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Soil priorities for Hungary

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1. The natural soil setting

Hungary is located in the Carpathian Basin. The 93,030 square km territory of the country occupies about 1% of Europe. The natural conditions allowed the formation of soils with favourable properties for performing important ecosystem services. The elevation in more than half of the country is less than 200 m, and only 2% is above 400 m above sea level. The mean annual temperature is 10 °C for most of the country and the mean annual precipitation is between 500 and 800 mm. The amount of precipitation tends to be higher in the western part of the country and in hilly areas, and lower on the lower lying plains.

The major soils covering the landscapes are defined as World Reference Base for Soil Resources Reference Soil Groups (IUSS Working Group WRB, 2015) in Fig. 1. The low elevation areas are mainly covered by Chernozems, Kastanozems and Vertisols and Arenosols, formed in aeolian and alluvial materials. In depressional areas Gleysols, Stagnosols, Solonetz, and Solonchak soils occur. Histosols and Fluvisols used to cover large areas, but due to the intensive drainage and river control works in the past 180 years their geographic coverage decreased significantly and hardly show up in the mapping scale presented in Fig. 1. Luvisols are the most common soils in high elevation, generally forested areas and are often associated with Cambisols, Regosols and Leptosols on eroded landscapes.

2. Historical changes in soil priorities

The understanding, interpretation and priorities of soils have changed over the past few decades. Before scientific approaches natural soil fertility was the major priority. As chemistry and field-based sciences developed, research became a stronger priority. During the early 1900s Hungary played a significant role in shaping priorities in soil science. At the initiative of Hungarian soil scientists in the Royal Hungarian Geological Institute, the 1st International Conference of Agrogeology was organized in Budapest in 1909 (Szabolcs, 1997). One of the major conclusions were that soil science lacks uniform methods of laboratory investigations and a uniform system of soil classification. These desired goals determined the research priorities for many years not only in Hungary but also in the International Society of Soil Science (van Baren et al., 2000). The coming years were characterized by intensive research in the laboratory and in the field. A national soil classification system and maps of different scales from national level to field scales were produced (Treitz, 1927; Kreybig, 1938; Stefanovits and Szűcs, 1961; Szabolcs, 1966). In the socialist period regular laboratory investigations where compulsory for proper nutrient management and

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several legislations on soil protection were launched together with the National Soil Conservation Service and the Soil Information and Monitoring System (SIMS).

As result of this renaissance of soil surveys and mapping activities significant amount of soil information accumulated in Hungary, however at around the end of the 20th century both the degree and the nature of needs for soil information changed. Spatial Soil Information Systems and Digital Soil Mapping have taken over the role of traditional soil maps in the field of data service, relying mostly on legacy soil data.

3. Current priorities

3.1. Combating, reversing soil degradation and maintaining healthy soils

Despite of the richness and diversity of the soil resources of Hungary, our soils are under severe threats. The agricultural lands that represent approximately 60 % of the country are threatened by soil sealing, organic matter decline, decrease in biodiversity and structural soil degradation, that often result in low infiltration and moisture storage causing extreme wet and dry soil conditions with low resilience.

Despite of the obvious agrotechnological advantages, and notwithstanding the implementation of integrated pest management measures, there has been no spectacular reduction in the use of pesticides. Pesticide use remains to present a significant threat in terms of diffuse soil and water pollution (Székács et al., 2015). It needs to be emphasized that soil fertility remains globally high and not substantially affected by diffuse pesticide contaminants, yet the effects of these xenobiotics on soil biodiversity is a permanent pressure on soil health. The objective by the EU Green Deal of the reduction of pesticide usage to 50 % by 2030 should be unequivocally beneficial in the protection of soil of Hungary.

The main priorities from a soil property point of view are to stop and reverse these processes by knowledge share, policy support and awareness raising of regenerative agriculture.

3.2. Digital soil mapping (DSM)

Hungarian Soil Spatial Data Infrastructure has been recently renewed in the frame of the DOSoReMI.hu initiative (https://dosoremi.hu/en/) to broaden the possibilities, how demands on spatial soil related information could be satisfied in Hungary, how the gaps between the available and the expected could be filled with optimized digital soil (related) maps. Soil property, soil type and functional soil maps have been compiled. The set of the applied DSM techniques has been gradually broadened incorporating and eventually integrating geostatistical, machine learning and GIS tools and very recently spatially non-exhaustive ancillary observations. The novel type spatial soil information in the form of nationwide, thematic digital soil maps have been utilized for the support of both (i) internationally initiated programs (Land Degradation Neutrality and Ecosystem Services assessment or support of the achievements of Sustainable Development Goals) and (ii) national activities (dedicated for example to the designation of areas suitable for irrigation; risk modelling of inland excess water hazard; mapping of potential habitats). Since DSM knowledge and environment can be considered well established, the development could and should be mainly expected from the availability of proper observation data.

