THESIS ON CIVIL ENGINEERING F

Biological diversity of agricultural soils in Estonia

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2008

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Dissertation was accepted for the defence of the degree of Doctor of Philosophy in Civil and Environmental Engineering on October 14, 2008.

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Defence of the thesis: December 8, 2008.

Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

/Annely Kuu/

ISSN 1406-4766
ISBN 978-9985-59-864-1

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INTRODUCTION

Agricultural landscapes in Europe are diverse, reflecting their geology, geographical relief, history and intensity of management. They vary from small-scale, enclosed landscapes to open types. Within these landscapes the majority of the land is farmed and crop and non-crop features comprise a diversity of habitats. These include arable land, grassland habitats that range from acid to alkaline communities with varying moisture regimes, aquatic and riparian zones and a variety of boundary and woodland types (Marshall *et al*, 2002). Soil is one of the most species-rich, yet one of the most poorly researched habitats of our planet (Anderson, 1975; Giller, 1996; Wolters, 1996; Decaëns *et al*, 2006). Soil and its biota are integral parts of terrestrial ecosystems (Rusek, 2000; Barrios, 2007) and affect each other directly and indirectly (Ivask *et al*, 2000). The composition and structure of soil communities reflect both the spatial organization of soil and the major role this environment plays in decomposition processes (Lavelle, Spain, 2001). However, soil organisms have been "out of sight, out of mind" for too long. Soil biota provide many services in a wide range of terrestrial ecosystems, but our knowledge of how to manage and protect species in the soil and the processes that they drive, is limited (van der Putten *et al*, 2004).

Agricultural activities such as soil tillage, turning the soil while ploughing, fertilization, irrigation, using pesticides, planting hedges, tree lines or small forest, etc have a very strong impact on soil biota, affecting the organisms living on the surface of the soil as well as underneath it (Paoletti *et al*, 1991). On the scale of specific farming practices, links between the farming and its ecological impacts have often been shown. Use of agrochemicals affects vegetation structure and biodiversity, invertebrates and vertebrates; the husbandry of crops and grasslands affects the density and breeding success of birds nesting or feeding in the same fields; the management of hedgerows and other field margin and boundary vegetation affects the abundance and diversity of flora, invertebrates and birds (Benton *et al,* 2003). Agricultural activities directly destroy habitats resulting in decrease of biological diversity in the water, air and soil (Gilpin *et al*, 1992). Agricultural activities change the diversity of the ecosystem directly influencing the survival of individuals, or indirectly, changing the level of resources. Cultivating the soil has mechanical effect on the biochemical cycling, rearranging soil particles and chaining the size of the pores, infiltration of gas and water and gas emission. Also, cultivation of land cracks the soil aggregates, closes the fissures and pores and predisposes drying up of the soil (Neher, Barbercheck, 1999). Several groups of soil biota are recognized as indicators of land use and agricultural activities, such as earthworms *Lumbricidae* (Kühle, 1983; Edwards, Bohlen, 1996; Ivask, 1996), springtails *Collembola* (Paoletti *et al*, 1991), spiders *Aranei* (Burel, Baudry, 1995), ground beetles *Carabidae* (Müller-Motzfeld, 1989; Decaëns *et al*, 2006) etc.

The contemporary floodplain meadows and coastal grasslands have developed in conditions where agriculture was dominant activity in the region and due to its extensive nature there was shortage of agricultural lands, including grasslands. Characteristic features of floodplain meadows include periodical flooding and continuous accumulation of organic and mineral sediments (Leibak, Lutsar, 1996). Diffuse load of nutrients depends both on natural conditions (soil texture, precipitation) and on the land use intensity (van der Putten *et al*, 2004). Both preservation and damaging of semi-natural landscapes are associated with the impact of human activity. To enlarge hay production and improve surface bearing, dredging activities were performed in a number of places, which caused changes in the water regime of rivers (Leibak, Lutsar, 1996). Knowledge about self-purification of surface water is still insufficient. Assuming that the function of soil ecosystem is strongly affected by the structure and activity of soil communities as well as biotic and abiotic factors, the transport and transformation of nutrients are also affected. Soil biota has direct effect based on chemical reactions by microbial community and indirect effect based on formation surface water quality by the soil invertebrates on different levels of food web (Lavelle, Spain, 2001).

The aim of this thesis is:

- to examine the specific composition of earthworm and epigeal fauna communities, their diversity and distribution in soil;
- to evaluate the abundance and diversity of soil biota in different types of agricultural landscapes (fields, wet meadows) in Estonia;
- to evaluate the influence of environmental factors on soil communities;
- to analyze the impact of agricultural activities (cultivation, crop husbandry, extensive management of grasslands) on communities of soil biota.

I would like to thank my supervisor Prof. Mari Ivask for her all-round help, patience and consistent strictness. I am deeply indebted to all my collegues who encouraged me and contributed to the present thesis. I would like to thank Prof. Lembit Nei and Dr. Jaak Truu for their support with advice, Milvi Purgas who performed soil analyses and Dr. Winfried Voigt (Friedrich-Schiller University Jena) for his contribution to this thesis. I am very grateful to my parents and family for their support, tolerance and understanding during the completion of this thesis. This study was partially supported by the Estonian Science Foundation grant No-s. 5571, 6005 and 6739.

List of publication included in this thesis

I Ivask M., Kuu A., Sizov E. 2007. Abundance of earthworm species in Estonian arable soils. European Journal of Soil Biology, Vol.43, S39-S42.

II Ivask M., Truu J., Kuu A., Truu M., Leito A. 2007. Earthworm communities of flooded grasslands in Matsalu, Estonia. European Journal of Soil Biology, Vol.43 (2), p.71-76.

III Ivask M., Kuu A., Meriste M., Truu J., Truu M., Vaater V. 2008. Invertebrate communities (Annelida and epigeic fauna) in three types of Estonian cultivated soils. European Journal of Soil Biology, x-x (in press).

IV Ivask M., Ööpik M., Kuu A. 2006. Abundance and diversity of earthworm communities in flooded semi-natural grasslands. In: Soil Zoology; 11th Nordic Soil Zoology Symposium and PhD course, Akureyri, Iceland 28-31 July 2006. Agricultural University of Iceland, Publication No 9, p.90-94.

V Kuu A., Ivask M. 2006. Pterostichus vulgaris (L., 1758) (=melanarius (Illiger, 1798)) and Harpalus pubescens (Müll., 1776) in agricultural fields. In: Soil Zoology; 11th Nordic Soil Zoology Symposium and PhD course, Akureyri, Iceland 28-31 July 2006. Agricultural University of Iceland, Publication No 9, p.94-98.

REVIEW OF THE LITERATURE

1. SOIL AS LIFE MEDIUM

1.1. Biological diversity in agricultural landscape

Biodiversity refers to all species of plants, animals and micro-organisms existing and interacting within an ecosystem (Altieri, 1991; Altieri, 1999). According to the Convention on Biological Diversity of 1992, biological diversity means ´the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems´ (Duelli, 1997). Diversity within each one of these three fundamental and hierarchically related levels of biological organization can be further elaborated as follows: genetic diversity is the variation within and between species population; species diversity refers to species richness, that is, the number of species in a site, habitat, ecological zone or at global scale; ecosystem diversity means the diversity of assemblages (and their environments) over a defined landscapes, ecological zone or at global scale (Duelli, 1997; Swift *et al*, 2004; Pidwirny, 2006).

Today, scientists worldwide are increasingly starting to recognize the role and significance of biodiversity in the functioning of agricultural systems. In natural ecosystems, the vegetative cover of a forest or grassland prevents soil erosion, replenishes groundwater, and controls flooding by enhancing infiltration and reducing water runoff. In agricultural systems, biodiversity performs ecosystem services beyond production of food, fiber, fuel and income (Altieri, Nicholls, 1999). Agrobiodiversity refers to the full diversity of organisms living in agricultural landscapes, including biota for which function, in the human utilitarian point of view, is still unknown (Jackson *et al*, 2007). The type and abundance of biodiversity in agriculture will differ across agroecosystems which differ in age, diversity, structure and management (Altieri, Nicholls, 1999). Biological diversity in agricultural ecosystem depends on four characteristics of agricultural ecosystems (Altieri, 1999; Altieri, Nicholls, 1999):

1. the diversity of vegetation within and around the agroecosystem;
2. the permanence of the various crops within the agroecosystem;
3. the intensity of management;
4. the extent of the isolation of the agroecosystem from natural vegetation.

The biodiversity components of agroecosystems can be classified in relation to the role they play in the functioning of cropping system. According to this, agricultural diversity can be grouped as follows (Swift, Anderson, 1993; Altieri, Nicholls, 1999; Altieri, 1999):

- productive biota: crops, trees and animals chosen by farmers which play a determining role in the diversity and complexity of the agroecosystem;
- resource biota: organisms that contribute to productivity through pollination, biological control, decomposition, etc;
- destructive biota: weeds, insect pest, microbial pathogens, etc. which farmers aim at reducing through cultural management.

According to Altieri (1999), Swift *et al* (2004) and Brussaard *et al* (2007), two distinct components of biodiversity can be recognized in agroecosystems. The first component, planned diversity is the suite of plants and livestock deliberately retained, imported and managed by the farmer and which will vary depending on the management inputs and crop spatial/temporal arrangements. The second component, associated biodiversity, includes all soil flora and fauna, herbivores, carnivores, decomposers, etc that colonize the agroecosystem from surrounding environments and that will thrive in the agroecosystem depending on its management and structure.

1.2. Soil biota

Soil invertebrates are enormously diverse. According to resent estimations, soil animals may represent as much as 23% of the total diversity of living organisms that has been described to date (Lavelle *et al*, 2006; Decaëns *et al*, 2006). Soil fauna (arthropods and invertebrates) populations influence soil biological processes, nutrient cycling and soil structure. Several properties or functions of soil fauna can be used to indicate soil quality: the presence of specific organisms and their populations or community analysis (functional groups and biodiversity) and biological processes such as soil structure modification and decomposition rates (Knoepp *et al*, 2000).

1.2.1. Earthworms

Earthworms belong to the class *Oligochaeta*. There are about 220 species of lumbricids, of which 19 are common in Europe (Edwards, Bohlen, 1996) and 13 are common in Estonia (Timm, 1999). Several schemes have been proposed to classify earthworm species into major ecological categories, which are based mainly on differences among species in the burrowing and feeding activities and vertical stratification in soil. Three major ecological groups are (Edwards, Bohlen, 1996; Timm, 1999; Ivask *et al*, 2000; Kuu, 2001):

1. Epigeic earthworms - These worms typically live on the soil surface or in the upper reaches of the mineral soil, beneath a litter layer, have relatively high reproductive rates and grow rapidly. In Estonian agricultural soils this group is represented mostly by *Lumbricus rubellus, Dendrobaena octaedra* and *L. castaneus*.
2. Anecic earthworms - They form permanent or semi-permanent vertical burrows in the soil, which descend into the mineral horizon and open at the surface, where the earthworm emerges to feed, primarily on dead leaves and other decaying organic materials. This group includes *L. terrestris*, and *Aporrectodea longa*.
3. Endogeic earthworms - These worms inhabit upper 30 cm longer the mineral soil horizons (*A. caliginosa, A. rosea, Allolobophora chlorotica*). They consume more soil and derive their nourishment from more humified organic matter, although some species will occasionally come to the surface to feed beneath the litter layer.

One scheme based on the soil horizons in which the earthworms were commonly found (Edwards, Bohlen, 1996):

1. The litter species form no burrows, are generally heavily pigmented dorsally and ventrally and feed on decomposing litter.
2. The topsoil species live in permanent burrows that descend into the mineral horizon. They have medium pigmentation dorsally, are unpigmented ventrally and feed on decomposing litter on the soil surface and some soil.
3. The subsoil species have constantly extending burrow systems and are unpigmented or lightly pigmented. They feed on soil and organic matter in the soil.

The four main management inputs into any farming system are cultivations, cropping patterns, fertilization and crop protection. Each of these four inputs interacts strongly with earthworm populations (Edwards, Bohlen, 1996):

- The effects of cultivations. The decreased number of earthworms that occur in cultivated arable land could be due to mechanical damage during cultivation, to the loss of the insulting layer of vegetation, to a decreased supply of food (Curry *et al*, 2002) as the organic matter content gradually decreases with repeated cultivations, or to predation by birds when earthworms are brought to the surface during cultivation (Edwards, Lofty, 1978). In most cases the effects of cultivation appear to be transitory and populations generally recover within 6 - 12 months in the presence of an adequate food supply (Curry *et al*, 2002).
- The effect of cropping. The most important factor controlling earthworm populations in arable land is the amount of organic matter that is available as

food for earthworms. The availability of food can limit the numbers of earthworms in grassland and arable land. The cropping can influence the number of earthworms in arable land considerably and the numbers of earthworms change every year according to the phase of the rotation. One of the more important factors affecting the influence of cropping on earthworm populations is the proportion of the plant material that is returned to the soil after harvest (Edwards, Bohlen, 1996).

- The effect of fertilizers. The effects of fertilizers (organic or inorganic) on earthworms may be direct by changing the acidity of soil or through toxicity, or indirect by changing the form and quantity of the vegetation that ultimately turns into decaying organic matter that provides food for earthworms. Liquid organic manures can have short-term adverse effect on earthworm population due to their ammonium and salt contents, but population usually recover quickly and increase thereafter (Edwards, Bohlen, 1996).
- The effect of chemicals. The chemicals that reach soils include pesticides and heavy metals. The degree of exposure of earthworms to such chemicals in soils depends upon a wide range of variable factors that may be associated not only with the chemical, the route of exposure and the soil type, but also the environmental conditions and the species and behavior of the earthworms. Earthworms' species can be exposed to chemicals to quite different degrees and in very different ways (Edwards, Bohlen, 1996).

1.2.2. Ground beetles

Insects are essential in the following roles within ecosystems (Gullan, Cranston, 2000):

- Nutrient recycling, via leaf-litter and wood degradation, dispersal of fungi, disposal of carrion and dung, and soil turnover;
- Plant propagation, including pollination and seed dispersal;
- Maintenance of plant community composition and structure, via phytophagy, including seed-feeding;
- Food for insectivorous vertebrates, including many birds, mammals, reptiles and fish;
- Maintenance of animal community structure, through transmission of disease of large animals, and predation and parasitism of smaller ones.

More than 40 000 species of ground beetles have been described so far; nearly 2700 are known in Europe (Lövei, Sunderland, 1996; Ekschmitt *et al*, 1997) and nearly 300 are know in Estonia (Haberman, 1968). Ground beetles are the largest family of adephagous beetles. Most temperate carabids live on the soil surface (ground beetles);

only a few species move up into the vegetation layer (Kromp, 1999). Ground beetles (*Coleoptera: Carabidae*) are generalist predators which can greatly reduce the abundance and of herbivore pests; only a few species are herbivores. Five to six species are dominant in a particular crop field, making up 90% of the total number of ground beetle individuals. The genera *Carabus*, *Pterostichus*, *Harpalus*, *Agonum*, *Brachinus*, *Bembidion*, *Trechus*, *Clivina* and *Dyschirius* characterize the agricultural landscapes of the northern temperate zone (Ekschmitt *et al*, 1997).

There are three reasons why surface-dwelling arthropods (mainly ground beetles and spiders, sometimes staphylinid beetles) are most often used for faunistic inventories in agricultural areas (Duelli *et al*, 1999):

1. Most of the species are polyphagous and thus the taxonomic groups as a whole are considered as beneficial organisms.
2. All three taxa are easily collected in pitfall traps and thus allow for standardized sampling and comparative interpretation.
3. The catches in most habitat types contain sufficiently high numbers of individuals to allow standard statistical treatment. Moreover, pitfall catches in agricultural habitats rarely contain protected or threatened species.

Soil cultivation affects ground beetle populations in two ways (Ekschmitt *et al*, 1997):

1. direct impairment of the population according to the intensity of cultivation, which mainly affects the spring breeding species;
2. indirect influence by habitat modification.

The vegetation that borders an agricultural field may be an important reservoir for ground beetles. Field borders may benefit ground beetle populations by providing refuge from agricultural practices such tillage and pesticide use and a stable microhabitat for overwintering. Field borders with a well-established; thick vegetative cover and a stable microhabitat such as hedgerow (or shelterbelt) have been shown to increase overwintering success compared with the bare, open ground of an agricultural field (Varchola, Dunn, 1999).

1.2.3. Other soil biota

Soil Microorganisms - The microorganisms in soil belong to many taxonomic groups of both animal and plant kingdoms. The micro-flora includes fungi, bacteria and actinomycetes as well as algae, while the protozoa and nematodes are the most important groups representing the microfauna. In soil with a moderately uniform texture, the highest concentration of microorganisms occurs in the first few centimeters below the surface, numbers decreasing rapidly with depth. It becomes evident that many species and especially fungal spores can be washed downward by rain, particularly in open, sandy soils. Fungi are more plentiful in acid soils. The ability of many fungi to produce resistant spores enables them to survive drought and frost. The numbers of bacteria capable of reproductively increases with depth down to approximately 30 cm, but below this depth numbers begin to decrease. Bacteria are the most numerous organisms in soil and play an important role in many soil processes. Moisture has its affect upon the vertical distribution of organisms (Brown, 1978).

Soil Arachnids and other small animals - Spiders (*Araneida*), harvestmen (*Opiliones*), false scorpions (*Chelonethi*) and mites (*Acari*) belong to the class *Arachnida*. Some groups of spiders, notably the trap-door spider, wolf spiders, and purse spiders, are closely associated with the soil community and prey on insects and other small arthropods. False scorpions are also found in moist vegetation on the surface of the soil, particularly amongst forest litter, although they are never very abundance in temperate soils. The *Collembola* are extremely abundant. They can be divided into two groups, those which live on or near the surface, and those which live beneath it. They show varying degrees of tolerance to different environmental factors such as the soil structure and its type, the presence of micro-flora and moisture content, not to mention the soil pore size which can be limiting factors. Indeed the presence or absence of a species could be an indication of micro-habitat conditions (Brown, 1978).

Larger Soil animals - Beetles are probably the most diverse in habitat and structure of all soil-inhabiting insects. The staphylinids are typical soil coleopterans. Other beetles or their larvae make an important contribution to the soil by their decomposition of organic material in various ways such as feeding on carrion or decaying wood which is returned to the soil in their excrements. Two main groups of land molluscs, slugs and snails, are widely distributed. Except for some slug species they are primarily detritus-feeders and so are often found in the soil litter which they ingest. Their distribution is governed primarily by moisture, calcium, shelter and food. There are about 10 000 species of ants (*Formicidae*) in the world (Curry, 1994) and when making nests, ants break down the soil to a fine powder and also bring up soil from lower levels. The *Diptera* larvae are usually confined to damper soils such as the fermentation and litter layers of forest soils, compost heaps and dung. Most of them are not able to burrow very much and therefore depend on existing soil crevices or making a passage through loose litter. *Myriapoda* is an important class of soil arthropods which can be classified into four groups: the *Pauropoda*, *Symphyla*, *Chilopoda* and *Diplopoda. Chilopods* (centipedes) are mostly carnivorous (feeding on many groups of soil and litter invertebrates), unable to move beneath the surface except by using soil crevices (Brown, 1978) and are widespread in most habitats in tropical and temperate regions. *Diplopods* (millipedes) are primarily woodland animals and are both phytophagous and saprophagous. Millipedes are often among significant soil invertebrates in litter decomposition in moist, undisturbed habitats (Curry, 1994).

1.3. Soil conditions

Soil consists of mineral material, the roots of plants, microbial and animal biomass, and organic matter in various states of decay, as well as water and a gaseous atmosphere (Kilham, 1994). Soils are essential sources of a wide diversity of ecosystem services defined as the goods and ecosystem functions that provide benefit to human populations (Lavelle *et al*, 2006). The main functions of soil have been identified (Knoepp *et al*, 2000; Arshad, Martin, 2002):

1. production function;
2. biotic environmental function;
3. climate-regulative function;
4. hydrologic function;
5. storage function;
6. waste and pollution control function;
7. living space function;
8. archive or heritage function;
9. connective space function.

1.3.1. pH

Soil pH is a measure of the concentration of the hydrogen ions in soil water. Soil pH most markedly affects plant growth through control of nutrient availability. High pH tends in particular to affect the plant adversely by reducing the availability of manganese and iron to the root system. Phosphorus availability is also reduced because of formation of calcium phosphates. Marked soil acidification tends to affect the plant adversely through increased availability of aluminum and also manganese.

Soil animal generally have fairly narrow pH requirements, although variation is considerable from one soil to another. Earthworms are generally highly sensitive to soil acidity; the species distribution is often highly indicative characteristic of soil pH. Earthworms have a mechanism of neutralizing soil acidity, possessing calciferous glands on the side of the pharynx. The narrow pH tolerance of many of the soil animals has an important bearing on the distribution in soil of larger soil animals that feed on them. The absence of earthworms in acid soils, for example, contributes to ensuring the absence of large populations of moles, the earthworms being its primary prey (Kilham, 1994).

1.3.2. Temperature

Temperature is a soil characteristic of great biological significance. It directly affects the rate of physiological reactions and also has many indirect effects on biological activity of soil through temperature-induced changes to other aspects of the soil physicochemical environment such as diffusion rates, mineral weathering rates, redox potentials, water activity etc. The ultimate source of heat energy for all soils is solar energy. About a third of the solar radiation incident on the soil plant system is reflected back to the atmosphere. About five % of net radiation is used for photosynthesis while most of radiation (about 80%) is used to evaporate water. Only a small amount of incident light energy is warming the soil.

Soil temperature is a factor of significant importance in terms of the distribution and activity of the soil animals. Soil animals are generally very sensitive to overheating and will tend to migrate down the soil to avoid high temperatures. This is largely because of the excessive respiratory oxygen demand associated with these temperatures. Generally, soil animals are less sensitive to extremes of low temperatures. Some soil animals such as earthworms migrate down the profile, if possible, to avoid frost under wintry conditions. Many other soil animals, including springtails (*Collembola*) and mites (*Acari*) can often be frozen in the soil, but will renew activity with the onset of warmer soil conditions. Soil temperature may be interacting with other factors such as soil moisture to regulate biological activity. A rise in soil temperature can only have a marked stimulatory effect on soil biological activity if the moisture status of the soil is not limiting the activity (Kilham, 1994).

1.3.3. Moisture

The degree to which the soil pores are filled with water has a fundamental importance in determining biological activity of the soil. Soil bacteria and protozoa tend to live in the soil water at all times. Soil fungi can grow across the air-filled pore spaces. Large soil animals tend to occupy the larger pore spaces that are generally filled with air and only become water-filled when the soil is saturated.

A sandy soil may have low water content, but most of this is available to plant roots. A clay loam on the other hand, may have higher water content, but a roughly similar amount of water available to the plant roots. This is because the clay loam has more small pores (and so a higher soil water tension) from which water is more difficult to extract. A strong correlation is found between soil water content and biological activity of the soil. Periodical environmental stress may cause some changes in the plant, microbial and animal community. Periodical water stress may prevent the establishment of an algal component to the soil microbial community. By the environmental stress lasting for a considerable period, the biota tends to differ more strongly in terms of species composition, form and activity compares with the biota of less extreme environments. Water stress influences also the abundance and activity of the soil animal community. There are very few soil animals that can survive in the soil for prolonged periods of drought although some components of the soil animal community are particularly sensitive to water stress. The number and activity of earthworms has strong correlation with soil moisture levels and thin soils that tend to dry readily discourage earthworms. It has long been known that the production of earthworms' casts as an excellent indicator of earthworm activity is directly related to rainfall and soil moisture status. Soil animals with protective chitinous exoskeletons such as many of the soil arthropods (ants, mites) tend to be much more resistant to soil water stress than the soil animals with exposed soft tissue such as the earthworms and the soil gastropods (slugs and snails), which tend to desiccate readily under dry conditions. Thick lipid layer in the cuticle is also a feature of many drought-resistant soil animals. Another strategy of avoidance of soil water stress by soil animals is through movement down the soil profile to wetter soil conditions (Kilham, 1994).

1.3.4. Light

Light is a primary determinant of soil biological activity. Light is a parameter that directly affects the distribution and activity of organisms above or very near to soil surface. The small amount of light penetration below the soil surface varies from one soil to another and is most remarkably affected by the character of the vegetation cover, topographic factors, and the structure of the pore system at the soil surface. This characteristic is controlled by soil type and also by the activity of burrowing soil animals and plant roots. Light provides the energy source for the photoautotrophic component of the soil biota. About 5% of net solar radiation is used for photosynthesis reactions in various components of the soil biota, mostly including the plants but also the soil algae and the photoautotrophic soil bacteria. Light may be an important agent in soil in triggering the activity of animals, particularly insects, living near the soil surface (Kilham, 1994).

2. AGRICULTURAL LANDSCAPES AS LIFE MEDIUM

2.1. Cultivated agriculture areas

Currently, 10% of the global land area is under modern, intensive agricultural use, 17% is under extensive use associated with the use of far fewer artificial inputs, and 40% is grazed by domestic livestock (Jackson *et al*, 2007). Arable land forms approximately a quarter of Estonian territory (Kõlli, Lemetti, 1999). Modern agriculture implies the simplification of the structure of the environment over vast areas, replacing nature´s diversity with a small number of cultivated plants and domestic animals (Altieri, 1999). There is a great variety of farming systems in the world. Most classifications recognize about 6 - 8 types of crop production system, e.g. shifting cultivation, recurrent (fallow-based) cultivation, permanent mixed crop cultivation (including rotations), permanent annual monocrops and perennial (i.e. plantation) crops (Swift, Anderson, 1993). Land cultivation consists of several stages all of which influence the multiplicity and diversity of soil biota (Tivy, 1990):

- Soil cultivation – physical scarification of land surface and the soil.
- Sowing or planting.
- Drainage and/or irrigation – arranging air and water in the soil.
- Fertilization – adding nutrients.
- Protecting the field fruits – checking for weeds, pests and diseases.
- Harvesting – final collection or removal of the end products from the field.

Modern agriculture encounters many problems (Jennersten *et al*, 1997):

1. Habitat loss – the result of effective modern agriculture is the disappearance of important natural habitat for many animal and plant species (ponds, ditches, wet and flooded meadows etc);
2. Habitat quality – the compatibility of the habitat to certain natural species decreases. The quality of the habitat is decreased, for example, by intensive grazing or use of pesticides and fertilizers;
3. Dispersal – if the detachment of the habitat increases, the number of the habitat islands decreases, the diffusion between the habitat deepens;
4. Drainage of genes – small and isolated populations will decrease, as the result of the drainage of genes the heterogeneity decreases; this brings along the threat of extinction through the mutually influencing genetic, demographic and environmental factors;
5. Interspecific interactions – specific correlations (e.g. predator-prey, pollinator-plant) are most likely especially sensitive to disturbance since influencing one trophic level damages the next level.

Mechanical disturbance of the soil caused by tillage and residue management is a crucial factor in determining soil biotic activity and species diversity in agroecosystems. Tillage usually disturbs at least 15…25 cm of the upper soil layer and soil surface (Altieri, 1999).

2.2. Non-cultivated agriculture areas

Wetlands, including wet grasslands, are characteristic of soil formation where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Wet meadows may support both aquatic and terrestrial species and vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation, and other factors, including human disturbance. Two general categories of wetlands are recognized (Environmental Protection Agency, 2006):

- Coastal wetlands - are found along the coasts. The saline and the fluctuating water levels combine to create a rather difficult environment for most plants.
- Inland wetlands - are most common on floodplains along rivers and streams (riparian wetlands), in isolated depressions surrounded by dry land.

Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs. An immense variety of species of microbes, plants, insects, amphibians, reptiles, birds, fish, and mammals can be part of a wetland ecosystem. Many of wetlands are seasonal -they are dry during one or more seasons every year- and particularly in the arid and semiarid may be wet only periodically. The combination of shallow water, high levels of nutrients, and primary productivity is ideal for the development of organisms that form the base of the food web and feed many species of fish, amphibians and insects. Many species of birds and mammals rely on wetlands for food, water, and shelter, especially during migration and breeding. Wetlands' microbes, plants and wildlife are part of global cycles for water, nitrogen, and sulphur (Environmental Protection Agency, 2006).

