A REVIEW ABOUT RESEARCHES ON SOIL SCIENCE

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ABSTRACT. *In review the most important scientific researches conducted during 2001−2010 at the Department of Soil Science and Agrochemistry of Estonian University of Life Sciences are analyzed. The review enfolds researches on Estonian soils' properties, functioning, status, protection and sustainable management. The list of concerned to treated topics references enables to become more profoundly acquainted with presented research problems.*

Keywords: *carbon sequestration, humus forms, soil degradation, management and protection.*

Introduction

A short review includes the most important scientific researches conducted at the Department of Soil Science and Agrochemistry of Estonian University of Life Sciences during the last (2001−2010) decade. The review was prepared in connection with 18th Biennial of Baltic Agronomy Forum, which was held in Tartu in June 30th and July 1st, 2011. As a rule the review enfolds the researches on Estonian soil resources, its characterization and sustainable management, which concluding results are published in scientific journals and collections. Therefore every reader may find the source, where the problem is treated more profoundly. The main task of this work is to introduce to colleagues from other countries our research themes and to find partners for collaboration in the future.

Soils' humus status: pedoecological regularities of organic carbon sequestration

During the last decade several generalizations on Estonian soils' humus status (or functioning of soil in relation to soil organic matter (SOM) stocks and cycling) were conducted (Kõlli, Ellermäe, 2003; Kõlli *et al.,* 2004a, 2007, 2009b, 2010a, 2010b, 2010d). The basic characteristics of soil humus status are the thickness and fabric of epipedon and soil cover, stocks and concentrations of SOM and SOC (soil organic carbon) in different soil horizons and layers, and humus quality – determined by humus forms. As result of these researches the pedoecological regularities of SOC retention in soil, the influence of land use change on SOC retention in soil cover, and the share of different mineral and organic soil types in various (arable, forests and grasslands) land use conditions in total Estonian SOC storage were identified. Every soil type has a specific SOC flow throughout the soil cover depending on pedo-ecological conditions. Land use change influence primarily the properties and fabric of the topsoil, but the humus status of subsoil remains practically unchangeable. The mean soil cover area weighted SOC stock of automorphic mineral soils is 78.9 Mg ha^{-1} and that of the hydromorphic soils 127.5 Mg ha^{-1}. The aggregate of SOC retained in the mineral soils of Estonia amounts to 323 ± 46 Tg (~42% in stabilized humus, 40% – instable raw-humous material and 18% forest floor and shallow peat layers).

Annual cycling of soil organic carbon

Annual cycling of SOC is the main driving force in the formation and functioning of soil cover. The systematized parameters of SOC mean annual cycling were analyzed by mineral soils' types (Kõlli, 2001b, 2002; Kõlli, Tamm, 2009). The annual SOC inputs and outputs in natural soils (0.2–3.6 Mg ha^{-1} yr^{-1}) were calculated on the basis of annual productivity. In researches the influence of land management peculiarities on the annual cycling and balance of SOC and the agrotechnological possibilities for regulation of SOC sequestration and cycling intensity were treated. The weighted mean humus status indices of soil types may be used as benchmarks in the arrangement of sustainable land use and ecologically sound protection of soils. The hereditary soil humus status and fertility of natural soils persists after their cultivation only in low input management conditions. The attainment of SOC cycling equilibration with soil capability is the main goal of sustainable SOC management.

Distribution and organic carbon sequestration capacity of Histosols

The distribution of peat soils was established by main peat soil groups, peat thickness and peat decomposition degree. From the digital soil map (1:10,000) database with 859,701 polygons the soil mapping unit code, formula of soil texture (including peat) and formula of epipedon fabric were compiled (Kõlli *et al.,* 2009a). Peat soils form altogether 10,038 km^2 or 23.5% of the total Estonian soil cover. From the peat soils the fen soils form 59.0%, bog soils 21.7% and transitional bog soils 14.7%. 45% of peat soils are well, 26% moderately and 29% slightly decomposed; by the peat thickness 13% are very shallow, 21% shallow and 66% thick. The dominant natural ecosystems formed on peatlands are: (1) mixed birch, alder, spruce and pine forests on thin (< 100 cm) *sapric* fen soils, and (2) a sparse pine forests and hummock-ridge-hollow raised bogs wooded sparsely by pine on thick (> 100 cm) *fibric* bog soils. The accumulation of organic carbon in peatlands soil cover (0–50 cm) totals 269.4 ± 12.7 Tg and in epipedon layer (0–30 cm) 129.9 ± 5.8 Tg. The SOC sequestered into peatlands soil cover forms 45.4% of total Estonian soil cover SOC. The properties and functioning of peat soil cover and especially its epipedon layer differ in great extent by soil varieties and in comparison with peats located in deeper layers.