3.3. Making soil data available for the end users

The Digital Agriculture Strategy (1470/2019. (VIII. 1.) Hungarian Parliament, 2019) defines a national plan for sharing publicly not available digital data (climate, different spatial datasets etc.) and creating new databases to support research and the society. One of the key datasets to be established is the SoilWeb database, which aims to automatically collect and share all georeferenced soil information

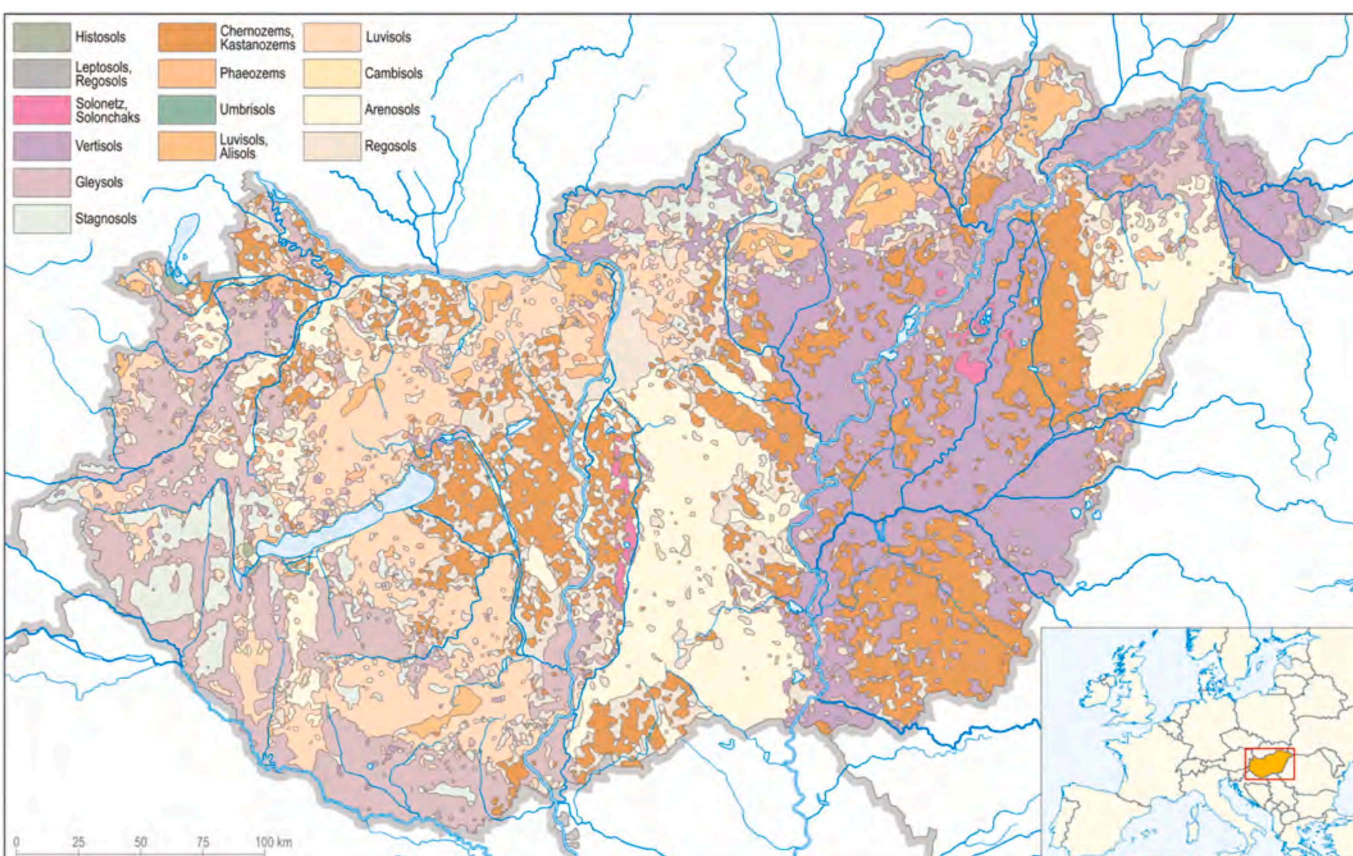

Fig. 1. Dominant Reference Soil Groups of Hungary according to the World Reference Base for Soil Resources. Source: Pásztor et al., 2018

measured in accredited public and private soil laboratories. The collection and integration of these currently mostly single purposely sampled and analysed soil information could yield approximately 200.000 spatially located soil analysis results annually. The estimated value of the laboratory measurements of this unused data source is over 2 M Euros annually, excluding the sampling and transportation costs. The database will be made available for government bodies, public and private companies and institutions and individuals, through an application granting different access levels to different end-users. The SoilWeb will serve research and to reach the targets of the Sustainable Development Goals and the European Green Deal (European Commission, 2020).

