https://doi.org/10.17221/66/2025-SWR

Possibilities of agricultural soils evaluation in the Czech Republic

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Citation: Ürge V., Formánek P., Vopravil J. (2025): Possibilities of agricultural soils evaluation in the Czech Republic. Soil & Water Res., 20: 243–252.

Abstract: In this study, the evaluation of soil quality was realised using the Analytic Hierarchy Process, and the obtained values were integrated with Evaluated Soil Ecological Units (BPEJs). Different maps of the Czech Republic were elaborated with BPEJs classified into five soil protection classes based on the obtained model values (with or without the values for production potential), the ratio of 80% (production potential values) to 20% (model values) or 60% (production potential values) to 40% (model values) and 40% (production potential values) to 60% (model values). The evaluation of BPEJs based on the mentioned criteria showed differences in their classification into individual soil protection classes and possibilities of their use or withdrawal from the agricultural land fund. Compared with the existing categorization of BPEJs into soil protection classes (according to Decree No. 48/2011 Coll.), the use of presented model (plus production potential) values, the ratio of 80 : 20%, 60 : 40% or 40 : 60% (production potential: model) caused the numbers of BPEJs increased in those soil protection classes where the withdrawal of soils from the agricultural land fund is possible only exceptionally or it is possible to use the soils for building purposes only under certain conditions.

Keywords: agricultural land resources; hydrological groups; physical soil properties; soil quality indicator; texture

The quality of soils is a major factor influencing crop yields and quality. It was, for example, described to play a role in decision-making processes, etc. The concepts of soil quality and soil health, or ecosystem services, including their history, etc., are, for example, described in the review by Bünemann et al. (2018), Janků et al. (2022b) or El Behairy et al. (2024). Different soil functions are also discussed in the review by Blum (2005); visualising the quality of nature, the evaluation of ecosystem services including their use in decision-making process, the reduction of risk and uncertainty or the measurement for management (and value for future) are, according to Janků et al. (2022b), the reasons for ecosystem services evaluation. The assessment of soil quality can be realised based on physical, chemical and biological soil properties, and the soil properties used for soil quality assessment may change with land-use changes, effects of soil erosion, etc.; for example, soil erosion may influence ecosystem services (e.g., crop production, carbon storage, etc.). (e.g., Guilin et al. 2007). Bünemann et al. (2018) evaluated 62 different publications and found that chemical (total organic carbon, soil pH, available P and K) and physical (water storage, bulk density, texture) soil properties are the most frequently used as soil quality indicators. Soil

Supported by the Ministry of Agriculture of the Czech Republic, the Projects MZE-RO0223 and QK23020013 and by IGA 2024B0036.

https://doi.org/10.17221/66/2025-SWR

texture is a stable soil property with the effect on soil porosity and macroporosity, aeration and hydraulic soil properties (hydraulic conductivity, water holding capacity, evaporation, etc.) or nutrients leaching, crop yields and plant diseases occurrence, etc.; it was found to influence soil erosion (as texture, soil organic matter content, etc. have an effect on soil erodibility) (e.g., Moreira & Rodrigues 2021; Wang et al. 2022; Marhoul et al. 2025b). Also, bacterial and fungal diversity and the turnover of soil organic matter in soils can be influenced by soil textural composition because of its adsorption on clay surfaces, etc. (e.g., Sharkov & Bukreeva 2004; Iranmanesh & Sadeghi 2019). The importance of texture in terms of soil functions is, for example, mentioned by Novák et al. (2010). Texture, soil organic matter content, constituent minerals, etc., as well as land use and management practices or natural processes, etc. influence values of bulk density; it was found in some studies that bulk density can be influenced by earthworms, etc. (e.g., Ahad et al. 2015; Rubinić & Safner 2019; Vopravil et al. 2021b; Akhila & Entoori 2022). Bulk density has effects on plant growth (roots penetration and elongation, etc.) and tillage or applied organic matter can decrease its values (e.g., Mylavarapu & Zinati 2009). Soil pH has effects on chemical reactions, nutrients and pollutants solubility (and availability) or microbial activity, soil microbial community shaping and other soil properties (e.g., Domagoj et al. 2014; Ye et al. 2022; Maurya et al. 2020). As stated by El Behairy et al. (2024), soil organic carbon influences many soil properties (physical, biological, etc.), and it is, for example, considered to be a marker of land degradation and soil fertility; it is important to preserve the physical quality of soils, including soil structure maintenance, etc. (Reeves 1997, etc.). Concerning available potassium and phosphorus, the nutrients are important for crop yields and quality, etc. (e.g., Poss & Saragoni 1992; Vopravil et al. 2025). Poss and Saragoni (1992), for example, mentioned potassium deficiency with stunted stems and short internodes (and dead plants). Phosphorus availability is also influenced by soil pH, etc. (e.g., Popović et al. 2010; Mete et al. 2015; Poudel et al. 2024). Except different chemical and physical soil properties, the possibility of biological soil properties use as soil quality indicators is discussed in the review by Maurya et al. (2020), including, for example, nematodes or different modern approaches (metagenomics, metaproteomics, etc.). Van Eekeren et al. (2010) attempted to find the value of soil biotic paramerters in case of soil quality assessment – grasslands, sandy soils. The authors used cross-validated stepwise regression for the identification of abiotic and biotic soil parameters that explain selected soil-based ecosystem services. According to the authors, the majority of process parameters underlying the studied ecosystem services were best explained by abiotic parameters.

