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Soil biota indicators for monitoring the Estonian agri-environmental programme

Kalev Sepp [a,*], Mari Ivask [a], Are Kaasik [a], Merit Mikk [b], Argo Peepson [a,b]

[a] *Environmental Protection Institute, Estonian Agricultural University, 4 Akadeemia St., 51003 Tartu, Estonia*
[b] *Centre for Ecological Engineering, 4 J.V. Jannseni St., 51005 Tartu, Estonia*

Abstract

The mandatory implementation of agri-environmental programmes (AEP) during the accession to the EU was a major policy development in the countries of Central and Eastern Europe. In Estonia the development of the AEP began in 1997 and the implementation of the AEP in pilot areas was launched in 2001. By this time, evaluation and monitoring methodologies of AEP had been elaborated. This paper summarises the Estonian AEP applied in 2001–2003 and presents selected indicators of biodiversity. The main focus is on the analysis of selected indicators of soil biota. Soil bioindicators (abundance, diversity, and ecological composition of earthworm communities and hydrolytical activity of the microbial community) were measured in 2001 and 2002. Two pilot areas of the AEP (Palamuse, representing a municipality with intensive agriculture, and Kihelkonna–Lümanda, representing extensive agriculture) and two reference areas where the AEP was not implemented (Mustjala and Saare municipalities) were investigated. Ten farms in both pilot areas and five in both reference areas were studied. There were differences in the abundance and number of earthworm species between Palamuse (intensive agriculture) and Saaremaa (extensive) pilot areas, but these were not statistically significant. However, the differences in the hydrolytical activity of the microbial community between Palamuse and Saaremaa pilot areas were statistically significant ($p < 0.05$). It is concluded that soil bioindicators are suitable for monitoring human pressure as well as the effects of AEPs. AEPs may increase the abundance and diversity of earthworms, decrease the dominance of *A. caliginosa*, and increase the activity of the microbial community.
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1. Introduction

The development and implementation of agri-environmental programmes (AEP) is a legal requirement for all EU Member States since the agri-environment regulation, Council Regulation No. (EEC) 2078/92, accompanied the reforms of the common agricultural policy in 1992. The mandatory implementation of AEPs during the accession to the EU was a major policy development in the countries of Central and Eastern Europe (including Estonia), and is likely to have a significant impact on farm management practices and the patterns of land use. In Estonia, the development of

* Corresponding author. Tel.: +372 7427434; fax: +372 7427432.
E-mail address: sepp@envinst.ee (K. Sepp).

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the AEP began at the end of 1997 with the "Agri-Environmental Programmes in Central and Eastern Europe" (MATRA) project (Avalon Foundation, 1998). Preparations continued under the PHARE projects "Development of the Agri-environmental Scheme in Estonia" and "Action Plan for Implementation of the Agri-environmental Programme for Estonia, N°ES 9620.01.01". The structure of the Estonian agri-environmental support scheme, the measures and the requirements for eligibility, and the administration and training system were elaborated during these projects, and a plan was drafted for the implementation of the scheme. The main activities and measures with their intended positive effect on biodiversity and landscape protection are presented in Table 1. For example, the aim of the "Environmentally Friendly Production Scheme" is to encourage the use of environmental planning by farmers and to reduce the risk of water pollution by nitrogen, while maintaining and increasing soil fertility. Farmers are required to have a Nutrient Management Plan and a Crop Rotation Plan. The total application of nitrogen (mineral fertiliser and manure/slurry) must not exceed an average of 170 kg/ha of cultivated area, and the total application of nitrogen as mineral fertiliser must not exceed 100 kg/ha of cultivated area. The crop rotation must meet the following requirements: at least 15% of the cultivated area must be under legumes or a mixture of legumes and grass species, and cereals must not be grown on the same field for more than three subsequent years.