West Estonia is a low and flat area encompassing approximately one fifth of the territory of Estonia. The Matsalu Nature Park is the best known among the coastal wetlands of Estonia, being also one of the largest breeding and roosting sites of migratory waterfowl in Europe (ESTONICA, 2006). Reserve was founded in 1957 mainly to protect nesting, moulting and migratory birds. In 1976 Matsalu was included to the list of wetlands of international importance under Ramsar convention

(Matsalu Rahvuspark, 2006). The Matsalu Nature Park covers a 476.4-km^2 land and water area encompassing Matsalu Bay along with the delta of the Kasari River and the surrounding communities- floodplain and coastal meadows, reed beds and woodlands, and also a part of the Väinameri Sea bordering the bay, including its more than 40 islands. Several rivers run into Matsalu Bay, the biggest of these being the Kasari River. The rivers carry large quantities of nutrient-rich sediments into the bay from an over 3500-km^2 catchment area. The sediments are deposited in river estuaries, allowing reedbeds to expand rapidly towards the sea (ESTONICA, 2006). There are 275 species of birds, 49 species of fish and 47 species of mammals registered in the area of nature reserve, also 772 species of vascular plants. Every spring over 2 million waterfowl pass Matsalu (ESTONICA, 2006). The landscapes are unique and deserve to be protected - floodplains, reedbed, coastal meadows, wooded meadows and islets (Matsalu Rahvuspark, 2006).

2.2.1. Characterization of meadows

2.2.1.1. Floodplain meadow

Floodplain meadows are periodically flooded semi-natural communities situated on the banks of rivers (or lakes). Floodplain meadows have generally arisen as a result of human activities - meadow communities developed through the grazing and mowing that followed the logging of floodplain forests. Due to the combination of human impact and natural conditions that affect the soils over the centuries (the sediments that accompany flooding as well as nutrient transport and over moistness) distinctive plant and animal communities have developed on floodplain meadows. The nutrients carried there by floods are very important because they result in the higher soil nutrient level (PKÜ, 2006).

Floodplain meadows are not widespread in Estonia because of the scarceness of large rivers. These communities are more common in Western and Southern Estonia. The largest flooded meadows of Western Estonia belong to the river basin of the Kasari. In 1960ies the total area of flooded meadows was presumably 83 000 ha. According to the inventory performed in 1978 - 81 the area had decreased to 27 584 ha. The inventory made by Estonian Fund for Nature (ELF) in 1993-1996 showed that the area of floodplain meadows in good or satisfying conditions is about 12 500 ha (PKÜ, 2006).

For centuries the human activities on floodplain meadows has included cutting wood and brushwood, making hay and grazing. Carrying nutrients away with hay did not influence the productivity - the high nutrient level of soil is caused by the sediments carried there by the floods. Consequently, there was no reason to use artificial fertilising on floodplain meadows (PKÜ, 2006). As floodplain meadows have developed as a result of human activities (cutting wood and brushwood, mowing and grazing), the further existence of those communities is wholly dependent on the continuity of management. Natural processes take over after the end of mowing and grazing, the plants typical of overgrown area begin to dominate (PKÜ, 2006).

2.2.1.2. Coastal meadows

Coastal meadows are flat and low, regularly grazed stretches of coast covered with herbs and grasses and directly influenced by saline sea water (ESTONICA, 2006). The coastal area can be divided into subsaline, saline and suprasaline zone depending on the altitude and the resulting intensity of the influence of seawater. The subsaline zone is a coastal area that is flooded permanently or for long periods, and where the lower parts of plants are permanently submerged; the saline zone is in the area of influence of seawater during wave action or high tide; marine influence usually does not reach the suprasaline zone. Coastal vegetation is also influenced by the mechanical effect of wind, waves and ice. As a result, a more or less clear zonation is characteristic of the vegetation of the seashore (PKÜ, 2006).

Coastal meadows are spread on the coastal areas; common in Western Estonia and on the islands and less can be found on the limestone coast of Northern Estonia. Coastal meadows have once been common everywhere in Europe where the conditions for the formation and preservation (grazing, mowing) were sufficient. Nowadays the area of coastal meadows has strongly decreased throughout the world either because of the changes in the use of coastal areas or, less often, the end of their management. Unlike in Western Europe, the main reason for the disappearance of coastal meadows in Estonia has been the end of their traditional use (PKÜ, 2006).

The vegetation of coastal meadows is characterised by the abundance of halophyte species. The largest meadows still preserved populations of many plant and animal species formerly common in cultural landscapes are presently associated with coastal meadows. A big part of the Estonian coastal meadows has met this fate during the last few decades (ESTONICA, 2006). Coastal meadows are valuable breeding and resting sites for numerous bird species; many of the coastal bird species have become rare in the entire Baltic Sea region due to the substantial decline in the area of coastal meadows (ESTONICA, 2006).

The outcome of overgrowing is the rapid decrease in the diversity of the halophilic flora as well as coastal communities, and the aesthetic value of coastal landscapes becomes debased. Grazing is the easiest way to maintain coastal meadows. Extensive grazing is the best method for the restoration of the slightly overgrown communities. If the meadow has been overgrown by junipers, then grazing sheep is most effective during first years. Unlike cattle, sheep eat the saplings of junipers and restrict bigger bushes. However, grazing is not enough if junipers are very dense, in that case one must think about cutting the bushes. If the coast has overgrown with reeds, the old reeds should be mown at first and in the next spring animals should be grazed on the mown territory. Young reeds are a good feed for cattle. In addition, the domination of reeds is limited because cattle demolish the rhizome of the reeds by trampling (PKÜ, 2006).

3. MATERIAL AND METHODS

3.1. Sample areas

Intensivety managed cultivated lands and extensively managed semi-natural flooded grasslands were selected as sample areas out of all agricultural landscapes.

3.1.1. Arable lands

Twenty four study areas of three most widespread soil types (pebble rendzinas- Calcaric Regosols, typical brown soils- Calcaric Cambisols and pseudopodzolic soils- Stagnic Luvisols) all over Estonia were selected. Arable lands under cultivation (24 fields) are situated in five region of Estonia: Saare (1), Jõgeva (2), Rapla (3), Järva (4) and Viljandi (5) counties, the sizes of fields are presented in Table 1.

Table 1. The location (region 1-5) and size (ha) of study fields. CR= Calcaric Regosols, CC= Calcaric Cambisols, SL= Stagnic Luvisols. 1= Saare county, 2= Jõgeva county, 3= Rapla county, 4= Järva county, 5=Viljandi county, Reg= Region, (mean value ± SE)

Calcaric Regosols			**Calcaric Cambisols**			**Stagnic Luvisols**		
Field nr	**Reg**	**Size (ha)**	**Field nr**	**Reg**	**Size (ha)**	**Field nr**	**Reg**	**Size (ha)**
CR1	1	1.0	CC1	2	3.9	SL1	2	3.6
CR2	1	4.7	CC2	2	85.0	SL2	2	1.6
CR3	1	1.2	CC3	4	64.3	SL3	2	3.0
CR4	1	1.2	CC4	4	25.3	SL4	2	3.0
CR5	2	11.0	CC5	4	67.3	SL5	2	0.3
CR6	3	2.0	CC6	3	0.6	SL6	5	1.8
CR7	3	0.3	CC7	3	1.7	SL7	5	4.0
CR8	3	2.1	CC8	3	0.5	SL8	5	15.0
Mean ±SE		2.9 ± 1.2			31.1 ± 12.6			4.0 ± 1.6

In each group of soil type, eight fields with different management practices were selected for studies on 2003 - 2004. In 2003 sampling was performed in 20cereal fields, 2 clover fields, 1 oilseed rape field, 1 perennial grass field; in 2004 in 16 cereal fields, 4 clover fields, 3 oilseed rape fields, 1 perennial grass field. Three-year history of agricultural management practice (tillage, amount of mineral and organic fertilizers and pesticides used) were recorded. Mineral nitrogen fertilizers (15 – 142.5 kg N ha^{-1} y^{-1}) were applied on 17 fields, including seven fields with herbicides applied and six fields with insecticides and fungicides applied; organic fertilizers were applied on 7 fields. *Leguminosae* (mostly *Tripholium*) were used in rotation of crop during last 3 years on 11 fields (Truu *et al*, 2008).

3.1.2. Flooded meadows

Soil biota communities were studied in Matsalu National Park on flooded meadows (West-Estonia) which are mown annually (floodplain meadows) or grazed with low intensity (coastal meadows), the transient grasslands are mown or grazed. Earthworm communities were studied in 10 locations in year 2005 and epifauna communities were studied in 11, 10 and 6 locations in West Estonia from 2004 to 2006, respectively. The sizes of meadows and characteristics are presented in Table 2 (Luhamaa *et al*, 2001). The investigation area was selected to represent grasslands that were temporarily flooded with freshwater or saline water or both (coastal grasslands, floodplains, or transient meadows, where fresh or saline water extent is indistinct). The flood duration is approximately one month in spring with shorter periods in autumn and summer.

Table 2. The location and size (ha) of study meadows

Site	Size (ha)	Habitat	Overflooded	Management
Kelu	30	Wet floodplain medow	Fresh	Mowing
Kloostri 1	34	Wet floodplain medow	Fresh	Mowing
Kloostri 2	42	Wet floodplain medow	Fresh	Mowing
Kasari 1	12	Fresh floodplain meadow	Fresh	Mowing
Kasari 2	28	Fresh floodplain meadow	Fresh	Mowing
Suitsu 1	54	Transient meadow	Fresh+saline	Grazing
Suitsu 2	32	Transient meadow	Fresh+saline	Mowing
Suitsu 3	25	Transient meadow	Fresh+saline	Grazing
Lõpe	46	Transient meadow	Fresh+saline	Grazing+mowing
Salmi 1	18	Coastal meadow	Saline	Grazing
Salmi 2	30	Coastal meadow	Saline	Grazing
Salmi 3	14	Coastal meadow	Saline	Grazing
Rõude 1	60	Fresh floodplain meadow	Fresh	Mowing

3.2. Collection and analysis of earthworms

On arable lands earthworm samples were collected during autumn period when earthworms are most active and when they can be found in the upper soil layers. For identifying and analyzing earthworms the method of sorting out the earthworms by hand was used (Satchell, 1967; Meyer, 1996). Three plots were installed in each field. The size of the plot is 50 x 50 x 40 cm. The soil taken from the plot was put on top of plastic film and sorted by hand. The earthworms found were counted. The abundance was calculated as an average of the blocks for one field per $1m^2$. Alive earthworms were washed and kept in the refrigerator for 48 hours on damp filter paper and afterwards the species were identified.

In meadows at each site five soil blocks (50 x 50 x 40 cm) were examined by hand sorting or using mustard solution as vermifuge (Gunn, 1992; Meyer, 1996). All individuals collected from the soil blocks were counted; the mean number of individuals in 1 m^2 soil surface and the standard error (SE) were calculated.

For identifying the species of earthworms several manuals and handbooks were used (Graff, 1953; Edwards, Lofty, 1972; Timm, 1999).

3.3. Collection and analysis of epifauna

Pitfall-traps were used when collecting the samples of epigeic invertebrates (Meyer, 1996). All the animals that have got caught in the traps were counted and identified, including also those which actually did not belong to the epifauna (springtails, etc). The traps were made of plastic and had a diameter of 7 cm. When placed in the field their upper side was aligned with the soil. The traps were filled with 20% NaCl solution up to quarter of the pitfall. The traps were covered with lids in order to avoid rainwater inundating the traps.

On the fields the traps were placed along transect from the middle of the border 1m outside (incase the field bed really existed) and 5m, 10m and (15m) 20m inside, one transect was placed in the centre of the field. Depending on the methods, the distance between traps was 1 m and the traps were emptied after 5 days. Traps were placed in 2003: 22.-24.07 and 12.-17.09; in 2004: 29.06-01.07 and 24.-26.08 – 29.-31.08 in autumn. Each different community bordering the field constitute one border, thus the number of borders is different for different fields.

On flooded meadows ten traps were put 100 m in the middle of flooded meadows at the distance of 10 m. The traps were emptied after 5 days, in June. For identifying the species several manuals and handbooks were used (Remm, 1967; Haberman, 1968; Merivee, Remm, 1973; Freude *et al*, 1976).

In every sample areas a composite soil sample was collected and moisture content (by 105^{o}C), pH (KCl), organic matter (in muffle furnace at 360°C), nitrogen concentration (Kjeldahl method) and soluble phosphorus concentration (lactate method), K- concentration (flame photometer) were determined.

3.4. Data processing

The mean number of earthworm individuals and epigeal fauna of soil surface and standard error (SE) were calculated. Data analyses were performed by using nonparametric statistical methods (dispersion analyses, of Kruskalls-Wallis), by using programs STATISTICA 7 and Microsoft Excel. The Shannon-Wiener diversity index and Simpson index "D" were calculated (Spellerberg, 1991; Krebs, 1999).

Canonical Correspondence Analysis (CCA) was used to analyze the data on epigeic fauna and ground beetle communities with regard to environmental variables using the program CANOCO 4.52 (ter Braak, 1994). The forward selection method with the Monte Carlo test (999 permutations), available in the CANOCO software, was used to select nominal explanatory variables (soil type and location of traps on the field) relevant for determining species of ground beetles and orders community composition.

4. RESULTS

4.1. Soil biota communities on arable lands in Estonia

4.1.1. Abundance and diversity of earthworm communities

The mean value of soil characteristics is given in Table 3. The statistically significant differences between mean values of soil type characteristics were not found, except the fact that soil pH was the lowest in Stagnic Luvisols but in statistical terms ($p<0.05$) it did not differ in Calcaric Regosols or Calcaric Cambisols

Table 3. Characteristics of soil of studied fields (mean value ± SE). CR= Calcaric Regosols, CC= Calcaric Cambisols and SL= Stagnic Luvisols. Asterisks designate group means which are statistically different according to multiple comparisons of mean ranks

Characteristics		**CR n=8**	**CC n=8**	**SL n=8**
Soil moisture, %	2003	13.18 ± 2.06	14.80 ± 0.82	16.93 ± 1.12
	2004	20.04 ±2.96	17.73 ± 0.98	20.48 ± 3.41
pH (KCl)		6.38 ± 0.35*	6.82 ± 0.27*	6.03 ± 0.75**
Organic matter content, %		4.15 ± 0.65	3.45 ± 0.26	4.16 ± 0.99
Total N, %		0.207 ± 0.037	0.158 ± 0.012	0.201 ± 0.055
Soluble P, mg per 100g dry soil		16.91 ± 3.18	11.19 ± 1.70	14.34 ± 2.78
K, mg per 100 g dry soil		18.24 ± 3.30	21.32 ± 2.10	17.24 ± 2.86

According to the data of National Environmental Monitoring Program, the sum of precipitation from July to October of each region is presented in Figure 1 (Keskkonnaülevaade, 2005).

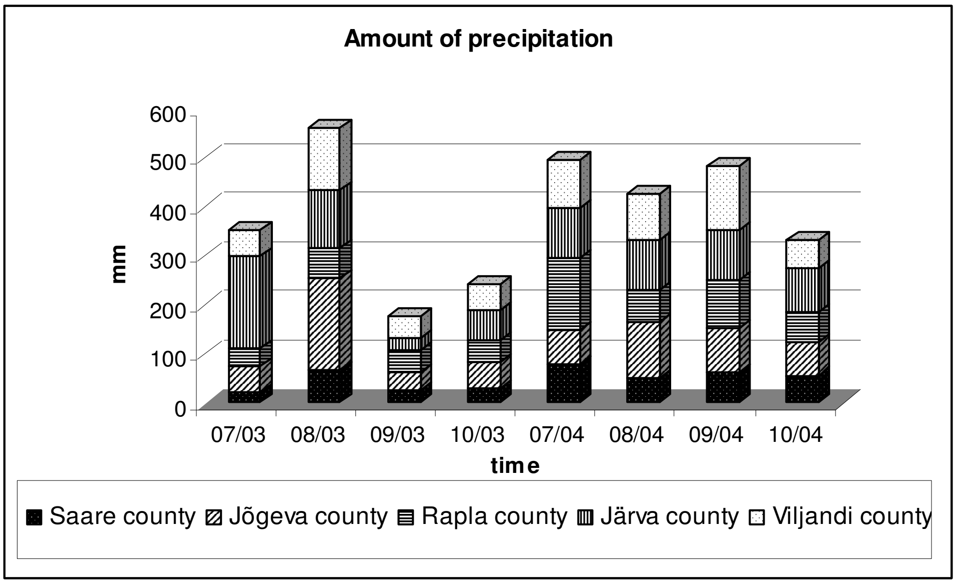

Figure 1. Sum of precipitation from 2003-2004. 07=July, 08=August, 09=September, 10=October

In Table 4 the mean values of earthworm communities' parameters (±SE) are given according to field with different soil type. The abundance of earthworms was the lowest in the Calcaric Regosols in 2003 and in 2004 (47.9 ± 11.3 and 45.7 ± 19.5 individuals per m^2, respectively). The highest mean abundance of earthworms in 2003 and 2004 was found in Stagnic Luvisols (107.1 ± 22.4 and 130.0 ± 33.0 individuals per m^2, respectively), the communities consisted mostly of individuals of the endogeic species *Aporrectodea caliginosa*. The mean abundance of this species was highest in 2003 (68.9 ± 13.0 individuals per m^2) and in 2004 (98.4 ± 23.4 individuals per m^2) in Stagnic Luvisols and the lowest in Calcaric Regosols (30.8 ± 13.5 and 27.4 ± 11.1 individuals per m^2 in 2003 and 2004, respectively. The mean values of earthworm community parameters (± SE) in case of three soil types are presented in Paper I and III.

Table 4. Characteristics of earthworm communities (mean value ± SE) in fields of different soil types fields. N= abundance, individuals per m^2, S= number of species

Soil types	**2003**		**2004**	
	N	**S**	**N**	**S**
Calcaric Regosols	47.9 ± 11.3	3.2 ± 0.5	45.7 ± 19.5	2.4 ± 0.6
Calcaric Cambisols	73.0 ± 15.1	3.5 ± 0.3	97.9 ± 20.0	3.0 ± 0.3
Stagnic Luvisols	107.1 ± 22.4	3.1 ± 0.5	130.0 ± 33.0	2.8 ± 0.6

The mean values of earthworm evenness and diversity indexes are given in Table 5. According this table, the Calcaric Cambisols have higher evenness, Shannon´s and Simpson´s diversity indexes in both 2003 and 2004 years.

Table 5. Evenness (E), Shannon´s (H) and Simpson (D) diversity index of earthworms in different soil types fields. CR= Calcaric Regosols, CC= Calcaric Cambisols and SL= Stagnic Luvisols

Soil types	**E**	**H**	**D**
	2003		
CR	0.400 ± 0.150	0.685 ± 0.283	0.3224 ± 0.1333
CC	0.715 ± 0.066	1.038 ± 0.082	0.5475 ± 0.0499
SL	0.613 ± 0.036	0.795 ± 0.081	0.4242 ± 0.0357
	2004		
CR	0.542 ± 0.099	0.714 ± 0.154	0.3789 ± 0.0786
CC	0.674 ± 0.033	0.961 ± 0.086	0.5307 ± 0.0369
SL	0.437 ± 0.094	0.593 ± 0.153	0.3116 ± 0.0801

In 2003 the mean value of total numbers of earthworms in the fields of cereal was 63.2 ± 12.8 individuals per m^2 and 75.3 ± 17.8 in 2004; in clover fields 95.0 ± 73.0 (in 2003) and 40.0 ± 2.3 (in 2004); in the field of perennial grass mean value was 153.3 ± 14.8 and in oilseed field it was 52.0 ± 2.3 in 2003. In 2004 the mean value of earthworm numbers of earthworms was 176.0 ± 26.6 in the field of perennial grass and 159.3 ± 6.0 in the field of oilseed. There was no difference in mean values of characteristics of earthworm communities in the fields with different arable crop (cereals, oilseed rape and clover). There were five species of earthworms found in all three types of soil: *Aporrectodea caliginosa* (23 fields out of 24), *Aporrectodea rosea* (23 fields), *Lumbricus terrestris* (16 fields), *Lumbricus rubellus* (15 fields) and *Aporrectodea longa* (9 fields) (Paper I and III).

4.1.2. Abundance and diversity of epifauna communities

In Appendix 1 and Appendix 2 the relative abundance of epigeic fauna (number of individuals per trap) is given on field and on field edge. Canonical correspondence analysis indicated that main difference in community composition of ground beetles and orders is related to location of traps in the field. In case of orders the preference of most of the species for near field edge habitat is clearly visible (Paper III, Figure 1). The second factor affecting the community composition of order is soil type. Fields of Calcaric Cambisols (CC) and Calcaric Regosols (CR) soil type have rather similar species compostion of orders, when fields with Stagnic Luvisols (SL) soil type differ from them (Paper III).

In Calcaric Regosols the mean number of individuals per trap on field in July 2003 was 54.5 ± 4.3. Individuals of *Coleoptera* formed nearly a half (48.1%) of the total number of invertebrates, including carabids which formed half of all beetles. The number of spiders, ants and diptera was notable. In September 2003 the total number of individuals was five times lower (11.4 ± 1.8 per trap), with carabids and spiders being dominat species. On field edges the mean number of individuals per trap was 115.0 ± 25.5. *Hymenoptera* consisting 36.7%, the numbers of *Coleoptera*, *Isopoda* and *Diptera* being noteworthy. In July 2004 the mean numbers of individuals per trap on field was 82.8 ± 10.3, individuals of *Coleoptera* formed 42.0% and the number of *Collembola* was considerable. On field edges the mean number of individuals per trap was 167.8 ± 6.2 in July 2003 and 64.6 ± 19.4 in September, number of *Coleoptera*, *Hymenoptera* and *Collembola* were noteworthy (Paper III).

The total number of individuals in Calcaric Cambisols was the lowest of studied soil types in July 2003 (24.8 ± 3.1 consisting 34.8% of beetles and showing high percentage of spiders). In September the mean number was 5.7 ± 2.3, and dominating species included *Coleoptera* and missing *Heteroptera*, *Hymenoptera*, *Isopoda*. On field edge the total number of individuals per trap was 66.9 ± 11.6 in July 2003 and 28.8 ± 6.2 in September 2003, and dominating species included *Coleoptera* and *Hymenoptera.* In July and September 2004 the lowest number of individuals was found in Calcaric Cambisols soils fields (73.2 ± 12.6 and 28.2 ± 3.1 respectively). In July 2004 the mean number of individuals on field edge was considerably higher (174.9 ± 80.0) than in the fields, in September 2004 the number of individuals per trap on field edge was 67.7 ± 21.4 (Paper III).

Total number of individuals per trap on Stagnic Luvisols was 42.7 ± 13.0 in July 2003 and 46.9 ± 9.4 in September 2003, the dominating group was *Hymenoptera* and *Coleoptera*. The number of individuals per trap on field edge was 120.8 ± 33.2, consisting of 59.8% of *Hymenoptera* and 13.0% *Coleoptera*. In September 2003 the number of individuals was high as well – 99.0 ± 34.9, consisting of 38.0% of *Hymenoptera*. In July 2004 total number of individuals on field edge was also high (142.7 ± 22.0) with the proportion of *Collembola* being 31.3%, in September 2004 total number of individuals was 109.1 ± 15.0 (Paper III). List of names of species and abbreviations on agricultural landscapes are given in Appendix 3.

Canonical correspondence analysis indicated that the main difference in community composition of ground beetles is related to the location of traps in the field. In the middle of the field species like Cl_fos (*Clivina fossor*) and Pt_nig (*Pterostichus niger*) are more abundant, while Bem_sp (*Bembidion sp*), Pt_cup (*Pterostichus cupreus*), Pt_vul (*Pterostichus vulgaris*) and Ca_can (*Carabus cancellatus*) are more frequently found on field edges. In case of ground beetles soil type did not have statistically significant impact on distribution of species in the studied fields (Paper III, Figure 2).

In Figure 2 are presented the results of Canonical Correspondence Analysis (CCA) for July 2003. The CCA ordination axes 1 and 2 accounted for 32.8 % (first axis) and 62.4 % (first and second axis together) of variance in the species–environment relation, respectively. The solid circles indicate the location of individual plots in the axis 1-, axes 2-space. The triangles indicate the location of predicted maximum abundance and optimum environmental conditions for each epigeal species in the ordination space. According to Figure 2; the phosphorus vector points to the left lower corner, the other vectors (N, OM, K) point to the right upper quadrant and pH vector point to the lower right corner and so they explain quite different species. The length of an arrow indicates the importance of environmental variable and the angles between arrows indicate correlations between individual environmental variables. According to Figure 2, K, OM and N are positively correlated, but together they are negatively correlated with P. All of these parameters, N and OM have strong impact on different species and K and pH are strongly correlated with the first CCA axis. While each sample point lies at the centroid of the species occurring at the site, the Figure 2 indicates that species Co_sep (*Coccinella septempunctata*) is most abundant in site CR3. The moisture was more importance for epigeal fauna in September 2003, based on Canonical Correspondence Analysis (CCA), and compared to summer 2003 the species are more dispersed in ordination.

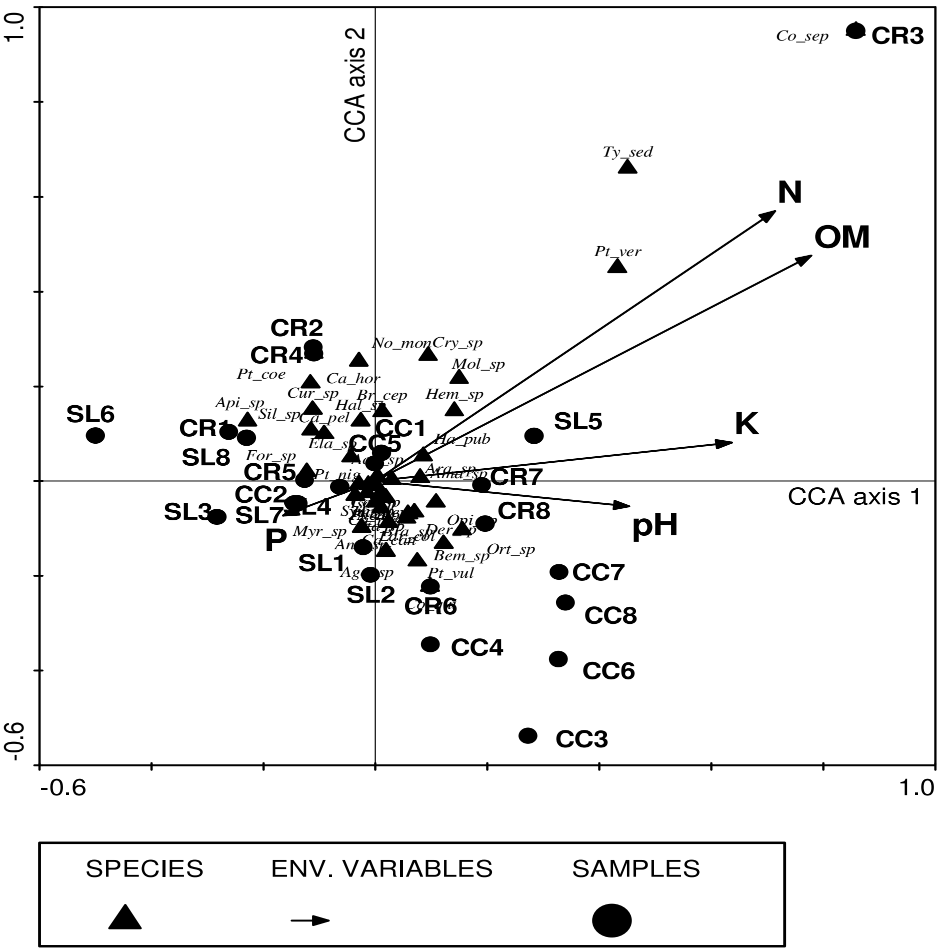

Figure 2. Ordination triplots with environmental variables based on Canonical Correspondence Analyses (CCA) of species in 2003 summer. Abbreviations: pH- acidity of soil, OM- organic matter (%), N- nitrogen (%), K- potassium (g/100g dry soil), N- nitrogen (%), P- soluble phosphorus (mg per 100g dry soil). Eigenvalues of the first two axes are 0.142 and 0.129; the sum of all canonical eigenvalues is 0.434.

