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The role of soil management in attaining environmental sustainability

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The last two decades' developments in soil management and in environmental sustainability research are considered on the basis of published papers and undertaken activities in Estonia. The main tasks of the review were to analyse (1) the actual status of research in soil resources and land use, (2) the last developments in soil management technology, and (3) the role of soils in forming environmental status. The holistic approach to soil conservation, or the unity of land use and soil protection, is propagated. The functioning of natural plant cover and cultivated crops in accordance with local pedo-ecological conditions is the main prerequisite for attaining sustainability in the environmental status. In Estonia, the research on conservation agriculture and a gradual introduction of its elements into soil management practice deserves much more attention. It is conceivable not to afforest soils suitable for agriculture, but to use them rather as grasslands or for growing energy crops.

Key words: conservation agriculture, environment sustainability, land use, soil management

INTRODUCTION

The optimization of land use on the basis of soil cover composition and properties is of utmost importance for reaching environmental sustainability in an area (farm, municipality, county) (Hellin, 2006). It is expedient to carry out a pedocentric analysis of soil (land) use and management from the agricultural, environmental, societal and political aspects (Blum et al., 2004; Van-Camp et al., 2004). In the actual review, the crucial problems of sustainable soil management and of the role of soil cover in the stabilization of environmental status on the basis of the last two-decade developments (experience) in Estonia are treated. Our review is based on information published in research papers, on the activities undertaken in the country and on actual collaboration with neighbouring countries. The main themes of the review are: (1) the actual status of research in soil resources and their quality, (2) the problems of environmentally sustainable use of soils, (3) latest developments in soil management technology, and (4) the role of soils in determining the environmental status of an area.

METHODS, CONDITIONS AND MATERIALS

Methodological principles

Our review is based on published research papers, defended doctoral theses, our conference materials and realized research projects since 1991. In addition, the manuals, guides, instructions, etc., available in printed or digital form, were also reviewed. Some standpoints may be taken as expert opinions of the authors. In the analysis of temporal developments, official national statistics were also used.

The smallest taxonomic units in analyses from the know-how aspect were soil species, the distribution and main properties of which are available from large-scale (1 : 10,000) digitized soil maps via the Internet http://xgis.maaamet.ee/. Elaborations on the suitability of soils for different agricultural crops, grassland swards and main tree species, and other information concerning better land use were available from manuals. The names of soils are used according to the WRB (FAO…, 1998).

From the territorial aspect, the most detailed level is soil contour or part of it (considered in precise agriculture), and the

highest level is the whole country level. Between these two extremities, the administrative (farm → municipality → county) or pedo-ecological (field → massive → landscape → eco-region) levels may be distinguished. In the analysis of land use and soil protection on a country level, it is rational to consider not only crop production on arable land, but to also to take into account the soil use in forestry, grassland husbandry and the protected areas associated with them.

Conditions

The main constraints of soil cover in Estonia (arranged in the order of decreasing importance) are: soil coolness (*frigid* temperature regime), continuous or periodic saturation and reduction (*aquic*) conditions, presence of acidic and low humus content topsoil, extremely coarse (skeletal) or very fine (cleyey) texture, presence of *lithic* or *skeletic* horizon in topsoil, very highly variable soil contour pattern, sub- or / and topsoil compaction, soil acidification, erosion vulnerability on hilly areas and drought vulnerability caused by a low amount of plant-available soil water. In our estimation, suitable for arable land area (or produced capital) constitutes 11,307 km^2 or 26.7% of the total Estonian soil cover. Despite the abovementioned constraints, ca. 3,419 km^2 or 30.2% of Estonian arable soils (all *Luvisols* and most of *Cambisols*) may be classified as good soils or the best soils of the region. About 28% or 3,200 km^2 of arable land needs drainage, but this has been done more than 30 years ago. At present, the proportion of well-drained lands is falling by 2–3% each year.

At the other end of the scale, soils practically suitable only for forest land (*Podzols*), with mainly in natural status soils (*Histosols, Fluvisols* and *Regosols*) are distributed together over 12,550 km^2. Hence 18,543 km^2 or 43.7% of the total area covered by soils may be classified as a reserve area for both arable and forestry use, but their use depends rather on societal, political and environmental aspects and not so much on soil suitability.