Estonia started to implement agri-environmental support in 2000, when assistance for organic farming and Estonian cattle breeding was made available nationwide. In the following year, nationwide assistance was granted, in addition, to the production of endangered crop varieties. The Ministry of the Environment began to support the management of semi-natural habitats in protected areas. At the same time, several additional agri-environmental measures were initiated in three pilot areas. The specific objectives of this pilot project for agri-environmental measures were:

- testing the practical implementation of the AEP in the Estonian context;
- evaluating the effectiveness of the proposed AEP;
- refining the management prescriptions of the AEP in order to better meet the objectives of the scheme;
- gaining an indication of the average AEP payments per farm;
- demonstrating and promoting the concept of the AEP in Estonia amongst farmers, policy makers, politicians and the general public;
- developing a control, monitoring and evaluation system;
- elaborating evaluation indicators for the AEP and testing them in the pilot areas.

2. Material and methods

2.1. Approaches for the selection of indicators in the Estonian AEP

2.1.1. Biodiversity indicators

Indicators are partial and imperfect reflections of reality. For the evaluation of the agri-environmental

Table 1
Pilot agri-environmental measures in Estonia (2001–2003)

Scheme	Main activities and measures favourable for biodiversity and landscape protection
Environmentally friendly Management Scheme (EMS)	Minimum requirements with respect to crop rotation
	Restricted nitrogen fertilisation
	Establishment of non-cultivated field margins
	Limitations of field size
	Maintenance of landscape elements, semi-natural and natural habitats
Supplementary Measures Scheme (SMS)	Restoration and management of semi-natural habitats
	Planting of hedges
	Restoration and management of stone walls
	Creation of ponds and wetlands
	Preservation of endangered local breeds, organic farming
Abandoned Land Scheme (ALS)	Shrub clearance and annual mowing starting from a certain date
Training and Demonstration Scheme	Training and demonstration

programme, we need many indicators, since there are several goals in the management and protection of agricultural landscapes. Indicators achieve political effectiveness only if they really contribute to policy development, which would suggest that indicators are powerful enough to support the formulations of political goals. To have such a strong policy impact, the suite of indicators must give correct and complete information, which allows us to assess whether a system evolves towards sustainability or not (Piorr, 2003). Indicators suitable for one function (habitat function, landscape aesthetic, etc.) may be totally inappropriate for others; effective indicators have a format that is designed with an explicit target group in mind (Braat, 1991; Notter and Liljelund, 1993).

The selection of biodiversity and landscape indicators is difficult, because both are complex and value-laden systems (OECD, 2001). Moreover, the processes and interactions within and between ecosystems are very complex. Despite the large number of articles on biodiversity indicators (e.g. CEC, 2000; OECD, 2001, 2002; Braband et al., 2003; Büchs, 2003a, 2003b; Herrmann et al., 2003; Hoffmann and Greef, 2003) there is no such thing as a universal set of biodiversity indicators. Each agri-environmental programme needs its own set of indicators depending on the objectives that should be achieved.

While selecting indicators it is important to adopt a hierarchical approach, linking the indicators to their respective level of analysis, such as field, farm and landscape. Some indicators can have relevance only at specific scales of analysis, while others can be used at different spatial levels. For instance, the indicator 'diversity of the scenery' has significance at the level of 'landscape', whereas the indicator 'length of field boundaries' is meaningful both at the level of 'field' and of 'agro-ecosystem'.

In our research we adopted the Drivers-Pressures-State-Impact-Responses (DPSIR) framework to promote the development of agri-environmental programmes. This is the framework proposed by international organisations such as the Organisation for Economic Co-operation and Development (OECD) and the European Environmental Agency (EEA) to integrate the complex information concerning the environment into the decision making process (OECD, 1999, 2000, 2001, 2002). The DPSIR framework is used for developing and integrating indicators for measuring the state of the environment, the driving forces (e.g. human socio-economic activities) that exert pressures on natural resources, and the impacts on the environment resulting from pressures. A group of Estonian experts adopted the DPSIR framework to the local situations and estimated the impact of pressures on biodiversity state indicators (Table 2).