Figure 3 illustrate the result of Canonical Correspondence Analysis (CCA) for July 2004. Axes 1 and 2 were accounted for 46.7 % (first axis) and 72.7% (first and second axis together) of variance in the species–environment relation, respectively. All environmental parameters (N, OM, K, P) have significant important value. Phosphorus had stronger impact on epigeal fauna in September 2004.

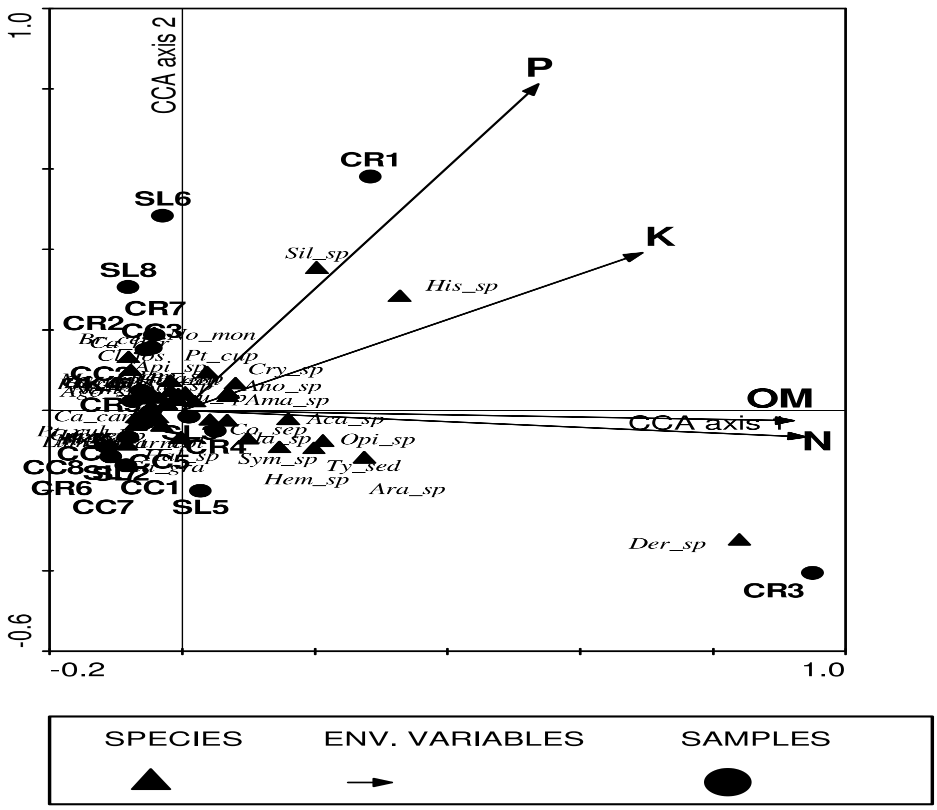

Figure 3. Ordination triplots with environmental variables based on Canonical Correspondence Analyses (CCA) of species in 2004 summer. Abbreviations: pH- acidity of soil, OM- organic matter (%), N- nitrogen (%), K- potassium (g/100g dry soil), P- soluble phosphorus (mg per 100g dry soil). Eigenvalues of the first two axes are 0.201 and 0.112; the sum of all canonical eigenvalues is 0.431.

The mean values of ground beetles in the fields of different crop are given in Table 6. According the table, ground beetles did not show significant preference for certain crops (Paper V).

Table 6. The mean values (± SE) of ground beetles in the fields of different culture

Time		Cereal	Clover	Oilseed rape	Perennial grass
2003.	Summer	11.7 ± 1.9	7.5 ± 0.5	4.0 ± 2.1	6.5 ± 2.0
	Autumn	5.4 ± 1.7	1.7 ± 0.7	5.7 ± 0.9	-

Time		Cereal	Clover	Oilseed rape	Perennial grass
2004.	Summer	13.6 ± 2.0	9.1 ± 3.4	14.8 ± 4.3	-
	Autumn	11.9 ± 1.9	3.7 ± 0.9	11.2 ± 5.2	-

The mean values of ground beetles diversity index and evenness are given in Table 7. Shannon´s diversity index was higher in Stagnic Luvisols (no statistically significant) in summer 2003 (1.612 ± 0.094) and 2004 (1.800 ± 0.092) compared to the data of Calcaric Regosols and Calcaric Cambisols data.

Table 7. Shannon´s diversity index and evenness of ground beetles in different soil types fields. CR= Calcaric Regosols, CC= Calcaric Cambisols, SL= Stagnic Luvisols

Soil type	Shannon´s diversity index		Evenness	
	2003			
	Summer	Autumn	Summer	Autumn
CR	1.548 ± 0.107	1.102 ± 0.219	0.742 ± 0.043	0.864 ± 0.050
CC	1.502 ± 0.063	1.531 ± 0.019	0.745 ± 0.033	0.952 ± 0.012
SL	1.612 ± 0.094	1.679 ± 0.101	0.807 ± 0.032	0.843 ± 0.027
	2004			
CR	1.520 ± 0.076	1.615 ± 0.069	0.788 ± 0.043	0.851 ± 0.033
CC	1.678 ± 0.083	1.603 ± 0.409	0.789 ± 0.028	0.692 ± 0.173
SL	1.800 ± 0.092	1.834 ± 0.051	0.784 ± 0.047	0.828 ± 0.020

4.2. Soil biota communities on flooded meadow

4.2.1. Abundance and diversity of earthworm communities

In 2005 earthworm communities were studied at 10 flooded meadows in Matsalu National Park, which are temporarily flooded with freshwater or saline water or both (coastal grasslands, floodplains, or intermediate transient meadows where fresh or saline water extent is indistinct). The mean value of soil characteristics are given in Table 8.

Table 8. Characteristics of soil of studied areas (mean value ±SE), fp= floodplain, grl= grasslands

Characteristics	Wet fp meadow (n=3)	Fresh fp meadow (n=2)	Transient grl (n=3)	Coastal grl (n=2)
Soil moisture, %	62.60 ± 4.0	44.00 ± 4.50	41.67 ± 5.81	50.94 ± 14.23
pH	5.4 ± 0.1	6.0 ± 0.3	6.1 ± 0.5	6.3 ± 0.1

Characteristics	Wet fp meadow (n=3)	Fresh fp meadow (n=2)	Transient grl (n=3)	Coastal grl (n=2)
Organic matter content,%	26.38 ± 0.95	13.56 ± 1.20	14.77 ± 4.23	21.54 ± 7.3
Total N, %	1.224 ± 0.012	0.704 ± 0.054	0.748 ± 0.181	1.169 ± 0.373
K, mg per 100g dry soil	19.5 ± 5.5	19.9 ± 0.9	28.7 ± 7.8	30.8 ± 5.6

1. Wet floodplain meadow (Kelu, Kloostri 1, Kloostri 2):
Total abundance of earthworms (40.0 ± 22.1 individuals per m^2) and number of species were low (3.0 ± 0.6). Dominant species was the semi-aquatic species *Octolasion lacteum* but the abundance of semi-aquatic epigeic *Eiseniella tetraedra* was high as well. Additionally, individuals of species *Lumbricus castaneus*, *Aporrectodea rosea* and *Dendrobaena octaedra* were found.
2. Fresh floodplain meadows (Kasari 1, Kasari 2):
Total number of earthworms per m^2 was 81.0 ± 26.0 and number of species was 4.5 ± 1.5. The endogeic semi-aquatic *O. lacteum* was the dominant species of the community, species tolerant to habitat conditions - *Aporrectodea caliginosa*, *A. rosea* and *Lumbricus rubellus* - were present as well. No Anecic species were found. We also found some individuals of epigeic species *Dendrodrilus rubidus* and *D. octaedra*.
3. Transient meadows (Suitsu 1, Suitsu 2, Lõpe):
Earthworm communities were less abundant, but more diverse (58.2 ± 22.2 individuals, 4.7 ± 1.2 species). Here the dominating species was *A. caliginosa* with the highest tolerance to ecological conditions, whereas *L. rubellus* was also relatively abundant. The community was diverse: there were species with various requirements – the tolerant species *A. rosea*, and, typical for wet habitats, *O. lacteum*, *E. tetraedra*, *L. castaneus*, as well as the epigeic species *D. octaedra*.
4. Coastal meadows (Salmi 1, Salmi 2):
Abundance of earthworm was very low (6.0 ± 5.0); only two endogeic species were present: *A. caliginosa* and *O. lacteum* (Paper IV)

The most abundant earthworm species on flooded meadows include semi-aquatic *Octolasion lacteum* and *Eiseniella tetraedra*, and *Aporrectodea caliginosa*, which is more tolerant to unfavorable ecological conditions. Mean abundance of species tolerant to ecological factors in different meadows are presented in Figure 4. Flooding by fresh water is a positive factor for semi-aquatic earthworms and is negative for all others. The salinity of flooding sea water constitutes an additional negative factor for all species of earthworms and the same effect comes from temporary drying off the coastal thin soil (Paper IV).

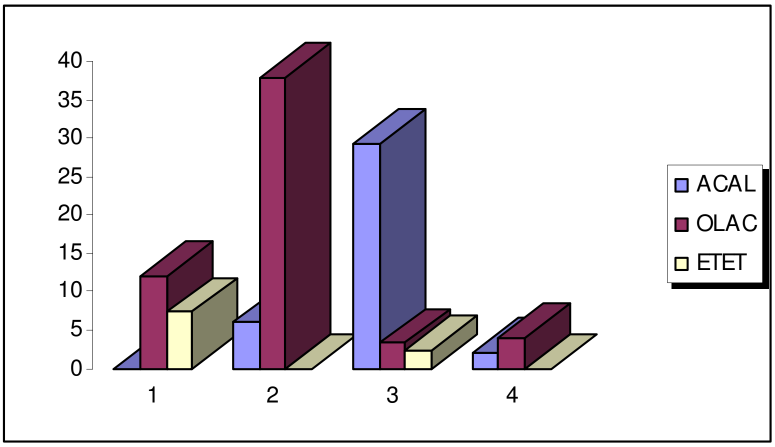

Figure 4. Mean abundance (individuals per m^{-2}) of tolerant to ecological factors species *Aporrectodea caliginosa* and semi-aquatic species (*Octolasion lacteum* and *Eiseniella tetraedra*) in different types of meadows (1 – wet floodplain meadows; 2 – fresh floodplain meadows; 3 – transient meadows; 4 – coastal meadows) (Paper IV)

The results of a Canonical Correspondence Analysis (CCA) are summarized in the ordination diagram based on the data on the earthworm species (Figure 5). The epigeic species of *E.tetraedra* and *D. octaedra* are positively influenced by moisture, organic matter and nitrogen. The endogeic species of *A. rosea*, *O. lacteum*, *L. castaneus* and the epigeic species of *D. rubidus* are positively influenced by pH and potassium and negatively affected by sodium. The epigeic species *L.rubidus*, the endogeic species *A. caliginosa* as well as the epigeic species of *E .tetraedra* and *D. octaedra* tolerate sodium and length of this vector indicates that this gradient is quite steep and has quite a big influence on the composition of species.

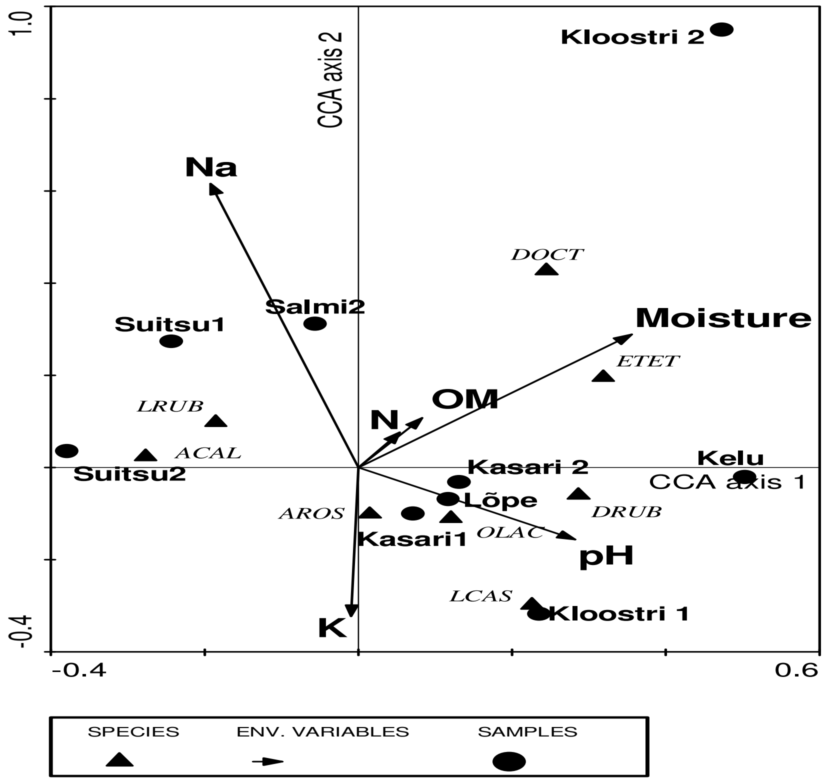

Figure 5. Ordination triplots with environmental variables based on Canonical Correspondence Analyses (CCA) of earthworm species. Abbreviations: pH- acidity of soil, OM- organic matter (%), Na- sodium (g/100g dry soil), K- potassium (g/100g dry soil), N- nitrogen (%). Eigenvalues of the first two axes are 0.598 and 0.339; the sum of all canonical eigenvalues is 1.498.

4.2.2. Abundance and diversity of epifauna communities

Data on soil biota communities was collected during the period from 2004 to 2006 in Matsalu National Park (2004: 11 sites, 2005: 10 sites, 2006: 6 sites). List of the name of species and abbreviations on wet meadows are given in Appendix 4 and 5. Table 9 presents data from sample areas collected in 2004-2005. The Shannon's diversity index was the highest in Kasari 2 (2.388) and the lowest in Kloostri 1 (1.423) in 2004 and in Suitsu 3 (2.559) and Lõpe (1.731) in 2005, respectively. Sample area Suitsu 1 had highest number of species in 2004 (22) and in 2005 (26). The lowest number of species was found in sample area Kelu (11) in 2004 and Kloostri 1 and Kloostri 2 in 2005 (17).

Table 9. Species number (S), Evenness (E), Shannon´s (H) and Simpson (D) diversity index of epigeal fauna in different flooded meadows in Matsalu (2004-2005)

Name	**2004**				**2005**			
	S	**E**	**H**	**D`**	**S**	**E**	**H**	**D`**
Kloostri 1	14	0.539	1.423	0.6178	17	0.350	0.990	0.3614
Kloostri 2	15	0.600	1.624	0.7151	17	0.425	1.203	0.4521
Kelu	11	0.737	1.767	0.7712	22	0.297	0.916	0.3225
Kasari 1	16	0.762	2.113	0.8494	20	0.676	2.026	0.7961
Kasari 2	17	0.843	2.388	0.8836	19	0.738	2.174	0.8287
Rõude	17	0.787	2.230	0.8477	-	-	-	-
Lõpe	-	-	-	-	23	0.552	1.731	0.7244
Salmi 1	18	0.756	2.185	0.8518	20	0.284	0.851	0.3207
Salmi 2	15	0.815	2.206	0.8638	-	-	-	-
Salmi 3	-	-	-	-	21	0.837	2.550	0.9006
Suitsu 1	22	0.618	1.910	0.7722	26	0.783	2.550	0.8902
Suitsu 2	18	0.748	2.162	0.8396	-	-	-	-
Suitsu 3	17	0.658	1.863	0.7858	25	0.795	2.559	0.8811

Figure 6 presents the results from Principal Components Analysis (PCA) in 2004. A PCA produces axes which represent linear combinations of the original variables oriented in the directions that describe maximum variation among individual sampling entities. There are three correlation areas between all species. More important species are *Chlaenius nitidulus* (Ch_nit), *Acarina* species (Aca_sp), *Pterostichus vernalis* (Pt_ver), *Lorocera pilicornis* (Lo_pil), which show positive correlation. *Formicidae* (For_sp), *Pterostichus cupreus* (Pt_cup), *P. minor* (Pt_min) and *P. vulgaris* (Pt_vul) are negatively correlated. The distance between the sample point symbols in the diagram approximates the dissimilarity of their species composition, measured by their Euclidean distance. Species composition dissimilarity is quite different between the sites Kloostri 1 and Suitsu 1-Suitsu 3 and a little different between the sites Suitsu 1-Suitsu 3, Suitsu 2-Rõude 1 and between the sites Kelu 1-Kasari 2-Salmi 2.

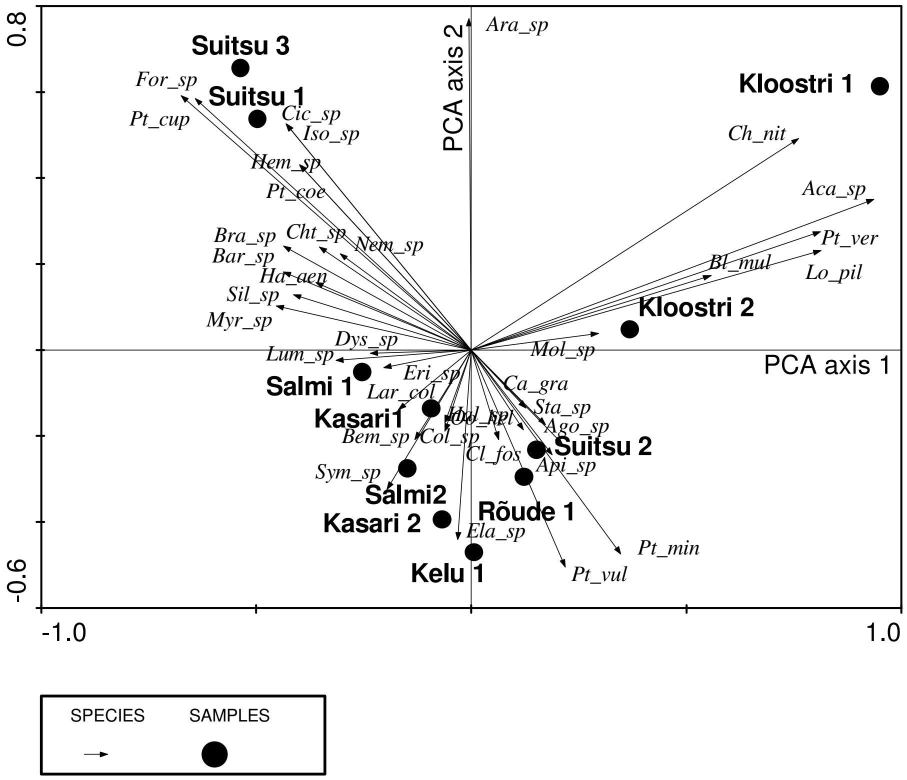

Figure 6. Ordination biplots based on Principal Components Analysis (PCA) of invertebrates species. Eigenvalues of the first two axes are 0.562 and 0.215.

Figure 7 shows the results of a Canonical Correspondence Analysis (CCA) in 2005. The solid circles indicate the location of individual plots in the axis 1-, axes 2-space. The triangles indicate the location of predicted maximum abundance and optimum environmental conditions for each species in ordination space. The vectors starting from the centre of the diagram represent the environmental factors. According to Figure 7 negative correlation between individual environmental variables is present between moisture, N and OM; and positive correlation is found between K and pH. While lengths of environmental condition arrows are quite similar, this indicates that they have quite similar importance with regard to samples and species. Species points and arrows jointly reflected species distribution on each environmental variable. Since each sample point lies at the centroid of the species occurring at the site, Figure 7 indicates which species are likely to be presented at any of the given sites. *Histeridae* species (His_sp) occurred only in site Lõpe and carabid species *Panagaeus crux-major* (Pa_cru) and *Isopoda* (Iso_sp) were collected only in site Suitsu 3.

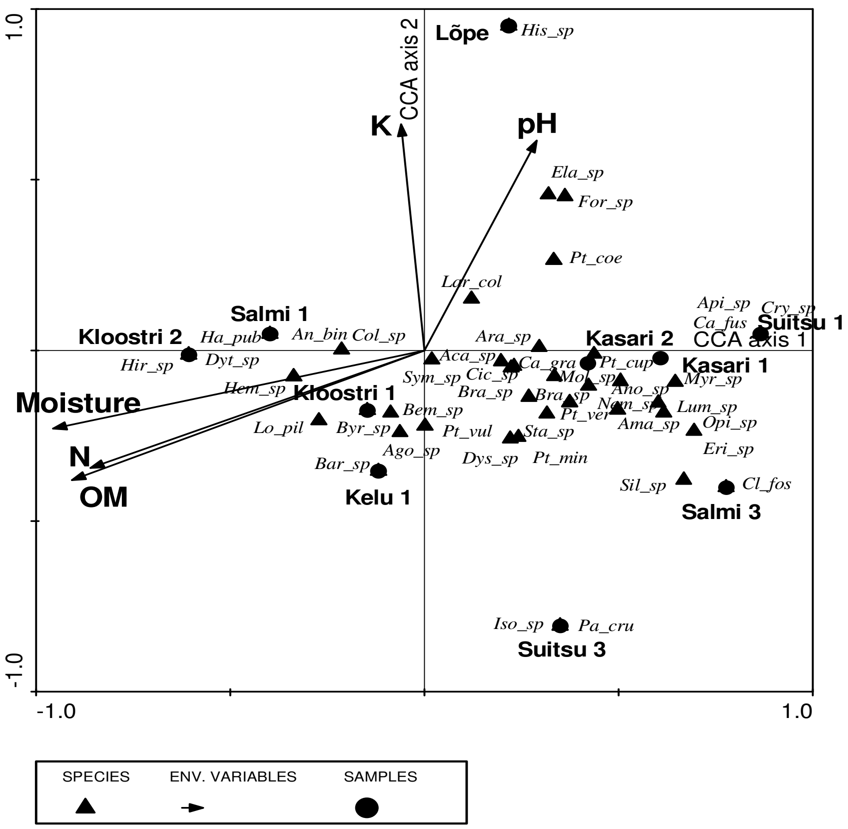

Figure 7. In the CCA triplot, the triangles represent species, circles represent samples and lines represent environmental condition. Abbreviations: pH- acidity of soil, OM- organic matter (%), N- nitrogen (%), K- potassium (g/100g dry soil). Eigenvalues of the first two axes are 0.418 and 0.114; the sum of all canonical eigenvalues is 0.690

Table 10 presents data from six sample areas in 2006 in Matsalu. The Shannon's diversity index was the highest in Kasari 1 sample area (2.264) and the lowest in Kloostri 1 and Kelu areas (1.682). Sample area Suitsu 1 has the highest number of species (31) and it was lowest in Kloostri 2 (18).

Table 10. Species number (S), Evenness (E), Shannon´s (H) and Simpson (D) diversity index of epigeal fauna in different flooded meadows in Matsalu 2006

Name	**S**	**E**	**H**	**D`**
Kloostri 1	26	0.516	1.682	0.6786
Kloostri 2	18	0.708	2.048	0.8384
Kelu	24	0.529	1.682	0.7372
Kasari 1	31	0.659	2.264	0.8594
Suitsu 1	22	0.732	2.261	0.8620
Suitsu 2	25	0.685	2.203	0.8524

Figure 8 shows the results of a Principal Correspondence Analysis (PCA) in 2006 in Matsalu. The PCA ordination axes 1 and 2 accounted for 62.9 and (together) 95.5% of variance in the species data, respectively. The distance between sample point symbols in the diagram approximates the dissimilarity of their species composition measured by their Euclidean distance. Species composition dissimilarity is quite similar between sites Suitsu 1, Suitsu 2, Kasari 1and Kloostri 2. Each species arrows points in the direction of steepest increase of values for the corresponding species. In 2006 more positive values has *Collembola* (Col_sp), *Staphylinidae* (Sta_sp), *Amara aenea* (Am_aen), *Notaris scripi* (No_scr), *Clivina fossor* (Cl_fos) and *Pterostichus coerulescens* (Pt_coe).

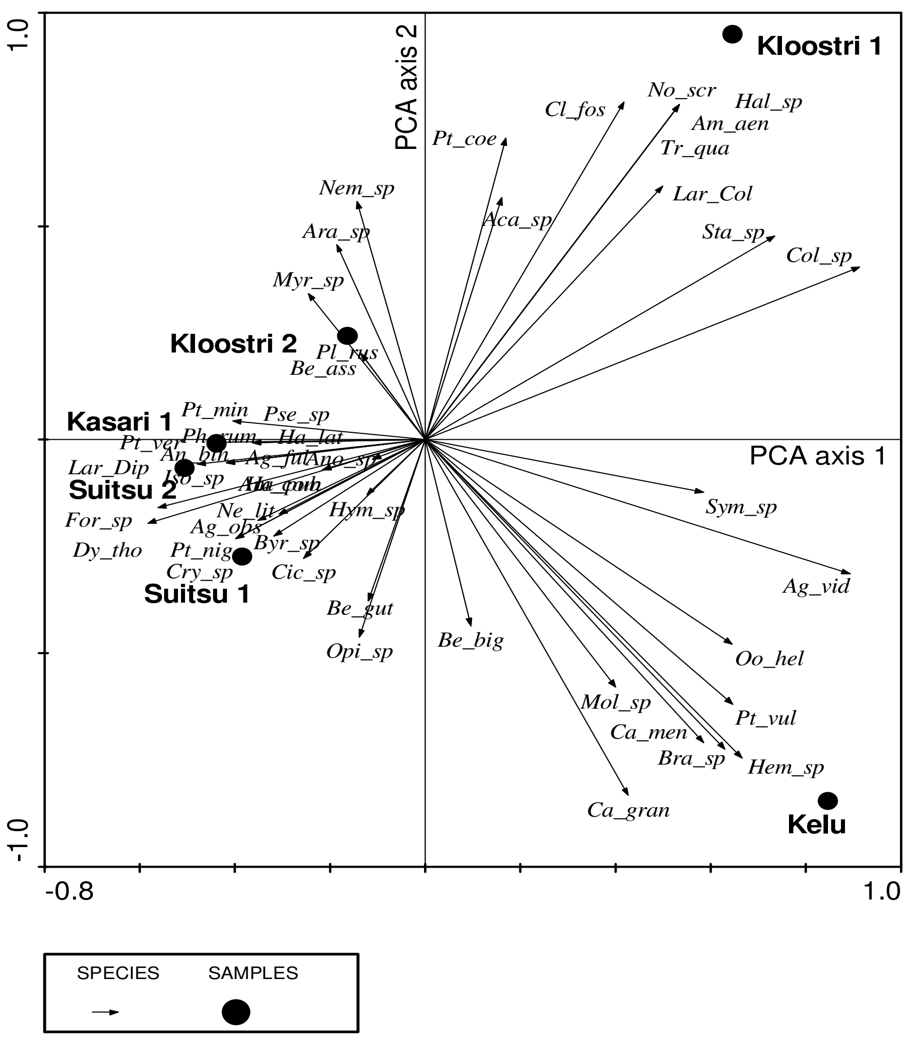

Figure 8. Ordination biplots based on Principal Components Analysis (PCA) of invertebrates species in 2006 Matsalu. Eigenvalues of the first two axes are 0.629 and 0.326.

