Chapter 3
Conservation and Sustainable Management of Soil Biodiversity for Agricultural Productivity

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Abstract Soil biodiversity represents the variety of life belowground whose interaction with plants and small animals forms a web of biological activity. It improves the entry and storage of water, resistance to soil erosion, and plant nutrition, while also controlling soil pests and disease, and facilitating recycling of organic matter in the soil. Soil biodiversity is therefore the driver of healthy soil for sustainable crop production.

However, intensive agricultural activities are reported to lead to loss of soil biodiversity. This has been attributed to environmental degradation, and consequently to climate change. This paper highlights the importance of soil biodiversity and some factors associated with its loss, and presents a case study on selected soil organisms in Kenya. Results from this study indicated that land use changes affect soil biodiversity, and soil biodiversity determines the distribution of the aboveground biodiversity.

Keywords Biological control • Crop productivity • Soil biodiversity • Soil health • Sustainable utilization of soil

3.1 Introduction

Loss of biodiversity has been a major global topic over the past decade with the main reference being the big animals, plants, birds, and other visible organisms that are mainly above ground with little or no reference to soil biodiversity. Yet the highest percentage of life, far superseding the aboveground, is in the soil (Bardgett 2005). The soil is home to a large proportion of the world's genetic diversity of organisms,

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amongst them microbes (fungi, bacteria, protozoa), mesofauna (nematodes, Acari, and Collembola), and macrofauna (arthropods, earthworms, and ants, among others), with the exception of megafauna (moles and rodents). It has been reported that in one gram of soil, there are over ten million microbes (Nannipieri et al. 1990). The food web is therefore incomplete without soil organisms. It is in fact fair to say that belowground biodiversity has not been given the prominence it deserves, despite the soil being the home of billions. Belowground biodiversity contributes greatly in the processes that form and stabilize the soil structure, decompose organic matter, control pests and disease, enable nutrient uptake by plants, and degrade harmful compounds in the soil. Macrofauna such as ants, termites, and earthworms are soil engineers, modifying soil structure to improve infiltration, retention, and availability of water and nutrients (Karanja et al. 2009). The process of conversion of organic matter to mineral elements is partly mediated by macrofauna. Soil microorganisms maintain soil functions such as decomposition, bioregulation of populations of plants and soil organisms, bioavailability of nutrients, detoxification, and bioremediation (Okoth 2004).

Current trends in climate change and the changing environment due to anthropogenic activities have tested the sustainability of the biosphere globally. Conversion of natural habitats for agriculture, mining, or construction is a major contributor to environmental degradation, an important precursor to climate change. These activities are carried out in an effort to provide food, shelter, and energy for the ever-increasing human population. Specifically, agricultural intensification has concentrated on gearing all effort toward maximum-yield production, including application of chemical fertilizers, pesticides, and extensive use of machinery, without any consideration for soil biodiversity. These practices have been identified as unsustainable and incompatible with nature, and their consequence is loss of soil biodiversity.

Loss of belowground biodiversity has been linked to an increase in soil pathogens, especially in agricultural ecosystems, leading to increased cost of production. Lack of awareness, knowledge, and understanding of belowground biodiversity has been identified as the major constraint on its management. Land intensification has challenged the conservation of soil biodiversity since it focuses only on increased crop yield with little or no regard to soil diversity. This leads to soil degradation and consequently to loss of soil biodiversity function. It is therefore important to conserve and sustainably utilize belowground biodiversity for increased agricultural productivity.

