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# Ecology of Soil Fauna in a Desertified System

中国沙地系统土壤动物生态研究

Chief Editor： Liu Rentao



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# Ecology of Soil Fauna in a Desertified System
## Editorial Board

# Foreword 1

A number of excellent textbooks on soil faunal ecology are currently available in China, including *Studies on Fauna and Eco-geography of Soil Animal*, *Subtropical Soil Animals in China*, *Pictorial Keys to Soil Animals of China*, *Soil Animals of China*, and *Study on Forest Soil Animals in Northeast China*, etc. However, to date, none have been dedicated to the study of soil faunal ecology in a sandy land ecosystem, in which soil fauna is one of the major components of the ecosystems and plays a key role in material circulation and soil fertility.

Presently the sandy land ecosystems, including Hoqin sandy land and Mu Us sandy land, have been subjected to desertification due to human activities and climate changes. However, there has been reversion of the desertified land since the middle of 1980s and there is a impending need to know the functioning of the soil fauna during desertification and its reversion for sustainable land use in the sandy lands in China. Dr. Liu Rentao has taken this issue not only into consideration, but also into systematic research since 2007 when he started to pursue his PhD degree in Horqin Sandy Land.

This is a well-polished, systematically organized and data-based book on the concepts and applications of soil faunal ecology of sandy land. It includes the topics of desertification and its revision, restoration management, grassland cultivation, land use/cover changes, implications of shrub cover, and "Arthropod Island" formation, etc.

I am sure that it is a proper reference for the pedologists and ecologists, as well as for the students and technitian in dryland ecology.

Zhao Xueyong

September, 2015

# Foreword 2

Soil fauna is one of important components of terrestrial ecosystems. Nowadays, there are several excellent textbooks regarding soil faunal ecology, including *Studies on Fauna and Eco-geography of Soil Animal*, *Subtropical Soil Animals in China*, *Pictorial Keys to Soil Animals of China*, *Soil Animals of China*, and *Study on Forest Soil Animals in Northeast China*, etc. Most of these textbooks have taken the forestry ecosystems into account. However, there is largely unknown about the ecology of soil fauna in a desertified system.

In northern China, Horqin sandy land and Mu Us sandy land have been subjected to desertification due to human activities and climate changes. Presently, these desertified sandy grasslands tend to become reversed on the basis of local afforested plantation and grazing management practices. However, there is a lack of systematic work on ecology of soil fauna in a desertfied system. The deficiency motivates the authors led by Chief Editor Dr. Liu Rentao to address the field in writing their text.

A reading of this work, entitled by "Ecology of Soil Fauna in a Desertified System", shows it to be very complete and summary in its conceptual plan and research method. In addition, it follows straightforwardly through a development which unfolds over additional seven substantial chapters.

I am sure that it will particularly interest today's pedologists and ecologists. Moreover, they will find a new view of soil fauna which, in the future, will no doubt be the important supplemental materials for the soil ecology, desert ecology and restoration ecology.

Lu Qing

October, 2015

# Perface

It has been well-established that soil biota plays a critical role in breaking down rotting plant material and animal remains, and in turning them into soil nutrients. Soil biota is therefore fundamental to the process of decomposition and material cycling as well as associated ecosystem functions. Soil faunal communities offer opportunities for us to study phenomena such as species interaction, resource utilization, and temporal and spatial distribution.

A number of aspects related to soil fauna have been developed in China. These include the function of soil fauna as bioindicators of ecosystem health, the identification and evaluation of soil organisms by using barcoding technology, soil biota and resource partitioning, soil biodiversity and global climate change, etc. Along a latitudinal gradient from southern to northern China, soil fauna data sets were collected from tropical, subtropical, and temperate regions. Soil faunal habitats investigated include forest, grassland, desert, wetland, farmland, and urban ecosystems. Several relevant books have been previously published, including *Studies on Fauna and Eco-geography of Soil Animal*, *Subtropical Soil Animals in China*, *Pictorial Keys to Soil Animals of China*, *Soil Animals of China*, *Study on Forest Soil Animals in Northeast China*, etc.