In the introduction of their publication, Novák et al. (2010) state a long history of productive soil functions assessment in the Czech Republic. Novák et al. (2010) also determined the values of soil non-productive functions from physical and chemical soil characteristics, etc. Recently, Janků et al. (2022a), Toth et al. (2023), etc., attempted to evaluate soil quality within the Czech Republic. This study was conducted with the aim of showing different possibilities of soil quality evaluation in the Czech Republic with the use of the Analytic Hierarchy Process.

MATERIAL AND METHODS

The used data were obtained from the online database bpej.vumop.cz as well as the publications by Vopravil et al. (2011) and Voltr (2011). Database functions were used to create a comprehensive dataset (physical, chemical and biological indicators, soil protection classes or production potential, etc.) containing information related to individual Main Soil Units (HPJ) of Evaluated Soil Ecological Units (BPEJs) described in the publication by Vopravil et al. (2015). Additional data from two localities (Hovorčovice and Železná u Smolova) was provided by Research Institute for Soil and Water Conservation. The description of the localities, including an average annual temperature and rainfall or a sum of air temperatures above 10 °C, etc., can be found in the publications by Vopravil et al. (2021a, 2024). Concerning the locality Hovorčovice, one example of BPEJ was evaluated – Haplic Chernozem according to IUSS Working Group WRB (2015) with high retention and available water capacity, hydrological group B, etc. This specific BPEJ belongs to soil protection class I, which means its high production value and strict restrictions on its withdrawal from the agricultural land fund (ZPF), permissible only in exceptional cases. Different soil types occur in the locality Železná u Smolova. The BPEJ evaluated in this study – Haplic Stagnosol (IUSS Working Group WRB 2015), hydrological group C, etc. For the spatial analysis in QGIS, the current BPEJ database from State Land Office and administrative boundary data from ArcČR (Ver. 4.0) were used.

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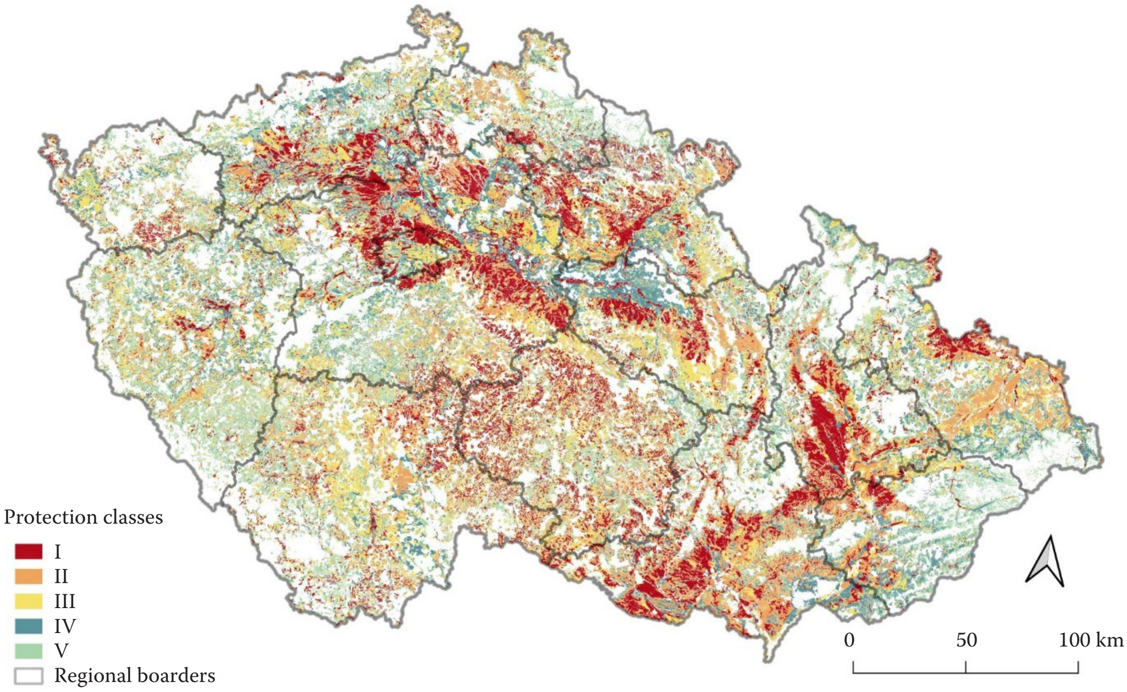