The development of agriculture during the analysed period is characterised by the data presented in Table 1. Some data about land use and land use scenarios are available on the Internet http://www.mantraeast.org/pdf/MANTRA-East_D2a.pdf.2003.

Materials

In our review, mainly the locally available (or "grey") research papers, which are published in transactions of EMU (Estonian University of Life Sciences) and ERIA (Estonian Research Institute of Agriculture) were used (Table 2). 39 and 56 papers have been published in the Transactions of EAAS (Estonian Academic Agricultural Society, issued in 1996–2001) and in the Journal of Agricultural Science (http://www.eau.ee/~aps), respectively. In the nineties, three Collections of the EAU Postgraduate and Doctoral Students' papers were also published,

Table 1. **Changes in agriculture and soil management**

Characteristic, unit	Year			
	1990	1995	2000	2005
Agriculture in total GDP, %	12.7	5.4	3.4	2.4
Agricultural employment, %	16.6	8.8	5.0	3.9
Used arable land, 10^3 ha	1116	851	810	561
Organic farming, %	–	–	1.0	7.1
Livestock density, LU/ha	0.8	0.4	0.28	0.3
Applied organic fertilisers[a], t/ha	11.5	5.2	2.8	3.1
Applied mineral fertilisers[a], kg/ha				
N	97	39	18	32
P	25	9	1	3
K	79	29	3	9
Nutrient annual balance on arable land[a], kg/ha				
N	112	32	–6	11
P	25	7	–5	–2
K	64	0	–28	–19

[a] 5-year average.

Table 2. **Transactions consisting of papers on land use, soil management and soil conservation**

Year	Institution	No.	Title of the issue	Editors	Number of papers
1993	ERIA	LXX	Estonian Soils, Their Amelioration and Fertilization	R. Kask, H. Tomson	8
1994	EAU	178	Agronomy	P. Kasearu	9
1994	EAU	179	Properties of Soil Cover and Plant Productivity	R. Kõlli	6
1996	EAU	187	90th birthday of Prof. O. Hallik	R. Kõlli	4
1996	EAU	187A	Agronomy	I. Põder	10
1998	EAU	199	Productivity and Quality of Agricultural Crops	R. Viiralt	8
1999	EAU	203	Agronomy	L. Metspalu	10
1999	EAU	205	Agronomy	E. Lauringson	10
2000	EAU	208	Agronomy	P. Põldma	7
2001	EAU	212	Efficient Conservation Agriculture	R. Kõlli	14
2004	*	219	Agronomy 2004	R. Lillak	11
2005	*	220	Agronomy 2005	R. Lillak	12
2006	*	–	Agronomy 2006	H. Nurmekivi	15
2006	ERIA	LXXI	Crop Production	J. Kadaja	12
2007	*	–	Agronomy 2007	J. Kadaja	6

* Since 2004 the joint transactions of three institutions (EMU, ERIA and JPBI) were published; ERIA – Estonian Research Institute of Agriculture, JPBI – Jõgeva Plant Breeding Institute.

Table 3. **Materials of conferences in the field of land use, soil management, and soil conservation**

Year	Title of proceedings or special issue	Institution	Editors	Number of papers
1991	Soil Conservation Problems in Estonia	EAS CNC	L. Reintam	15
1995	Soil and Fertilization	ISSS SF	E. v Boguslawski et al.	9
1995	Problems of Field Crop Husbandry and Soil Management in Baltic States	EAU	P. Kasearu, I. Põder	10
2001	Conference on Sustainable Agriculture in Baltic States	EAU	E. Lauringson et al.	8
2001	1st International Conference of BSB ISTRO	ISTRO	E. Nugis	7
2004	Soils in the Ecosystem, Monitoring, and Conservation.	EAS CNC	L. Reintam	12
2006	Soil Conservation in Nordic Countries. Special issue. Archives of Agronomy and Soil Science	ESSC	E. Schulz, R. Kõlli	6

which contained papers on soils and their management: in 1993 (ed. V. Kivi) with 4, 1994 (ed. P. Kasearu) with 6 and 1997 (eds. A. Toomsoo and K. Sepp) with 7 papers. About 20 papers addressing soil conservation were published in periodically (each 3 year) issued books on Contemporary Problems of Ecology.