However, systematic research related to soil faunal ecology in desertified ecosystems is limited. There is a lack of information regarding the distribution of soil faunal communities and the underlying mechanisms that explain such distribution patterns. Soil fauna is one of the most important components in desertified ecosystems. Relevant studies can offer important evidence that the soil fauna can be used for quality assessments, the maintenance and management of ecosystems, and the restoration of degraded ecosystems.

Since 2007, the authors of this book has gained vast experience in studying soil faunal ecology in the Horqin Sandy Land and the Mu Us Sandy Land in northern China as well as in the Negev desert in southern Israel. In these regions, desertification has become one of the most serious environmental and socioeconomic problems due to overgrazing, cultivation practices, and climatic change. Many measures have been taken to manage sandy grassland, control desertification, and restore degraded ecosystems. In particular, shrub canopies have been found to play an important role in ecological recovery of shifting sandy land. Studies related to the bioprocesses of degradation and recovery of sandy grassland has therefore become a new challenge in soil faunal community research.

Chapter 1 provides details related to the concept and classification of soil fauna and its research methods. Chapter 2 deals with the effects of desertification and stabilization of shifting sand dunes on soil faunal communities. Chapter 3 examines the effects of restoration management on soil faunal community distribution. Chapter 4 deals with the effects of grassland cultivation on soil faunal community distribution. Chapter 5 examines the effects of land use/cover changes on soil faunal community distribution. Chapter 6 deals with how shrub cover acts as a stimulus to arthropod communities in sandy lands. Chapter 7 examines the spatiotemporal distribution of soil faunal communities in relation to shrub cover. Finally, Chapter 8 deals with the formation of the "Arthropod Island" effect and its relation to grazing management.

This book was written by the following people: Section 1 in Chapter 1 was written by Liu Rentao; Section 2 in Chapter 1 was written by Liu Rentao and Zuo Xiaoan; Sections 1 and 2 in Chapter 2 was written by Liu Rentao; Section 1 in Chapter 3 was written by Liu Rentao; Section 2 in Chapter 3 was written by Liu Rentao and Zhu Fan; Sections 1 and 2 in Chapter 4 were written by Liu Rentao; Section 1 and Section 2 in Chapter 5 was written by Liu Rentao; Section 1 in Chapter 6 was written by Liu Rentao; Section 2 in Chapter 6 was written by Liu Rentao and Zhu Fan; Section 1 in Chapter 7 was written by Liu Rentao and Zhu Fan; Section 2 in Chapter 7 was written by Liu Rentao; Section 1 in Chapter 8 was written by Zhao Halin and Liu Rentao; and Section 2 in Chapter 8 was written by Liu Rentao and Xi Weihua. Finally, the manuscript was revised by Liu Rentao and Zuo Xiaoan in its entirety.

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Many thanks are also given to the support by Professor Li Xuebin etc. from Science and Technology Department of Ningxia University, and by Professor Song Naiping etc. from Breeding Base for State Key Lab. of Land Degradation and Ecological Restoration in Northwest China (Key Laboratory of Ministry of Education).

We hope that this book on ecology of soil fauna in a desertified system is useful to soil ecologists, conservation biologists, desert ecologists, geographers, policy makers, lecturers as well as others who are interested in soil faunal ecology in arid and semiarid regions.

Dr. Liu Rentao

September, 2015

# Contents

# Chapter 1 Concept, Classification, and Research Method of Soil Fauna

Soil fauna can be found in almost every environment on earth, including Antarctica. It is composed of an extremely diverse group of organisms. Different species require different conditions to grow, while all soil organisms require sufficient supplies of carbon and nutrients, moisture, and oxygen as well as an optimum pH and temperature condition to survive. However, the optimum levels of pH and temperature vary between species. Certain organisms can not survive under dry or very cold conditions, while they may leave eggs in the soil that will hatch when conditions become favourable. Other soil organisms remain inactive until the conditions become favourable for their survival. Larger soil organisms, such as earthworms, may live deeper in the soil subsurface when the conditions near the soil surface are unfavourable for their survival (Pankhurst 1997).