3.4. Modernizing and harmonizing methodologies

Having good quality and sufficient quantity of soil information plays crucial role in the protection of vital functions and ecosystem services of soils. Thus, the development of time and cost-effective methodologies are needed to meet the requirements for quantitate data in soil surveys. Recognizing the importance of the soil's preservation, the temporal and financial limitations of traditional laboratory technologies and the urgent need of spatially and temporally rich soil information the Agrotechnology National Laboratory (ANL) is under establishment to develop methods and technologies for the spread of environmentally and climate friendly, digitally supported agriculture in Hungary. The Hungarian Soil Spectral Library (HSSL) based on visible – near-infrared and middle-infrared spectral measurements will be among others the core elements of the ANL. The data integration, data harmonization and the establishment of the HSSL with standardized methods and soil property estimation services the standards and protocols of the GLOSOLAN (Global Soil Laboratory Network) are adopted.

Another important initiative to satisfy global soil information compatibility is the modernization of the Hungarian Soil Classification System. The developed “diagnostic” system is based on the accumulated data and experiences with the earlier genetic system as well on the application of new pedometric tools. The definitions and limits of the diagnostic categories (horizons and properties) correspond with the World Reference Base for Soil Resources, but are not identical, they are much simpler, and adopted for the environmental setting of the Carpathian Basin (Michéli et al., 2019).

3.5. Education and outreach

Soil science and its technological support has been improving fast in the last few decades, while the practical interpretations and application of the new findings are far behind. Due to the political and economic changes in the early 1990s, the land-ownership structure has changed and the ratio of landowners having no agricultural education has increased. The modern agricultural production is driven by technology and gives almost no room for scientific perspective. There are three main pillars influencing the practical applicability of soil science. On one hand there is a fast development in technology and science, while communicating the importance of soil properties, the soil functions and the risks of soil degradation is lagging behind. There is a huge gap between the academic knowledge and the application of it. Since the practical implementation of soil protection could be performed only by the farmer education, outreach, and public awareness raising are the key elements for protecting our soil resources and helping the end-users better managing of their soils. Farmers are eager for knowledge, which should be satisfied by appropriate training tools, demonstrations, lighthouses. Besides of the expert level support - continuous training of soil experts and strengthening the human resources of the universities and research institutes for successful outreach - the key components of the strategy are the strong training campaigns for kindergartens, schoolteachers, demonstrations to the farmers, and community level awareness raising. Outreaching towards the political bodies may help strengthening the soil related legislation and the legislative level integration of soil science.

3.6. Good examples for the power of bringing science to citizens and practice

The impact of the 2015 International Year of Soils (IYS) in Hungary proved the power of awareness raising, bringing education and outreach to a priority in soil science. Unbelievable impact was observed in the understanding of soil functions in the broad society as the result of the awareness raising campaigns, infographics and events. Significant portion of the population understood that a tablespoon of soil hosts more organisms than people of the planet, and soil biodiversity is an important issue, and other key messages of the IYS.

Research, outreach and practice relationships are well demonstrated in case of carbon management. The communication of the need and ways of increasing soil carbon content was one of the driving forces of the significant afforestation in Hungary. As result the soil organic carbon stock increased by 14.9 Tg C (1 teragram $= 10^{12}$ g) between 1992 and 2012 in Hungary (Szatmári et al., 2019) under afforested Luvisols. Some other Reference Soil Groups showed an increase as well, except Histosols, leaving the important message that wetlands and restoration activities need more research and attention.

Another favourable impact of the afforestation is the reduced potential soil erosion in Hungary by up to 0.28 t/ha/year on average in Hungary between 1990 and 2018 reported by Waltner et al. (2020).

It is also worth to mention that ploughing was the dominant practice, and limited tillage was refused by the majority of the farmers. Thanks to research results (Dekemati et al., 2019) and long-term tillage experiments and demonstration farms and events, farmers tend to understand the significance of the resulted structural degradation in the best soils and realize moisture saving in better tillage practices.

The examples highlight that beside research priorities, education, outreach, and the implementation of scientific results in practice are equally important in preserving or improving soil resources.

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Declaration of Competing Interest

None.

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