In order to interpret results, biodiversity monitoring needs benchmarks. National indicators describing environmental functions were identified, and the corresponding Environmental Minimum Requirement (EMR) values to allow their performance were assessed (see also Table 5). Baseline values were identified for each biodiversity indicator in each study area and were compared to their actual values. This allows us to define whether the agricultural use of an area is within its "ecological sustainability" and whether it maintains or enhances its environmental functions or, on the contrary, impairs them. In the current article we focus on soil biota indicators.

2.1.2. *Indicators of soil biota*

Soil biota play a key role in the functioning of soils, and some parameters can indicate the impact of human activities on the soil. There is evidence that measures of the size and activity of the soil biota communities, e.g. earthworm numbers, microbial biomass, soil respiration and soil enzyme activity, have considerable potential as early indicators of soil degradation or improvement (Haynes and Tregurtha, 1999). The use of soil macro-fauna – and earthworms in particular – as bioindicators relies on their prominent place in the community of soil organisms and their function in promoting processes that are considered to be linked to soil health (Doube and Schmidt, 1997). They are sensitive and efficient indicators of changes in soil health and for assessing the effects of agri-environmental measures (Haynes and Tregurtha, 1999; Paoletti, 1999; Büchs, 2003a; Schloter et al., 2003).

Earthworms possess a number of qualities that animals being used for bio-monitoring of terrestrial ecosystems need; they are large, numerous, easy to sample, easily identifiable, widely distributed, and relatively immobile; they are in full contact with the substrate in which they live and they consume large

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Table 2
Relation between pressure and national indicators of biodiversity in pilot areas

State indicators	Pressure indicators								
	Nutrient management		Livestock density		Crop rotation	Pesticide use	Land management		
	High amount of mineral fertilisers	High amount of manure	High livestock density	Low livestock density	No planned crop sequence	High amount of pesticides	Low landscape maintenance	Abandonment	Simplified landscape structure and large field
Abundance and composition of plant species in fields and field edges	−2	−1	−1		−2	−3		−2	−2
Number and diversity of carabids (*Carabidae*) in fields and field edges	−2	−1	−1	−1	−2	−2		−2	−2
Number and diversity of soil earthworm (*Lumbricidae*) communities	−2	−2	−1	−1	−1	−2		−/+1	
Functional structure and hydrolytical activity of soil microorganisms	−2	−2	−1	−1	−1	−2		−/+1	
Presence of protected species (communities) in agricultural landscape	−2	−1	−2	−1		−2		−/+1	−2
Presence of indicator species in agricultural landscape (birds, bumblebees)	−2	−1		−2	−2	−2			−2
Diversity of cultivated crops					−3				−2
Share of managed semi-natural grasslands in the total area of semi-natural grasslands				−3				−3	
Share of natural area	−1	−1				−1		+2	
Average field size					−2		−3		
Total length of field margins					−2				
Share of managed linear landscape elements from total linear landscape elements							−3	−2	
Variability of different land cover types					−1			−1	−2

	No impact	3	High impact
1	Low impact	+	Positive impact
2	Significant impact	−	Negative impact

The table shows the hypothetical estimated impact of pressure indicators for agricultural soil use on state indicators for biodiversity.

volumes of this substrate (Edwards and Bohlen, 1996). They are traditionally considered to be convenient indicators of land use and soil fertility (Graefe, 1999; Paoletti, 1999). According to Lavelle and Spain (2001), 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.

Earthworm community composition and diversity allows us to infer on soil microclimatic and nutritional conditions. According to different authors (Edwards, 1983; Paoletti, 1999; Curry et al., 2002), earthworm abundance and diversity in cultivated land are generally lower than those found in undisturbed habitats; agricultural activities such as ploughing, various tillage operations, fertilising and the application of pesticides strongly affect these animals. Decreases in earthworm abundance can be directly attributed to injuries caused by cultivation practices, or indirectly to habitat disruption and reduction in food supply, as well as high predation during and after tillage operations. Paoletti (1999) suggests the use of biomass, species number, and ecological categories (e.g. epigaeic, endogaeic and anecique) as key indication parameters in agro-ecosystems.