3.2 Soil Biodiversity and Its Importance to Agriculture

Biodiversity is usually defined as the variety and variability of living organisms and the ecosystems in which they occur. The soil is inhabited by a wide range of microorganisms (Davet and Francis 2000). Soil contains one of the most diverse assemblages of living organisms, although they are not visible to the naked eye (Giller et al. 1997). A typical healthy soil contains several species of vertebrate animals, several species of earthworms, 20–30 species of mites, 50–100 species of insects, tens of species of nematodes, hundreds of species of fungi, and perhaps thousands of species of bacteria and actinomycetes. Nannipieri et al. (1990) reported that in one gram of productive soil there can be over 100 million microorganisms. Hagvar (1998) noted that it is only in soil that organisms are densely packed in nature. Hawksworth and Mound (1991) reported some of the available estimates on the number of presently described species among selected soil biota that have been better studied. The number of soil-dwelling fungal species described ranges from 18 to 35,000, while the projected number may be greater than 100,000 (Hawksworth and Mound 1991). Nematodes and mites presently described comprise only 3 % and 5 %, respectively, of the total species (Hawksworth and Mound 1991). The estimates for bacteria and Achaea species are particularly problematic because of the differences in classification, and the present inability to culture many of these organisms (Hawksworth and Kalin-Arroyo 1995). However, it is a fact that these estimates are still preliminary and much lower than the estimated total number of species within each group. Soil biodiversity therefore reflects the mixture of living organisms in the soil. All these living things interact with one another and also with plants, forming a web of biological activity.

Soil microorganisms are very important in agriculture. Every chemical transformation taking place in the soil involves active contributions from each of them. In particular, they play an active role in soil fertility as a result of their involvement in the cycle of nutrients like carbon and nitrogen, which are required for plant growth (Muya et al. 2009). They are responsible for the decomposition of the organic matter entering the soil and therefore for the recycling of nutrients in soil (Okoth 2004). Other beneficial effects from soil microorganisms include: (1) organic matter decomposition and soil aggregation, (2) breakdown of toxic compounds including both metabolic by-products of organisms and agrochemicals, (3) inorganic transformations that make available nitrate, sulphate, and phosphate, as well as essential elements such as iron and manganese, and (4) nitrogen fixation into forms usable by higher plants (Anderson 1994). They have also been associated with management of soil pests and diseases. In summary, soil microorganisms improve the entry and storage of water, resistance to erosion, plant nutrition, and breakdown of organic matter. Other microorganisms will provide checks and balances to the food web through population control, mobility, and survival from season to season. In this regard, soil health has been defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran et al. 1996). Despite the important role played by soil biodiversity in ecosystems, anthropogenic processes are still providing challenges to the utilization and management of soil biodiversity.

3.3 Loss of Soil Biodiversity

The processes of land conversion and agricultural intensification are a significant cause of soil biodiversity loss. The factors controlling land conversion and agricultural intensification, and hence loss of soil biodiversity, are: population increase, national food insufficiency, internal food production imbalances, progressive urbanization, and a growing shortage of land suitable for conversion to agriculture. This has a negative consequence both on the environment and the sustainability of agricultural production. As land conversion and agricultural intensification occur, the planned biodiversity above ground is reduced (via monocultures) with the intention of increasing the economic efficiency of the system. This impacts the associated biodiversity of the ecosystem including microorganisms and invertebrate animals both above and below ground, thus lowering the biological capacity of the ecosystem for self-regulation, leading to further need for substitution of biological functions with agrochemicals and petrol energy inputs. The sustainability of these systems thus comes to depend on external and market-related factors rather than internal biological resources. Other practices that lead to loss of biodiversity are continuous cultivation of land without a period of rest, monoculture, removal of crop residues by burning or transfer for use as fodder, soil erosion, soil compaction due to degradation of the soil structure, and repeated application of pesticides.

Changes in the belowground biodiversity are often thought to reflect those above ground (Wall and Nielsen 2012). There is evidence that the soil community may be more functionally resilient than the aboveground biota. It is often hypothesized that reduction in the diversity of the soil community, including cases of species extinction, may cause a catastrophic loss in function, reducing the ability of an ecosystem to retain its self-perpetuating characteristic.