Chemical composition and formation of histic epipedons

The chemical properties of the superficial layers of fens and transitional bogs, together with slightly acid *peaty mull*, strongly acid *peaty moder* and very strongly acid *peaty mor* layers were studied (Kõlli *et al.,* 2010b, 2010c). Thus, it spans organic soils *(Histosols)* together with *Histic Gleysols* and *Histic Podzols*, which are intermediate between organic and mineral soils. Moderately acid eutrophic and very strongly acid mesotrophic peats of *Histosols* were uniformly characterised up to 40 cm depth, whereas histic soils were examined their full thickness extent (10–30 cm). The results show that Al, K and heavy metal contents are significantly higher and organic carbon content is lower in histic soils than in *Histosols*. The amounts of Ca, Mg, Mn and Fe are significantly higher and C:N ratio, exchangeable acidity and content of free H^+ lower in less acidic than in more acidic soil types. The total concentration of elements (excluding heavy metals) extracted by *aqua regia* is considerably higher in less acidic soils, at 28–45 g kg^{-1} *versus* 10–12 g kg^{-1}. The mean contents of elements decrease in the order Ca > Fe > S ≥ Al > Mg ≥ P > K > Mn > Na. The most abundant heavy metals are Pb (12–33 mg kg^{-1}), Zn (7–41), Cu (3–12), Cr (2–23) and Ni (2–8). Cd and Hg contents are very low, ranging from 0.2 to 0.5 mg kg^{-1}. In the forming of epipedon from forest floor, (1) the content of *aqua regia* extractable Fe, Cr, Al, Pb and Ni are increased to a great, but S, Na and Hg – to medium extent; (2) the contents of Zn, K and Mn have decreased to great, but Mg and P – to medium extent; (3) the contents of Ca, Cu and Cd remain at the same level. The comparison of *Histosols*' subsoil and substratum peats with *Histosols'* epipedon demonstrates the considerable accumulation of Mn, Pb, Cd, Zn, Hg and Na into mires thin (20 cm) superficial peat layer.

Humus forms and their classification

The humus forms are the base for the interpreting SOM role within ecological framework (Kõlli, 1992, 2010; Kõlli *et al.,* 2008b, 2009; Zanella *et al.,* 2010). In European Reference Base for humus forms the main accent is given (1) to the general structure and principles of classification and (2) to the characterization of terrestrial (formed on automorphic soils) and semiterrestrial (semi- and hydromorphic soils) humus forms. The adequate explanations and comparative analysis are given for zoogenically and non-zoogenically formed organic horizons of humus forms taking into account the structure of organo-mineral horizons and the dominant species of soil animals. Our comparative research into European and Estonian humus forms classifications revealed inclination of the first one toward Mediterranean pedo-ecological conditions.

Soil protection: a pedocentric and ecosystem approach

The constraints of soil are features or circumstances (deficiency, shortcoming, disability) which hinder (limit, prevent) the optimal functioning of soil and prevent to reach the productivity level characteristic to the bioclimatic region. The main constraints are waterlogging, scarcity of organic carbon in topsoil, extremely coarse soil texture, water erosion, flooding, drought hazards, be the presence of lithic, strongly podzolized and compacted soil layers. Soils' degradation features and their causes are widely variegated (Reintam *et al.*, 2001). Soil degradation is deterioration of soil quality, i.e. the partial or entire loss of one or more potential functions of the soil (Kõlli, 2001a; Kõlli *et al.,* 2006, 2008a; Kõlli, Kanal, 2010). More complicated is to identify ecological (soil type-specific) degradation: destruction of soil functioning, degeneration of biological activity, depletion from nutrition elements, worsening of humus status, and presence of deficiency or excess in trace elements. The measures to prevent soil degradation are as numerous and various as the factors which cause the problem: starting from the public awareness, introduction of sound measures for the sustainable use, protection and systematic monitoring of soils to state-supported programs for liming of arable soils, restoration of contaminated soils, reconstruction of drained areas and others. Very important is the enforcement of legislation for protecting fertile soils.