In addition, soil microbial community parameters have been widely used in the monitoring of soil quality (Anderson, 2003; Büchs, 2003a; Schloter et al., 2003). The soil microbial community is a component of the terrestrial ecosystem that assures the degradation of organic residues and the biogeochemical cycling of minerals. As mentioned by Beylich and Graefe (2002), the microbial activity of the soil influences its O_2 concentration and consequently the survival of earthworms.

The soil microbial properties (microbial biomass, enzyme activities) provide a reliable tool for the estimation of early changes in the dynamics and distribution of soil microbial processes within soil profiles (Kandeler et al., 1999). The validation of the discriminant function by other data sets may well yield a means of predicting the temporal dynamics of the response of soil microbial communities and their functional diversity to different management practices used in agro-ecosystems.

2.2. Study areas

In order to effectively pilot the national agri-environmental programme (AEP), two pilot areas were selected according to the following criteria:

1. contrasting areas with respect to natural conditions which shape the landscape;
2. contrasting areas with respect to agricultural activity (including farmers' attitudes), biodiversity and landscape interest;
3. areas with the following common characteristics necessary for successful project implementation:

- easily defined, with clear boundaries (e.g. by the administrative boundaries of local municipalities), and of a manageable size;
- availability of secondary data (i.e. to make best use of limited resources for data collection);
- local political support/approval of the project and AEP in general, co-operative local partners;
- clear values to protect and agri-environmental problems to solve.

Taking into account all above-mentioned selection criteria, Palamuse municipality in Jõgeva County and Kihelkonna and Lümanda municipalities in Saare county (hence forth Saaremaa pilot area) were selected in 2001 as pilot areas for testing the national AEP and the proposed agri-environmental indicators (Fig. 1) (Table 3).

Saaremaa pilot area represents an example of extensive agriculture in Estonia. The agriculture of the Saaremaa study area was also extensive during the Soviet period (before 1991) and the use of agrochemicals was much lower than the Estonian average. Since the end of the Soviet era it has further decreased and at present, most of the farmers in the Saaremaa pilot area use very little or no mineral fertilisers, and pesticide use has dropped to almost zero. None of the monitored farms were using any pesticides. The average size of fields was 2 ha. The main soil type according to FAO classification (FAO-UNESCO, 1994) is pebble rendzinas (*Rendzic Leptosols*). In Palamuse, which is a typical area of intensive agriculture, the use of fertilisers is much higher (up to 170 kg/ha of NPK); pesticides are used mainly for cereal cultivation with average quantities between 0.8 (mixed crop) and 3.8 l/ha (oat). The average field size in Palamuse was