All such soil dwellers play a part in breaking down the rotting plant materials and animal carcasses and in turning them into nutrients for new plants to grow. Directly, soil dwelling organisms could contribute to nutrient cycling in soil when they release mineralized nutrients in their excreta. Soil organisms can also improve soil structure by forming channels and pores, concentrating fine soil particles together into aggregates and by fragmenting and mixing organic matter throughout soil subsurface. Indirectly, they contribute mostly by: ① grazing on the microbial biomass, which alters the rate at which organic matter breaks down; ② fragmenting organic matter and increasing its surface area to promote microorganisms permeation; ③ controlling nematode grazing pressure on microorganisms; and ④ mixing soil and organic matter and providing microorganisms with fresh organic matter to feed upon. These heterotrophs are a group of soil organisms that also participate in elaborate food webs containing several trophic levels. Such soil faunal communities can offer our opportunities to study phenomena related to species interactions, resource utilization, and their temporal and spatial distributions (Coleman et al. 2004).

This chapter deals with: ① the concept and classification of soil fauna; ② the research method including extracting, field sampling, community index selection, and statistical analysis on the dataset. The writing of this chapter will be a very complete and summary in its concept plan and research method.

## Section 1 Concept and classification of soil fauna

The different organisms that characterize soil biota are numerous and diverse. The array of species is very broad and includes representatives from all terrestrial phyla. Consequently, soil ecologists cannot hope to become experts in all such animal groups. When conducting research at the soil ecosystem level, two things are required: the cooperation of zoologists and the aggregating of animals into functional groups. Although these groups have often been taxonomically identified, species with similar biology are often grouped together for purposes of integration (Coleman et al. 1983; 1993; Hendrix et al. 1986). In terms of classification standardarizing, several types of soil fauna have been conceptualized into groups as will be discussed in the following subsections.

### 1 Characterization of soil fauna by degree of occurrence in soil or by microhabitat utilization under different life forms

As it pertains to inhabiting different soil strata, three groups can be classified: aboveground dewellers, ground-active dwellers (i.e., organisms that dwell within the soil surface layer), and belowground dwellers (i.e., organisms that dwell under the soil surface layer) (Liu et al. 2012). There are also transient species exemplified by the ladybird beetle, which hibernates in the soil while otherwise lives within the plant stratum of the garden (Fig. 1.1; Coleman et al. 2004).

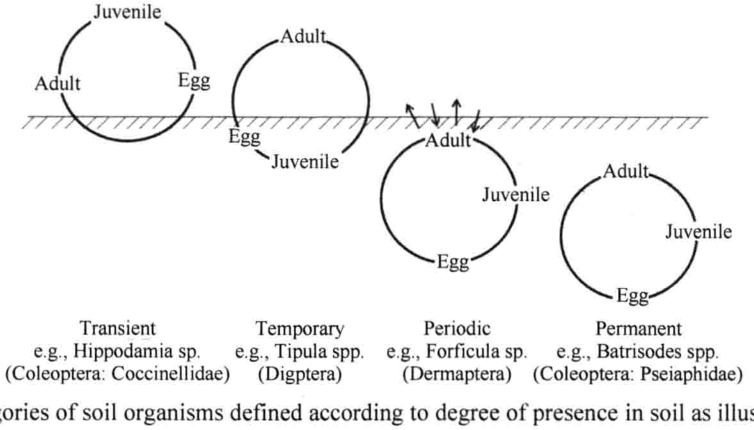


Fig. 1.1 Categories of soil organisms defined according to degree of presence in soil as illustrated by some groups of insects (Wallwork 1970)

Gnats (Diptera) are representative of temporary residents in the soils due to the adult stages living aboveground. They lay eggs in the soil, and their larvae feed on decomposing organic matter. Under certain soil conditions, dipteran larvae are important scavengers.

Species that dwell on the soil surface or within the litter layer may be large, pigmented, and equipped with long antennae and a well-developed jumping apparatus (furcula). Within mineral soil, collembolans tend to be smaller with unpigmented, elongated bodies and a much reduced furculae, given that jumping is not required within the soil strata. Periodic residents spend their lives belowground, with adults such as the velvet mites emerging perhaps to reproduce. From this perspective, soil food webs are linked to aboveground systems, making trophic analysis far more complex.