Although local papers are not traditionally included into reference lists of internationally distributed journals, they are valuable not only on a country level, but also on a regional level (Baltic area). Thanks to their English summaries, they are to a certain extent usable outside the country. The main shortcoming of such kinds of publications is their brevity which makes it difficult to open problems sufficiently from a practical aspect and decreases their value for the following generations. To increase the efficiency of their use, the collected articles require periodically repeated reviews and generalizations, which promote their better use by stakeholders.

During the period under analysis, seven doctoral theses concerning the problem were defended (Ameerikas, 1993; Astover, 2007; Kanal, 1996; Lauringson, 2003; Leedu, 1998; Loide, 2002; Noormets, 2006; Reintam, 2006). Organized conferences were dedicated to different actual problems such as fertilization, sustainable land use, role of soils in environment, soil management and conservation, and others (Table 3). Research on land use, soil management and soil conservation was financed mainly by target financed projects, by grants of the Estonian Scientific Foundation, by contracts for R & D and by baseline funding (since 2005). An international research project with Estonian participation was KASSA (Knowledge Assessment and Sharing for Sustainable Agriculture; see http://kassa.cirard.fr/).

RESULTS AND DISCUSSION

Generally about developments in soil management theory and practice

Globalization requires that land use and soil management problems are treated more widely – on a European and global level (Ameerikas, 1993; WOCAT…, 2007). Despite differences among countries in pedo-ecological conditions, in cultural traditions and in economic capabilities, it is advisable to find possibilities for joint actions on common interests and to seek compromises to overcome differences. The awareness of society as a whole (especially of stakeholders) concerning existing problems, the availability of detailed information about the actual status of soil cover, the presence of elaborated treatments for the mitigation or elimination of soil degradation features and others are the basis for a realistic and fruitful collaboration. Management of sustainable soil use is the task of the state soil service which, unfortunately, has not yet been restored in our country. In such a situation, soil scientists must do their best to raise awareness in society and to introduce these problems to policymakers. It is important not only to retain the experience of our predecessors, but also to introduce the experience of neighbours working in pedo-ecologically equivalent and economically similar conditions, and the innovations of world science (Derpsch, 2007).

On the basis of the historical background and pedo-climatic conditions, Estonia should maintain or re-create its good traditions in agricultural activity and in the arrangement of rural life. The rural society is interested in nature conservation and new agricultural technologies. The success of agriculture depends on farmers, the produced infrastructure and the quality of land resources. The suitable area for innovative soil management practices seems to be conservation agriculture (CA). The contemporary effective CA is concerned with the issue of fitting food and feed production into the natural cycle of matter. Here, success depends on the advances in agro-ecology and on technological possibilities. Therefore, the quality and composition of arable soils, their properties, constraints and degradation must be monitored.

According to our understanding, national agriculture should not be oriented mainly to organic agriculture (OA) because OA is characterised by a low effectiveness and some negative aspects in connection with soil protection. For example, in many cases arable soils may be overexploited and nutrients may be depleted below the critical level, which causes some irreversible processes in the soil. Also, the optimal ratio of nutritional elements needed for plant growth may be destroyed. OA needs a much more profound scientific approach in comparison with conventional agriculture, but as a niche activity is necessary for society.

In the majority of European countries, the percentage of arable areas is considerably higher (35–75%) in comparison with Estonia (~25%), and we must be very critical about reforestation of set-aside arable lands. Reforestation of arable lands is only justified in limited areas, but not in the majority of cases. In addition, the demand for agricultural products and phytomass for energy production has grown. Existing arable land patterns among natural ones increase biological diversity and enhance the appearance of the landscape. A further decline in agricultural land use is therefore inconceivable.

Main themes of scientific researches

The large-scale soil map of Estonia was prepared before the analysed period, but thanks to its digitalization (during 1998–2001) the soil map and associated databases became available to all (Reintam et al., 2003). After regaining independence, a drastic decline in the area of arable land and in the production of cereal, meat and milk took place (Astover, 2007). It was the result of opened markets, introduced liberal trade policy and the absence of access to the European Union (EU) market. Negative effects included soil degradation (insufficient investments into maintaining soil fertility), ineffective use of pedo-climatic resources, low profitability and competitiveness of agriculture. The balance of main nutrient elements in arable soils became negative. Limited investments into soil liming and drainage have deteriorated the growing conditions on hydromorphic soils, increased soil acidity, and therefore have caused a decline in the fertility of certain soils (Schulz, Kõlli, 2006). The positive effect of reduced agriculture is reflected in a decrease of soil erosion and nutrient leaching into ground and surface water (Mander et al., 2000).