5. DISCUSSION

5.1. Soil biota communities on arable lands in Estonia

5.1.1. Abundance and diversity of earthworm communities on arable lands

Arable land forms approximately a quarter of Estonian territory. Calcaric Regosols forms 9.0% of Estonian arable land, Calcaric Cambisols form 9.7% of arable land and Stagnic Luvisols forms 15.1% of arable land (Kõlli, Lemetti, 1999). Calcaric Regosols are characterised by high humus and nutrient content, but they are sensitive to drought. The biological activity is higher only when the soil is not dried off and soil moisture is sufficient. Calcaric Cambisols are most productive agricultural soils in Estonia; water regime is more stable during vegetation period and the activity of soil biota is high. Stagnic Luvisols soils are characterised by low humus content and relatively high acidity of soil, because of such conditions their biological activity is lower (ESTONICA, 2006). Due to some agricultural activities (liming, organic fertilizing) the abundance of earthworms may be higher (Kõlli, Lemetti, 1999).

Earthworms are the most important invertebrates decomposing organic matter in the soil and at the same time connected to the processes taking place in the ecosystem. There is a reciprocal connection between earthworm community and the soil environment; this is based on several characteristics of earthworm community (Kühle, 1983; Ivask *et al*, 2000):

1. they are in the first place in soil fauna for biomass, respiration intensity and ability to improve the structure of the soil;
2. they form a huge burrow system (4…9000 km of burrow in 1 ha of grassland soil) in the pedosphere which is very important habitat for other biota in soil;
3. earthworms play a determining role in the decomposition of organic matter (remains of plants etc);
4. earthworms are also important food web component in the food chain.

Thirteen earthworm species have been identified in Estonia (Timm, 1999), including species from the genera *Lumbricus, Allolobophora*, *Aporrectodea, Dendrobaena, Dendrodrilus, Eisenia, Octolasion* and *Eiseniella* with different tolerance to ecological factors and agricultural management. The specific composition of an earthworm community is a good indicator of agricultural practice intensity in the field. The species that is the most tolerant to agricultural practice - *Aporrectodea caliginosa* - was found in all studied fields (except for one with very special conditions), dominance of this species in field soil communities is characteristic for Estonian soils. The endogeic species *Aporrectodea rosea* is also ecologically tolerant and common in field soils having lower abundance and biomass. The epigeic species *Lumbricus rubellus*, presented in 50% of fields, is also tolerate, but more affected by tillage and agrochemicals. Anecic species like *Lumbricus terrestris*, *Aporrectodea longa* and endogeic *Allolobophora chlorotica* are more sensitive to agricultural activities (Paper I and III).

Several scientists have proposed that the presence or absence of earthworm species can be used as bioindicators for the soil type and characteristics (Kühle, 1983; Paoletti *et al*, 1991), although many attempts to judge the situation in soils based on earthworms have been unsuccessful. The reason for this may be that ecological factors such as moisture capacity, pH, organic matter content, etc., are not always directly linked to soil type (Edwards, Bohlen, 1996). Comparing these three soil types studied by us, the highest abundance of earthworms was in Stagnic Luvisols (Table 4). According to Kõlli and Lemetti (1999) this soil type has more unfavourable conditions for soil biota (medium humus, high acidity, low biological activity) consequently the highest abundance of earthworms follows from precipitation. According to the data of National Environmental Monitoring Program, the year 2003 was considerably more arid than 2004 (Keskkonnaülevaade, 2005). The regional differences were also observed: North-East and South Estonia had more precipitation whereas less precipitation fell down in West Estonia in studied years (Figure 1). Probably the uneven distribution of precipitation in 2003-2004 was the reason for highest abundance of earthworms in the South and East of Estonia where Stagnic Luvisols are mostly distributed.

Calcaric Cambisols are distributed mostly in Central Estonia and have higher activity of soil biota (Kõlli, Lemetti, 1999). The soil moisture was optimal for earthworms in 2003-2004 (Table 3). Calcaric Regosols were mostly distributed in West and North of Estonia where the precipitation and the mean abundance of earthworm communities was the lowest. When comparing the data from Table 5 we found that evenness, Shannon's and Simpson diversity index of earthworms in fields with different soil type's was also highest in Calcaric Cambisols (Paper III), where the soil conditions were more suitable and stable, in comparison to other soil types.

The cropping has considerable impact on the number of earthworms in arable land. One of the crucial factors affecting the influence of cropping on earthworm populations is the proportion of the plant material that is returned to the soil after harvest. According to literature, cereals encourage the build-up of earthworm population much more than growing crops like legumes, while cereals leave considerable residues to soil. Clover is particularly beneficial to the build-up of earthworm population because of the absence of tillage and high protein content of the residue of this plant (Edwards, Bohlen, 1996). Plants may also influence earthworm populations through their seeds, which may be preferentially ingested (Brussaard, 1999). We did not make conclusions about influence of cropping on communities of earthworms because of low number of fields of perennial grass and oilseed studied.

5.1.2. Abundance and diversity of epifauna communities on arable lands

Arthropods constituting epigeic fauna are frequently used as ecological indicators because they represent >80% of global species richness (Work *et al*, 2002). Coleoptera are important in terms of agroecological research because of their role as biological control agents (Melnychuk *et al*, 2003).

Conditions of field habitats for epigeic invertebrates are formed by soil characteristics, agricultural practice and climate. Invertebrates living on the soil surface are in continous contact with the soil. Carabids are the predatory group of soil biota important for the agriculture. Diversity of carabids is formed by conditions of field' habitat (microclimate, soil type, hydrogeology, topography) and agricultural practice (cultivated crop, crop rotation, intensity of tillage, fertilizers, agrochemicals) as well as by characteristics of surrounding areas and field edges (Kromp, 1999). The total number of carabids in cultivated fields commonly ranges from 5 to 50 individuals per square meter (Ekschmitt *et al*, 1997).

Despite the regular disturbance by cultivation measures, arable land harbours a typical carabid fauna. The negative effects of tillage on carabid populations are less pronounced on sandy soil then on loamy soils, because the crushing forces exerted on the animals are smaller in loose sandy soil then in loamy soil. Larger carabid species more then smaller can be vulnerable to soil cultivation (Ekschmitt *et al*, 1997). Species are classified as habitat generalists or soft edge species, habitat specialists or hard edge species and as edge species (French, Elliott, 1999). Several studies showed that *P. vulgaris* avoids bare areas because of this microclimate constraint (Fournier, Loreau, 2001). In Estonia, 8 species of carabids are frequent and characteristic, additionally 31 species are common on fields. The most common and important genus of carabids on agricultural lands are *Carabus*, *Pterostichus*, *Harpalus* and *Amara*, they are most abundant in the habitats with low intensity of agricultural practice and suitable for concealment and feeding (Ekschmitt *et al*, 1997; Võõbus *et al*, 2005). According to Lövei & Sunderland (1996), ground beetles have been used as indicators for several assessments like assessments of environmental pollution or habitat classification for nature protection. Agriculture profoundly influences the composition, abundance and spatial distribution of ground beetles through the use of agrochemicals, changes in habitat structure from cultivation methods and crop type (Lövei, Sunderland, 1996).

Soil texture may be of critical importance for ground-beetles. Many species obviously prefer fields with clay soil to those with sandy soil. The greater abundance on clay soil is probably due to a combined effect of higher moisture content, denser vegetation cover and higher productivity of organic substances which ensure a better food supply (Ekschmitt *et al*, 1997). Changes in temperature, light intensity and humidity also influence the activity of ground beetles (Lövei, Sunderland, 1996). Three different types of soils studied by us had different texture, but all of them were characterized by rather high humus content, moisture condition and productivity and did not differ by conditions for carabids.

Agricultural systems are complex and there are many factors that influence the abundance of ground beetles. In July, total N and organic matter contents had higher environmental values; the species had strong correlationwith the conditions and with other species (Figure 2-3). In September, the species were more dispersed; probably they are more affected by other conditions predominant autumn. Plants affect soil biota directly by generating inputs of organic matter above and below ground surface and indirectly by physical effects of shading, soil protection and water and nutrient uptake by roots (Neher, Barbercheck, 1999). Population density of carabids encountered in root crops has generally been lower than in cereals. Autumn breeders are often more frequent among root crops and spring breeders are associated with cereals (Ekschmitt *et al*, 1997). In current research ground beetles did not show significant preference for crops, it is likely that the abundance of ground beetles in agricultural landscapes depends on several other factors.

Pitfall-traps are commonly used for collecting ground beetles. Data from pitfall samples can be used to describe annual activity patterns, spatial distributions, habitat associations, relative abundances of species and other ecological aspects of epigaeic populations and communities (Digweed *et al*, 1995). In our study the abundance of ground beetles did not show significant preferences for soil types, crops and field and field edges, but some methodological problems occur here. Collecting rates of pitfall trapping may be subject to a variety of factors including trap size, habitat structure, temperature, daily and seasonal activity patterns. The pitfall method for collecting arthropods is used to measure activity rather then density. From a monitoring perspective, decisions about trapping methods, different traps sizes, should precede the design of monitoring and estimating biodiversity.

5.2. Soil biota communities on flooded meadow in Matsalu National Park

5.2.1. Abundance and diversity of earthworm communities on flooded meadows

Floodplain meadows are periodically flooded semi-natural communities situated on riverbanks. The largest area of flooded meadows in Western Estonia is found in the river basin of the Kasari River. The nutrients carried there by floods are very important because they cause higher soil nutrient level. The quantity of sediment, its physical and chemical properties as well as flood duration represents the main factors that determine the soil and vegetation types on floodplains (Truus, Tõnisson, 1998). Total abundance of earthworms and number of species are low and mostly depends on flooding conditions. The species commonly found in all habitats, such as *Aporrectodea caliginosa* and *Lumbricus rubellus,* are absent in some years because of long flood period. Anecic species *L. terrestris* and *A. longa* are missing every year because of high groundwater level. Semi-aquatic species or species that prefer high soil moisture are present in the soil of flooded meadows (Paper II, IV).

Moderately moist floodplain (fresh) meadows represent a more suitable habitat for earthworms because of better soil aeration and shorter flooding period. Transient grasslands are flooded by fresh and by saline water. These meadows have soil characteristics (pH, moisture, organic matter content, total N) similar to those of fresh floodplain meadows. These grasslands are situated between two different water bodies (fresh and saline) and obviously marine water has certain impact on the specific structure of earthworm community: earthworm communities are less abundant, but more diverse (Paper II, IV).

Coastal meadows are characterised by very low abundance of earthworms (6.0 ± 5.0) and very low diversity of species (only two endogeic species) because saline water acts as a strong limiting factor. This type of grassland is not suitable for earthworms, over-flooding and high contents of K^+ and Na^+ ions in soil, especially in floor layer, set strict limits for earthworms (Paper II, IV).

5.2.2. Abundance and diversity of epifauna communities on flooded meadows

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. Wetlands are cradles of biological diversity, providing water and primary productivity which provides basis for the survival of countless species of plants and animals. They support high concentrations of birds, mammals, reptiles, amphibians, fish and invertebrate species (PKÜ, 2006). The number of published result of studies on wetland insect communities has grown steadily since the mid 1980s but data of insect's communities in Estonian wetlands are still incomplete. Natural and semi-natural floodplains contain a high biodiversity of both plant and animal species and have important functions for the water and nutrient budget of riverine landscapes (Rothenbücher, Schaefer, 2006). Many wetlands dry off seasonally or unpredictably, invertebrates that thrive in these habitats exhibit have to cope with a more or less regular cycle of wet and dry condition (Batzer, Wissinger, 1996; Rothenbücher, Schaefer, 2006). In general, two types of adaptations can be distinguished: migration activity before and after the flooding period and submersion tolerance (Rothenbücher, Schaefer, 2006).

According to our results the number of epigeal fauna varied during all three years of the study (2004-2006). In 2004 two distinct types of areas were observed: wet floodplain grasslands (Kloostri 1 and Kloostri 2) and transient grasslands (Suitsu 1 and Suitsu 3). In 2005 dissimilarity between sites, species and environmental conditions was quite homogenous. Moisture, nitrogen and organic matter had negative effect to species abundance and transient grasslands with two sites were separated (Lõpe and Suitsu 3). In 2006 the study areas were divided in three groups, Kloostri 1 and Kelu, clearly separated from others, both being wet floodplain grasslands. There are many factors that influence the abundance and diversity of soil epigeal fauna of wet meadows. Sample area Suitsu 1 had the highest number of species during the period of the study and sample area Kloostri 2 had the lowest species number in 2005 and 2006. Site Suitsu 1 is transient grassland flooded with saline and fresh water and managed by grazing. This site has several different environmental factors for epigeic fauna (hay, dung, saline and fresh water). The highest Shannon-Wiener diversity index was observed in sites Kasari 1 and Kasari 2 which were fresh floodplain meadows managed by mowing. The list of wet meadows epigeal fauna is one of the most valuable results of this research.

5.3. Relationships between biota, management and function of soils

About third of the Estonia territory (14 331 km^2) forms arable land and agricultural holdings specialize in three types of production: 45% of the farms are engaged in crop production, 21% in dairy farming and 31% in mixed production (crop and livestock). The total area of coastal meadows with higher nature conservation value can be estimated to be 5100 hectares and the total area of floodplain meadows estimated to 12 500 hectares. The existing coastal and floodplain meadows have developed in conditions agriculture being the dominant activity in the region and due to its extensive nature there was considerable shortage of agricultural lands.

Soil is a living and dynamic entity that requires a unique balance between its physical, chemical and biological components in order to remain productive (Gupta, Yeates, 1997). According to literature (Bardgett, 2005), soil can be characterised by vast biodiversity and by functional significance of soil biota for plant communities and ecosystem processes. The study of soil biodiversity and its consequences for ecosystem properties is a relatively new field of ecology. The macrofauna is a significant component of soil ecosystems and their food webs. Earthworms have been playing a key role in soil ecosystem. There is clear evidence that they can accelerate organic matter decomposition and nutrient release in agroecosystems. They exert a controlling activity through their strong interactions with microorganisms in the decomposition process (Edwards, 2000). Ecosystem engineers directly affect soil physical properties and decomposition, by their digestion and transfer of organic matter and soil (Lavelle *et al*, 1997). Decomposition pathways and rates are determined in the following order: climate, soil characteristics, quality of decomposing resources, currently living macro-organisms and micro-organisms. Invertebrates affect decomposition directly through comminution and digestion and indirectly, by their effects on microbial activities. Some other macroarthropods also participate in both above- and belowground parts of terrestrial ecosystems. Macroarthropods may have a major influence on the microarthropod portion of belowground food webs. *Collembola* are important food items for spiders, thus providing a macro-to-micro connection. Other macroarthropods such as cicades emerging from soil may serve as prey for some vertebrate animals. The millipedes are litter feeding species and have major influences on the decomposition process (Crossley, 2004). Soil macrofauna break dead organic matter into smaller pieces and facilitate decomposition by soil bacteria and fungi that start to mineralization (Barrios, 2007).

Soil biodiversity of agricultural landscapes is influenced by human activities in intensively managed soils (arable lands) as well as in extensively managed semi-natural meadows soil. Agricultural fields are heterogeneous communities depending on soil types, vegetation, climate, agricultural management etc. Agricultural activities such as soil tillage, fertilizers, grazing and mowing affect the soil biota in both group of studied soils. In cultivated soils these activities affect soil communities mechanically (rearranging soil particles) or chemically (by fertilizing and agrochemicals), the soil biological diversity of semi-natural areas is more influenced by the continuity of extensive management (mowing, grazing), soil characteristics (reduced fertility) and overflooding type and flood duration.

There are different reasons for variability of biodiversity in differently managed and used soils. By the comparison of three most widespread in Estonia types of field soil (Calcaric Regosols, Calcaric Cambisols and Stagnic Luvisols) we concluded that soil biota communities differ by the abundance and diversity of soil invertebrates depending on habitat conditions, precipitation and intensity of agricultural activities. Ecological and specific structure of a field community is based on higher abundance of ecologically tolerant species in a community supporting the assertion that intensification of land-use cause's reduction of soil biodiversity and extinction of epigeic and anecic earthworms that feed on plant residues. Abundance and diversity of epigeic invertebrates is influenced by environmental conditions (connected to soil texture factors like moisture, organic matter content and pH) and by intensity of agricultural practice (tillage, using of fertilizers and agrochemicals). Diversity of ground beetles is formed by conditions of field habitat (microclimate, soil type, hydrogeology) and agricultural practice (cultivated crop, intensity of tillage) as well as by characteristics of surrounding areas and field edges.

The extensively managed flooded meadows differ by soil and salinity of flood and duration of flooding. Flooding of soil by fresh water is a limiting factor for earthworm abundance and diversity except for semi-aquatic species, flooding of soil by saline water is strong limiting factor for all earthworm species. The influence of extensive agricultural activities (mowing or grazing) on soil communities is not a limiting factor; traditional agricultural methods rather preserve soil communities.

Lists of soil invertebrate species of cultivated and semi-natural lands are the valuable result of current research. Species in the lists are adapted to habitat conditions. Characteristic for arable soils species are more tolerant to human activities, species characteristic for semi-natural meadow soils are tolerant to temporary overflooding and high soil moisture but sensitive to intensive agricultural activities like tillage.

Soil biodiversity and adaptation of soil biota to habitat conditions is important for agriculture but besides this soil also performs five essential functions: regulating water, sustaining plant and animal life, filtering potential pollutants, cycling nutrients and supporting structures. Term "soil quality" means the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil biota plays a major role in soil quality (Tugel *et al*, 2000). To preserve soil fertility we need environmental friendly agricultural management. Field borders may benefit ground beetle populations by providing refuge from agricultural practices such tillage and pesticide use and a stable microhabitat for overwintering. To protect our semi-natural meadows, continuity of extensive agricultural activities like grazing and mowing are essential. The role of the farming community is crucial to the maintenance of Matsalu National Park biodiversity. As area of potentially threatened wet meadows of European importance, Matsalu National Park requires a full inventory of their soil biodiversity and the factors affecting it. Studies of temporal and spatial variability in soil invertebrate communities are of priority importance.

The purpose of researching and assessing soil quality is to protect and improve long-term agricultural activities, water quality, and habitats of all organisms including people. The results and conclusions of current research are with innovative importance for achieving these purposes.

CONCLUSION

- The list of epigeal fauna in arable land soils and flooded semi-natural soils is one of the most valuable results of this research.

- By the comparison of biodiversity of three types of field soil we concluded that diversity of earthworms was the highest in Calcaric Cambisols. Periodical drying-off of Calcaric Regosols is limiting factor for sensitive to soil moisture species of earthworm. Stagnic Luvisols were characterized by the highest abundance of earthworms and the highest diversity of ground beetle species.

- The most abundant earthworm species on flooded grasslands are semi-aquatic Octalasium lacteum and Eiseniella tetraedra as well as Aporrectodea caliginosa which is tolerant of unfavorable ecological conditions. Results of studied three years (2004-2006) varied in numbers of epigeal fauna.

- Soil biota communities in three most widespread field soil types in Estonia (Calcaric Regosols, Calcaric Cambisols and Stagnic Luvisols) are influenced by environmental conditions, the factors connected to soil texture including moisture, organic matter content and pH being the most essential.

- Flooding by fresh water is a positive factor for semi-aquatic earthworms and negative for all others. The salinity of flooding sea water is an additional negative factor for all species of earthworms. Many factors influence abundance and diversity of soil epigeal fauna of wet meadows wherefrom moisture, nitrogen and organic matter had negative effect to species of epigeic abundance.

- The specific composition of earthworm community indicates the intensity of agricultural activity. The occurence in field soils of species only like *Aporrectodea caliginosa*, *Aporrectodea rosea*, *Lumbricus rubellus* tolerant to disturbance is the result of intensive tillage and agricultural practice. A community including more sensitive species indicates more favorable agricultural or ecological conditions of habitat. There are many factors that influence epigeal fauna because of complexity of agricultural ecosystems.

- The main difference in specific composition of ground beetles community is related to location of traps in the field. The most common and important genus of carabids on agricultural lands are *Carabus*, *Pterostichus*, *Harpalus* and *Amara*. Soil crop had no statistically significant impact on distribution of earthworm and carabid species among studied fields.

- The soil conditions on extensively managed flooded meadows differ due by soil and salinity of flood and duration of flooding. The influence of extensive agricultural activities (mowing or grazing) on soil communities is not a limiting factor; traditional agricultural methods rather preserve soil communities.

SUMMARY

Soil organisms are an integral part of soil ecosystems, especially in food chain and decomposition process. The aim of this thesis is to examine the specific composition of earthworm and epigeal fauna communities, their diversity and distribution in soil; to evaluate the abundance and diversity of soil biota in different types of agricultural landscapes (fields, wet meadows) in Estonia; to evaluate the influence of environmental factors on soil communities; to analyze the impact of agricultural activities (cultivation, crop husbandry, extensive management of grasslands) on communities of soil biota

All over Estonia arable lands and wet meadows out of all agricultural landscapes were selected to study soil biodiversity. Intensively managed cultivated lands and extensively managed semi-natural flooded grasslands were selected as sample areas. Soil communities were studied on twenty four study areas of three most widespread soil types (Calcaric Regosols forms 9.0%, Calcaric Cambisols forms 9.7% and Stagnic Luvisols forms 15.1% of arable land in Estonia). The largest flooded meadows of western Estonia belong to the river basin of the Kasari; thirtheen study areas in Matsalu National Park (West-Estonia) were selected to estimate soil biota, including floodplain meadows (mown annually), coastal meadows (grazed with low intensity) and transient grasslands (mown annually or grazed).

Calcaric Regosols are characterised by a higher humus and nutrient content but this type of soil is sensitive to drought. The biological activity is high only when the soil is not dried off and soil moisture is sufficient. The diversity of earthworm community was the higest in Calcaric Cambisols which are the most productive agricultural soils in Estonia; water regime is more stable during vegetation period and the activity of soil biota is high. The third type of soil, Stagnic Luvisols, are characterised by low humus content and relatively high acidity of soil and their biological activity is lower because of conditions. In our study the abundance of earthworm was the highest because of higher precipitation in the region. For epigeic invertebrates the conditions of field habitats are formed by soil characteristics, agricultural practice and climate. Invertebrates living on the soil surface are in continous contact with the soil. The negative effects of tillage on carabid populations are less pronounced on sandy soil then on loamy soils.

Semi-natural landscapes are rapidly disappearing in Europe due to changes in land use. Species diversity of semi-natural areas is influenced by the continuity of extensive management (mowing, grazing); historical management influences plant species accumulation and soil characteristics. In floodplain meadows the total abundance of

earthworms and number of species were low and depends mostly on flooding conditions. Flooding by fresh water is a positive factor for semi-aquatic earthworms and negative for all others. Anecic species *L. terrestris* and *A. longa* are missed every year because of high groundwater table. Characteristic for coastal meadow are very low abundance and diversity of earthworm and because of saline water what is a strong limiting factor. Flooding by fresh and saline water also is limiting factor to abundance and diversity of earthworms and epigeic fauna.

One of most valuable results of this research is the list of epigeal fauna in arable land soils and flooded semi-natural soils. In order to evaluate changes in soil quality and to relise various combinations of management practices, we must understand and know soil indicators.

Knowledge of soil biota biodiversity and their specific contribution to ecosystem function is still limited. The most promising way to enhance or restore species richness in agricultural landscapes is the environment-friendly management of fields and preservation and conservation of natural and semi-natural habitats.

KOKKUVÕTE

Mullaelustikul on lahutamatu osa mulla ökosüsteemist ning oluline roll toiduahelas kui ka lagunemisprotsessides. Käesoleva doktoritöö eesmärkideks on välja selgitada vihmausside ja epigeilise fauna liigiline koosseis, nende mitmekesisus ja levik põllumajanduslikes muldades; hinnata mullaelustiku arvukust ja mitmekesisust Eesti erinevates põllumajandusmaastikes (haritavad põllud, üleujutatavad rohumaad); hinnata keskkonnafaktorite toimet ja analüüsida põllumajandustegevuste mõju (mullaharimine, põllukultuur, rohumaade ekstensiivne majandamine) mullaelustiku kooslustele.

Kogu Eesti põllumajandusmaast valiti muldade bioloogilise mitmekesisuse hindamiseks põllumaad ja märgalad, neist proovialadeks valiti intensiivselt majandatavad haritavad maad ja ekstensiivselt majandatavad pool-looduslikud üleujutatavad rohumaad. Põllumuldade elustikukoosluste uuringud teostati kahekümne neljal proovialal kolmel enam levinud mullatüübil (rähkmullad, mis moodustavad 9% Eesti haritavast põllumajandusmaast, kahkjad mullad moodustavad 9.7% ja leostunud muldade osakaal on 15.5%). Lääne-Eesti suurimad üleujutatavad rohumaad asuvad Kasari jõe ääres. Matsalu Rahvuspargi (Lääne-Eesti) territooriumil valiti mullaelustiku uuringuteks kolmteist prooviala, valim sisaldab lamminiite, mida kord aastas niidetakse; rannaniite, kus toimub madala intensiivsusega karjatamine, ja üleminekurohumaid, mida niidetakse kord aastas ja/või karjatatakse.

Rähkmuldasi (Calcaric Regosols) iseloomustab kõrge huumuse- ja toitainetesisaldus, kuid antud mullatüüp on põuatundlik. Bioloogiline aktiivsus on kõrge ainult juhul, kui muld ei kuiva läbi ja mullaniiskus on piisav. Vihmaussikoosluse bioloogiline mitmekesisus on kõrgeim leostunud muldades (Calcaric Cambisols), mis on kõige viljakam põllumajanduslik mullatüüp Eestis, kus veerežiim on stabiilne kogu vegetatsiooniperioodi jooksul ja mullaelustiku aktiivsus on kõrge. Kolmandat mullatüüpi, kahkjat mulda (Stagnic Luvisols), iseloomustab madalam huumuse sisaldus ja suhteliselt kõrge mulla happesus. Sellest tingituna võiks bioloogiline aktiivsus antud mullatüübis olla madal, käesoleva töö tulemuste põhjal on vihmausside arvukus kõrgeim. Epigeilised selgrootud elavad mulla pinnal ja on pidevas kontaktis mullaga, kusjuures mullaharimise negatiivne efekt on üldiselt vähem tuntav liivmuldades kui liivsavi muldades. Epigeilise selgrootute elupaigatingimused põldudel kujundatakse mulla parameetrite, põllumajandustegevuste ja kliima poolt.

Pool-looduslikud maastikud on igal pool Euroopas kiiresti kadumas muutuva maakasutuse tõttu. Bioloogilist mitmekesisust mõjutavad pool-looduslikel aladel pidev ekstensiivne majandamine (niitmine, karjatamine). Vihmausside arvukus ja liigiline mitmekesisus on lamminiitudel madalad ja on mõjutatud üleujutuse tingimuste poolt. Üleujutus mageda veega on positiivne faktor pool-veelistele vihmaussiliikidele ja negatiivne kõikidele teistele liikidele. Põhjavee kõrge taseme tõttu puuduvad üleujutatavatel niitudel aneetsilised liigid *L. terrestris* ja *A. longa.* Rannaniite iseloomustab väga madal vihmausside arvukus ja mitmekesisus, tingituna soolase vee mõjust, mis on tugev limiteeriv faktor vihmaussidele. Üleujutus nii mageda kui ka soolase veega on samuti limiteerivaks faktoriks epigeilise fauna arvukusele ja bioloogilisele mitmekesisusele.

Antud uurimustöö üheks oluliseks väärtuseks on põllumuldade ja pool-looduslike maade epigeilise fauna nimekiri. Hindamaks muutusi mulla kvaliteedis ja mõistmaks seoseid, mis lähtuvad erinevatest majandamisviisidest, on oluline tunda mullaelustikukooslusi, nende talitlust ökosüsteemis ning indikaatorliike.

Teadmised mullaelustiku bioloogilisest mitmekesisusest ja selle osast ökosüsteemi funktsioneerimisel on siiani lünklikud. Üks lootustandvamaid võimalusi suurendamaks või taastamaks liikide rohkust põllumajandusmaastikes on põllumaade keskkonnasäästlik majandamine ning pool-looduslike rohumaade säilitamine ja kaitsmine.

