	0.36	0.01	-0.32
<i>Rabi</i>		-0.95**	-0.45*	-0.94**	-0.40	-0.55**	-0.94**
Fertilizer x Pesticide Treatments							
<i>Kharif</i>		0.92**	0.98**	0.71**	0.94**	-0.09	-0.51*
<i>Rabi</i>		0.84**	0.80**	0.86**	-0.95**	-0.65**	0.52*

* r (5 %) = 0.43; ** r (1%) = 0.55

Table 20. Productivity and Biodiversity

Soil Biota (Abundance)	Degraded Land	Natural Grassland	Sown Pasture	Silvipasture
Actinomycetes (x 10 ⁵ cfu/g)	99.10	181.4	204.1	281.9
Bacteria (x 10 ⁵ cfu/g)	36.3	105.9	133.1	114.3
Fungi (x 10 ⁵ cfu/g)	6.81	11.0	10.36	19.75
Azotobacter (x 10 ⁴ cfu/g)	3.5	----	-----	10.2
Microfauna (x 10 ⁴ /m ²)	8.60	42.76	39.33	36.75
Mesofauna(x 10 ⁴ /m ²)	2.09	20.25	14.89	19.34
Macrofauna (/m ²)	29.06	52.21	41.06	59.90
Productivity (t/ha)	<0.02	0.10 - 1.50	2.10 - 5.80	3.00 - 7.80

Table 21. Carbon Sequestration in grasses and silvipasture systems

Systems	Micro flora population (10 ⁵ cfu/g)			Micro fauna population (10 ² /m ²)			CSV (mgC/ha)	CSS (mgC/ha)	TCS (mgC/ha)
	Fu	Am	Ba	Mt	Cl	Nm			
Pm	6.73	75.40	47.93	48.86	40.72	1994	6.59	3.61	10.20
Cc	5.13	87.53	38.47	44.45	29.52	1819	4.27	1.13	5.40
Sh	5.00	99.40	74.67	60.74	21.72	1628	2.93	3.38	6.31
Pm+Sh+Ll	7.87	92.20	66.20	63.79	23.41	1896	8.63	2.70	11.33
Pm+Sh+Go	6.20	111.3	71.93	54.63	44.45	2047	8.48	2.93	11.41
Cc+S.h+Ds	2.87	95.93	46.80	82.80	26.81	1711	5.70	2.26	7.96
Cc+ Sh +At	4.47	95.93	38.13	59.72	34.95	1839	6.68	2.03	8.71
CD (5%)	1.74	37.87	29.76	17.15	10.34	106.4	-	-	-

(Am = Actinomycetes; Ba = Bacteria; Fu = Fungi; Cl = Collembola; Mt = Mites; Nm = Nematode; CSV = Carbon sequestration in vegetation; CSS = Carbon sequestration in soil; TCS = Total Carbon sequestration; Pm = Panicum maximum; Cc = *Cenchrus ciliaris*; Sh = *Stylosanthes hamata*; Ll = *Leucaena leucocephala*; Ds = *Dalbergia sisoo*; At = *Acacia tortilis*; Go = *Grewia optiva*)

Soil Biodiversity and Forage Production

The goal of efficient pastures and silvipasture systems is to develop a sustainable ecosystem with minimal dependence on agrochemical and energy inputs. These systems have found developed ecological interactions and synergy among biological components which made the systems to sponsor their own soil fertility and production. These organisms in the soil also partially determine soil resilience (Table 20).

The silvipasture systems viz., *Panicum maximum* + *Stylosanthus hamata* + *Leucaena leucocephala* / *Grewia optiva*, which are promoted for highly degraded soils, were found to have maximum carbon restoration capacity as well as soil biota (Bhatt *et al.*, 2006). Similarly among the grasses the *Panicum maximum* was the most suitable species for high carbon sequestration and highest soil biota population (Table 21).

□

Summing Up

Declining land productivity and inadequate response of inputs in terms of the outputs on account of deterioration in soil health is recognized as a major problem of recent times. So the interest in maintenance of soil ecosystems and monitoring of soil health is growing.

As the biological activities of soil are intimately linked with the maintenance of soil structure and productivity, sound understanding of various aspects of soil flora and fauna in the maintenance of soil fertility in fodder production systems is vital. Based on the research done at this institute, present state of knowledge on these lines is depicted in Table 22.

On account of generally poor site conditions on which fodder production systems are generally practiced, monitoring of their community structure and seasonal patterns will lead to development of much needed bio-indicators of soil health. In order to practice sustainable fodder production systems the future studies should be directed towards filling the major gaps in the available information, preferably in accordance with regional priorities. The suggested areas are:

- Standardization of the benchmarks for different groups of soil biota in fodder production systems for general screening of soil health.
- Identification of specific soil enzymes for different land uses for serving as the most useful diagnostic indicator.

Table 22. Relative strengths in our knowledge on taxonomic characterization and possible roles of major soil organisms

Organisms	Taxonomy	Possible Functions				Environmental affect	
		SOM Dynamics	Soil Physical	Decomposition/ Mineralization	Plant Health	Enhanced CO ₂	Biotic/ Abiotic
Protozoa	**	*	*	*	*	*	*
Nematodes	***	**	*	**	***	***	***
Collembola	***	***	*	***	**	***	***
Mites	***	***	*	***	**	***	***
Rhizobium	***	***	*	*	***	*	*
VAM	***	*	*	*	***	*	*
Micro-flora	***	**	*	***	***	***	**
Termites	***	**	**	**	**	*	*
Ants	***	*	**	*	*	*	**
Earthworm	*	*	*	*	*	*	*
Other Arthropods	***	*	*	*	***	*	***

*** = Experimental evidences; ** = Indirect evidences; * = Work Not initiated; (SOM = Soil organic matter)

Summing Up

- Development of bio-indicators those are easy to use under field conditions and assessable by both specialist and producers and cover a range of ecological and socio-economic conditions.
- Coordinated development of standards for soil quality/health by the agencies and interest groups involved in agriculture, the environment, resource conservation etc. to assess sustainability changes.
- Greater emphasis is accorded on long-term studies instead of short-term experimentation for validating the hypotheses.
- Careful integration of local knowledge of soil organism in designing the systems for improving the technical feasibility, economic profitability and adoptability.

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