The 6th round of arable soil fertilization demands measurement proceeded in 1990–1997, but the 7th round was started in 2002. The EU environmental program of agriculture as a compulsory measure for Estonia was initiated in 2001. In 1996–1999, a survey on soil contamination in previously heavily polluted areas was started. Produced since 2005, the pilot project data on the monitoring of polycyclic aromatic hydrocarbons and pesticide residues in the soil are available via the Internet http://eelis.ic.envir.ee.88/seireveeb/.

More intensive research was continued on soil tillage technology and on the application of crop rotations (Table 4). The main topics in this area were the effects of long-term rotations on crop yields, on soil humus content, on weed seed bank and others (Lauringson, 2003). The application of organic (among them green) and mineral fertilizers were studied from different aspects (Ameerikas, 1993).

Although many long-term field experiments on soil liming were interrupted, a certain activity was mentioned throughout the study period. The systematic liming of soils began again in 1998. About 60% of Estonian arable soils have a deficiency of plant-available magnesium (Mg). The application of the industrial-origin dolostone powder enables simultaneously to solve Mg fertilization and high acidity problems (Loide, 2002).

A discernible progress was reported in research on soil compaction. The impact of compaction on plant nutrition and the biological methods of preventing soil over-compaction were investigated (FAO…, 1998; Nugis, 1996; Reintam, 2006). Another branch in biological soil science that has developed recently is research into soil organisms' (mainly earthworms and *Collembola*) role in soil functioning.

Lately, very popular among farmers are new developments in soil tillage technology and its influences on soils and productivity. The most powerful tool in CA is no-tillage and/or minimum tillage which replace mechanical seedbed preparation and amelioration of soil physical status with soil edafon activity, using additional or produced *in situ* organic matter (Derpsch, 2007). According to the preliminary data, the most suitable soils for this technology are well drained, biologically active loamy soils where weed control is supported externally (chemically or mechanically).

Thanks to the subsidizing of OA, many experimental studies are devoted to comparing organic and conventional soil management. Developments in OA are introduced on the web pages http://www.wwoof.ee/ and http://www.ceet.ee/

Research into sustainable land use is of increasing importance mainly because of EU regulations. The EU CAP cross-compliance and EU agri-environmental policy schemes require

Table 4. **Research topics and active researchers specialized on it from the aspect of land use, soil management and soil protection**

Research topics	Main active researchers in Estonia
Soil resources	
Nutrient status and use of arable land	H. Roostalu, R. Kask, A. Astover, E-G. Hannolainen, I. Tamm, J. Kanger
Practice of soil management and soil conservation	
Soil tillage technology	P. Viil, T. Võsa, A. Kallas
Role of crop rotations in soil management	E. Lauringson, H. Vipper, M. Häusler, E-G. Hannolainen
System of fertilization; application of organic and mineral fertilizers	P. Kuldkepp, E-G. Hannolainen, A. Toomsoo, E. Leedu, M. Järvan, T. Teesalu
Ecological soil management	E-G. Hannolainen, E. Lauringson, M. Järvan, I. Põder, E. Ilumäe, A. Hansson, E. Akk, J. Kanger
Liming and amendment of soil magnesium status	V. Loide, M. Järvan
Weediness and weed control	E. Lauringson, S. Uusna, V. Kastanje
Edafon of arable soils	E. Lauringson, H. Vipper, M. Ivask, A. Kanal
Soil compaction and its rehabilitation	E. Nugis, E. Reintam, J. Kuht, R. Lehtveer, T. Sepajõe, L. Edesi, K. Trükman
Soil contamination	V. Petersell, M. Järvan,
Mined lands and their recultivation	E. Leedu, E. Soovik, M. Noormets
Theory and practice of soil conservation	L. Reintam, E. Reintam, R. Kõlli, I. Lemetti
Latest developments in soil management and conservation	
Minimum- and no-tillage; precision farming	P. Viil, E. Lauringson, T. Võsa, K. Tamm
Monitoring of soil nutrient status	P. Penu, E-G. Hannolainen, T. Köster
Comparative researches on organic and conventional soil management	K. Sepp, P. Kuldkepp, K. Tamm, O. Ellermäe, E-G. Hannolainen
Conservation agriculture; unity of land use and soil protection	R. Kõlli, O. Ellermäe, T. Köster