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Keel	Tase
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Inglise keel	Kesktase
Saksa keel	Kesktase

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Õppimise aeg	Täiendõppe läbiviija nimetus
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6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2007- praegu	Tallinna Tehnikaülikool, Tartu Kolledž	Lektor/ Teadur

2001-2004	Eesti Põllumajandusülikool, Keskkonnakaitse Instituut	Insener
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7. Teadustegevus

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- M.Sc. teema "Põllumuldade elustik ja seda mõjutavad tegurid"
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Mullaelustik, keskkonnakaitse

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Estonian Agricultural University	2003	environmental protection/ M.Sc,
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4. Language competence/skills (fluent, average, basic skills)

Language	Level
Estonian	Fluent
English	Average
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5. Special Course

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2007- present	Tallinn University of Technology, Tartu College	Lector/ Researcher

2001-2004	Estonian Agricultural University Environmental Protection Institute	Engineer
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7. Scientific work

Since 2002. Estonian Academic Agricultural Society. Young member

8. Defended thesis

- M.Sc thesis: „The factors affecting field soil biota"

- B.Sc. thesis "Temporal and species structure and diversity of soil biota in conventional and ecological farms".

9. Main areas of scientific work/ Current research topics

Soil biota, environmental protection

10. Other research projects

- Diversity and function of soil biota of seminatural communities, ETF 6739

Appendix 1.

Table 1. The relative abundance of epigeic fauna (number of individuals per trap) in 2003. CR= Calcaric Regosols, CC= Calcaric Cambisols, SL= Stagnic Luvisols

	CR N=8		CC N=8		SL N=8	
	July					
	field	edge	field	edge	field	edge
Aranei	5.9±1.1	5.4±1.0	3.7±0.7	3.5±0.7	2.3±0.5	10.1±5.5
Opiliones	4.5±0.8	14.1±3.5	2.5±0.7	8.3±2.9	0.9±0.3	5.3±1.8
Coleoptera Only: Carabidae	26.2±1.8 16.7±1.8	28.0±1.1 16.4±3.8	8.6±1.0 7.4±1.0	21.9±7.2 19.8±7.4	12.0±0.9 7.7±0.9	15.9±1.7 10.3±1.7
Heteroptera	1.4±0.4	2.5±0.6	0.2±0.1	2.0±0.8	0.2±0.1	1.1±0.6
Hymenoptera	5.4±1.1	42.2±1.2	2.6±0.4	20.9±4.6	20.0±13.0	72.3±32.0
Diptera	4.9±0.3	6.9±1.3	1.4±0.4	3.3±0.7	3.5±0.3	4.2±0.6
Acarina	1.1±0.4	1.8±0.6	0.3±0.1	0.6±0.2	0.5±0.2	0.5±0.2
Collembola	3.7±1.1	3.2±1.1	4.5±1.5	3.9±0.9	2.3±0.4	7.1±2.1
Isopoda	0.5±0.2	8.6±4.4	0.8±0.7	0.6±0.3	0.2±0.1	3.5±2.4
Myriapoda	0.4±0.1	1.0±0.4	0.1±0.0	0.4±0.2	0.2±0.1	0.2±0.1
Total N of individuals per traps	54.5±4.3	115.0±25.5	24.8±3.1	66.9±11.6	42.7±9.0	120.8±33.2
	September					
Aranei	1.7±0.3	2.0±1.0	1.5±0.2	1.5±1.0	2.5±0.4	2.1±0.3
Opiliones	0.1±0.1	6.4±1.7	0.5±0.2	7.0±2.6	2.5±0.5	13.4±4.9
Coleoptera Only: Carabidae	4.4±2.0 2.6±0.5	5.0±0.4 2.4±1.4	2.2±0.5 1.8±0.6	5.5±2.7 4.3±1.6	12.0±1.7 10.5±1.9	13.0±2.2 10.2±2.4
Heteroptera	0.5±0.4	0.2±0.2	0.0±0.0	1.3±0.3	0.3±0.1	0.6±0.2
Hymenoptera	0.0±0.0	0.6±0.4	0.0±0.0	1.5±0.4	5.5±1.2	37.6±11.8

	CR N=8		CC N=8		SL N=8	
	September					
	field	edge	field	edge	field	edge
Diptera	1.3±0.2	1.0±0.2	0.5±0.3	2.0±0.6	3.4±0.3	2.6±0.4
Acarina	0.5±0.4	0.6±0.2	0.1±0.1	1.0±0.6	0.8±0.4	1.3±0.5
Collembola	1.5±0.6	2.4±1.4	0.8±0.4	6.3±3.5	17.7±4.6	19.1±3.5
Isopoda	0.5±0.2	5.0±3.1	0.0±0.0	0.8±0.8	0.9±0.4	3.0±1.7
Myriapoda	0.4±0.2	1.6±0.7	0.1±0.1	0.8±0.8	0.6±0.2	3.7±2.2
Total N of individuals per traps	11.4±1.8	25.8±5.0	5.7±2.3	28.8±6.2	46.9±18.0	99.0±34.9

Table 2. The relative abundance of epigeic fauna (number of individuals per trap) in 2004. CR= Calcaric Regosols, CC= Calcaric Cambisols, SL= Stagnic Luvisols

	CR N=8		CC N=8		SL N=8	
	July					
	field	edge	field	edge	field	edge
Aranei	7.6±3.5	10.9±4.0	2.9±0.5	3.5±1.4	3.2±0.6	2.6±0.5
Opiliones	0.6±0.3	3.7±1.6	0.4±0.3	3.1±1.2	0.3±0.2	3.6±1.6
Coleoptera Only: Carabidae	34.8±6.3 12.8±1.6	43.6±9.9 14.1±4.0	24.8±2.6 14.2±1.3	29.6±6.1 19.1±5.2	24.2±1.6 13.1±1.2	27.7±5.1 9.4±2.4
Heteroptera	0.2±0.1	0.6±0.3	0.0±0.0	0.3±0.3	0.2±0.1	0.1±0.1
Hymenoptera	2.9±0.8	35.8±12.9	1.5±1.5	49.6±32.4	0.7±0.4	34.1±15.9
Diptera	5.4±1.2	4.2±0.7	2.8±0.4	4.6±1.6	8.2±1.7	4.9±0.7
Acarina	1.6±0.4	3.3±1.5	0.9±0.2	1.3±0.3	1.4±0.3	1.9±0.5
Collembola	22.8±4.2	38.0±10.6	31.4±9.2	20.5±6.7	54.0±9.6	44.7±14.2
Isopoda	0.8±0.2	14.8±5.8	2.6±1.7	45.3±38.2	0.1±0.1	9.3±2.1
Myriapoda	3.0±0.8	6.8±3.6	0.5±0.2	1.0±0.5	0.9±0.3	2.8±0.8
Total N of individuals per traps	82.8±10.3	167.8±6.2	73.2±12.6	174.9±80.0	98.4±11.6	142.7±22.0
	September					
Aranei	1.8±0.3	2.2±0.8	2.7±0.6	1.7±0.6	1.8±0.2	1.7±0.4
Opiliones	1.4±0.4	1.4±0.6	2.7±1.0	10.0±7.9	1.7±0.5	13.0±5.5
Coleoptera Only: Carabidae	15.7±3.9 9.9±2.1	14.0±3.3 5.3±1.2	13.6±1.7 10.0±1.4	21.9±8.6 13.0±5.7	20.0±1.5 14.3±1.2	19.0±2.5 7.9±1.8
Heteroptera	0.1±0.1	0.3±0.2	0.1±0.1	0.1±0.1	0.0±0.0	0.1±0.1
Hymenoptera	1.4±1.0	15.6±11.1	0.3±0.1	12.0±4.9	0.2±0.1	18.2±9.1

	CR N=8		CC N=8		SL N=8	
	September					
	field	edge	field	edge	field	edge
Diptera	1.4±0.4	1.4±0.6	1.8±0.6	1.9±0.7	3.5±0.5	4.0±0.7
Acarina	2.6±1.1	3.0±1.1	1.5±0.4	4.4±2.8	1.6±0.3	1.1±0.3
Collembola	5.5±1.1	5.8±1.8	2.8±0.8	7.1±3.4	18.7±2.4	23.5±5.3
Isopoda	2.5±0.8	14.6±6.3	0.6±0.2	3.7±1.5	1.5±0.5	15.9±9.6
Myriapoda	1.1±0.3	2.6±0.9	0.7±0.3	1.0±0.7	0.6±0.2	2.9±1.0
Total N of individuals per traps	35.0±5.3	64.6±19.4	28.2±3.1	67.7±21.4	52.4±3.1	109.1±15.0

Appendix 3

Table 3. List of the name of species and abbreviations on agricultural landscapes in 2004-2005

Aranei sp	Ara_sp
Opiliones sp	Opi_sp
Carabus granulatus	Ca_gra
Carabus cancellatus	Ca_can
Carabus hortensis	Ca_hor
Harpalus pubescens	Ha_pub
Harpalus aeneus	Ha_aen
Pterostichus vulgaris	Pt_vul
Pterostichus niger	Pt_nig
Pterostichus vernalis	Pt_ver
Pterostichus cupreus	Pt_cup
Pterostichus coerulescens	Pt_coe
Calathus melanocephalus	Ca_mel
Bembidion sp	Bem_sp
Amara sp	Ama_sp
Agonum sp	Ago_sp
Cantharis	Ca_pel
Broscus cephalotes	Br_cep
Clivina fossor	Cl_fos
Notiophilus sp	Not_sp
Tytthaspis sedecimpunctata	Ty_sed
Coccinella septempunctata	Co_sep
Coccinella quinquepunctata	Co_qui
Notoxus monoceros	No_mon
Halticinae sp	Hal_sp

Elateridae sp	Ela_sp
Histeridae sp	His_sp
Silphidae sp	Sil_sp
Cryptophagidae sp	Cry_sp
Staphylinidae sp	Sta_sp
Curculionidae sp	Cur_sp
Apioninae sp	Api_sp
Acarina sp	Aca_sp
Hemiptera sp	Hem_sp
Formicidae sp	For_sp
Brachycera sp	Bra_sp
Nematocera sp	Nem_sp
Collembola sp	Col_sp
Symphypleona sp	Sym_sp
Myriapoda sp	Myr_sp
Dermaptera sp	Der_sp
Orthoptera sp	Ort_sp
Isopoda sp	Iso_sp
Mollusca sp	Mol_sp
Larvae (Coleoptera sp)	Lar_col
Anoplura sp	Ano_sp
Lumbricidae sp	Lum_sp
Aculeata sp	Acu_sp
Cicadinea sp	Cic_sp

Appendix 4

Table 4. List of name of species and abbreviations on wet meadows in 2004-2005

Aranei sp	Ara_sp	*Halticinae sp*	Hal_sp
Opiliones sp	Opi_sp	*Elateridae sp*	Ela_sp
Blethisa multipunctata	Bl_mul	*Staphylinidae sp*	Sta_sp
Carabus granulatus	Ca_gra	*Cryptophagidae sp*	Cry_sp
Oodes helopioides	Oo_hel	*Apioninae sp*	Api_sp
Chlaenius nitidulus	Ch_nit	*Dytiscidae sp*	Dyt_sp
Panagaeus crux-major	Pa_cru	*Baridinae sp*	Bar_sp
Anisodactylus binotatus	An_bin	*Brachyderinae sp*	Bra_sp
Amara sp	Ama_sp	*Erirrhinae sp*	Eri_sp
Harpalus pubescens	Ha_pub	*Chtysomelinae sp*	Cht_sp
Harpalus aeneus	Ha_aen	*Acarina sp*	Aca_sp
Pterostichus vulgaris	Pt_vul	*Hemiptera sp*	Hem_sp
Pterostichus cupreus	Pt_cup	*Formicidae sp*	For_sp
Pterostichus coerulescens	Pt_coe	*Brachycera sp*	Bra_sp
Pterostichus minor	Pt_min	*Nematocera sp*	Nem_sp
Pterostichus vernalis	Pt_ver	*Collembola sp*	Col_sp
Calathus fuscipes	Ca_fus	*Symphypleona sp*	Sym_sp
Bembidion sp	Bem_sp	*Myriapoda sp*	Myr_sp
Agonum sp	Ago_sp	*Isopoda sp*	Iso_sp
Lorocera pilicornis	Lo_pil	*Mollusca sp*	Mol_sp
Clivina fossor	Cl_fos	*Lumbricidae sp*	Lum_sp
Dyschirius sp	Dys_sp	*Cicadinea sp*	Cic_sp
Silphidae sp	Sil_sp	*Larvae (Coleoptera sp)*	Lar_col
Histeridae sp	His_sp	*Hirudinea sp*	Hir_sp
Byrrhidae sp	Byr_sp	*Anoplura sp*	Ano_sp

Table 5. List of name of species and abbreviations on wet meadows in 2005

Aranei sp	Ara_sp	*Plateumaris rustica*	Pl_rus
Opiliones sp	Opi_sp	*Necrodes littoralis*	Ne_lit
Carabus menetriesi	Ca_men	*Byrrhidae sp*	Byr_sp
Carabus granulatus	Ca_gran	*Halticinae sp*	Hal_sp
Oodes helopioides	Oo_hel	*Agriotes obscurus*	Ag_obs
Anisodactylus binotatus	An_bin	*Staphylinidae sp*	Sta_sp
Amara aenea	Am_aen	*Cryptophagidae sp*	Cry_sp
Amara communis	Am_com	*Phytonomus rumicis*	Ph_rum
Harpalus pubescens	Ha_pub	*Notaris scripi*	No_scr
Harpalus latus	Ha_lat	*Acarina sp*	Aca_sp
Pterostichus niger	Pt_nig	*Hemiptera sp*	Hem_sp
Pterostichus vulgaris	Pt_vul	*Formicidae sp*	For_sp
Pterostichus coerulescens	Pt_coe	*Brachycera sp*	Bra_sp
Pterostichus minor	Pt_min	*Nematocera sp*	Nem_sp
Pterostichus vernalis	Pt_ver	*Hymenoptera sp*	Hym_sp
Bembidion biguttatum	Be_big	*Collembola sp*	Col_sp
Bembidion assimile	Be_ass	*Symphypleona sp*	Sym_sp
Bembidion guttula	Be_gut	*Myriapoda sp*	Myr_sp
Agoonum viduum	Ag_vid	*Isopoda sp*	Iso_sp
Agonom fuliginosum	Ag_ful	*Mollusca sp*	Mol_sp
Trechus quadristriatus	Tr_qua	*Cicadinea sp*	Cic_sp
Clivina fossor	Cl_fos	*Larvae (Coleoptera sp)*	Lar_Col
Dyschirius thoracicus	Dy_tho	*Larvae (Diptera sp)*	Lar_Dip
Pselaphidae sp	Pse_sp	*Anoplura sp*	Ano_sp

Paper I

Ivask M., Kuu A., Sizov E. 2007. Abundance of earthworm species in Estonian arable soils. European Journal of Soil Biology, Vol.43, S39-S42.

Paper II

Ivask M., Truu J., Kuu A., Truu M., Leito A. 2007. Earthworm communities of flooded grasslands in Matsalu, Estonia. European Journal of Soil Biology, Vol.43 (2), p.71-76.

Paper III

Ivask M., Kuu A., Meriste M., Truu J., Truu M., Vaater V. 2008. Invertebrate communities (Annelida and epigeic fauna) in three types of Estonian cultivated soils. European Journal of Soil Biology, x-x (in press)

Paper IV

Ivask M., Ööpik M., Kuu A. 2006. Abundance and diversity of earthworm communities in flooded semi-natural grasslands. In: Soil Zoology; 11th Nordic Soil Zoology Symposium and PhD course, Akureyri, Iceland 28-31 July 2006. Agricultural University of Iceland, Publication No 9, p.90-94

Paper V

Kuu A., Ivask M. 2006. Pterostichus vulgaris (L., 1758) (=melanarius (Illiger, 1798)) and Harpalus pubescens (Müll., 1776) in agricultural fields. In: Soil Zoology; 11th Nordic Soil Zoology Symposium and PhD course, Akureyri, Iceland 28-31 July 2006. Agricultural University of Iceland, Publication No 9, p.94-98.

Available online at www.sciencedirect.com
ScienceDirect
European Journal of Soil Biology 43 (2007) S39−S42
EUROPEAN JOURNAL OF SOIL BIOLOGY
http://www.elsevier.com/locate/ejsobi

Original article

Abundance of earthworm species in Estonian arable soils

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Available online 21 September 2007

Abstract

Specific composition of earthworm community has indicative value for evaluating the impact of agricultural practice on soil. The occurrence of species only like *Aporrectodea caliginosa*, *Aporrectodea* rosea, *Lumbricus rubellus* tolerant to disturbance is the result of intensive tillage and agricultural practice or the influence of strong limiting ecological factor. A community including more sensitive species *Lumbricus terrestris* and *Aporrectodea longa*, or the most sensitive species *Allolobophora chlorotica* and *Lumbricus castaneus*, indicates more favourable conditions of habitat.

Keywords: Earthworms; Species; Bioindication; Hydrolytical activity of microbial community; Organic farming

1. Introduction

Agricultural management practice affects soil biological and physical properties, the habitat of soil organisms and hence soil fauna. The parameters of an earthworm community can indicate a number of soil characteristics such as soil texture, content of organic matter, porosity, acidity, and moisture. Species number and ecological categories are favoured by Paoletti [8] as key indication parameters in agroecosystems. Measures of the size and activity of soil biota, e.g. abundance, diversity and ecological composition of earthworm communities have considerable potential as early indicators of soil degradation or improvement [3].

The aim of the article was to study the abundance and diversity of earthworm communities in arable soils of Estonia and to discuss the use of community characteristics as indicators of the impact of agricultural practice on soil.

2. Materials and methods

Data on earthworm communities was collected from 2003 to 2005 in 58 cereal fields of several soil type and texture, located all over Estonia. Three-year history of agricultural management practice (organic or conventional type of farming) was recorded. Earthworm communities were studied in September and October, on one to three study areas per field depending on diversity of soil type on the field. In all study areas five soil blocks of $50 \times 50 \times 40$ cm were studied by hand sorting method introduced by Meyer [7]. The living earthworms were washed, kept in refrigerator for 48 h, counted; species were identified according to Timm [11]. The mean number of individuals in 1 m^2 of soil surface and standard error (SE) were calculated for each studied field. Soil samples were composed from the soil of all studied plots of the field. In all

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1164-5563/$ - see front matter
doi:10.1016/j.ejsobi.2007.08.006

composite soil samples the texture, moisture content (105 °C), pH (KCl) and organic matter content (in muffle furnace at 360 °C) were determined. Total activity of microbial community was measured using fluorescein diacetate method which estimates the activity of dehydrogenase enzymes in a composite sample [9].

Data analysis was performed using non-parametric statistical methods (dispersion analysis of Kruskall–Wallis, Mann–Whitney *U*-test, Spearman's correlation analysis), programs STATISTICA 7 and Microsoft Excel.

3. Results

Mean abundance of earthworm communities in field soil was 81.4 ± 7.6 individuals m^{-2} (the abundance varied between values 7 and 292 individuals m^{-2}), mean number of species per field was 3.7 ± 0.2 (1–8 species). Mean abundance in 2003 ($n = 10$) was 74.7 ± 13.8 and in 2004 ($n = 34$) 81.9 ± 10.6. In 2005 ($n = 14$) the abundance was 84.9 ± 7.4 individuals m^{-2}.

Table 1 presents the frequency of ecological groups (% of the number of individuals of a group from total abundance). Occurrence of ecological groups was not correlated with the values of soil ecological factors (moisture content varied 12.26–27.51%, pH –4.53–7.32; organic matter content–2.17–7.41%), except for one: no earthworms of epigeic group were found in sandy soils.

Table 2 gives the species abundance and mean, minimal and maximal values of ecological factors for the fields where the individuals of each species were present.

Mean hydrolytical activity of microbial community in the soil of 58 fields was 0.701 ± 0.02 OD g^{-1} dry soil (varied from 0.446 up to 1.046 OD g^{-1} dry soil), no statistically significant correlations between earthworm community parameters and hydrolytical activity were found. Mean values of soils where different species were present were similar in widely distributed species: 0.701 ± 0.02 OD g^{-1} dry soil for *Aporrectodea caliginosa* (Savigny, 1826), 0.702 ± 0.03 for *Lumbricus terrestris* Linnaeus, 1758, 0.707 ± 0.03 for *Aporrectodea longa* (Ude, 1885), 0.716 ± 0.02 for *Aporrectodea rosea* (Savigny, 1826), 0.716 ± 0.07 for *Lumbricus rubellus* Hoffmeister, 1843. Mean activity of microbial community was higher ($p < 0.05$) for two species: *Allolobophora chlorotica* (Savigny, 1826) 0.791 ± 0.02 and *Lumbricus castaneus* (Savigny, 1826) 0.8 ± 0.05 OD g^{-1} dry soil.

In organic ($n = 25$) and conventional ($n = 33$) fields the total abundance, number of species, soil parameters and hydrolytical activity of microbial community did not differ statistically as well as abundance of species except the abundance of epigeic *Lumbricus* species (*Lumbricus rubellus* and *Lumbricus castaneus*) was higher ($p < 0.05$) in the soil of organic fields (Table 3).

Table 1
Density of ecological groups of earthworms in fields from 2003 to 2005 (*N*–number of fields; *D*–density, % of total number of individuals)

Ecological group	*N*	*D* (mean value ± SE)	Minimal *D*	Maximal *D*
Epigeic	35	4.1 ± 1.0	1	16
Endogeic	58	88.2 ± 1.3	56	100
Anecic	44	9.7 ± 1.2	1	31

4. Discussion

According to Paoletti [8] and Curry et al [1], abundance and diversity of earthworms in cultivated land are on most cases lower than those found in undisturbed habitats. Any management practices applied to soils are likely to have some positive or negative effects on earthworm abundance and diversity; these effects are primarily the result of changes in soil temperature, soil moisture and organic matter quantity or quality [4]. Tillage, single crop, toxicants, soil acidification and residue removal are the factors decreasing earthworm abundance and diversity, whereas no tillage management, rotation of crop, liming and organic amendments are the increasing factors of earthworm abundance and diversity. In general, the greater the intensity and frequency of disturbance, the lower the population density or biomass of earthworms [6]. Earlier measures of the size and activity of the soil communities in Estonia support the conclusion that soil biota has considerable potential as early indicators of soil degradation or improvement [10].

Some ecological factors of habitat like soil moisture, pH and organic matter content are related to soil type and texture and influence the quantitative characteristics of earthworms (abundance, biomass) [2]. Qualitative characteristics (ecological and specific structure of community) seem to reflect the impact of agricultural practice on differently sensitive species (Table 1). In arable soils, mostly all earthworms are endogeic, dominating *Aporrectodea caliginosa*. Epigeic species were present only in 35 fields and in 44 fields we found anecic species which are less sensitive than epigeic. Analysis of specific structure (Table 2) indicates that some endogeic species (*Aporrectodea caliginosa*,

Table 2
Species abundance (individuals m^{-2}) of earthworms and ecological factors (mean values ± SE of fields where the species was present) in arable soils

Species	*N*	Abundance (mean ± SE) (ind m^{-2})	Min. abundance	Max. abundance	Moisture content ± SE (%)	pH ± SE	Organic matter content ± SE (%)
Aporrectodea caliginosa	58	60.69 ± 5.5	5.3	240	17.26 ± 0.4	6.21 ± 0.11	3.39 ± 0.14
Aporrectodea rosea	49	7.81 ± 1.3	1.3	45.3	17.32 ± 0.43	6.17 ± 0.13	3.47 ± 0.15
Lumbricus rubellus	36	3.87 ± 0.6	1.2	16	17.74 ± 0.18	6.24 ± 0.33	3.52 ± 0.48
Aporrectodea longa	26	3.83 ± 0.01	1.3	26.7	17.6 ± 0.64	6.4 ± 0.14	3.78 ± 0.24
Lumbricus terrestris	26	2.72 ± 0.53	1.3	17.3	17.41 ± 0.5	6.32 ± 0.16	3.49 ± 0.19
Allolobophora chlorotica	17	2.27 ± 0.66	1.3	28	19.29 ± 0.2	6.24 ± 0.09	4.01 ± 0.08
Lumbricus castaneus	3	2.2 ± 0.3	1.3	4	18.63 ± 1.17	5.9 ± 0.58	2.98 ± 0.22

A. rosea) are not sensitive to changes of soil conditions and they are also distributed in soils where some factors do not have optimal values for earthworms. *Lumbricus rubellus* is tolerant epigeic species but more affected by agricultural practice than endogeic. Both anecic species *Lumbricus terrestris* and *Aporrectodea longa* were found in less than half of the fields. There were no statistically significant differences in mean values of soil characteristics but agricultural practices like tillage and chemicals disturb earthworms by breaking burrows and debasing food quality. Two species are not common in field soils—*Allolobophora chlorotica* and *Lumbricus castaneus*. These two species mainly preferred habitats with higher soil moisture compared to other species, despite that some individuals of the species were found in soils with non-optimal moisture.

Table 3
The earthworm abundance (mean value ± SE) and soil parameters (mean value ± SE) in organic and conventional fields

Parameter	Organic fields (*N* = 25)	Conventional fields (*N* = 33)
Number of earthworms, m^{-2}	84.98 ± 10.03	78.52 ± 9.14
Number of earthworm species	3.84 ± 0.23	3.60 ± 0.29
Epigeic earthworms, %	5.2 ± 1.1	3.3 ± 0.7
Endogeic earthworms, %	85.8 ± 1.8	90.2 ± 2.0
Anecic earthworms, %	9.0 ± 1.3	6.5 ± 1.3
Aporrectodea caliginosa, individuals m^{-2}	60.86 ± 7.85	60.56 ± 7.72
Aporrectodea rosea, individuals m^{-2}	9.22 ± 2.18	6.75 ± 1.58
**Lumbricus rubellus*, individuals m^{-2}	5.09 ± 1.13	2.94 ± 0.66
Lumbricus terrestris, individuals m^{-2}	2.88 ± 0.84	2.60 ± 0.70
Aporrectodea longa, individuals m^{-2}	4.64 ± 1.58	3.21 ± 0.80
Allolobophora chlorotica, individuals m^{-2}	2.08 ± 1.19	2.42 ± 0.76
**Lumbricus castaneus*, individuals m^{-2}	0.21 ± 0.17	0.04 ± 0.04
Soil moisture, %	17.39 ± 0.62	17.15 ± 0.52
pH	6.0 ± 0.17	6.36 ± 0.08
Soil organic matter, %	3.39 ± 0.20	3.39 ± 0.19
Hydrolytical activity of microbial community, OD/g	0.724 ± 0.03	0.670 ± 0.04

* Statistically significant ($p < 0.05$) differences.

The most tolerant to agricultural practice species *Aporrectodea caliginosa* was found in all studied fields. Other species were present as follows: *Aporrectodea rosea* in 84% of fields, *Lumbricus rubellus*—62%, *Lumbricus terrestris*—45%, *Aporrectodea longa*—45%, *Allolobophora chlorotica*—29%, *Lumbricus castaneus*—5%. Two individuals of *Eisenia foetida* in one field must have come to the soil with manure and they are not able to survive in the soil. *Dendrodrilus rubidus* was found only in a single field and its' presence there was occasional. *Octolasion cyaneum* is not a common species in Estonia but in some regions the abundance can be high, in this case it can be a competitor for the most common species *Aporrectodea caliginosa* because of similar demand for ecological condition (authors' data from 2006). As the mean values of soil characteristics did not differ statistically significantly between species' habitats, different agricultural activities may be the reason for differences in distribution of species. According to Hole et al. [5], there is evidence from comparative studies under arable regimes which indicated a general trend for higher earthworm abundance under organic management; our results confirm this conclusion (Table 3). Activity of soil microbial community as an important characteristic of earthworm habitat is higher in conditions of environment-friendly agricultural practice and it correlates positively ($p < 0.05$) with the number of presence of more sensitive species.