## 2 Characterization of soil fauna through many and varied body designs and size differences

Soil fauna is typically separated into size classes by a generalized classification of length. These are grouped as microfauna, mesofauna, macrofauna, and megafauna (Fig. 1.2). This classification encompasses soil organisms that range from the smallest to the largest (i.e., from microflagellates approximately 1 to 2 micrometers [μm] to several meters in size, such as Australia's giant Gippsland earthworms). Microfauna range in body size from 0.0002 cm to 0.002 cm (0.00008 in to 0.0008 in) are composed of Protozoa. Mesofauna range from slightly greater than 0.002 cm to 1 cm (0.0008 in to 0.4 in) and include mites, springtails, spiders, pseudoscorpions, pot-worms, insect larvae as well as smaller millipedes and isopods. Macrofauna are at least 1 cm (0.4 in) in length or greater and include earthworms, the largest insects and arachnids, and soil-dwelling vertebrates.

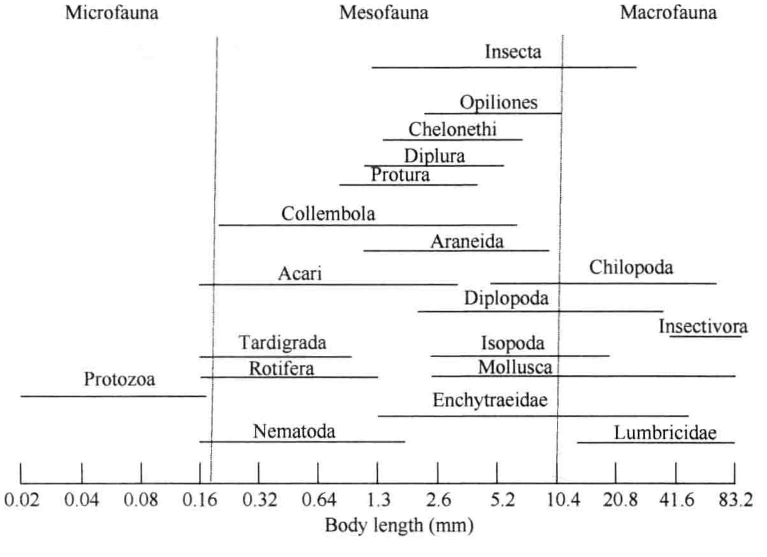


Fig. 1.2 A generalized classification of soil fauna by body length (Wallwork 1970)

## 3 Considerable gradation prevailing in classification based on body width

The body width of fauna is related to the microhabitats they reside in (Fig.1.3).

Microfauna (protozoa and small nematodes) inhabit water films. Mesofauna is largely restricted to exist in air-filled pore spaces within the soil. Macrofauna, on the other hand, can create its own spaces through their burrowing, and like the megafauna, can have a significant influence on gross soil structure (Lavelle and Spain 2001; van Vliet and Hendrix 2003). The smaller mesofauna exhibits characteristics of the microfauna. Nevertheless, classification continues to have considerable utility. The vast range of body sizes among soil fauna suggest that their influences on soil processes occur at a range of spatial scales.