3.4 Management and Conservation of Soil Biodiversity: A Case Study in Kenya

Management strategies encompassing minimum tillage, crop rotation, and incorporation of crop residues and manure, alter the soil quality and the capacity of soil to perform its functions. Farming practices that minimize soil disturbance (plowing) and return plant residues to the soil allow gradual restoration of soil organic matter. Reduced tillage also tends to increase build-up of beneficial organisms. On the other hand, soil compaction, poor vegetation cover and/or lack of plant litter covering the soil surface tend to reduce the number of beneficial soil organisms.

Based on previous research and experiences with regard to management of belowground biodiversity in Kenya, a survey of selected belowground organisms was monitored over a land use gradient. The study was based on the hypothesis that beneficial soil microorganisms decline with land use intensification (Vandermeer et al. 1998). The land use types ranged from natural forest to horticulture farms through maize bean systems and fallow. The natural forest represented the undisturbed systems while the horticulture farms represented the intensively cultivated land use types. The magnitude of land use intensification was determined by tillage, application of fertilizers, pesticides, and herbicides, as well as regular turning of soil. The forests were therefore the least disturbed land uses and were regarded as the benchmark while the horticulture was regarded as the most intensively cultivated

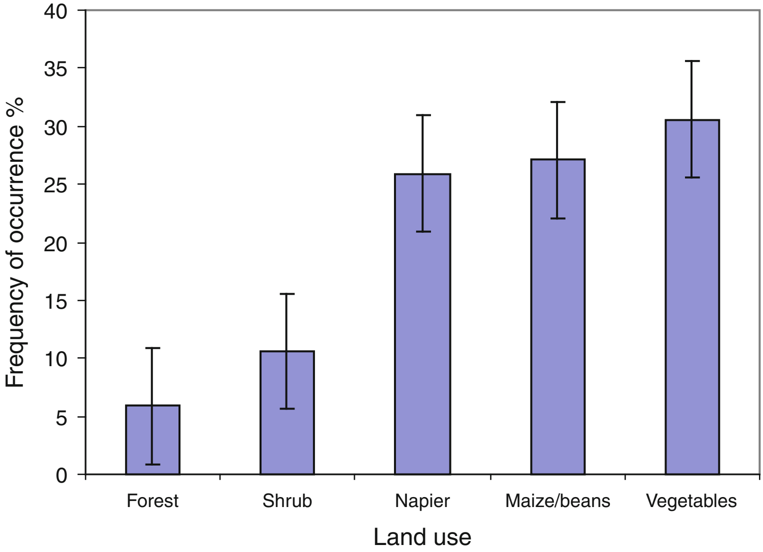

Fig 3.1 Frequency of occurrence of nematode-destroying fungi under different land use types in Taita Taveta, Kenya (Wachira et al. 2009)

Table 3.1 Comparison of plant parasitic nematodes (PPN), free-living nematodes (FLN), and ratio of free-living to plant parasitic nematodes in soils under different uses in Taita Taveta, Kenya

Land use	PPN	FLN	FLN:PPN
Natural forest	189	759	4.01
Planted forest	353	526	1.49
Fallow	796	458	0.57
Coffee	948	419	0.44
Maize	938	120	0.13
Vegetable	915	191	0.21
LSD ($p<0.05$)	122	137	

land use. In this study, soil microorganisms (represented by selected fungal groups), mesofauna (represented by nematodes, Acari, and Collembola) and macrofauna (represented by ants and earthworms) were studied. Laboratory and field extractions were conducted for the microorganisms and macrofauna respectively.

A general build-up of soil pathogens (*Pythium, Fusarium,* and *Rhizoctonia*) was observed as land intensification increased. The study also revealed that land use intensification (land disturbance) negatively influences the abundance and species richness of soil Collembolan communities. In particular, the nematode population and diversity were higher in natural forest than in the horticulture farms. A decline in beneficial microorganisms, for example, entomopathogenic nematodes, was also observed as land intensification increased, except for nematode-destroying fungi whose diversity increased with land use intensification (Fig. 3.1). The ratio of plant parasitic nematodes to free living nematodes under vegetable land use (0.21) was lower than the ratio recorded in natural forest, which was 4.01 (Table 3.1). Comparing land uses under crops, those with perennial crops like coffee recorded