It can be concluded, that the specific composition of an earthworm community indicates the intensity of agricultural activity in the field. The occurrence of species only like *Aporrectodea caliginosa*, *Aporrectodea rosea*, *Lumbricus rubellus* tolerant to disturbance is the result of intensive tillage and agricultural practice or the influence of strong limiting ecological factor. A community including more sensitive species *Lumbricus terrestris* and *Aporrectodea longa*, or the most sensitive species *Allolobophora chlorotica* and *Lumbricus castaneus*, indicates more favourable agricultural or ecological conditions. Specific composition of earthworm community has indicative value for evaluating the impact of agricultural practice on soil.

Acknowledgements

This study was supported by Estonian Science Foundation grants No 5571 and No 6739. The authors are grateful to Mrs. K. Muoni for the correction of manuscript.

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European Journal of Soil Biology 43 (2007) 71–76
EUROPEAN JOURNAL OF SOIL BIOLOGY
http://www.elsevier.com/locate/ejsobi

Original article

Earthworm communities of flooded grasslands in Matsalu, Estonia

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Received 18 April 2005; accepted 16 September 2006
Available online 10 November 2006

Abstract

Earthworm communities in the soil of flooded (coastal and floodplain grasslands) and non-flooded (boreo-nemoral) meadows were studied. The average number of species in coastal and floodplain meadows was low, earthworm communities of boreo-nemoral meadows were diverse and the average number of species was high. Specific composition of earthworm communities varied between the three types of meadows. Earthworm communities of flooded meadows possess specific characteristics being low in both numbers and species due to periodical anaerobic conditions during over flooding and negative effect of sea water in coastal meadows.

Keywords: Earthworm communities; Specific diversity; Coastal meadow; Floodplain meadow; Soil characteristics

1. Introduction

Semi-natural communities (traditional rural landscapes) are rapidly disappearing in Europe due to changes in land use. The environmental value and the cultural importance of these landscapes have only recently become evident: most of the previously semi-natural communities are now overgrown, afforested or cultivated. Species diversity of semi-natural areas is influenced by the continuity of extensive management (mowing, grazing); historical management influences plant species accumulation and soil characteristics.

In Estonia, several inventories of semi-natural communities have been undertaken recently [11]. Semi-natural wetlands, such as coastal and floodplain meadows, are an integral part of the compensation network included in the NATURA 2000 ecological network. The biodiversity of coastal and floodplain meadows in Estonia has been investigated recently, with a particular focus on plant and bird communities. A significant part of the species diversity in meadows consists of invertebrates, of which beetles and butterflies have been most thoroughly studied. Available data on other invertebrate fauna in coastal and floodplain meadows are mainly by-products of other studies [13], whereas there are no data published on soil invertebrates.

The aim of this study was to determine the abundance and species composition of earthworm

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doi:10.1016/j.ejsobi.2006.09.009

communities in addition to their relationship with a habitat features in the soil of coastal and floodplain meadows in West Estonia.

2. Materials and methods

2.1. Site description

Earthworm communities were studied in years 1999–2001 at 26 locations in West Estonia. All flooded meadows were situated in Matsalu National Park, including coastal meadows (1–6) on the south and east coast of Matsalu Bay and floodplain meadows (7–15) near the Kasari River (Table 1). In order to compare earthworm communities and to obtain information from unflooded meadows, an additional 11 sites of boreo-nemoral meadows with similar type and soil texture were selected close to Matsalu National Park. Agricultural practices are similar for all sites; the meadows are mown annually or grazed with very low intensity. Table 1 features the site and soil characteristics of the flooded meadows.

The term ‘‘coastal meadow’’ refers to a meadow directly influenced by sea, i.e. flooded at least by storm waves. The soils of West Estonian coastal grasslands are saline littoral soils. The distribution of vegetation on the shore may be regarded as a spatial expression of coastal grassland succession; as a result of land uplift, the soils and vegetation of Estonian coastal grasslands undergo a series in their development, in response to changes in the hydrological and chemical properties of the substrate over time [14]. A key factor for preservation of the biodiversity of seashore grasslands is the continuation of traditional land-use practices, especially regular grazing.

‘‘Floodplain meadows’’ are flooded grasslands in river valleys (on floodplains). These meadows feature periodic flooding and continuous accumulation of organic and mineral sediments. The volume and extent of the sediments depend on flood duration and water level and on the local surface and soil. The flood duration is one month in spring with shorter periods in autumn and summer. Estonian floodplain grasslands hold considerable environmental worth, supporting plant communities important from an international perspective as well as many plant species that are rare in Estonia and the Baltic region. The term ‘‘boreo-nemoral meadows’’ refers to open dry and fresh meadows, which have developed on the sites of former boreo-nemoral forests.

2.2. Methods

Meadow soils were classified according to the system of the World Reference Base for Soil Resources [8] (Table 1). At each site five soil blocks (50 × 50 × 40 cm) were examined by the hand sorting method [12,15]. Earthworms were washed and the adult individuals were identified [9,19]. The mean number of individuals per 1 m^2 of soil surface and standard deviation (SD) were calculated. Moisture content (105 °C), pH, organic matter (in muffle furnace at 360 °C),

Table 1
Soil and site characteristics of flooded meadows

No.	Site	Soil type	Location	Distance to the coastline or river (m)	Management
Coastal meadows					
1	Kloostri1	Calcari-skeletic gleysol	58°44′36″, 23°49′07″	100	Grazing
2	Kloostri2	Calcari-skeletic gleysol	58°44′30″, 23°49′04″	100	Grazing
3	Kloostri3	Endogleyi-calcaric cambisol	58°44′25″, 23°49′80″	150	Grazing
4	Pagarand	Epigleyi-hyposalic regosol	58°43′35″, 23°35′54″	50	Grazing
5	Salminiit1	Stagni-hyposalic fluvisol	58°44′30″, 23°40′09″	50	Grazing
6	Salminiit2	Stagni-hyposalic fluvisol	58°43′34″, 23°39′58″	300	Grazing
Floodplain meadows					
7	Matsalu1	Epigleyic fluvisol	58°45′30″, 23°48′36″	600	Mowing
8	Matsalu2	Epigleyic fluvisol	58°45′12″, 23°48′55″	500	Mowing
9	Matsalu3	Epigleyic fluvisol	58°45′13″, 23°49′31″	300	Mowing
10	Kelu1	Endoabrupti-fluvic histosol	58°45′24″, 23°53′20″	1000	Mowing
11	Kelu2	Endoabrupti-fluvic histosol	58°45′38″, 23°53′17″	600	Mowing
12	Kelu3	Endoabrupti-fluvic histosol	58°45′42″, 23°53′15″	400	Mowing
13	Kloostri4	Epigleyic fluvisol	58°45′29″, 23°50′22″	500	Mowing
14	Kloostri5	Histic fluvisol	58°45′33″, 23°49′31″	1200	Mowing
15	Kloostri6	Histic fluvisol	58°45′39″, 23°49′15″	1500	Mowing

nitrogen concentration (Kjeldahl method) and soluble phosphorus concentration (lactate method), K- and Na-concentration (flame photometer) were determined for each composite soil sample to characterize soil conditions (Table 2). Total activity of the microbial community complements physical and chemical parameters; it was measured by the fluorescein diacetate method, which estimates the activity of dehydrogenase enzymes in a composite sample [16].

All data were analyzed using non-parametric Kruskall-Wallis' test. The relationships between the number of earthworms and specific soil parameters were analyzed by Spearman's correlation coefficient. Canonical Correspondence Analysis (CCA) was used to identify the main gradients in the composition of the earthworm community using the program CANOCO 4.52 [18]. The forward selection method with the Monte Carlo test (999 permutations), available in the CANOCO software, was used to select environmental variables relevant for determining earthworm community composition. In addition to the measured quantitative environmental variables, meadow type was used as the nominal explanatory variable in CCA.

3. Results

3.1. Soil conditions

Soil parameters show statistically significant differences between three types of meadows (Table 2). The measured range of pH (4.5–7.3) is optimal for most of the earthworm species, being higher in coastal and boreo-nemoral meadows and lower in floodplain meadows. Water content in soil varies depending on the time of the latest flooding; soil moisture, as well as the organic matter content are the highest in the floodplain meadows. The concentrations of some elements in soil differ depending on the characteristics of flooding. K^+ was the highest in boreo-nemoral meadows; Na^+ concentration was the highest in floodplain meadows. Extremely high concentrations of potassium and sodium were found in the top layer of the humus horizon of the coastal soils (66.0–89.1 mg K/100 g dry soil, 78.8–193.5 mg Na/100 g dry soil). N and P concentrations reveal little difference among different types of meadows nevertheless N concentration was the highest in floodplain meadows. By contrast, P concentration was very low in floodplain meadows, as a result of leaching from soils during floods. There were no significant differences in N and P concentrations between coastal and boreal-nemoral meadows. Microbiological analysis of soils in the Matsalu area has shown clear differences in soil microbial community activity between meadows affected and unaffected by sea flood or fresh water flood. The hydrolytical activity of the microbial community was higher in floodplain soils than in coastal and boreo-nemoral meadows.

3.2. Earthworm communities

The mean abundance of earthworms in boreo-nemoral meadows was 194.4 ± 113.4 individuals per square meter. The mean number of individuals in flooded meadow soils was low (32.2 ± 32.5 individuals per square meter in coastal meadows and 36.5 ± 23.7 in floodplain meadows). No earthworms were found at two coastal meadow sites with typical saline plant communities (sites 4 and 5 in Table 1) that are nearest to the coast under the highest influence of sea water. Earthworms in all floodplain meadows were counted although the abundance varied greatly (8.0–74.7 individuals per square meter) (Table 3).

The number of earthworm species in coastal meadows varied from 0 to 3. *Aporrectodea caliginosa* (Savigny, 1826) comprised 85% of all individuals with the remainder consisting of *Lumbricus rubellus*

Table 2
Mean values of soil parameters in different types of meadow (mean value and standard deviation)

Characteristic	Coastal meadows ($n = 6$)	Floodplain meadows ($n = 9$)	Boreo-nemoral meadows ($n = 11$)
pH*	6.8 ± 0.9	5.7 ± 0.3*	6.7 ± 0.6
OM (%)*	10.9 ± 6.0	18.9 ± 6.9*	8.6 ± 3.0
Nitrogen (%)*	0.60 ± 0.33	0.92 ± 0.30*	0.47 ± 0.15
Phosphorus (g/100 g dry soil)*	8.6 ± 1.9	1.9 ± 0.7*	8.7 ± 6.6
Potassium (g/100 g dry soil)	7.15 ± 2.62	9.98 ± 3.8	14.43 ± 3.35
Sodium (g/100 g dry soil)	8.65 ± 3.34	18.80 ± 5.57	7.15 ± 1.13
Moisture (%)*	35.0 ± 14.2	47.7 ± 11.2	27.6 ± 7.6*
Hydrolytical activity of microbial community OD per 100 g dry soil*	1.12 ± 0.15	1.49 ± 0.34*	1.04 ± 0.34

*Statistically significant ($p < 0.05$) differences (by Kruskall-Wallis' test).

Table 3
Mean values of earthworm species (individuals per m^2) and community (mean value and standard deviation)

Characteristic	Coastal meadows ($n = 6$)	Floodplain meadows ($n = 9$)	Boreo-nemoral meadows ($n = 11$)
Allolobophora chlorotica	0	0	2.5 ± 1.8
*Aporrectodea caliginosa**	27.5 ± 26.4	14.0 ± 13	85.2 ± 56.8*
*Aporrectodea rosea**	0.8 ± 2.0	0	20.7 ± 25*
Dendrodrilus rubidus	0	1.8 ± 2.1	2.9 ± 9.7
Eiseniella tetraedra	0	10.4 ± 15.8	0
Lumbricus castaneus	0	0	2.6 ± 4.0
*Lumbricus rubellus**	1.3 ± 2.8	4.2 ± 5.6	23.9 ± 20.8*
Lumbricus terrestris	0	0	15.5 ± 12.5
Total number of individuals*	32.2 ± 32.5	36.5 ± 23.7	194.4 ± 113.4*
Number of species*	1.2 ± 1.2	3.0 ± 1.0	5.3 ± 1.3*

*Statistically significant ($p < 0.05$) differences (by Kruskall-Wallis' test).

(Hoffmeister, 1843) and *Aporrectodea rosea* (Savigny, 1826). The number of species in floodplain meadows varied from 2 to 4. The most tolerant endogeic species *A. caliginosa* comprised 38% of the population. The remaining species were epigeic *Eiseniella tetraedra* (Savigny, 1826) 28%, *L. rubellus* 11%, *Dendrodrilus rubidus* (Savigny, 1826) 5%; 18% of individuals were immature. Earthworm communities of boreo-nemoral meadows were diverse; the number of species varied from 3 to 7. The most tolerant species *A. caliginosa* comprised 43.8% of the population with the remainder consisting of endogeic species *A. rosea*, *Allolobophora chlorotica* (Savigny, 1826), *Octolasion lacteum* (Örley, 1881) as well as epigeic species *D. rubidus*, *Lumbricus castaneus* (Savigny, 1826), *L. rubellus*, and anecic species *Lumbricus terrestris* (Linnaeus, 1758) and *Aporrectodea longa* (Ude, 1885). The abundance of *A. caliginosa*, *A. rosea*, *L. rubellus* and *L. terrestris* had significant relationships with measured soil parameters. The most important environmental factors for earthworm species were soil pH, organic matter content and moisture. The abundance of endogeic and anecic species was related to soil pH, in addition anecic species number correlated with organic matter and nitrogen content. The abundance of epigeic species was more closely associated with Na-concentration and these species were more tolerant to soil moisture (Table 4).

The results of CCA, based on the earthworm species data, are summarized in the ordination diagram (Fig. 1). Three environmental variables (pH, humidity, organic matter) and meadow type explained 64.9% of overall earthworm data variation. The CCA ordination axes 1 and 2 were both statistically significant ($p < 0.001$) and accounted for 37.6 and 15.5% of variance in the species data, respectively. The first CCA axis emphasizes differences between the meadow types – communities of flooded meadows are different from other types of meadows. Semi aquatic *E. tetraedra* was the typical species for flooded meadows community positively influenced by moisture and organic matter content. *A. chlorotica* preferred habitats with higher values of pH, mostly boreo-nemoral meadows. Second CCA axis depicts differences between coastal meadows and boreo-nemoral meadows, location of *A. caliginosa* on the figure close to the crossing of two axes indicates high tolerance of this species to ecological factors

Table 4
Spearman's correlations between earthworm community density and soil parameters

Species or group	pH	Organic matter	N total	P total	Moisture	Sodium Na^+	Hydrolytical activity
Aporrectodea caliginosa	0.52	−0.59	−0.54	0.47	−0.62	−0.47	−0.50
Aporrectodea rosea	0.70	−0.62	−0.55	0.48	−0.65		−0.55
Dendrodrilus rubidus	−0.53						
Eiseniella tetraedra	−0.56	0.59	0.6		0.52		
Lumbricus castaneus		−0.62	−0.64		−0.65		−0.61
Lumbricus rubellus		−0.58		0.57	−0.50	−0.67	
Lumbricus terrestris	0.78	−0.77	−0.73	0.56	−0.72	−0.48	−0.61
Epigeic		−0.59	−0.45	0.53	−0.49	−0.67	−0.49
Endogeic	0.55	−0.59	−0.55	0.45	−0.61	−0.48	−0.49
Anecic	0.76	−0.74	−0.70	0.55	−0.67	−0.49	−0.55

Only statistically significant ($p < 0.05$) correlation are shown.

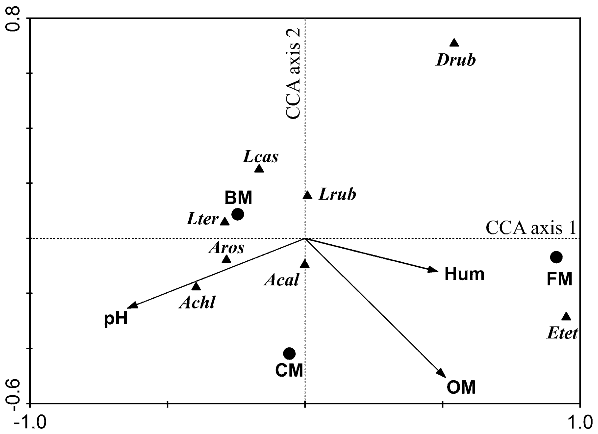

Fig. 1. Ordination biplot based on the Canonical Correspondence Analysis (CCA) of earthworm species for all studied meadows, displaying 53.1% of variance in the abundances and 81.8% of variance in the fitted abundances. The qualitative variable meadow type is indicated by the filled circles. Abbreviations: pH, acidity of soil; Hum, soil moisture (%); OM, organic matter (%); BM, boreo-nemoral meadows; CM, coastal meadows; FM, flooded meadows.

(*L. rubellus* has similar distribution pattern to *A. caliginosa*). The presence of individual *D. rubidus* in meadows soils is accidental and not related to meadow type or ecological conditions.

4. Discussion

Earthworms and mesoarthropods comprise most of the invertebrate biomass in grassland soil; the invertebrate communities are diverse and complex. Regardless of numerous papers and reports on diversity of earthworms in grassland soil only a few studies of earthworm communities in coastal and flooded grasslands have been published. The soil faunal dynamics of flooded meadows in temperate climate were studied by Emmerling [7], who concluded that the main factors affecting the distribution of soil macrofauna are the long-term influence of land-use, soil organic matter content as well as soil moisture and flooding characteristics. Annelid coenoses of wetlands were also studied by Beylich and Graefe [2], who found that species composition in wet soils expresses the prevailing living conditions; the decomposer community integrates the influence of fluctuating over time abiotic and biotic conditions. Moreover, microbial activity of soil influences the O_2 concentration and consequently earthworm survival [2].

Ausden et al. [1] studied macroinvertebrate fauna in flooded grasslands in England and found that the biomass of earthworms was significantly lower in flooded soils as compare to unflooded soils. The authors mentioned the relatively high abundance of *E. tetraedra* in flooded soils. Several authors [4,17] concluded that periodical flooding has species-specific influence on earthworm population, mostly decreasing the abundance and diversity of communities during flooding. Edwards and Bohlen [5] suggested that earthworm abundance is lower in alluvial soil compared to other soil types.

The only previously published study of soil invertebrates in the Baltic coastal region was made by Eitminaviciute et al. [6] in the 1970s. They described the fauna of two different types of meadows and found that wet meadows dominated by *E. tetraedra*, in flooded coastal meadows earthworms were not recorded.

The measured range of pH (4.5–7.3) is optimal for most of the earthworm species suggesting that soil acidity is not a limiting factor for earthworms in the meadows studied. K and Na concentrations in the soil of coastal meadows reflect the influence of seawater. Though the salinity of Matsalu Bay is low (5–6‰) and nearly fresh at the river mouth, high content of ions are accumulated in humic horizon of soil with partially decomposed plant material [14].

The activity of microbial community in soil responsible for the decomposition of organic matter is affected significantly by the activity of soil macroinvertebrates, especially earthworms [3]. Hydrolytical activity of microbial community was significantly higher in soil of flooded grasslands due to high organic matter content as compared with other types of grasslands. High moisture of soil as the limiting factor for earthworms restricts the increase in abundance and diversity of earthworms.

The abundance of earthworms per square meter on semi-natural grasslands in Estonia is 200–400 individuals and the number of earthworm species varies between 3 and 8 [10]. Different types of meadows vary in pH, organic matter, N and P content as well as in hydrolytical activity of the microbial community.

The abundance of earthworm communities in the soil of boreo-nemoral meadows varied between 8 and 404 individuals per square meter. The average number of earthworms (Table 3) counted in boreo-nemoral meadows was close to the average number of Estonian meadows [10]. The differences in number and specific composition of communities of different types of meadows are caused by flooding. Although the great amount of organic-rich sediments deposited during flooding favor earthworms, their abundance is restricted by extremely poor aeration of soil. Semi aquatic *E. tetraedra* as a typical species in flooded meadows was positively influenced by moisture and organic matter content. Additionally, the salinity of sea water limits the population and affects the species composition in coastal meadows. Salt ions accumulated in the surface layer create a poor quality environment. Partly decomposed surface layers also occur on floodplain meadows; hence 54% of individuals living in the floor layer are epigeic. *A. caliginosa* and *L. rubellus* are species highly tolerant to ecological factors (Fig. 1). The ecological composition of boreo-nemoral meadows (endogeic species 69.4%, epigeic species 19.9% and anecic species 10.7%) is characteristic of natural grasslands without flooding [10].

Depending on meadow type, soil organisms especially earthworms are an integral part of food chains in meadow ecosystems. The flooded grasslands are important both for nesting and foraging birds particularly in maritime areas [20]. Some earthworm-feeding birds such as waders have seen a rapid decline in recent years, these species and their habitats are becoming extinct in many parts of Europe [1]. The main reasons for the decline of these birds are the cessation of agricultural management of floodplain and coastal meadows as well as brushwood overgrowth that are decreasing factors for soil invertebrates as a food reserve for birds [13]. Sustainable management of flooded grasslands can conserve this type of grasslands to preserve natural soil invertebrate communities.

In summary, the earthworm communities of semi-natural landscapes have a specific character, their communities are low in both numbers and species due to periodical anaerobic conditions and additionally specifically negative affect of sea water in coastal meadows.

Acknowledgements

This research was supported by the grants No 5571, 6005 and 6739 from the Estonian Science Foundation. The authors would like to thank Mrs. E. Mägi from Matsalu National Park for her useful advice, Dr. R. Szava-Kovats and Mrs. K. Muoni for language corrections.

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EUROPEAN JOURNAL OF SOIL BIOLOGY XXX (2008) 1–9

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Original article

Invertebrate communities (Annelida and epigeic fauna) in three types of Estonian cultivated soils

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ARTICLE INFO

Article history:
Received 23 April 2008
Received in revised form
9 September 2008
Accepted 10 September 2008
Published online ■

Keywords:
Soil biodiversity
Soil type
Earthworms
Enchytraeids
Epigeic invertebrates
Ground beetles
Spiders

ABSTRACT

The abundance and diversity of invertebrate communities (annelids and epigeic fauna) in three types of cultivated soils were studied. Soil biota communities in the three most widespread soil types in Estonia (Calcaric Regosols, Calcaric Cambisols and Stagnic Luvisols) are influenced by environmental conditions, the factors connected to soil texture including moisture, organic matter content and pH being the most essential, and by the intensity of agricultural practice. Potentially high biological activity and low intensity of agricultural human activity of Calcaric Regosols occurs in parameters of communities of organisms not sensitive to soil which dries off, i.e. epigeic fauna living on the soil surface and preferring dry and warm habitat; temporarily dried off soil is not a suitable habitat for Oligochaeta. Both groups of Oligochaeta (earthworms, enchytraeids) appear to prefer Calcaric Cambisols where soil moisture conditions are more stable. The abundance of invertebrate communities is the highest and the diversity is the lowest in Stagnic Luvisols. Some trends occurred in community characteristics along the soil surface following a hypothetical gradient; the number of carabids per trap and diversity of spiders decreased from the edge to the centre of the field. The results presented here on spatial variability in distribution of soil organisms are preliminary.

1. Introduction

Biodiversity is the key factor of the structure and function of ecosystems [28,53]. Due to intensive agricultural practice, loss of biodiversity occurs in agricultural ecosystems compared to natural ecosystems. Soil biological and chemical properties and habitat conditions alter drastically when natural habitat is converted to agricultural; frequent tillage and use of agro-chemicals have impact on soil organisms and habitats [7,28,36]. Agricultural activities have positive or negative impact on abundance, diversity and activity of soil fauna mostly following the changes in soil temperature, moisture, and quantity and quality of organic matter [17]. Fields which are more diverse, stable, isolated and managed with low intensity have preference for ongoing ecological processes compared with simple and disturbed agricultural systems. Uncultivated habitats between fields could enhance species diversity of many organism groups, and function as refuges

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1164-5563/$ – see front matter
doi:10.1016/j.ejsobi.2008.09.005

Please cite this article in press as: M. Ivask et al., Invertebrate communities (Annelida and epigeic fauna) in three types of Estonian cultivated soils, Eur. J. Soil Biol. (2008), doi:10.1016/j.ejsobi.2008.09.005

[24,25]. Spatial variability in dispersion of soil organisms can be a key to understanding the structure and function of soil biodiversity [10].

One of the most important challenges in agriculture today is to discover the heterogeneity of biota on field and regional scale to regulate pests using unique habitat conditions and entomofauna [1]. To date the data on soil invertebrate communities are incomplete in many regions. The aim of the present research was to determine the abundance and diversity of invertebrate communities (annelids and epigeic fauna) in three types of cultivated soils in Estonia, to investigate relationships between characteristics of invertebrate communities of fields and field edges and some soil-related ecological and agricultural factors, and qualitatively describe invertebrate fauna moving along the soil surface following a hypothetical gradient.

Questions asked were:

- How abundant and diverse are annelida and epigeic invertebrate communities in cultivated soils in Estonia?
- Is diversity of earthworm and epigeic invertebrate communities of cultivated soil influenced by soil type?
- How do carabid and spider diversities change along the soil surface following a hypothetical gradient?

2. Materials and methods

2.1. *Materials*

Estonian soil cover is highly variable due to the great variability of the soil ecological situation [38]. Twenty-four study areas of three most widespread soil types (by FAO-UNESCO (1994) terminology) all over Estonia [20,22] were selected. For each of three soil type groups—pebble rendzinas Calcaric Regosols, typical brown soils Calcaric Cambisols and pseudopodzolic soils Stagnic Luvisols—eight fields were selected for studies in 2003 (Enchytraeidae, Lumbricidae, epigeic fauna) and 2004 (Lumbricidae, epigeic fauna). The surface of each study field varied from 0.3 ha up to 85 ha, and soil type and texture was determined (Table 1). The cover crops and three-year history of agricultural management practice (tillage, amount of mineral and organic fertilizers, and pesticides used) were recorded and presented previously [51].

2.2. *Methods*

2.2.1. *Soil analyses*

In each studied field soil samples were collected randomly from the upper 20 cm layer with a soil corer (diameter 2 cm) [51]. Composite soil sample moisture content (105 °C), pH_{KCl}, organic matter content (in muffle furnace at 360 °C) [44], nitrogen concentration (by the Kjeldahl method) [35]), soluble phosphorus concentration (by lactate method [34]) and the concentration of potassium (by flame photometry [34]) were determined in all samples.

2.2.2. *Sampling*

For sampling of potworms (Enchytraeidae), five soil samples were taken from each field with a soil corer of 5 cm diameter, four samples from different parts and one sample from the centre of the field. The samples were divided according to soil depth: 0–2 cm, 2–5 cm, 5–10 cm and 10–15 cm. The samples

Table 1 – Soil characteristics of studied fields soil

Field no.	Soil type	Soil texture	Field size, ha	pH	Dry matter, %	Organic matter, %	Soluble P, mg per 100 g dry soil	Tot. N, %	K, mg per 100 g dry soil
1	CR	sl	1.00	7.12	74.7	9.18	44.5	0.491	40
2	CR	ls	4.70	7.56	94.9	2.95	10.1	0.152	10.4
3	CR	sl	1.20	7.4	79	20.21	15	1.366	60.2
4	CR	ls	1.20	7.48	92.5	3.82	13.1	0.218	17.1
5	CR	l	11.00	6.28	86	2.54	13.4	0.125	19
6	CR	cl	2.00	7	86.9	4.16	19.4	0.189	23.5
7	CR	cl	0.30	7	86.7	3.67	8.7	0.153	8.4
8	CR	cl	2.10	6.12	87.8	3.65	7.8	0.161	12.4
9	CC	sl	3.90	7.01	86.7	2.09	3.4	0.113	14.8
10	CC	l	85.00	6.8	87.6	3.99	12.5	0.097	21.5
11	CC	l	64.30	7.27	84.5	3.99	12.3	0.179	36.2
12	CC	l	25.30	6.68	82.6	4.48	22.4	0.213	30.8
13	CC	l	67.3	6.83	84.6	3.52	13.3	0.73	16.5
14	CC	cl	0.6	6.45	86.6	4.31	9.2	0.186	24.2
15	CC	cl	1.70	7.09	86.9	4.2	7	0.181	15.7
16	CC	cl	0.50	7.19	90	4.93	12.4	0.115	22.4
17	SL	l	3.60	6.21	83.3	2.45	9.4	0.115	22.4
18	SL	l	1.60	5.5	84.7	2.92	14.4	0.14	22.6
19	SL	sl	3.00	5.95	84.4	2.19	15.9	0.136	32.3
20	SL	ls	3.00	5	85.2	2.29	9.7	0.103	12.6
21	SL	l	0.30	7.35	75.9	4.55	3	0.226	10.9
22	SL	sl	1.80	7.09	83.2	3.86	49.4	0.171	17.2
23	SL	sl	4.00	6.06	83.3	3.16	21.5	0.148	18.8
24	SL	sl	15.00	5.33	86	2.1	15.7	0.099	12.7

Soil type: CR, Calcaric Regosols; CC, Calcaric Cambisols; SL, Stagnic Luvisols. Texture: sl, sandy loam; ls, loamy sand; l, loam; cl, clay loam.