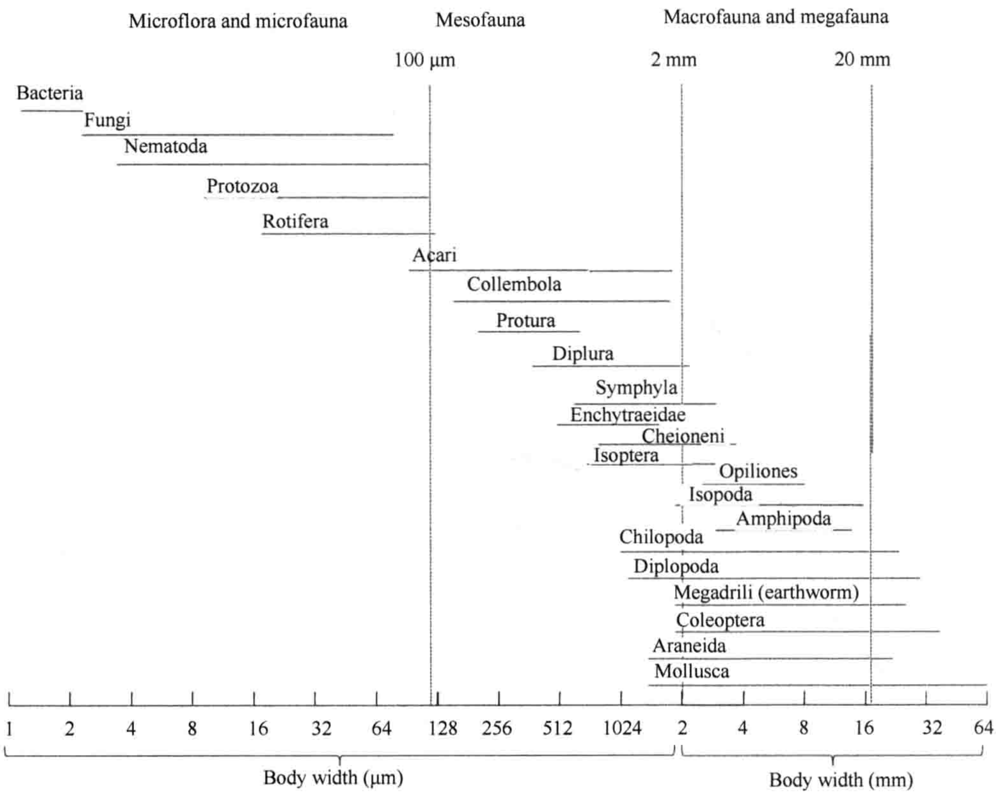


Fig. 1.3 Size classification of organisms in decomposer food webs by body width (Swift et al. 1979)

## 4 Soil fauna by body size and respiratory pattern

There are two distinctive responses to soil constraints through a variety of adaptive strategies: hydrobionts or hygrobionts.

(1) Hydrobionts are aquatic organisms that live and feed in free water and soil (Table 1.1). They mainly belong to the microfauna group (protists and nematodes) (Lavelle and Spain 2001). Their size rarely exceeds 10 μm to 50 μm and most are only a few micrometres long. They are generally well adapted to periodic desiccation and/or shortages of food within their microenvironments. The spatial scale at which they operate is a few millimetres and their generation times range within a few hours to a few days.

**Table 1.1 Key parameters of adaptive strategies of organisms living in soil**

| Functional group | Microflora | Microfauna | Mesofauna | Macrofauna |
|---|---|---|---|---|
| Body width | 0.3-20 μm | < 0.2 mm | 0.2-10 mm | > 10 mm |
| Taxa | Bacteria<br>Fungi | Protists<br>Nematodes | Microarthropods<br>Enchytraeidae | Termites<br>Earthworms<br>Ants |
| Water relationships | Hydrobiont | Hydrobiont | Hygrobiont | Hygrobiont |
| Interactions with microorganisms | Antibiosis+Others | Predation | Predation | Mutualism<br>(External rumen, facultative or obligate internal mutualism) |
| Ability to change physical environments | None | None | Limited<br>(faecal pellets) | High<br>(Galleries, burrows, acroaggregates) |
| Resistance to environmental stress | High | High | Intermediate | Low (with possibility of behavioral compensation) |
| Intrinsic digestive capabilities | High | Intermediate | Low | Low |

(2) Hygrobionts are invertebrates that use an aerial respiration system while are still dependent on high moisture levels and often require the presence of free water in their environments. Depending on size, two main categories are defined. Mesofauna includes microarthropods and Oligochaeta (Enchytraeidae); both groups have body widths ranging from 0.1 mm to 2 mm, which allows them to move freely through large pore networks within surface litter and soil. They operate at scales of space and time of, respectively, centimeters, and weeks to months. Macrofauna, the larger invertebrates, are much wider than most soil pores; they therefore live within the surface litter (e.g., this includes most arthropods) or dig galleries in the soil (this includes most earthworms, termites and endogeic Coleoptera larvae). Average scales of space and time at which they operate are, respectively, months to years and decimeters to meters.

# Section 2 Research methods of soil fauna

## 1 Extracting method

Methods used to study these faunal groups are in large part size-dependent. For example, methods used to study microfauna primarily rely upon microbiological techniques (i.e., Baermann funnel method for nematode extraction). Microscopic techniques, however, are required for the study of mesofauna (i.e., the Tullgren funnel method for microarthropods extraction) as well as specialized extraction procedures for collection. Macrofauna may be sampled from field collections, often by hand sorting, and populations of individuals are usually measured (Coleman et al. 2004).