Environment protection ability of soils

The environmental protection ability (EPA) of soils is an integrated capability of the soil cover to stabilize the functioning of the soil's ecosystem in the discharging of environmentally harmful fluxes of substances into the soil. The influence of soil cover on the environmental conditions of an area depends greatly on soil type peculiarities (Kõlli *et al.,* 2004a, 2004b, 2008d, 2009c). Soils with a low EPA are highly vulnerable to degradation, but those with high EPA are more resistant to negative influences and may be used more intensively for agricultural purposes. For evaluation of soils' EPA the soil humus status, texture, specific surface area, cation exchange capacity, calcareousness, thickness, biological activity and fabric of epipedon were used. If the EPA of the epipedon is determined first by the content and quality of SOM, then the EPA of the metric soil layer can be calculated mainly by soil particle size composition and the presence of coarse soil material. The soil management strategies, which lead to higher soil productivity, also enhance the soil's ability to protect the environment. Soil cover is a medium through which the environmental status of an area can be improved.

Contamination of soils

Organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) were analyzed in selected Estonian soils (Sajwan *et al.,* 2008; Kumar *et al.,* 2009). The predominant contaminants were PCBs, followed by OCPs and PBDEs. The PBDEs in Estonian soils were reported for the first time. Based on the data on PCBs, OCPs, and PBDEs, the contamination level of these persistent organic pollutants is relatively low. The results also confirm that Estonia is one of the cleanest eastern European countries.

Changes in agriculture, soil nutrient balances and status of Estonian arable soils

The decrease in agricultural land use and production was very large-scale in the transition to a free market economy and continued until EU CAP was implemented in Estonia (Astover *et al.,* 2006a). The regional differences in land use changes in the 1990s were determined mainly by local bio-physical disadvantages such as soil quality. The efficiency and expediency of natural and economic resources use from the aspects of different soil management, manner of production and market situation were analysed (Vasiliev *et al.,* 2006; Vasiliev *et al.,* 2008; Astover *et al.,* 2008). Plant nutrient (N P K) balances in Estonian arable soils ascertain since 1990s potential degradation of their agrochemical status, which was caused by low investments into arable land (Astover *et al.,* 2006a; Tamm *et al.,* 2009). In collaboration with colleagues from Latvia, Lithuania and other Eastern Europe countries the results of national agro-chemical survey on P status and balances in arable soils were summarized (Csatho *et al.,* 2007; Kõlli *et al.,* 2008c). In Estonia only 40–50% of the yield potential of cereals is realised in actual farming conditions and low realisation of potential is partly due to the insufficient use of fertilisers (Roostalu *et al.,* 2001; Vasiliev *et al.,* 2006).

Soil compaction and its monitoring: the effect of agricultural activity on soil deformation and plants productivity

The soil compaction and fertilization influence: (1) on soil physical properties – bulk density, penetration resistance, water content, porosity, water and air permeability, shear strength and others, (2) on content of plant available P, K, Ca, Mg, total N and SOC, (3) on pH, and (4) on cultural plants and weeds production, development of their shoots and roots, changes in plant community and others were studied (Kuht *et al.,* 2003; Kuht, Reintam, 2004; Reintam, 2011; Reintam, Kuht, 2003; Reintam *et al.*, 2005, 2006, 2008, 2009a, 2009b; Trükman *et al.,* 2006, 2008). The roots resistance to loads, assimilation of nutrients from the compacted soil and roots affect on soil properties were investigated on intensively managed grasslands. The grassland cultures with their extensive root system reduce (due their regeneration ability) the harmful effect of soil compaction and improve soil properties.

Development of spatial agro-economic decision support system

The application of soil information systems, digital soil maps and pedo-ecological models for land use planning were under the research (Astover *et al.,* 2006b). In order to stabilise agricultural production the optimal land use and agricultural production models for diferent regions were elaborated. Optimization of land use and agricultural production in Estonia proceeding from pedoclimatic, environmental protection related and economic conditions were studied. Systematically generalized soil cover data, know-how about functioning peculiarities of different soil types and digitized soil maps have been a ground for GIS based exploitation of land (soil) resources and creating of internet based advisory services for farmers. On the base of each agricultural massive (field) soils analysis the efficacy, expediency and related with production processes risks in exploitation of natural and economical resources in dependence of land use peculiarities, specificity of management (production) and market situation were explained. Pedotransfer functions (compatible with the large-scale soil map of Estonia) for soil bulk density prediction were provided (Suuster *et al.,* 2011). The compilation of digital databases for elaboration optimal land use and agricultural production models for different Estonian regions are under way.