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were conserved at 5 °C. Enchytraeids were extracted from soil samples using a slightly modified wet funnel method, half-spherical sieve with diameter 10 cm, the sieve bottom being in immediate contact with water while the upper side of the sample was warmed with an electric bulb. The individuals were collected from the water using a stereomicroscope, then conserved in ethanol and counted. Specific composition of community was studied qualitatively; the individuals were identified by Dr. R. Schmelz [42]. Biomass was calculated after volume, taking the specific wet weight of worms with empty digestive tract, near 1.0. Volume was calculated after the length and mid-body diameter [49].

For sampling of earthworms (Lumbricidae), earthworms were collected in September and October when the activity of individuals was the highest. In all study fields five soil blocks of 50 × 50 × 40 cm were studied using a hand sorting method [33]; the living earthworms were washed, kept in a refrigerator for 48 h, weighed and counted. Earthworms were preserved in ethanol and the species were identified [15,48]. The mean number of individuals in 1 m^2 of soil surface and ecological composition of community according to Bouché [3] (±S.E.) were calculated.

Epigeic invertebrate fauna was sampled using pitfall traps (plastic cup with diameter 7 cm and height 12 cm) one third filled with 20% NaCl solution and placed for 7 days in the soil in July and September. In each of 24 fields three traps were placed on all the edges with different characteristic features 1 m outside the field, three traps in the field 5 m inwards the edge, three traps were placed in the centre of the field. An additional three traps to check the distribution of invertebrates in the field were placed at 10 m and 20 m from the edge. All individuals in traps were counted and identified to species (ground beetles, spiders), genus (ground beetles) or family (all other groups) level [13,16,39,40]. To study spiders, in addition sweep-netting was carried out in the edge community of each field, and approximately 100 m inside the field edge.

2.3. Data analysis

Data analysis was performed using nonparametric statistical methods (Kruskall–Wallis dispersion analysis, Mann–Whitney *U*-test, Spearman correlation analysis). The Shannon–Wiener diversity index and Simpson index "D" (for spiders only) were calculated. Canonical Correspondence Analysis (CCA) was used to analyze epigeic fauna and carabid communities data with respect to environmental variables using the program CANOCO 4.52 [47]. The forward selection method with the Monte Carlo test (999 permutations), available in the CANOCO software, was used to select nominal explanatory variables (soil type and location of traps on the field) relevant for determining composition of field epifauna.

3. Results

3.1. Soils

Measured characteristics of studied soils are given in Table 1. Soil types did not differ in chemical characteristics except that soil pH was the lowest in Stagnic Luvisols (6.03 ± 0.75) but statistically did not differ in Calcaric Regosols or Calcaric Cambisols (6.82 ± 0.27 and 6.38 ± 0.35, respectively; $P < 0.05$).

3.2. Soil invertebrates

3.2.1. Enchytraeids

The mean biomass (total and per soil layers) of enchytraeids in three soil types is presented in Table 2. The differences between soil types and management types of fields were not statistically significant. Biomass of enchytraeids correlated (statistically significant, $P < 0.05$, Spearman correlation) with soluble P content in soil negatively, with soil pH and organic matter content positively. Seven common in Europe species of genus *Fridericia* were found in Calcaric Cambisols, 3 species of

Table 2 – Characteristics of annelids communities (mean value ± S.E.) in the fields of different soil type (N = 8 for each soil type)

Parameter	Calcaric Regosols	Calcaric Cambisols	Stagnic Luvisols
Lumbricidae			
Abundance, individuals m^{-2}	47.94 ± 11.25	72.97 ± 15.13	107.11 ± 22.4*
Mean number of species	3.2 ± 0.5	3.5 ± 0.3	3.1 ± 0.5
Total number of species	6	6	6
Epigeic individuals, %	3.7 ± 2.1	7.0 ± 3.2	2.2 ± 1.0
Endogeic individuals, %	85.2 ± 4.3	81.5 ± 6.1	89.8 ± 2.3
Anecic individuals, %	11.1 ± 2.7	11.5 ± 4.5	8.0 ± 2.0
Biomass, g m^{-2}	33.39 ± 6.44	29.32 ± 6.91	45.05 ± 8.51
Biomass of individual, g	0.79 ± 0.12	0.42 ± 0.05*	0.51 ± 0.07
Shannon's biodiversity index	0.841 ± 0.187	0.969 ± 0.135	0.831 ± 0.126
Enchytraeidae			
Mean biomass, g m^{-2},	0.43 ± 0.12	0.58 ± 0.16	0.36 ± 0.10
Mean biomass 0–2 cm, g m^{-2}	0.13 ± 0.04	0.20 ± 0.07	0.19 ± 0.08
Mean biomass 2–5 cm, g m^{-2}	0.11 ± 0.03	0.14 ± 0.07	0.13 ± 0.10
Mean biomass 5–10 cm, g m^{-2}	0.09 ± 0.03	0.12 ± 0.04	0.00 ± 0.00
Mean biomass 10–15 cm, g m^{-2}	0.10 ± 0.04	0.12 ± 0.04	0.04 ± 0.02

Asterisks designate group means which are statistically different according to multiple comparisons of mean ranks.

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Fridericia in Calcaric Regosols, in Stagnic Luvisols one species of *Fridericia* and non-identified individuals of genus *Mesenchytraeus* were found.

3.2.2. *Earthworms*

The abundance of earthworms was 107.11 ± 22.4 individuals per m^2 in Stagnic Luvisols, 72.97 ± 15.13 individuals per m^2 in Calcaric Cambisols and 47.94 ± 11.25 individuals per m^2 in Calcaric Regosols; there was no difference in the mean number of represented earthworm species (3.1 ± 0.5 to 3.5 ± 0.3 species) in every soil type. The mean values of earthworm community parameters (±S.E.) in three soil types are presented in Table 2. Statistically significant differences ($P < 0.05$) between earthworm community characteristics of soil types were in the abundance of earthworms in Stagnic Luvisols and in the mean biomass of individual in Calcaric Cambisols. Mostly the communities consisted of endogeic individuals (mostly species *Aporrectodea caliginosa* (Savigny, 1826)), the percentage being the highest (89.8 ± 2.3) in Stagnic Luvisols. The percentages of epigeic and anecic individuals were the highest in Calcaric Cambisols (7.0 ± 3.2 and 11.5 ± 4.5, respectively). Seven species of earthworms were present: *Aporrectodea caliginosa* (in 23 fields), *A. rosea* (Savigny, 1826) (in 23 fields), *Lumbricus terrestris* Linnaeus 1758 (in 16 fields), *L. rubellus* Hoffmeister, 1843 (in 15 fields), *A. longa* (Ude, 1885) (in 9 fields), *Allolobophora chlorotica* (Savigny, 1826) (in 4 fields) and *Octolasion cyaneum* (Savigny, 1826) (in one field). The Shannon diversity index was the highest (0.969 ± 0.135) in Calcaric Cambisols and the lowest (0.831 ± 0.126) in Stagnic Luvisols. There were no statistically significant differences between mean values of characteristics of earthworm communities in the fields with different cover crop (cereals, oilseed rape and clover).

3.2.3. *Epigeic fauna*

The numbers of epigeic fauna orders per trap are given in Table 3. In Fig. 1 the relationships between the abundance of epigeic fauna orders (number of individuals per trap) and soil type is given for field and field edge in July. In Calcaric Regosols 13 orders of invertebrates were present in the traps in July. Individuals of Coleoptera formed nearly half (48.1%) of the total number of invertebrates, including carabids which formed half of all beetles. The number of spiders, ants and Diptera was noteworthy. On field edges Hymenoptera (mainly ants) consisted 36.7% of total number of individuals, the numbers of Coleoptera, Isopoda and Diptera being noteworthy. In September the total number of individuals was fivefold lower in the field and on the field edge. In Calcaric Cambisols the total number of individuals in July was the lowest of the three soil types, consisting of 34.8% of beetles

Table 3 – The mean numbers of individuals per pitfall trap (±S.E.) on order and subclass level in different type of soil, in July and in September 2003

Order	Number of individuals per trap					
Soil type:	Calcaric Regosols		Calcaric Cambisols		Stagnic Luvisols	
Trap location:	Field	Edge	Field	Edge	Field	Edge
JULY						
Aranei	5.9 ± 1.1	5.4 ± 1	3.7 ± 0.7	3.5 ± 0.7	2.3 ± 0.5	10.1 ± 5.5
Opiliones	4.5 ± 0.8	14.1 ± 3.5	2.5 ± 0.7	8.3 ± 2.9	0.9 ± 0.3	5.3 ± 1.8
Coleoptera	26.2 ± 1.8	28.0 ± 1.1	8.6 ± 1	21.9 ± 7.2	12 ± 0.9	15.9 ± 1.7
Heteroptera	1.4 ± 0.4	2.5 ± 0.6	0.2 ± 0.1	2 ± 0.8	0.2 ± 0.1	1.1 ± 0.6
Hymenoptera	5.4 ± 1.1	42.2 ± 1.2	2.6 ± 0.4	20.9 ± 4.6	20 ± 13	72.3 ± 32
Diptera	4.9 ± 0.3	6.9 ± 1.3	1.4 ± 0.4	3.3 ± 0.7	3.5 ± 0.3	4.2 ± 0.6
Dermaptera	0.3 ± 0.1	1.1 ± 0.6	0.1 ± 0.0	0.1 ± 0.1	0.00	0.1 ± 0.1
Orthoptera	0.1 ± 0.1	0.00	0.1 ± 0.1	0.3 ± 0.2	0.00	0.00
Isopoda	0.4 ± 0.2	8.6 ± 4.4	0.8 ± 0.7	0.6 ± 0.3	0.2 ± 0.1	3.5 ± 2.4
Subclass Diplopoda	0.4 ± 0.3	1 ± 0.4	0.1 ± 0.2	0.4 ± 0.4	0.2 ± 0.1	0.2 ± 0.1
Gastropoda	0.00	0.2 ± 0.0	0.00	0.1 ± 0.1	0.00	0.4 ± 0.3
Total *N* of individuals per trap	54.50	115.00	24.80	66.90	42.70	120.80
SEPTEMBER						
Aranei	1.7 ± 0.3	2 ± 1	1.5 ± 0.2	1.5 ± 1	2.5 ± 0.4	2.1 ± 0.3
Opiliones	0.1 ± 0.1	6.4 ± 1.7	0.5 ± 0.2	7 ± 2.6	2.5 ± 0.5	13.4 ± 4.9
Coleoptera	4.4 ± 2	5 ± 0.4	2.2 ± 0.5	5.5 ± 2.7	12 ± 1.7	13 ± 2.2
Heteroptera	0.5 ± 0.4	0.2 ± 0.2	0.00	1.3 ± 0.3	0.3 ± 0.1	0.6 ± 0.2
Hymenoptera	0.00	0.6 ± 0.4	0.00	1.5 ± 0.4	5.5 ± 1.2	37.6 ± 11.8
Diptera	1.3 ± 0.2	1 ± 0.2	0.5 ± 0.3	2 ± 0.6	3.4 ± 0.3	2.6 ± 0.4
Dermaptera	0.00	0.2 ± 0.1	0.00	0.00	0.00	0.00
Orthoptera	0.00	0.00	0.00	0.00	0.1 ± 0.1	0.00
Isopoda	0.6 ± 0.5	5 ± 3.1	0.00	0.8 ± 0.2	0.9 ± 0.2	3 ± 0.8
Subclass Diplopoda	0.4 ± 0.2	1.6 ± 1	0.1 ± 0.1	0.8 ± 0.3	0.6 ± 0.1	3.7 ± 1.1
Gastropoda	0.1 ± 0.1	0.4 ± 0.2	0.00	0.3 ± 0.1	0.5 ± 0.2	1.9 ± 1.2
Total *N* of individuals per trap	11.40	25.80	5.70	28.80	46.90	99.00

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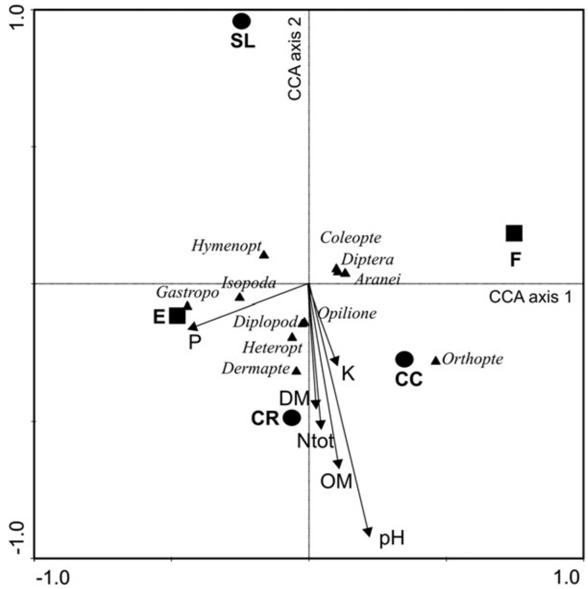

Fig. 1 – Canonical correspondence analysis ordination diagrams of epigeic invertebrates data displaying 13.1% of the inertia in the abundances and 89.1% variance in the weighted averages of orders with respect to environmental variables. The qualitative variable soil type is indicated by the circles labelled CC, SL and CR. DM, soil dry matter; OM, soil organic matter; Ntot, total nitrogen; P, soluble phosphorus content; K, potassium content; pH. The qualitative variable edge (E) and centre (F) of field is indicated by the squares. Eigenvalues of the first two axes are 0.053 and 0.029; the sum of all canonical eigenvalues is 0.095.

and a high percentage of spiders. In September Coleoptera was dominant in traps and Heteroptera, Hymenoptera, Dermaptera, Orthoptera, Isopoda were absent. On field edges Coleoptera and Hymenoptera (mainly the ants) dominated. Total number of individuals per trap on Stagnic Luvisols was 43 ± 9 in July and 47 ± 18 in September; the dominating group was Hymenoptera consisting of ants, and Coleoptera. The number of individuals per trap on the field edge was the highest of the three soil types, consisting of 59.8% ants and 13% beetles. In September the number of individuals was high as well, consisting of ants (38%) and Opiliones as dominant. In the case of whole epifauna the preference of most of the species for near field edge habitat is clearly visible (Fig. 1).

Some statistically significant differences ($P < 0.05$) were found by statistical analysis of individual numbers in traps. The abundance of spiders was the lowest in Stagnic Luvisols (2.3 ± 1.2). The number of carabids was the highest (16.7 ± 10.2) in Calcaric Regosols. The number of individuals of family Cryptophagidae in Calcaric Regosols and Staphylinidae in Stagnic Luvisols differed statistically significantly despite there being no differences in the total number of Coleoptera in the three soil types. The number of Heteroptera was the highest in Calcaric Regosols and the lowest in Calcaric Cambisols. Calcaric Regosols and Calcaric Cambisols differed regarding the number of Homoptera. Analysis of carabid species in traps on field edges did not reveal any statistically significant differences between soil types.

Comparing the traps contents in the field and on field edge, some statistically significant differences ($P < 0.05$) were found between the numbers of individuals. There were more individuals of Opiliones, Homoptera, Heteroptera, Diptera, Isopoda and Hymenoptera (Fig. 1) as well as carabids of genera *Bembidion* and *Amara* and of species *Pterostichus cupreus* (L., 1758), *Pterostichus vulgaris* (L., 1758) and *Carabus cancellatus* (Ill., 1798) on field edges (Fig. 2). In the fields more individuals of *Harpalus pubescens* (Müll., 1776) were found compared to field edges; in the middle of the field species such as *Clivina fossor* (L., 1758) and *Pterostichus niger* (Schall., 1783) were more abundant (Table 4). Canonical correspondence analysis (Fig. 2) indicated that the main difference in community composition of ground beetles is related to location of traps in the field. Soil type had no statistically significant impact on distribution of species among studied fields. The number of individuals per trap decreased 15 m onwards from the field edge to the field centre, being highest in the field where a ditch abuts the field

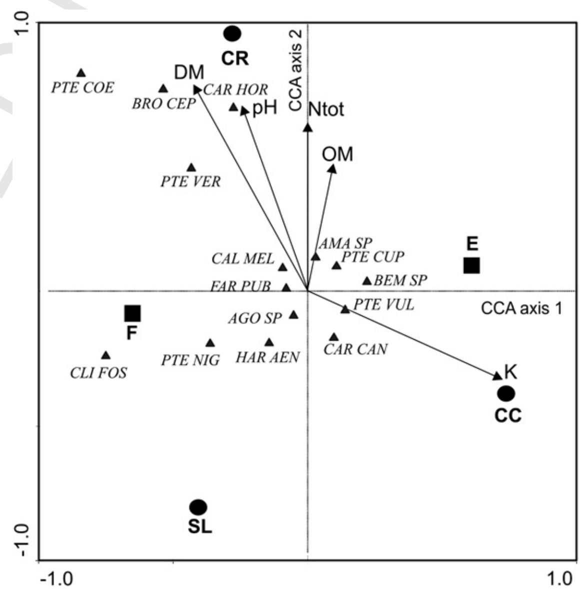

Fig. 2 – Canonical correspondence analysis ordination diagrams of carabid species data displaying 7.4% of the inertia in the abundances and 86.8% variance in the weighted averages of species with respect to environmental variables. The qualitative variable soil type is indicated by the circles labelled CC, SL and CR. DM, soil dry matter; OM, soil organic matter; K, potassium content; pH. The qualitative variable edge (E) and centre (F) of field is indicated by the squares. Eigenvalues of the first two axes are 0.045 and 0.026; the sum of all canonical eigenvalues is 0.079. Pte_coe, *Pterostichus coerulescens*; Br_cep, *Broscus cephalotes*; Ca_hor, *Carabus hortensis*; Pt_ver, *Pterostichus vernalis*; Ama_sp, *Amara* sp.; Ca_mel, *Calathus melanocephalus*; Pt_cup, *Pterostichus cupreus*; Ha_pub, *Harpalus pubescens*; Bem_sp, *Bembidion* sp.; Ago_sp, *Agonum* sp.; Pt_vul, *Pterostichus vulgaris*; Ca_can, *Carabus cancellatus*; Cl_fos, *Clivina fossor*, Pt_nig, *Pterostichus niger*; Has_aen, *Harpalus aeneus*.

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Table 4 – Mean number of carabid individuals per trap (±SE) in different soil types, in July and in September 2003

Species/genus	Number of individuals per trap					
Soil type:	Calcaric Regosols		Calcaric Cambisols		Stagnic Luvisols	
Location of traps:	Field	Edge	Field	Edge	Field	Edge
JULY						
Carabus cancellatus	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1
Carabus hortensis	0.0	0.1 ± 0.1	0	0	0.0 ± 0.0	0
Harpalus pubescens	6.1 ± 1.1	3.9 ± 0.6	1.5 ± 0.4	2.5 ± 0.8	2.7 ± 0.9	2.8 ± 0.6
Harpalus aeneus	0.3 ± 0.1	0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.5 ± 0.2
Pterostichus vulgaris	2.6 ± 1	4.4 ± 1.4	2.7 ± 1	7.7 ± 2.3	1.2 ± 0.4	2 ± 0.3
Pterostichus niger	0.3 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.4 ± 0.1	0.2 ± 0.1
Pterostichus vernalis	0.1 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0	0.0 ± 0.0	0
Pterostichus cupreus	0.6 ± 0.2	1.4 ± 0.3	0.2 ± 0.1	1.6 ± 0.4	0.2 ± 0.1	0.9 ± 0.5
Pterostichus coerulescens	0.2 ± 0.1	0	0	0	0	0
Calathus melanocephalus	0.3 ± 0.2	0.6 ± 0.2	0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.1
Bembidion sp.	1.5 ± 0.7	1.00 ± 0.3	0.2 ± 0.1	3.4 ± 1.3	0.4 ± 0.1	1.3 ± 0.5
Amara sp.	1.6 ± 0.2	2.8 ± 1.2	0.4 ± 0.2	1.8 ± 0.8	0.4 ± 0.2	0.8 ± 0.3
Agonum sp.	0.3 ± 0.1	0.6 ± 0.3	0.4 ± 0.3	0.8 ± 0.3	0.4 ± 0.2	0.4 ± 0.2
Broscus cephalotes	1.1 ± 0.4	0.2 ± 0.2	0.0 ± 0.0	0	0	0
Clivinia fossor	0.3 ± 0.2	0	0	0	0.2 ± 0.1	0.1 ± 0.2
Carabidae sp. *larvae*	1.3 ± 0.5	0.9 ± 0.6	1.3 ± 0.4	1.4 ± 0.5	1.2 ± 0.2	1 ± 0.4
Total N of individuals per trap	16.7	16.4	7.4	19.8	7.7	10.3
SEPTEMBER						
Carabus cancellatus	0	0	0.1 ± 0.1	0.5 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
Harpalus pubescens	0.6 ± 0.2	1.4 ± 0.4	0.1 ± 0.1	0	1.8 ± 1.1	3 ± 1.1
Harpalus aeneus	0. ± 0.1	0	0	0	0.1 ± 0.2	0.3 ± 0.1
Pterostichus vulgaris	0.5 ± 0.4	0	0.3 ± 0.1	0	0.5 ± 0.1	0.3 ± 0.2
Pterostichus niger	0	0	0	0.3 ± 0.1	0	0
Pterostichus vernalis	0	0.2 ± 0.2	0	0	0.2 ± 0.1	0
Pterostichus cupreus	0	0	0.5 ± 0.3	0.3 ± 0.2	3 ± 0.8	1.4 ± 0.5
Calathus melanocephalus	0.1 ± 0.1	0	0	0.3 ± 0.2	0.3 ± 0.1	0
Bembidion sp.	0.1 ± 0.0	1.4 ± 0.4	0.4 ± 0.2	0	1.4 ± 0.6	0.7 ± 0.3
Amara sp.	0.6 ± 0.2	0	0	0	1.5 ± 1	0
Agonum sp.	0	0	0	0.5 ± 0.2	0.4 ± 0.4	1.4 ± 0.7
Clivinia fossor	0	0	0	0	0.1 ± 0.1	0
Carabidae sp. *larvae*	0.7 ± 0.3	0.4 ± 0.1	0.4 ± 0.1	2.5 ± 0.9	1.1 ± 0.2	2.9 ± 1.2
Total N of individuals per trap	2.64	2.4	1.76	4.25	10.53	10.15

edge and having high value of abundance in the fields bordered with pasture and cultural grassland.

In July, 41 species of spiders were collected with pitfall traps, 84% of individuals consisting of five species: *Oedothorax apicatus* (Blackwall, 1852)—53%, *Pardosa prativaga* (L. Koch, 1872)—15.1%, *Pardosa palustris* (L., 1760)—7.7%, *Pardosa agrestis* (Westring, 1863)—4.6% and *Erigone dentipalpis* (Wider, 1836)—3.2%. Mostly individuals of two families were collected: Linyphiidae (47% of all individuals including juveniles, 278 individuals), and Lycosidae (43% of all individuals including juveniles, 256 individuals). The abundance of dominant species *Oedothorax apicatus* increased and abundance of individuals of genus *Pardosa* in addition to species richness decreased from the edge to the centre of the field. Values of indices of biodiversity (Simpson, Shannon–Wiener) decreased from the edge to the centre of the field but increased in the centre (Fig. 3). Species richness and dominant species did not differ in the fields with different crops. The abundance of spiders in the centre of the field was dependent on the size of the field: spiders were more numerous in smaller fields ($P < 0.05$). The data collected in September showed the same results. The total number of spiders in pitfall traps in the fields was the highest on Calcaric Regosols and lower on other soil types. On field edges no differences were found between Calcaric Regosols and Calcaric Cambisols; on Stagnic Luvisols the number of individuals per trap was fivefold higher on edges.

4. Discussion

Soil type is one of the primary determinants of soil microbial structure as shown by studies of soil bacterial community composition [14,45]. Based on our previous study results [51] we found that microbial biomass, activities of dehydrogenase and alkaline phosphatase are dependent on soil type being higher in Calcaric Regosols, whereas measured soil chemical parameters showed practically no variation between the studied three soil types; these differences in soil microbial parameters due to soil type may be related to qualitative structure of soil organic carbon as well as to soil texture [46]. We assumed the relationship between soil microbial

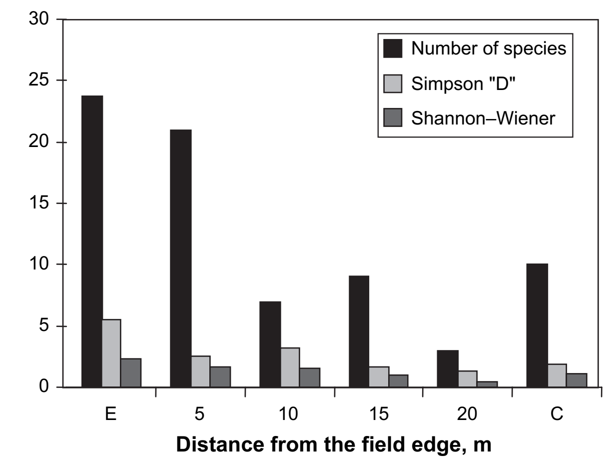

Fig. 3 – Number of spider species and values of Simpson and Shannon–Wiener indices in different distances from edge of field to field centre. E, edge; C, centre.

community and soil invertebrate communities [53] and paid more attention to connection between soil type and invertebrates.

The studied three soil types differ in invertebrate communities. There are potentially optimal conditions (aeration, moisture and acidity) for soil microbial and invertebrate communities in the upper layer of Calcaric Regosols albeit drought causes damage to soil communities in some years. In Calcaric Cambisols the water regime is more stable and the activity of soil biota is high. Stagnic Luvisols are characterized by lower biological activity because of relatively lower content of humus and higher acidity of soil. Microbial community influences the abundance and activity of soil invertebrate communities with their interactions with biotic and abiotic soil components [27].

Enchytraeidae (potworms) are small invertebrates with high abundance and high feeding and respiration activity, widely distributed in terrestrial soils and playing an important role in the cycling of matter and energy in the uppermost soil layers. Faunistic diversity of potworms is still underestimated in Europe and greatly unknown in most other regions [50]. In Estonia, 46 species have been recorded to date; the species composition of Estonian enchytraeids reflects largely the common North-Western and Central European fauna [43]. Genus *Fridericia* is the most varied and most common in soils of temperate climate [48]; in our samples several species of *Fridericia* as well as some individuals of genus *Mesenchytraeus* were identified. Distribution of enchytraeids biomass in the 15 cm upper soil layer was similar in Calcaric Regosols and Calcaric Cambisols but differed in Stagnic Luvisols, reflecting the distribution of organic matter in soil and higher intensity of agricultural measures in Stagnic Luvisols [23].