Figure 1. The distribution of soil protection classes according to a Regulation of the Ministry of the Environment of the Czech Republic (Decree No. 48/2011 Coll.)

A minimum data set was created (texture, maximum capillary water capacity, available water capacity, retention water capacity, infiltration rate, pH_{KCl}, carbonates and organic matter content) and used for the analysis. The analytic hierarchy process (AHP) was implemented using R Studio (Ver. 4.2.2) and the multiple criteria decision analysis (MCDA) package. Pairwise comparison matrices were created and geometric means were calculated to obtain normalised weights (Toth et al. 2023, etc.); a synthesis matrix was used to calculate the final synthetic preference indices. Different value for each HPJ was obtained, and the HPJs were ranked in descending order, allowing a preliminary assessment of their ecological importance. The resulting model values were then integrated with individual BPEJs using database functions to create a comprehensive table that included BPEJ values, HPJ, production potential values, soil protection class, preference synthesis, and model values derived from the preference synthesis. Subsequently, the BPEJ were classified into five different classes based on the assigned model points (to ensure comparability with the existing system of protection classes). The categorisation into five classes, designed to match the existing protection classes (Figure 1), was based on the obtained model values with or without the values for production potential, the ratio of 80% (production potential) to 20% (model values) as well as 60% (production potential) to 40% (model values) or 40% (production potential) to 60% (model values). The maps were created using QGIS (Ver. 3.12) by linking the model results with the BPEJ layer obtained from the State Land Office.

RESULTS AND DISCUSSION

This study contributes to a growing body of literature on soil quality assessment and valuation of soil ecosystem services; it builds on previous research that has highlighted the limitations of traditional production-oriented approaches to land valuation and the need to incorporate environmental considerations into decision-making processes (e.g., Bünemann et al. 2018). The results of the model (converted to a 100-point scale to align them with the production function values and imported into QGIS and linked to the existing BPEJ layer using database queries), categorised into five soil protection classes, are shown in Figure 2. In Figure 3, the categorisation into five soil protection classes based on the values from the model (environmental considerations) plus production potential is shown. The

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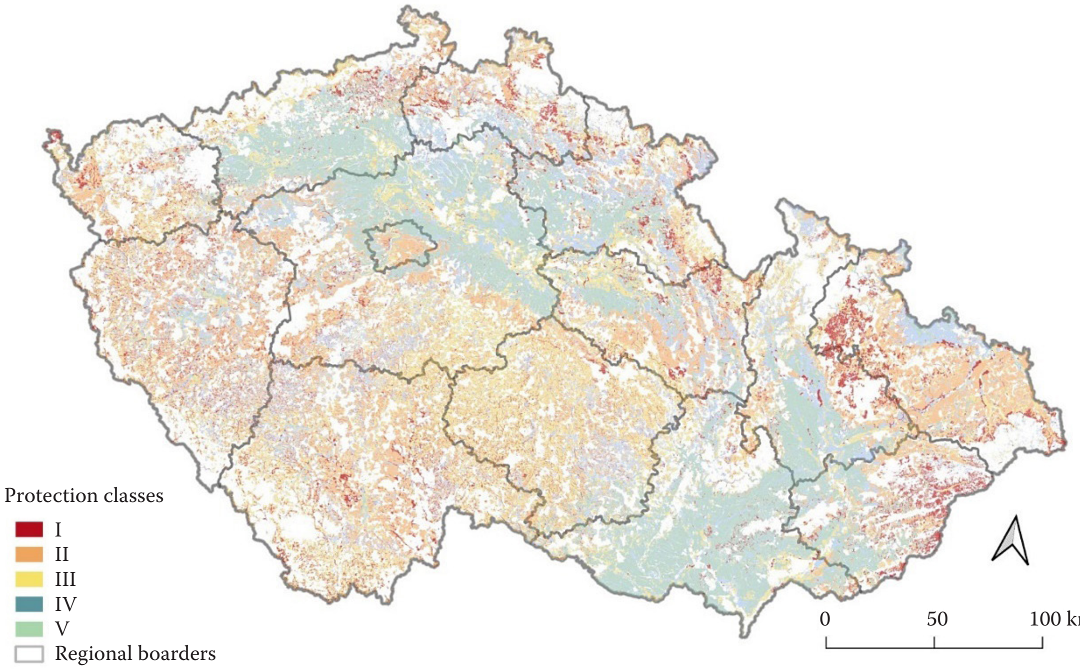