Researches conducted in long-term field experiment

IOSDV (Internationale Organische Stickstoff Dauerdüngungs Versuche) long-term field experiment in Tartu was established in 1989. Effect of mineral and various organic fertilisers on crops yields and its quality, soil properties (Teesalu *et al.,* 2003; 2006; 2008; 2009; Raave *et al.,* 2004; Szajdak *et al.,* 2006; Leedu *et al.,* 2008; Toomsoo *et al.,* 2009) and biota (Kautz *et al.,* 2002), energy efficiency (Astover *et al.,* 2009) etc was studied. The nutrient cycles in system plant-soil, plant nutrition, nutrients efficiency of fertilization and balanced fertilization were studied on the base of long term field rotation: application of different soil nitrogen forms in depending from crop, fertilizing load, soil management and weather conditions; using of cereals straw and soil improvement material (1:1 − bog peat : oil shale cock) as soil organic fertilizers (Teesalu *et al.,* 2006). Soil improvement material is not suitable for spreading directly to the field as organic manure. For fertilizing agricultural crops it recommended to mix (to compost) with town wastewater sludge or solid fraction of pig slurry. These composts improve soil agrochemical parameters in same amount like farmyard manure (Raave *et al.,* 2004). On the base of field trial the effect of organic and mineral fertilizers on soil humus status, on available K, P, and soluble S content in soil as well the actual and residual effect of manure on grain yield and chemical elements ratio in hay were studied. The highest yields were received with the coeffect of organic and mineral fertilizers (increase 58–70%).

The influence of produced from semi-coke recultivation substance and composts on soil characteristics, yield of field crops and environment was studied (Raave et al., 2004). The recultivation substance (oil shale semi-coke with acid bog peat) is (thanks to high Ca and Mg content) suitable for neutralizing acid soils, but its effect on humus pools is not significant. Recultivation substance should be enriched with some nutrient rich organic matter, for which sediment mud from water treatment plants and pig manure prove highly suitable. The environmental hazard of recultivation substance weathered for six months is low.

Complex characterization of Estonian soils: properties, functions, productivity, ecology

Soils properties, functioning and ecology were systematized on three soil matrixes (postlithogenic and synlitho-

genic mineral soils, and organic soils). On the background of these matrixes the generalized data by soil types and pedoecological regularities are presented (Kõlli *et al.,* 2003, 2008b, 2009a; Kõlli, Teras, 2007). Our researches give a systematic characterization of arable and forest soils properties on soil species level, elucidate soil ecology in dependence of land use peculiarities and form a base for soil use in harmony with local conditions. The comparative analysis of arable and natural soil properties and functioning helped to detect wrong perceptions, which have been rooted into everyday land (soil) management. The composition (bio-ecological quality) of SOM (as indicator of soil ecosystem functioning activity) was investigated in concordance with local ecological conditions on the background of generalized SOM quantitative characterization (Szajdak *et al.,* 2005, 2006; Kõlli *et al.,* 2009c). The *Histosols'* peats decomposition and transformation mechanisms and kinetics in natural and cultivated conditions with an aim to create the model of peat transformation kinetics for cultivated exhausted peatlands are investigated.

Soil phosphorus status and its sustainable management

In collaboration with colleagues from Latvia and Lithuania the results of national agro-chemical survey on P status in arable soils over last five decades were summarized (Csatho *et al.,* 2007; Kõlli *et al.,* 2008c). Changes in plant available soil P supply was researched in context of agronomic and environmental aspects. P surplus in arable soils of Baltic countries rests in average under 10%, but P deficiency varies in limits from 27 to 38%. On these areas the mitigation of soil scarcity and optimization of soil P status are needed.

Open cast oil shale quarries and waste dumps: soil formation and agricultural reclamation.