### 1.1 Soil free-living nematode extraction: the Baermann funnel method

(1) Principle

The principle behind nematode extraction is straightforward: When nematodes move from the substrate toward the water, and gravity forces them to sink to the bottom of the funnel stem (Fig. 1.4). This method is suitable for the extraction of shifting nematodes from substrates such as soils and sediments, plant material, and litter (material is cut into small pieces before nematode extraction).

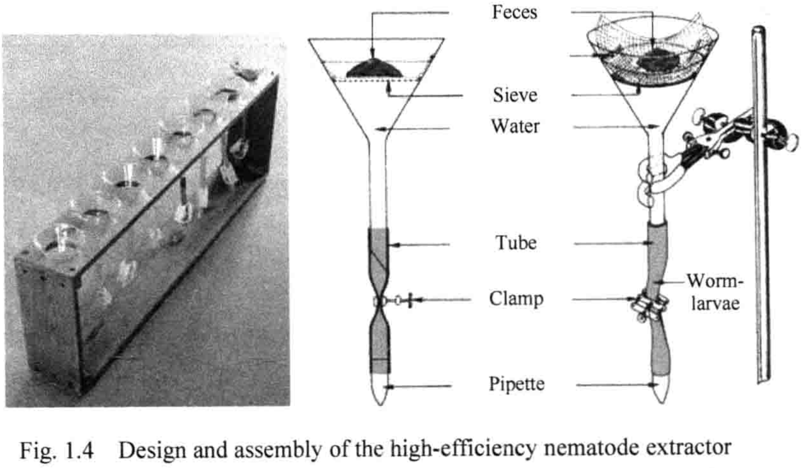


Fig. 1.4 Design and assembly of the high-efficiency nematode extractor

Advantages of this method are that it is inexpensive and simple, and extraction efficiency is good if the sample is small relative to the funnel diameter (with only a thin layer of substrate on the sieve). Disadvantages are that extraction efficiency decreases rapidly when the sample is larger.

(2) Procedure

- Place the funnel on the rack. Verify that it is level. Fill the funnel with clean water. Remove air bubbles by squeezing the rubber tube or by draining water by opening the clamp.
- Carefully mix the soil sample (note that excessive mixing will destroy nematodes). Separate a 10 g subsample on a double layer of Kimwipe tissue. Record sample weight. Place the sample on the screen in the funnel. Do this carefully so that small soil particles do not penetrate the tissues and obscure nematode samples.
- Soil should be moist while not totally submerged. Adjust the water level in the funnel by using a spray bottle (do not spray on the sample itself for the same reasons discussed in step two), or drain by opening the clamp. Cover the funnel with a Petri dish or wax paper to avoid dust exposure and evaporation.
- Extraction time is from 2 to 4 days. The longer the extraction, the more nematodes can be harvested. However, it remains questionable whether this increase is due to additional time to catch slow moving nematodes, or due to additional hatchlings from eggs in the soil or larvae from fast reproducing species (some species have a 2-day life cycle, especially under lab temperature). For this reason, 48 hours is considered optimal. However, verify that the soil is moist after the first 24 hours.
- Harvest samples by opening the clamp and extracting approximately 10 ml in a centrifuge tube (e.g., a Corning polypropylene centrifuge tube within screw cap). Store immediately under refrigeration for a maximum of one week in order to kill and preserve (using 5% formaldehyde) the nematodes for identification of nematode feeding groups.

## 1.2 Microarthropod extraction: the Tullgren funnel method

(1) Principle

The Tullgren funnel method works by creating a temperature gradient over the sample so that moving organisms will move away from higher temperatures and fall into a collecting vessel, where they perish and will be preserved for examination (Fig. 1.5).

The great majority of microarthropods in many soil types are found within 5 cm of the surface. They may be distributed more deeply in grassland soils and disturbed soils, and therefore additional 5 cm increments may need to be extracted to a depth of 15 cm or more. Sample cores should be extracted in a high-efficiency extractor as soon as possible. Storage for any significant period of time will result in lower numbers of microarthropods extracted.

(2) Procedure

- The sample is placed on a coarse sieve fixed across the wide end of a funnel. A piece of gauze (i.e., a single layer of cheesecloth) is placed between sample and funnel to prevent soil entering the liquid. This is because samples contaminated by soil are difficult to sort. Care must also be taken to keep mineral and sandy soil from falling into the sample.