Figure 2. The results of the model categorised into five classes

categorisation based on the ratio of 80% (production potential) to 20% (model values), 60% (production potential) to 40% (model values) or 40% (production potential) to 60% (model values) is shown in Figures 4–6. Two examples of BPEJs (Haplic Chernozem and Haplic Stagnosol) evaluation (based on the results from the model with or without production potential values, the above mentioned categorisation 80 : 20%, 60 : 40% and 40 : 60%) are shown in Figure 7 and 8. Compared with the ex-

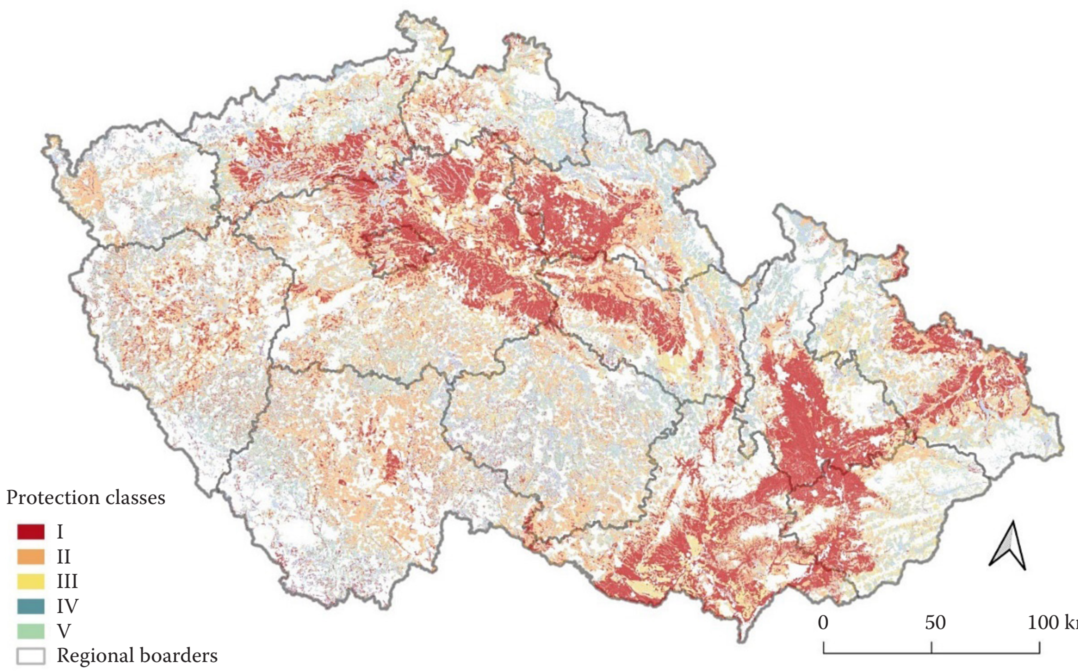

Figure 3. The values of the model and production potential categorised into five classes