Researches of primary pedogenesis on skeletal quarry detritus of open-cast oil-shale mines show that the humus-accumulative process together with argillisation in situ and development of exchangeable complex are more intensive in cultivated detritus (Reintam, 2004, 2010). On long-term experimental areas situated on antropogenically influenced materials the physical properties, chemical content, recultivation technology and development of microflora were studied (Leedu, 2010a, 2010b; Leedu *et al.,* 2010). In the same region the impact of surface deformation (following to underground oil shale mining) and application of recultivation substance to crop yields were as well studied.

Conservation agriculture: ecologically sound and sustainable use of soil resources

In management of arable soils the tools of conservation agriculture should be used (Kõlli, 2001a; Lahmar *et al.,* 2006). The soil cover is protected (or sustainable land use is attained) in circumstances when soil fertility and functioning is maintained according to the soil type capability (Kõlli et al., 2008a). With the decisive importance in the arrangement of sustainable land use is the matching of soil cover with suitable plant cover on natural areas, and with crops on arable lands (Kõlli, Kanal, 2010).

Biomass potential from agricultural land for bio-energy

Agricultural land resource (including abandoned land) potential for bio-energy production was studied in several regions of Estonia (Suuster *et al.,* 2008; Kukk *et al.,* 2010a; Kask *et al.,* 2011). Soils of abandoned areas are generally of low quality and with limited suitability for crop production; as a result soil-crop suitability analyses could form the basis of knowledge-based bio-energy planning. Agronomic and socio-economic criteria affecting the efficiency of energy crop production were analysed (Astover *et al.,* 2009; Kukk *et al.,* 2010b).

Besides named above researches was as well conducted many episodic researches. For exemple: taxonomy of Estonian soils and its harmonization with international systems (Reintam, Köster, 2006; Reintam, 2007; Kõlli, 2010), biochemically active organic compounds in soils (Szajdak *et al.,* 2005, 2006), peats decomposition ecology and kinetics in Histosols (Tõnutare, 2011) and others, which short characterization was not presented above.

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ÜLEVAADE MULLATEADUSE-ALASTEST UURIMUSTEST

Raimo Kõlli, Alar Astover ja Endla Reintam

EMÜ mullateaduse ja agrokeemia osakond

Kokkuvõte

Ülevaade käsitleb EMÜ mullateaduse ja agrokeemia osakonna mullateaduse-alaseid uurimisi aastatel 2001−2010 teemade lõikes. Ülevaade koostati seoses Balti agronoomide foorumi 18. biennaaliga, mis toimus Tartus 2011. aastal 30. juunist kuni 1. juulini. Töö käsitleb peamiselt Eesti muldkatte kui loodusressursi omaduste ja kestliku majandamisega seotud probleeme, eesmärgiga tutvustada neid Balti kolleegidele ja leida võimalikke temaatikaid edaspidisteks ühisuurimusteks. Esitatud on ennekõike need uurimused, mille kohta on publitseeritud kokkuvõtvad artiklid (vt kirjanduse loetelu). Loodetavasti annab taoline esitluslaad põhjalikuma ülevaate meie kompetentsist erinevate probleemide lahendamisel.

Ülevaates käsitletud uurimisprobleemid on: mulla orgaanilise süsiniku akumuleerumise ökoloogilised seaduspärasused ja aastakäive; orgaanilise süsiniku akumuleerumine turvasmuldades ja turvastunud epipedonite keemiline koostis; huumusvormid (ehk huumuskatted) ja nende klassifitseerimine; muldade keskkonnahoiuvõime hindamine lähtuvalt ökosüsteemi tasemelt; muldade saastumine; põllumuldade toiteelementide bilanss ja seisund; muldade tihenemine ja selle seire; põllumajandusliku tegevuse mõju muldade deformatsioonile ja taimkatte produktiivsusele; muldade kasutamise ruumilise agro-ökonoomilise nõuandesüsteemi arendamine; pikaaegsete põldkatsetepõhised uurimused; Eesti muldade kompleksne iseloomustus – omadused, talitlemine, produktiivsus, ökoloogia; muldade fosforiseisund ja selle kestlik majandamine; mullateke põlevkivikarjääridel ja jäätmekuhjatistel ning nende rekultiveerimine põllumajanduslikuks kasutamiseks; muldkatet säästev (keskkonnahoidlik) maakasutus; põllumajandusliku maa potentsiaal bioenergia otstarbelise taimse massi tootmisel.