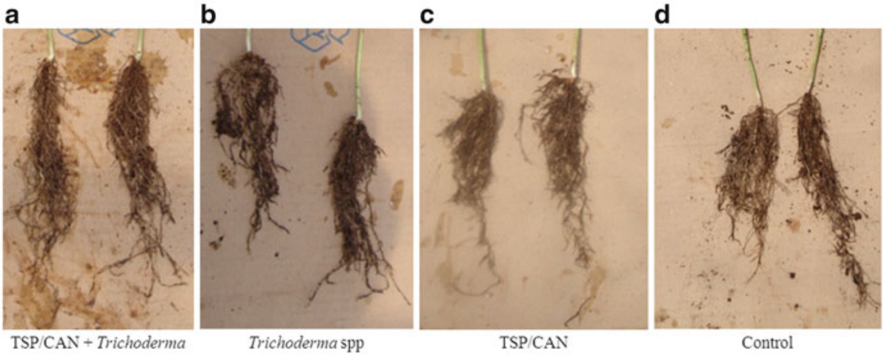

Fig 3.2 Effect of *Trichoderma* on root growth of bean seedlings. (**a**) TSP/CAN+*Trichoderma,* (**b**) *Trichoderma* spp, (**c**) TSP/CAN, (**d**) Control

high population and diversity of soil microorganisms compared to land uses under annual crops. The results from this study generally revealed that the undisturbed land uses had higher soil biodiversity both in abundance and diversity compared to the disturbed.

Best-bet practices were selected and tested under field conditions on their ability to retain soil biodiversity and improve the crops. They included bio-inoculants (*Trichoderma*, Bacillus, Arbuscular mycorrhiza fungi (AMF), fertilizers (Mavuno and triple super phosphate (TSP) + calcium ammonium nitrate (CAN)), cow manure, and combinations involving inoculants and fertilizers or manure. The potential of soil fertility management practices such as Mijingu + CAN, Mavuno, manure, and TSP + CAN were also demonstrated. The efficacy of bio-inoculants, especially when combined with manure and fertilizers, had a positive and synergistic effect on yield in maize. Compared to other treatments in this study, application of TSP + CAN combined with *Trichoderma* enhanced root growth in beans leading to better anchorage and nutrient supply (Fig. 3.2).

From this research, it was reported that increased soil biodiversity results in increased capacity of the soil to control soilborne pathogens and pests. This reflects the fact that some of the organisms, which respond to addition of organic substrates, are antagonistic to the pathogenic ones. In particular, application of manure led to an increase in the soil of nematode-trapping fungi, natural enemies of plant parasitic nematodes that capture and kill nematodes (Wachira et al. 2009). As a result of this study, it is recommended that repeated application of the bio-inoculants should be encouraged to build up their numbers in the soil (Okoth et al. 2011). Another management strategy is the use of crop rotation. Crop rotation is a widely known practice that helps to break the life cycles of plant pathogens and pests. Unrelated crops are usually selected and grown in succession. Planting several crops (intercropping as opposed to monoculture) at the same time or in relay cropping systems helps to reduce build-up of one group of organisms at the expense of others. Examples of intercrop systems that have value in building up soil biodiversity and controlling harmful organisms include maize/bean, cabbage/cowpea, spider plant/egg plant.

3.5 Conclusion

Soil organisms are the primary agents of nutrient cycling, and hence of food and fiber production; they therefore determine the occurrence and distribution of the aboveground biodiversity. The soil fauna plays a major role in modification of the soil structure that in turn regulates water dynamics. Despite their functional role, soil biota remain an unexplored area, and scientific understanding is therefore lacking. One of the reasons is inadequate knowledge and understanding regarding the appropriate methods to study these microorganisms due to their enormous numbers. Therefore agricultural activities that promote their population in the soil should be promoted for crop production.

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