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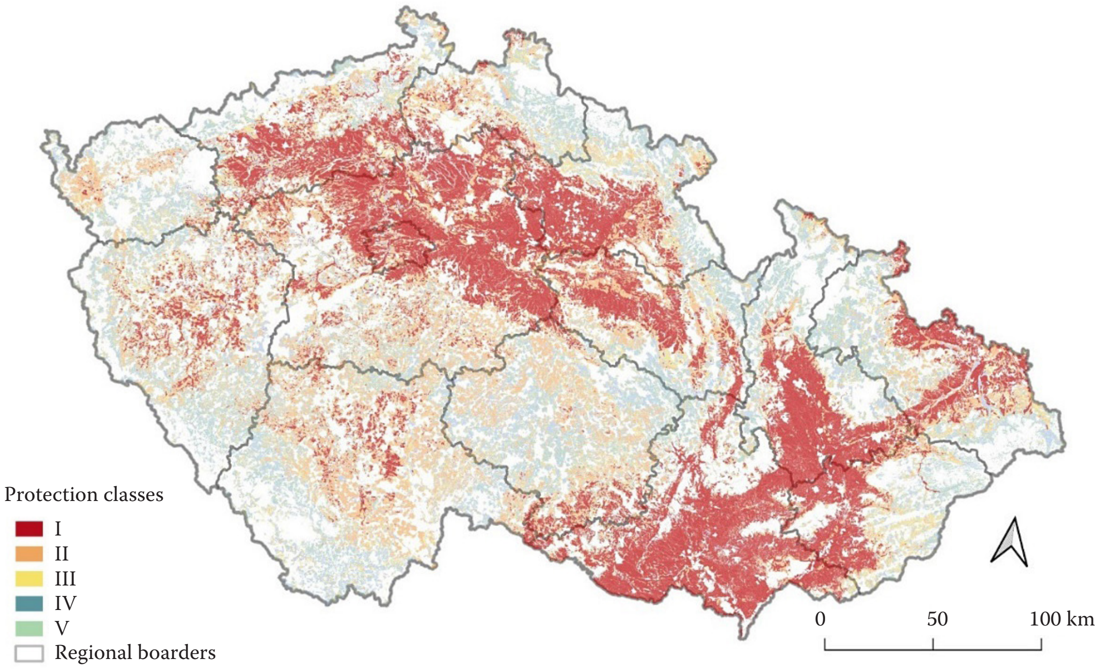

Figure 4. The categorisation based on the ratio of 80% (production potential) to 20% (model values)

isting categorisation of BPEJs into soil protection classes, the categorisation based on the model values showed that the number of BPEJs in soil protection classes I–III increased (by 234–391) and in soil protection classes IV–V decreased (by 368–619) (Table 1). In case of the values from the model (environmental considerations) plus production potential or the ratio of 80% (production potential) to 20% (model values), the numbers of BPEJs in soil protection classes I–III increased by 133–359 and in soil

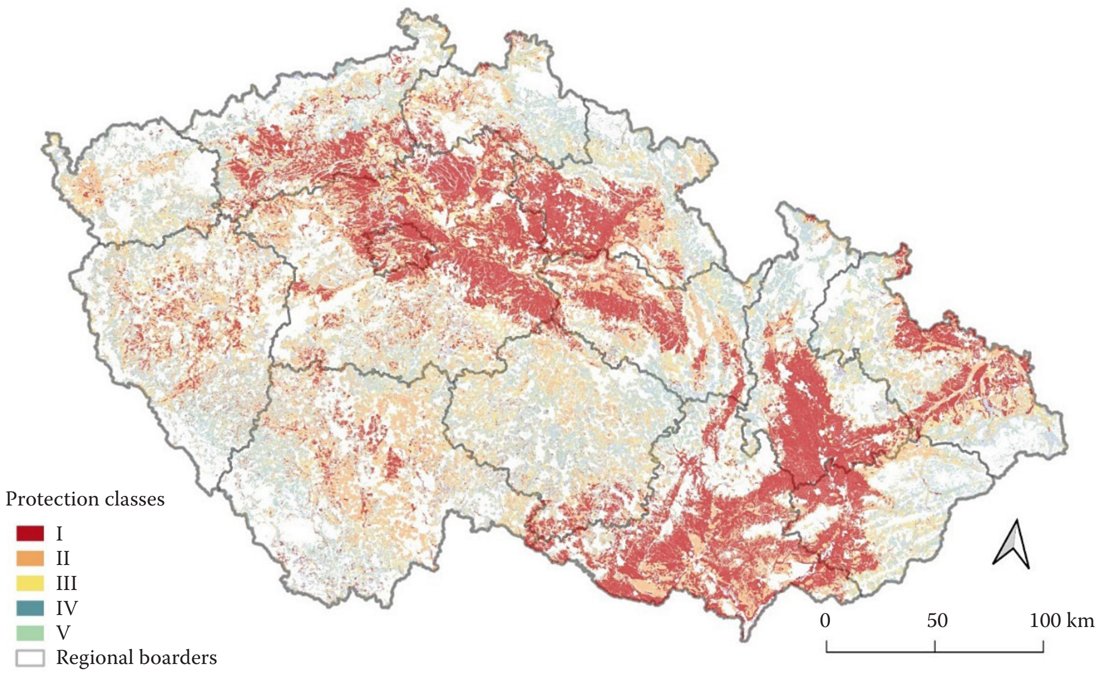

Figure 5. The categorisation based on the ratio of 60% (production potential) to 40% (model values)