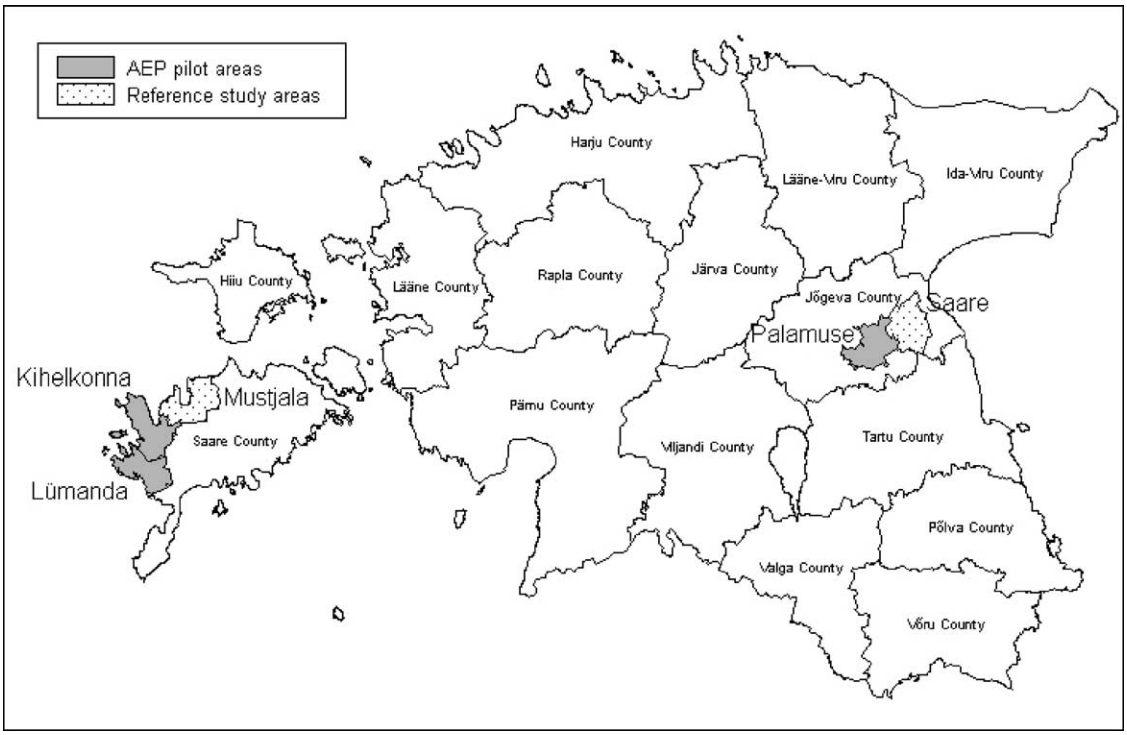


Fig. 1. Location of AEP pilot areas (Kihelkonna–Lümanda and Palamuse) and reference study areas (Saare, Mustjala).

Table 3
Application of selection criteria in the pilot areas

Selection criteria	Palamuse community	Kihelkonna and Lümanda communities (Saaremaa pilot area)
Size	Total area: 21,607 ha; total agricultural land: 10,286 ha	Total area: 44,543 ha; total agricultural land: 8841 ha
Natural factors	Situated in Upper Estonia[a] Hillocky landscape. More continental eastern climate	Situated in Lower Estonia[a] on Silurian limestone. Semi-maritime climate
Agricultural activity and biodiversity/landscape	An area of intensive agricultural production with relatively fertile soils. Unique (drumlin area) heritage landscape value	An area of extensive agricultural production on thin pebble rendzinas. Encompasses valuable (high biodiversity) semi-natural habitats
Project administration factors	Co-operative local actors present: Community government, Jõgeva County government	Co-operative local actors present: Community government, Viidumäe Nature Protection Reserve
Availability of secondary data sources	Good	Good
Local political support/approval	Community government was very interested to have its community chosen for a pilot area and they recognised the need for agri-environment measures	Community governments were very interested to have their communities chosen for a pilot area and they recognised the need for agri-environment measures

[a] Estonia is divided into Upper and Lower Estonia. After the retreat of the glacier, the waters of ice lakes or of the Baltic Sea inundated Lower Estonia during the last 10,000 years in Holocene. Lower Estonia is more marshy, more densely wooded, and flatter than Upper Estonia, which has been untouched by flooding from glacial lakes and the sea in Holocene.

4.8 ha. Typical brown soils (*Calcaric Cambisols*) and pseudopodzolic (*Podzoluvisols*) soils are dominant. In both pilot areas, 10 farms who had joined the AEP and had implemented the measure of ''Environmentally Friendly Production Scheme'' were selected. In each farm a cereal field was selected for monitoring. For both pilot areas reference areas (Mustjala for Saaremaa and Saare for Palamuse) were selected and in both areas, five farms not participating in the AEP were monitored. In these farms, fields of similar size and with the same crops as the AEP study farms were chosen.

2.3. Measurements

In both pilot test areas of the AEP, soil biotic indicators were measured in 2001 and 2002. Monitoring parameters of the earthworm populations were: abundance of earthworms, number of species, biomass per m^2, mean fresh body biomass, ecological composition of community, dominancy; additionally hydrolytical activity of microbial community was determined. Soil moisture content and acidity, as the most important limiting factors for earthworms, were also measured.