Earthworms may contribute to the decomposition of organic matter and N mineralization directly, by affecting the growth rates of other populations of soil organisms through grazing (e.g. negatively through reduction of the prey number or positively by reducing growth limiting factors for the soil organisms), by influencing soil moisture and aeration through soil structure, by fragmenting and redistribution of plant material, and excreting nutrient rich faeces; the indirect contributions are difficult to separate [8]. According to the literature [27,31] the regional abundance of earthworms and the relative importance of the different ecological categories are determined by large scale climatic factors (mainly temperature and rainfall) as well as by their phylogenetic and biogeographical histories together with regional parameters such as vegetation type and soil characteristics. Thirteen earthworm species have been identified in Estonia [48], with different tolerance to ecological factors and agricultural management. In the studied communities the species were characterized by frequency of species in cultivated soil [20]. A community consisting of species such as *Aporrectodea caliginosa*, *Aporrectodea rosea*, and *Lumbricus rubellus* tolerant to disturbance is the result of intensive tillage and agricultural practice or the influence of strong limiting ecological factors (mostly too low moisture). The occurrence of species *Lumbricus terrestris*, *Aporrectodea longa* and *Allolobophora chlorotica* indicates more suitable agricultural or ecological factors for habitat. Diversity of earthworm community was the highest in Calcaric Cambisols. Periodical drying-off of Calcaric Regosols and some typical characteristics of Stagnic Luvisols (lower content of organic matter, pH) are limiting factors for some sensitive species of earthworms [8,19]. Abundance was highest in Stagnic Luvisols despite expected low earthworm activity in this soil type [23]. Ecological and specific structure of a community is based on higher abundance of ecologically tolerant species in a community. This supports the assertion [27] that intensification of land-use causes reduction of biodiversity and extinction of epigeic and anecic earthworms that feed on plant residues.

Arthropods have been widely sampled by pitfall traps for comparison of the epigeic fauna of different habitats [5,54]. Conditions of field habitats for epigeic invertebrates are formed by soil characteristics, agricultural practice and climate. Invertebrates living on the soil surface are in continuous contact with the soil; many live all or part of their lives within the fields and are thus vulnerable to cultivation [6,18]. Tillage has an essential and mostly negative impact on soil invertebrates including beetles and spiders as the most abundant groups of predatory macroarthropods.

Carabids are among the more familiar insects caught in pitfall traps or active on soil surface of agroecosystems [37]. They are connected to habitat, sensitive and reacting to every change of environment. Diversity of carabids is formed by conditions of field habitat (microclimate, soil type, hydrogeology, topography) and agricultural practice (cultivated crop, crop rotation, intensity of tillage, fertilizers, agrochemicals) as well as by characteristics of surrounding areas and field edges [21]. Species are classified as habitat generalists or soft edge species, habitat specialists or hard edge species, and as edge species [12]. Despite the regular disturbance by cultivation measures, arable land harbours a typical carabid fauna. Several studies showed that the most common species in the fields, *Pterostichus vulgaris*, prefers open habitats and is rather favoured by agriculture [2,4,11]. In Estonia, eight species of carabids are frequent and characteristic in fields; an additional 31 species are common in this habitat [30,52]. According to the literature [29] the most common genera of carabids on

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agricultural lands are *Carabus*, *Pterostichus*, *Harpalus* and *Amara*, who eat what they can swallow; this species are most abundant in the habitats suitable for concealment and feeding, and with low intensity of agricultural practice [9].

The numbers of spiders in agricultural soils are low [5]. The absence of dominant species, remarkably low species richness and the relative importance of immature spiders were characteristic of the spider community inside the field. This proves the field vegetation to be unsuitable for spiders that inhabit the grass layer: they are sporadic in the fields [32]. *Pardosa prativaga* was the most abundant spider species on Estonian fields, the other 36 species in the fields being present occasionally with a very low abundance despite*Pardosa prativaga* being not considered as one of the common agrobionts by some authors [26,41]. According to the data collected in July, the total number of spiders remained consistent from the edge of the field to the centre, but the species composition changed. The abundance of wolf spiders (Lycosidae) that are predators to small *Oedothorax apicatus* decreases towards the centre as they are predominant on the edge. The abundance of *Oedothorax apicatus* increases towards the centre, which is probably caused by more secure conditions in the centre of the field. A high number of juvenile wolf spiders rather than mature ones was characteristic of the autumn catch. On field edges, well developed spider fauna was found, the dominating species being *Pardosa prativaga* and *Enoplognatha ovata* (Theridiidae).

Soil biota communities in the three most widespread soil types in Estonia (Calcaric Regosols, Calcaric Cambisols and Stagnic Luvisols) are influenced by environmental conditions, the factors connected to soil texture including moisture, organic matter content and pH being the most essential, and by the intensity of agricultural practice. The three studied soil types differ in potential activity of soil biota and intensity of agricultural practice on the fields. Potentially high biological activity and low intensity of agricultural human activity of Calcaric Regosols become apparent in characteristics of communities not sensitive to soil which dries off, i.e. epigeic fauna living on soil surface and preferring dry and warm habitat; temporarily dried off soil is not a suitable habitat for Oligochaeta. Both groups of Oligochaeta appear to prefer Calcaric Cambisols where soil moisture conditions are more stable. The abundance of invertebrate communities is the highest and the diversity is the lowest in Stagnic Luvisols where the intensity of agricultural measures is high and herewith some species less tolerant to habitat have been replaced with the species tolerant to agricultural activities. Some trends occurred in community characteristics along the soil surface following a hypothetical gradient: the number of carabids per trap and diversity of spiders decreased from the edge to the centre of the field. The results reported here on spatial variability in distribution of soil organisms are preliminary but more attention will be paid to it in our next studies.

Acknowledgements

This study was supported by Estonian Science Foundation (Grant Nos. 5571 and 6739). The authors thank Dr. Tarmo Timm (Estonian University of Life Sciences) for helpful advice and Dr. Rüdiger M. Schmelz (University of La Coruna) for help with the identification of *Enchytraeidae*.

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Please cite this article in press as: M. Ivask et al., Invertebrate communities (Annelida and epigeic fauna) in three types of Estonian cultivated soils, Eur. J. Soil Biol. (2008), doi:10.1016/j.ejsobi.2008.09.005

Abundance and diversity of earthworm communities in flooded semi-natural meadows

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Floodplain and coastal meadows are semi-natural landscapes rapidly disappearing in Europe due to changes in land use. The uniqueness, environmental value and cultural importance of these landscapes have become evident too late: most previously semi-natural communities are today overgrown, afforestated or cultivated. Today the species diversity of semi-natural areas is influenced by the continuity of extensive management (mowing, grazing); historical management influences the formation of both plant communities and soil characteristics (reduced fertility). Soil organisms are an integral part of meadow ecosystems, especially in food chain and decomposition process.

The aim of this study is to determine the abundance and species composition of earthworm communities in the soil of coastal and floodplain meadows in West-Estonia, to find out how the flooding of meadows influences earthworm communities and to investigate how earthworm communities' abundance and diversity are related to floods and salinity gradient of grasslands.

Material and methods

The investigation area was selected to represent grasslands temporary flooded with freshwater or saline water or both (coastal grasslands, floodplains, or intermediate transient meadows where fresh or saline water extent is indistinct). The flood duration is approximately one month in spring with shorter periods in autumn and summer. Earthworm and plant communities were studied on 11 flooded meadows in Matsalu National Park (West-Estonia) which are mown annually (floodplain meadows) or grazed with low intensity (coastal meadows), the intermediate grasslands are mown or grazed.

At each site five soil blocks (50 x 50 x 40 cm) were examined by the hand sorting or using mustard solution as vermifuge (Meyer, 1996; Gunn, 1992). Species were identified (Graff, 1953; Timm, 1999) and individuals were counted. The mean number of individuals per m^2 of soil surface and standard error (SE) were calculated. Moisture content (105^0C), pH (KCl), organic matter (in muffle furnace at 360°C), nitrogen concentration (Kjeldahl method) and soluble phosphorus concentration (lactate method), K- and Na- concentration (flame photometer) were determined for each composite soil sample.

We calculated soil ecological parameters in obliquely using plant species Ellenberg's indicator values (salt, water, reaction, and nitrogen demands in soil for plant communities using small scale qualitative list of species and coverage of each species). In addition to, we estimated soil and plant communities' species richness and analyzed ecological structure of together adapting communities (Table 1).

All earthworm and vegetation data were analyzed using non-parametric dispersion analysis of Kruskall-Wallis.

Results and discussion

Flooded grasslands of different type (Table 1) differ by soil characteristics and plant communities. Abundance of earthworm species differs as well depending on habitat conditions. To describe the habitat we used Ellenbergs' indicator values of cover forming plant species and some parameters determined directly from the composite sample of study sites. Light, temperature and soil reaction values did not differ statistically significant between meadow' types and are not analyzed.

Table 1. Characterization of investigated vegetation categories (distinguished according to moisture regime and salinity gradient). For majority of characteristics has given gradation over categories (from 1 (min. value) to 4 (max. value)), and also statistically relevant differences between four types compared (Kruskal-Wallis ANOVA, p<0.05).

General vegetation categories/ Characteristics	**I. Wet floodplain grassland**	**II. Fresh floodplain grassland**	**III. Transient grassland**	**IV. Coastal grassland**
Transects (study areas)	Kelu, Kloostri I, Kloostri II	Kasari I Kasari II	Suitsu I, Suitsu II, Lõpe	Salmi I Salmi II
VEGETATION				
Community types (by Krall *et al.*, 1980)	Wet floodplain grasslands with tall sedge or floodplain fens: Carice*tum distichae, Caricetum acutae etc*	Moderately moist floodplain meadows, sometimes describes as dry impoverished floodplain grasslands	Species rich paludified grasslands: *Scorzonero-Caricetum pallescentis,* in grazed sites *Deschampsio-Ranunculetum acris*	From saline to suprasaline paludified grassland: *Junco-Glaucetum, Deschampsio-Caricetum nigrae*
Herb layer characterization, dominant and/or character species	High and lush, sometimes lodged *Carex disticha, Carex acuta Deschampsia cespitosa*	Lush and dens, rather species-rich, high diversity of vegetation associations and variants; *Lychnis flos-cuculi, Sesleria coerulea, Geum rivale,Filipendula ulmaria*	Medium and species rich (comparable with boreo-nemoral grasslands), in grazed sites, lower, poorer and tufted. *Scorzonera humilis, Ranunculus acris, Deschampsia cespitosa*	Variable, from low and sparse to high and lush; *Juncus gerardii, Glaux maritime, Triglochin maritimum;* *Carex nigra, Potentilla anserina Festuca sp.*
Mean vegetation coverage per 1m² ±SE (%)	79.3±2.5 1. (different from 3 and 4)	94.5±2.2 4. (1)	92.1±2.5 3. (1)	88.5±2.8 2.
Small scale species richness (mean sp no per 1m² ±SE)	6.6±0.5 1. (different from 3 and 4)	13.4±0.9 3. (1)	16.4±0.9 4. (1 and 2)	10.6±0.8 2. (4)
ECOLOGY: Ellenbergs' indicator values (Ellenberg 1991; Lindacher 1995)				
Demand for continentality (mean ±SE)	0.6±0.2 1. (different from 3 and 4)	2.2±0.2 3. (1)	2.6±0.3 4. (1 and 2)	0.8±0.2 2. (4)
Demand for moisture (mean ±SE), moisture regime	8.1±0.3 4. (1 and 2) Long-lasting fresh water overflow, poorly drained to saturated or permanently saturated	7.2±0.2 3. (1 and 2) Fresh water overflow, regularly flooded, well drained	5.5±0.4 2. (3 and 4) Occasional and short-term flooding. Area, where fresh and salted water flow together	4.9±0.4 1. (3 and 4) Regular saline water overflow, highly fluctuating moisture regime
Demand for salinity (mean ±SE)	0.04±0.02 1. (3 and 4) Affected by fresh water	0.08±0.03 2. (4) Affected by fresh water	0.13±0.03 3. (1) Affected by fresh and saline water at the same time	2.44±0.78 4. (1 and 2) Affected by saline water
Demand for nitrogen (mean±SE)	4.2±0.2 4. (1 and 2)	4.0±0.2 3. (1)	2.8±0.2 1. (3 and 4)	3.2±0.3 2. (4)

Wet floodplain grasslands vegetation is classified as tall sedge meadows or even floodplain fens. Dominating community types are *Caricetum distichae* and *Caricetum acutae.* Ellenbergs' values indicate flooded and poorly drained soil. The quantity of sediment, its physical and chemical properties as well as flood duration are the main factors that determine the soil and vegetation types on floodplains (Truus & Tõnisson, 1998). Soil moisture is high (62.6±4.0%) even in period without flood and limits the abundance of most earthworm species except semi-aquatic ones. Organic matter and nitrogen contents are high because of poorly decomposed sediments; Ellenbergs' value of nitrogen demand shows temporary nitrogen rich soil. Total abundance of earthworms (40±22 individuals per m^{-2}) and number of species are low. Common in all habitats in Estonia species *Aporrectodea caliginosa* and *Lumbricus rubellus* are missing because of high moisture; anecic species are missing because of high groundwater table. Dominant species is semi-aquatic *Octolasion lacteum*, abundance of semi-aquatic epigeic *Eiseniella tetraedra* is high as well; additionally we found individuals of species *Lumbricus castaneus, Aporrectodea rosea* and *Dendrobaena octaedra.* Composition of earthworms' community is characterized by semi-aquatic species or species who like conditions of high soil moisture.

Moderately moist (fresh) floodplain meadows are more suitable habitat for earthworm: soil moisture 44.0±4.5% is high but does not limit the presence of common species. Rate of decomposition is higher because of better aeration of soil resulting to lower organic matter and nitrogen content of soil. Total number of earthworms per m^{-2} is 81±26. Endogeic semi-aquatic *Octolasion lacteum* is dominant of community, tolerant to habitat conditions species *Aporrectodea caliginosa*, *Aporrectodea rosea* and *Lumbricus rubellus* are presented as well. Anecic species are missing. We also found some individuals of epigeic species *Dendrodrilus rubidus* and *Dendrobaena octaedra.*

Transient grasslands are located between floodplain and coastal grasslands and are flooded by fresh and marine water. Very low content of marine water in flooding is not detectable but it obviously influences the specific structure of community. Soil characteristics (pH, moisture, organic matter content) are similar to characteristics of moderately wet grasslands, Ellenbergs' values of plant communities indicates soil conditions less acidic, less wet and poorer by nitrogen. Earthworm communities are less abundant but more diverse (58.8 individuals, 4.7 species). Most tolerant to ecological conditions species *Aporrectodea caliginosa* is dominating and *Lumbricus rubellus* is relative abundant. Community is diverse: species with various demands are presented – tolerant *Apporrectodea rosea*, typical for wet habitat *Octolasion lacteum, Eiseniella tetraedra*, *Lumbricus castaneus,* epigeic *Dendrobaena octaedra*.

Coastal grasslands are meadows under direct influence of a sea i.e. flooded at least by storm waves. Very low abundance of earthworm (6.0±5.0) is characteristic for coastal grasslands; only two endogeic species are present: *Aporrectodea caliginosa* and *Octolasion lacteum*. Marine water is limiting factor despite the salinity of water in Matsalu bay is very low (5-6‰). This type of grassland is not suitable for earthworms, overflooding and high contents of K^+ and Na^+ ions in soil, especially in floor layer, are strongly limiting factors for earthworms, in saline zones closed to coastline no earthworm were found. Ellenberg's value indicates concentrations of chloride ions in soil 0.05-0.3%. Real soil moisture (measured in august) is high (61.2±3.75%), in period between overfloodings the upper layer of coastal soil can dry off. This is an additional limiting factor for earthworms and reflects in Ellenbergs' value of demands for moisture (Table 1).

The most abundant on flooded grasslands earthworm species are semi-aquatic *Octolasion lacteum* and *Eiseniella tetraedra* or tolerant to unfavorable ecological conditions *Aporrectodea caliginosa*. The abundance of species depends on moisture content of soil – semi-aquatic species react positively to this parameter and other species negatively (Fig. 1).

Flooding by fresh water is positive factor for semi-aquatic earthworms and negative for all others. Salinity of flooding sea water is additional negative factor for all species of earthworms as well temporary drying off the coastal thin soil.

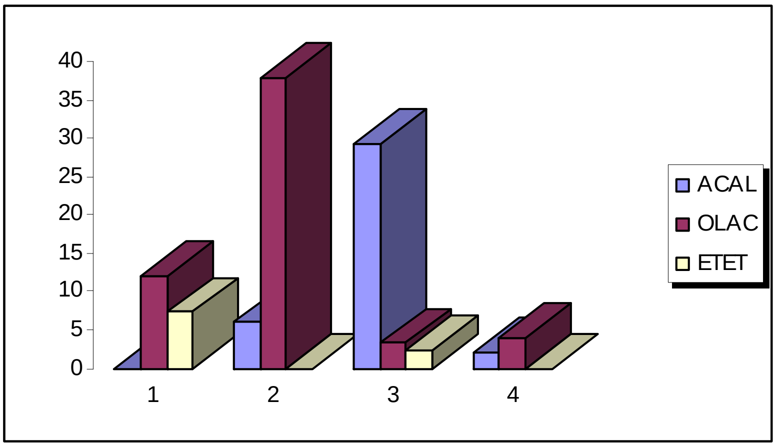

Fig.1. Mean abundance (individuals per m^{-2}) of tolerant to ecological factors species *Aporrectodea caliginosa* and semi-aquatic species (*Octolasion lacteum* and *Eiseniella tetraedra)* in different types of grasslands (1 – wet floodplain grasslands; 2 – fresh floodplain grasslands; 3 – transient grasslands; 4 – coastal grasslands)

Conclusion

The meadows differ by soil and communities' characteristics. Ellenbergs' indicator values are valuable characteristics of habitats' conditions, integrating the changes in different seasons. Flooding of soil by fresh water is limiting factor for earthworms' abundance and diversity except semi-aquatic species. Flooding of soil by marine water is limiting of abundance of all earthworm species as well as temporary drying off the thin soil layer.

Aknowledgements

This study is supported by Estonian Science Foundation, grants No 6005 and 6739.

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Pterostichus vulgaris (L.,1758)(=*melanarius* (Illiger, 1798)) and *Harpalus pubescens* (Müll.,1776) in agricultural fields

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More than 40000 species of ground beetles (*Carabidae*) have been described so far; nearly 2700 are known in Europe (Ekschmitt *et al*, 1997; Lövei, Sunderland, 1996) and nearly 300 are know in Estonia (Haberman, 1968). Ground beetles are probably the most diverse in habitat and structure of all soil-inhabiting insects. The ground beetles with their long legs are well adapted to running over the surface of the soil (Kromp, 1999). Frequently only five to six species are dominant in a particular crop fields, making up 90% of a total number of carabid individuals. Among the more important genera from agricultural perspectives are *Carabus, Pterostichus, Harpalus, Agonum, Calathus, Amara, Brachinus, Bembidion, Trechus, Clivina* and *Dyschirius.*

Pterostichus vulgaris and *Harpalus pubescens* are nocturnal autumn breeding carabids, during the day they hide under grass or stones. These carabids prefer open habitats and are rather favored by agriculture. As in many ground beetles, *P. vulgaris* has a very unspecific diet; both larvae and adults are predatory, preying on slugs and aphids (Fournier, Loreau, 2002; Fournier, Loreau, 2001); *H. pubescens* feed on seeds or strawberries (Haberman, 1968).

Agricultural activities change the diversity of the ecosystem directly, influencing the survival of individuals; or indirectly, changing the level of resources (Neher, Barbercheck, 1999). Agricultural activities such as soil tillage, turning the soil while plowing, fertilization, using pesticides, planting hedges, tree lines or small forest etc influence very strongly the soil biota, affecting the organisms living on the surface of the soil as well as underneath it (Paoletti *et al*, 1991).

One important reservoir for carabids may be the vegetation that borders an agricultural field. Field borders may benefit carabid populations by providing refuge from agricultural practices such tillage and pesticide use and a stable microhabitat for overwintering. Field borders with a well-established; thick vegetative cover and a stable microhabitat such as hedgerow (or shelterbelt) have been shown to increase overwintering success compared with the bare, open ground of an agricultural field (Varchola, Dunn, 1999). The aim of the research is to evaluate the influence of soil types, crops and borders on ground beetles in the soil of different agricultural landscapes in Estonia.

Methods

Twenty four study areas of three most widespread soil types (pebble rendzinas, typical brown soils and pseudopodzolic soils) all over Estonia were selected. In each group of soil type, eight fields with different management practices were selected for studies on 2003-2004. Collecting the samples of ground beetles on the soil the pitfall-traps were used (Meyer 1996). Depending on the purpose of the research, the traps were put in the middle of the border of the selected fields 1m outside from border of the field (in case there is a field bed) and 5m, 10m and (15m) 20m inside from the border of the field and in the middle of the field. Depending on the methods, the distance between traps is 1m and the traps are emptied after 5 days. Each different community bordering the field constitute one border, thus the number of borders is different for different fields. The traps are filled up to ¼ with 20% salt solution. The traps are covered with covers in order to avoid rainwater from getting in the traps.

In all composite soil samples moisture content (by 105 C) was determined.

Results

Mean abundance of *H. pubescens* and *P. vulgaris* did not show significant prefers for soil types and for soil moisture (Table 1). The same situation was about borders. We estimated 11+1 different type of borders but where without significant prefers. These 11+1 different field borders were: hedge, pasture, cereal, hay, road, forest, clover, corn, rape, heap of stone, melilotus and middle of field.

Table 1. Characteristics of soil of studied fields (mean value ± SE) and mean abundance of *P. vulgaris* and *H. pubescens* in different soil types. Pbr= pebble rendzinas, Tbs= typical brown soils, Pps= pseudopodzolic soils

Time	**Type of soils**	**Soil moisture %**	***P. vulgaris***	***H. pubescens***
Summer 2003.	Pbr	-	2.4 ± 1.0	**5.0 ± 1.5**
	Tbs		**4.7 ± 2.7**	2.2 ± 0.5
	Pps		1.6 ± 0.5	3.1 ± 0.8
Autumn 2003.	Pbr	13.18 ± 2.06	0.3 ± 0.1	0.8 ± 0.3
	Tbs	14.80 ± 0.82	0.2 ± 0.1	0.1 ± 0.1
	Pps	**16.93 ± 1.12**	0.4 ± 0.1	2.0 ± 1.0
Summer 2004.	Pbr	-	2.9 ± 1.6	2.8 ± 0.6
	Tbs		**3.5 ± 1.3**	3.2 ± 0.7
	Pps		1.8 ± 0.3	**4.7 ± 2.7**
Autumn 2004.	Pbr	20.04 ± 2.96	0.8 ± 0.3	2.6 ± 1.0
	Tbs	17.73 ± 0.98	1.4 ± 0.5	0.9 ± 0.3
	Pps	**20.48 ± 3.41**	2.6 ± 0.7	0.8 ± 0.2

The mean abundance of *H. pubescens* and *P. vulgaris* was the highest in cereal or cereal/clover fields and in fields of rape (Table 2).

Table 2. Mean abundance of *P. vulgaris* and *H. pubescens* in different culture fields

		Cereal	**Cereal/ clover**	**Clover**	**Rape**	**Hay**
Summer 2003.	*P. vulgaris*	**3.4 ± 1.3**	1.8 ± 1.3	1.1 ± 0.5	1.6 ± 0.7	2.5 ± 1.0
	H. pubescens	3.6 ± 0.9	**4.8 ± 1.0**	3.0 ± 0.6	1.2 ± 1.0	1.8 ± 0.5
Autumn 2003.	*P. vulgaris*	0.2 ± 0.0	**0.7 ± 0.1**	0.0 ± 0.0	**0.7 ± 0.7**	-
	H. pubescens	0.8 ± 0.3	**3.7 ± 2.2**	0.3 ± 0.3	0.3 ± 0.3	-
Summer 2004.	*P. vulgaris*	2.2 ± 0.8	4.1 ± 2.1	1.5 ± 0.8	**5.6 ± 2.7**	-
	H. pubescens	**4.6 ± 1.6**	2.0 ± 1.6	2.7 ± 1.2	1.6 ± 1.1	-
Autumn 2004.	*P. vulgaris*	1.8 ± 0.5	1.9 ± 0.7	0.4 ± 0.2	**2.4 ± 1.2**	-
	H. pubescens	1.6 ± 0.6	**3.0 ± 1.0**	0.6 ± 0.2	0.4 ± 0.2	-

Discussion

Arable land forms approximately a quarter of Estonian territory. The pebble rendzinas forms 9.0% of Estonian arable land, typical brown soils forms 9.7% of arable land and pseudopodzolic soils forms 15.1% of arable land (Kõlli, Lemetti, 1999). Pebble rendzinas soils are characterised by a high humus and nutrient content but sensitive to drought and these soils are largely cultivated. Typical brown soils are most productive agricultural soils in Estonia; these soils have high activity of soil biota. Pseudopodzolic soils are characterised by medium humus content and relatively high acidity of soil and these have also largely been cultivated (ESTONICA, 2006).

Soil texture may be of critical importance for carabids. Many species obviously prefer fields with clay soil to those with sandy soil. The greater abundance on clay soil is probably due to a combined effect of higher moisture, denser vegetation cover and higher productivity of organic substances which ensure a better food supply (Ekschmitt *et al*, 1997). While our three different types of soils are characterised by quite good humus content and productive agricultural soils, probably soil type do not play so important role for abundance of *P.vulgaris* and *H.pubescens*.

Insects are ordinarily not affected directly by normal precipitation but indirectly through the effect of precipitation on humidity and soil moisture (Ross, 1956). Different species of carabids strongly differ with respect to their preferred humidity range and generally carabids are well adapted to the drought conditions (Ekschmitt *et al*, 1997). According to Table 1, there was no prefers between species of carabids and soil moisture %. Thus, soil moisture is not critical factors in our research that affecting abundance of *P.vulgaris* and *H.pubescens.*

As described by Lövei and Sunderland (1996), habitat and microhabitat selection is influenced by temperature or humidity extremes (especially of overwintering sites), food availability, presence and distribution of competitors and the type of life history and seasonality. Lower population densities of carabids have generally been encountered in root crops then in cereals (Ekschmitt *et al*, 1997). Plants affect soil biota directly by generating inputs of organic matter above- and belowground and indirectly by the physical effects of shading, soil protection and water and nutrient uptake by roots (Neher, Barbercheck, 1999). Field ground beetle species prefer warm and dry sites (Kromp, 1999) whereas polyphagous *Harpalus spp* aggregate in crops and *P.vulgaris* moved from winter wheat to a weed strip within wheat field where feeding conditions were better (Lövei, Sunderland, 1999) like in this research where mean abundance of *P.vulgaris* and *H.pubescens* was highest in the fields where cereal, cereal/clover or rape was (Table 2).

Many species of ground beetles overwinter in the field margins and many ground beetles disperse into cereal grains from field edges, other species may remain near edge areas. Species are classified as habitat generalists or soft edge species, habitat specialists or hard edge species and as edge species (French, Elliott, 1999). Several studies showed that *P.vulgaris* avoids bare areas because of this microclimate constraint (Fournier, Loreau, 2001). In our research was no significant prefers between mean abundance of carabids and borders, probably influence abundance of carabids another factors like an age of edge, mowing, herbicide etc.

According to Lövei and Sunderland (1996), carabids can and have been used as indicator organisms for assessment of environmental pollution, habitat classification for nature protection, characterization of soil-nutrient status in forestry or describe landscape mosaic parts (Paoletti *et al*, 1991); *P.vulgaris* is good bioindicator species for conventional cultivation (Kromp, 1999).

Conclusions

Agricultural fields are heterogeneous community depending on soil types, vegetation, climate, agricultural management etc. It makes hard to investigation them through ground beetles as bioindicators organisms which are influenced by several other factors at the same time. Probably the most important factor affecting carabids are chemical compounds and agricultural management but these require further investigation.

Acknowledgements

This research was supported by the Estonian Science Foundation grant no 5571.

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