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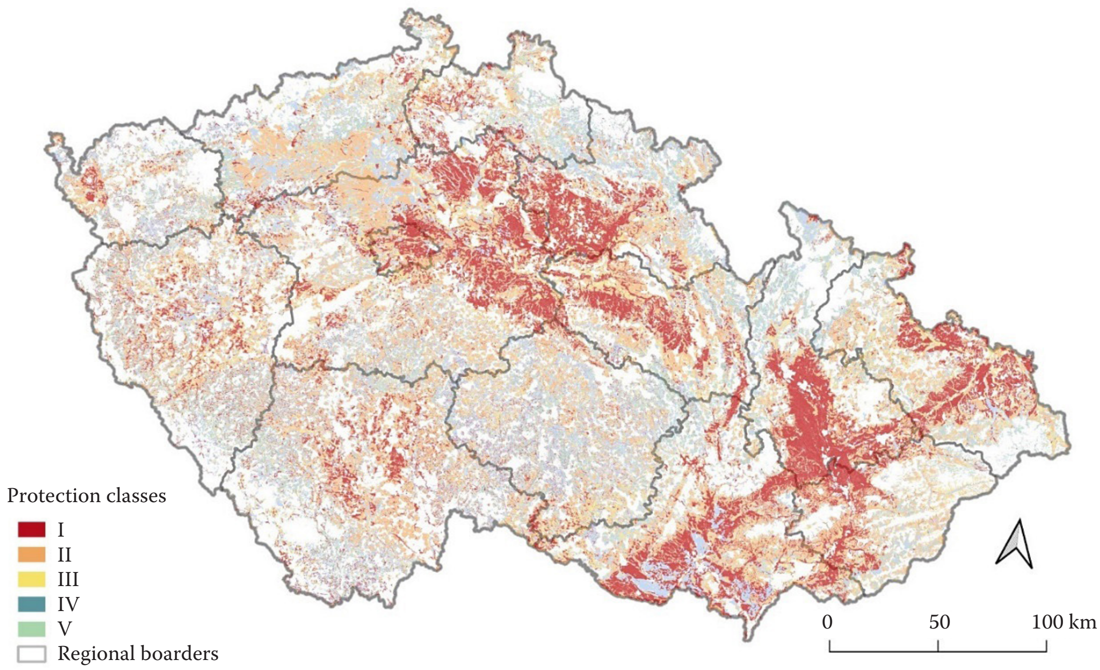

Figure 6. The categorisation based on the ratio of 40% (production potential) to 60% (model values)

protection classes IV–V decreased by 114–665. Also, the numbers of BPEJs in soil protection classes I–II increased (by 71–29) and in soil protection classes IV–V decreased (by 17–250) when 60% (production potential) to 40% (model values) or 40% (production potential) to 60% (model values) were used (Table 1); in case of 40% (production potential) to 60% (model values), the numbers of BPEJs also decreased (by 112) in soil protection class III.

In this study, different indicators were used for soil quality evaluation using the analytic hierarchy process. Bünemann et al. (2018) described different criteria for soil quality indicators (and their interpretation) and approaches to obtain minimum datasets