In all study fields, five randomly selected soil blocks of 50 cm × 50 cm × 40 cm in the centre of the field were studied by the hand-sorting method (Satchell, 1969; Meyer, 1996); samples were washed and weighed and species were identified according to Graff (1953) and Timm (1999). The mean number of individuals per m^2 of soil surface and standard error (S.E.), as well as the ecological composition and dominancy of communities, were calculated. In all composite soil samples, gravimetric moisture content (at 105 °C), pH (KCl), total N (Kjeldahl) and organic matter content (at 360 °C) were measured.

The total activity of the microbial community was measured using the fluorescein diacetate method, which estimates the activity of dehydrogenase enzymes in a composite sample (Schnürer and Rosswall, 1982). All data was analyzed using the dispersion analysis of Kruskall–Wallis.

3. Results and discussion

The climatic conditions in 2001 were suitable for earthworm communities. The summer (June–September) mean air temperatures were close to normal for these regions. In the Saaremaa pilot area the summer mean temperature is 14.5 °C; in 2001 it was 14.2 °C. In Palamuse the summer mean temperature is 13.3 °C; in 2001 it was 14.4 °C. Soil moisture conditions were optimal for earthworms between August and September, when average soil moisture at depth 0–40 cm was 15.6% in the Palamuse pilot area, 14.9% in Saare municipality, 21.5% in Saaremaa and 18.1% in Mustjala municipality.

There were statistically significant differences in some soil characteristics (nitrogen concentration, soil pH). Saaremaa soil pH was 7.2 ± 0.2; Palamuse soil pH was 5.9 ± 0.2. Organic matter content and total nitrogen concentration were also higher in Saaremaa soils compared to Palamuse soils (organic matter content 7.5 ± 2.0 and $2.8 \pm 0.3\%$, total nitrogen content 0.47 ± 0.14 and $0.14 \pm 0.02\%$, respectively).

Differences in abundance and number of earthworm species between AEP pilot areas and their reference areas (Lümanda–Kihelkonna and Mustjala; Palamuse – Saare) did not exist. In both Saaremaa and Palamuse test areas, six earthworm species were found. Only the species tolerant to agricultural activities (one epigeic, three endogeic, two anecic) were discovered and more sensible species were not found. The dominant species in communities was *Aporrectodea caliginosa* (81 and 89%, respectively, of all individuals). The abundance of earthworms was 32.0–224.0 m^{-2}, 1–5 species, in the Palamuse area. The abundance of earthworms was 0–614.0 m^{-2}, 0–5 species, in the Saaremaa area. There were differences between Palamuse and Saaremaa pilot areas, but these were not statistically significant (Table 4). The abundance and number of species was higher in Saaremaa; no differences were found in earthworm biomass and the ecological composition of communities between the two areas. Eighty one percentage of the individuals in Saaremaa and 89% of the individuals in Palamuse belonged to the earthworm species most tolerant to human impact, *Aporrectodea caliginosa*; although it is not statistically significant, this difference gives an indication of the higher intensity (use of fertilisers, lack of crop rotation) of agricultural activity in the Palamuse area prior to the implementations of the AEP. We expect the number of individuals of the dominant species *A. caliginosa* to decrease and some other species (*Aporrectodea rosea*,

Table 4
Characteristics of earthworm and microbial communities (mean value ± S.E.)

Parameter	Palamuse (intensive agriculture)	Saare (reference area to intensive agriculture)	Kihelkonna/Lümanda (extensive agriculture)	Mustjala (reference area to extensive agriculture)
N, individuals per m^2	117.1 ± 18.6	111.4 ± 24.2	149.3 ± 58.6	150.7 ± 55.6
S, number of species per m^2	3.1 ± 1.0	3.33 ± 1.0	3.3 ± 1.3	3.0 ± 1.5
M, g per m^2	45.5 ± 11.4	27.0 ± 8.4	45.4 ± 21.2	82.9 ± 54.2
Body mass of individual, g	0.37 ± 0.03	0.27 ± 0.07	0.39 ± 0.04	0.66 ± 0.03
Dominancy, %	88.2 ± 4.1	90.3 ± 3.5	80.4 ± 5.0	82.9 ± 13.3
Epigaeic earthworms, %	1.0 ± 0.7	0	4.3 ± 2.0	0.8 ± 1.4
Endogaeic earthworms, %	83.2 ± 9.5	95.4 ± 2.3	69.0 ± 11.9	87.7 ± 28.0
Anecique earthworms, %	5.8 ± 2.0	6.7 ± 2.6	6.7 ± 2.6	11.5 ± 8.2
Hydrolytical activity, OD per g dry soil	0.54 ± 0.05	0.57 ± 0.11	0.87 ± 0.09	0.74 ± 0.05