that all agricultural land is kept in a good agricultural and environmental condition (Van-Camp et al., 2004). The implementation of the EU Thematic Strategy for Soil Protection will further increase the demand for policy-relevant soil information (Blum et al., 2004).

We have propagated in our works the holistic approach, or unity in land use and soil protection, proposed in internationally known works (Hellin, 2006). The environmental protective ability (EPA) of mineral soils was found to depend on soil biological activity, substratum (lying under subsoil) composition, soil textural properties and pedo-climatic conditions. Soils with a low protective rating are highly vulnerable to degradation, but those with a high rating are more resistant to negative influences and may be used more intensively for agricultural purposes. *Haplic&Gleyic Luvisols, Stagnic&Umbric&Gleyic Albeluvisols,* as well as *Calcaric & Mollic & Gleyic Cambisols*, which have a thick loamy or cleyey substratum, have a good EPA. The EPA of a thin and drought sensitive *Rendzic Leptosols* and *Skeletic Regosols*, which are very sensitive to pollution and to surpluses of substances in soil water, is very low.

Case study in Tartu County

For optimisation of agricultural land use and fertilization, the agro-economic field-specific decision support system (DSS) for Nõo rural municipality (Figure) has been proposed as an example (Astover et al., 2006). Relationships between spring barley yield, soil properties and fertilisation were obtained from the regression analysis of a database containing the results of >600 field experiments conducted in Estonia. A GIS-based database of soil properties was developed on the basis of 8,560 ha of arable land. Soil nitrogen (N) supply was evaluated according to soil humus content, and the economically effective rates of mineral N were found for each arable field. The economically effective N norms, which ensure the highest profit, range from 60 to 80 kg ha^{-1} on 51% of arable fields, but on 75 fields is was unprofitable to apply N for spring barley (Figure). Visualisation of the results by means of thematic maps enables the spatial variability in the soil management recommendations at a regional level to be clearly presented. The thematic maps can be used in field-specific decision-making and in allocation of agricultural production. The benefit of this approach is that