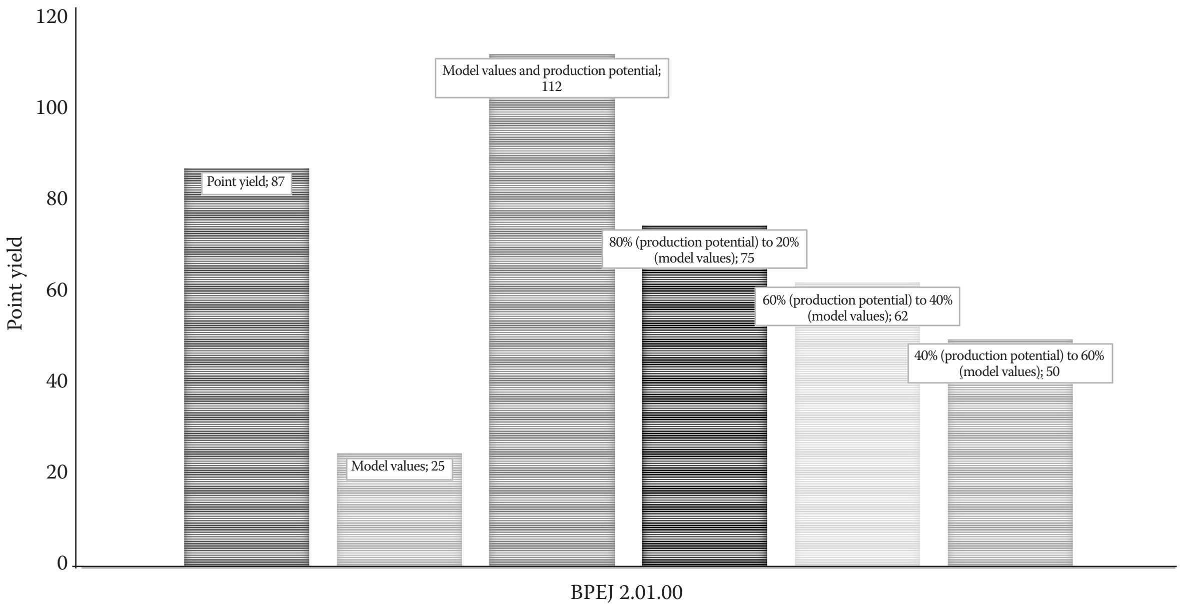

Figure 7. An example of Evaluated Soil Ecological Unit (BPEJ) evaluation (Haplic Chernozem)

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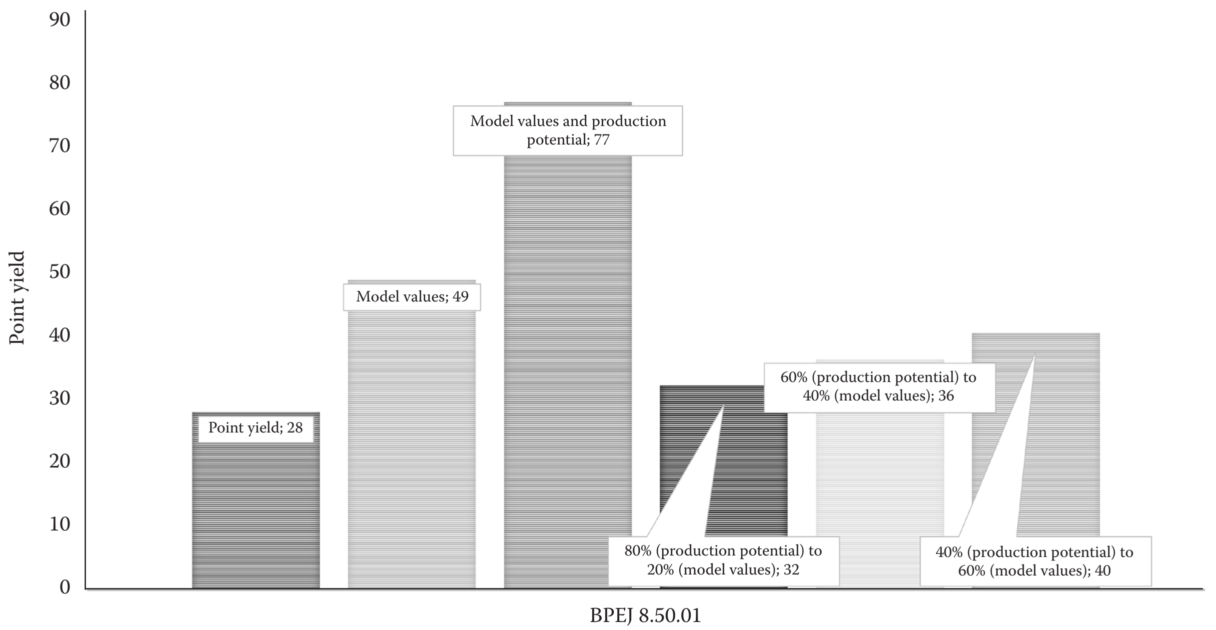

Figure 8. An example of Evaluated Soil Ecological Unit (BPEJ) evaluation (Haplic Stagnosol)