Table 5
Environmental Minimum Requirements (EMR) of monitored soil parameters in pilot areas

Parameter	Mean value	Minimum value	Maximum value	EMR[a]
Abundance of earthworm communities, individuals per 1 m^2, Palamuse	96	32	224	82
Abundance of earthworm communities, individuals per 1 m^2, Saaremaa	104	0	614	65
Number of earthworm species on 1 m^2, Palamuse		1	5	2
Number of earthworm species on 1 m^2, Saaremaa		0	5	2
Hydrolytical activity of microbial community, OD per 1 g dry soil, Palamuse	0.622	0.375	1.022	0.618
Hydrolytical activity of microbial community, OD per 1 g dry soil, Saaremaa	0.756	0.446	1.128	0.751

[a] Environmental Minimum Requirement (EMR) values are calculated on the basis of the national environmental monitoring data from the period 1995–2001, separately for different landscape (soil) regions. EMR = mean value − S.D. (for both areas $n = 60$).

Lumbricus rubellus, *Lumbricus terrestris*, etc.) to be found after a prolonged application of AEP.

The hydrolytical activity of the microbial community was significantly higher ($p < 0.05$) in Saaremaa than in Palamuse (0.87 ± 0.09 and 0.54 ± 0.05 OD (Optical Density, according to Schnürer and Rosswall, 1982) per gram dry soil, respectively). The differences between AEP pilot areas and their reference areas (Lümanda–Kihelkonna: 0.87 ± 0.09; Mustjala: 0.74 ± 0.05) were not statistically significant.

We have derived Environmental Minimum Requirements (EMR) for Saaremaa and Palamuse areas using the mean values and standard deviations of parameters of earthworm and microbial communities (Table 5). All calculated soil indicators were above EMRs, which indicates the stability of soil ecosystems.

4. Conclusions

The pilot project provided valuable experience in testing agri-environmental measures and indicators of biodiversity for evaluating and refining new developments in the Agri-environmental Programme in Estonia.

The set of state indicators for biodiversity (Table 2) provides a comprehensive framework to assess the level of human pressure on different categories of agricultural land. Within this framework, measures of the size and activity of soil biota, e.g. abundance, diversity and ecological composition of earthworm communities, hydrolytical activity of the microbial community, have considerable potential as early indicators of soil degradation or improvement and could be applied for monitoring the effects of AEP. There were differences in the abundance and number of earthworm species between Palamuse (intensive) and Saaremaa (extensive) pilot areas, but these were not statistically significant. However, the differences in the hydrolytical activity of the microbial community between Palamuse and Saaremaa pilot areas were statistically significant ($p < 0.05$). Two years is a too short period to evaluate the impact of AEP measures on soil biota. The collected data will be a baseline for future evaluations of the effects of different AEP measures.

The possible results of the application of AE measures are an increase in the abundance and diversity of earthworms, a decrease in the dominancy of *A. caliginosa*, an increase in the activity of the microbial community.

Comparisons between the Environmental Minimum Requirement (EMR) values of the chosen indicators and their actual values allow to assess whether agricultural use of an area is within the range considered ecologically sound and whether it maintains or enhances the area's environmental functions or, on the contrary, impairs them. The concept of Environmental Minimum Requirement is difficult to apply for some indicators, because scientific evidence is lacking. Still, wherever possible, it can be used to support the policy maker in defining quantified ecological objectives.

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