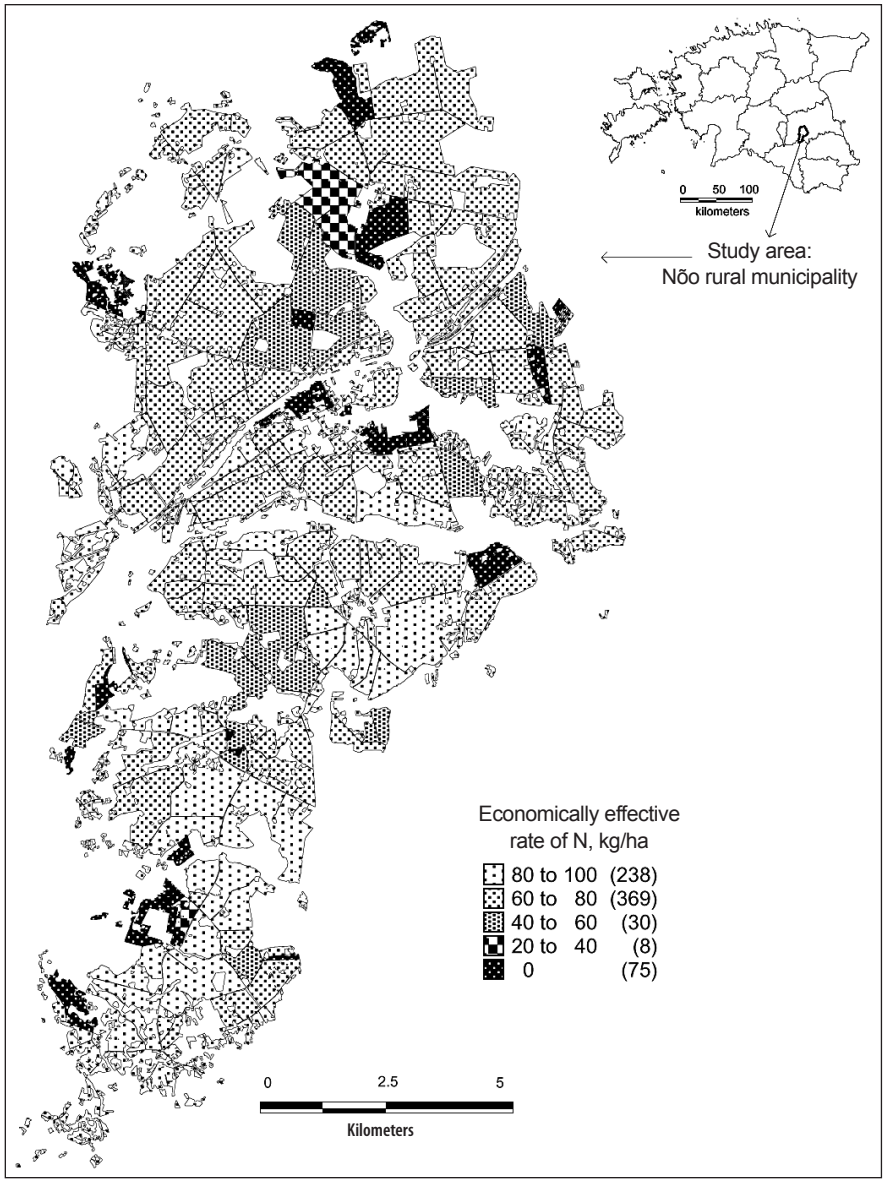

Figure. Economically effective norms of N for barley in arable fields of Nõo rural municipality. The number in brackets for each denoted range shows the number of fields

information from different sources is collected, processed and integrated into a unified system which makes decision-making more effective.

CONCLUSIONS

1. The large-scale soil maps and associated databases available on the Internet deserve a much greater utilization in the arrangement of land use and in the optimisation of soil management technology. However, first, society's awareness about soils must be raised.

2. In soil conservation, it is conceivable to introduce the holistic approach, or unity of land use with soil protection. The functioning of natural plant cover and cultivated crops in accordance with local pedo-ecological conditions is the main prerequisite in attaining environmental status sustainability.

3. In Estonia, the research on conservation agriculture and the gradual introduction of its elements into soil management practice deserve much more attention. It is conceivable not to afforest the soils suitable for agriculture, but to use them rather as grasslands or for growing energy crops.

4. In order to enhance the usefulness of local scientific papers published in a brief form, their periodically repeated critical reviewing is indispensable.

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DIRVOŽEMIO NAUDOJIMO VAIDMUO SIEKIANT APLINKOS TVARUMO

Santrauka

Pastaruosius du dešimtmečius Estijoje atliktų dirvožemio naudojimo ir aplinkos tvarumo tyrimų rezultatai paskelbti mokslinėse publikacijose. Straipsnyje siekta išanalizuoti ir atskleisti šiuos pagrindinius tikslus: 1) dirvožemio išteklių ir žemės naudojimo tyrimų aktualumą, 2) naujausių žemdirbystės technologijų plėtrą ir 3) dirvožemio vaidmenį tvarkant aplinką. Jame propaguojama vieningas (holistinis) požiūris į dirvožemio apsaugą, arba žemės naudojimo ir dirvožemio apsaugos vienybė. Natūralių augalų dangos ir kultūrinių augalų derinimas atsižvelgiant į vietos dirvožemio ekologines sąlygas yra pagrindinė prielaida siekiant aplinkos tvarumo. Estijoje žemės ūkio apsaugos tyrimams ir jų dalies elementų taikymui žemdirbystės praktikoje palaipsniui skiriama vis daugiau dėmesio. Žemės ūkiui tinkamus dirvožemius rekomenduojama ne apsodinti miškais, o verčiau apsėti žolynais ir juose auginti augalus energetikai.

Raktažodžiai: žemės ūkio apsauga, aplinkos tvarumas, žemės naudojimas, žemdirbystė