(e.g., expert knowledge, principal component analysis (PCA), etc.). Furthermore, Maurya et al. (2020) summarise examples of minimum datasets used in different studies. For example, Guilin et al. (2007) used PCA and Norm-value computation to obtain minimum datasets; also, multivariate analysis and multiple comparison were used to determine the effect of land-use change and land-use duration on soil parameters. Different methods can be used for evaluation of soil quality, including scoring function analysis, regression analysis, etc. (e.g., El Behairy et al. 2024). Toth et al. (2023) mentioned possibilities of soil quality assessment to be used for regional planning, including, for example, the SQUID index and the BOKS index – see the Introduction of the publication by Toth et al. (2023) and Drobnik et al. (2018). Meitasari et al. (2024) compared adding soil quality index (SQI_a) versus weighting soil quality index (SQI_w) obtained with the use of total or selected (PCA) indicators. According to the authors, soil quality was better predicted with the use of SQI_w and PCA-selected indicators. Fernández et al. (2020) calculated integrated quality index (IQI) using two types of weighting of ten soil quality indicators (PCA or AHP) and two types of standard scoring functions (more is better or less is better); cation exchange capacity, clay content, available potassium and phosphorus were found to be important from the point of soil quality.

Different soil evaluation studies related to the Czech Republic were published (e.g., Janků et al. 2022a; Toth et al. 2023). Based on previous studies cited in the publication by Janků et al. (2022a), the authors used databases and obtained as well as selected

Table 1. Evaluated Soil Ecological Units (BPEJs; Vopravil et al. 2015) in different soil protection classes

Soil protection class	Regulation of the Ministry of the Environment of the CR	Model values	Model plus production potential values	80% (production potential values) and 20% (model values)	60% (production potential values) and 40% (model values)	40% (production potential values) and 60% (model values)
I	80	314	439	434	370	354
II	174	536	459	443	302	245
III	303	694	438	436	307	191
IV	586	218	472	446	414	370
V	1 056	437	391	440	806	1 039

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(and classified and scored) data on soil properties (two depths), climate, land use and soil productive capacity that, according to the authors, contribute the most to productive and ecosystem services. The average score of each site or the total sum of points of each site within the Central Bohemian Region of the Czech Republic was used for the final evaluation of the results. The authors, for example, state that the quality of soils varied considerably within the studied region; the highest soil quality was found in its northeastern part (and these soils should not be removed from the agricultural land fund). According to Janků et al. (2022a), the obtained results can be used to adjust the criteria for classification of soils into soil protection classes, etc. Toth et al. (2023) prepared a procedure for an assessment of soil quality within the Czech Republic with the use of a modification of the method developed by Thomas L. Saaty in the 1970s (Saaty 1987). The authors obtained data (soil characteristics from the Czech soil information system PUGIS – see Marhoul et al. 2025a, ecosystems quality – CORINE Land Cover 2012, data from eKatalog BPEJ – Evaluated Soil Ecological Units as described in the publication by Vopravil et al. 2015) from different databases and selected production (variable and stable) and non-production indicators of soil quality. Consequently, the data scoring and analytic hierarchy process matrices formation or the calculation of weights, were realised. Toth et al. (2023), for example, state that humus content was the most significant from the group of variable production indicators, soil texture from the group of stable production indicators and hydrological soil group from the group of non-production indicators. The authors, for example, calculated total soil value (also presented within a map) from total scores of production and non-production indicators when 95% versus 5% (production versus non-production indicators of soil quality) and 60% versus 40% (variable versus stable production indicators) were used. Concerning examples of some other studies, Meitasari et al. (2024), for example, studied soil quality on slopes with different land use; the authors found the best soil quality in the case of forests (upper slopes) and the lowest in the case of mix gardens (middle and lower slopes). The study of Fernández et al. (2020) was related to rangelands in Spain and can be interpreted as an upscaling of previous studies realised at farm scales; using interpolation methods, Fernández et al. (2020) also obtained regional maps of the spatial distribution of the integrated quality index.

CONCLUSION

Compared with the existing categorization of BPEJs into soil protection classes (Decree No. 48/2011 Coll.), the categorisation based on the model values (with or without the values related to production potential) or the ratio of 80 : 20%, 60 : 40% or 40 : 60% (production potential:model) showed an increased number of BPEJs in those soil protection classes where the withdrawal of soils from the agricultural land fund is possible only exceptionally or it is possible to use the soils for building purposes only under certain conditions.

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Received: June 5, 2025
Accepted: July 23, 2025
Published online: August 19, 2025