

A nationwide multi-criteria classification of agricultural land parcels for shape optimisation in the Czech Republic

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ABSTRACT

Efficient agricultural land management increasingly requires the integration of operational, environmental, and spatial factors influencing field performance. This study presented an updated nationwide classification of agricultural land parcels in the Czech Republic according to their suitability for shape optimisation. The classification was based on a multi-criteria analysis (MCA) integrating ten criteria describing terrain morphology, parcel geometry, accessibility constraints, and soil susceptibility to machinery-induced compaction. The analysis was applied to 301 558 arable land parcel identification system (LPIS) agricultural parcels covering 2.49 million hectares. The resulting suitability index classified parcels into four categories representing increasing levels of spatial complexity and optimisation potential. The results revealed a strong relationship between parcel suitability classes and terrain conditions. Classes III and IV, representing the parcels with high optimisation potential, accounted for 39.3% of the national arable land area and were most frequently associated with larger parcels and topographically heterogeneous landscapes. The resulting nationwide map layer provides a decision-support tool for the identification of the agricultural parcels requiring shape optimisation or spatial reconfiguration.

Keywords: field shape optimisation, optimisation of the internal spatial arrangement, environmentally-technical areas, production areas, soil conservation, traffic-induced soil compaction, soil erosion risk.

INTRODUCTION

Agriculture is undergoing a profound technological transformation driven by increasing demands for food production, environmental sustainability, and economic efficiency. The spatial characteristics of agricultural fields are among the key factors determining the efficiency of crop production, the operational demands of field management, and the magnitude of environmental risks associated with agricultural land use. Field shape, size, slope, slope length, accessibility, the presence of internal obstacles, and within-field variability all influence machinery performance, the number of headland turns, application

overlaps, fuel consumption, and the intensity of traffic-induced soil compaction (Hamza and Anderson, 2005; Bochtis and Sørensen, 2009). Most of these characteristics also determine whether, and to what extent, erosion control and other soil conservation measures can be effectively implemented (Spekken et al., 2016).

The relationship between agricultural landscape structure, field size, and farming practices has long been debated from both production and ecological perspectives. Practically, larger and more regular fields have contributed to reduced labour and fuel requirements while facilitating agricultural mechanisation (Demetriou et al., 2013). However, field consolidation can be

associated with reduced biodiversity in agricultural landscapes. Fahrig et al. (2015) and Clough et al. (2020) demonstrated that increasing field size and simplifying landscape structure may conflict with the biodiversity conservation objectives. Consequently, the assessment of field characteristics must balance operational efficiency with the broader environmental implications of agricultural land management.

From agronomic and economic perspectives, field shape and size are closely related to the efficiency of field operations. Brunotte and Fröba (2007) showed that increasing the average working pass length and field area reduces both annual machinery operating costs and fuel consumption per unit area. However, most machinery performance models have been developed for regular field geometries, whereas agricultural parcels are frequently characterised by wedge-shaped sections, non-parallel boundaries, and irregular field margins, all of which may substantially affect operational efficiency (Alturk, 2024).

The spatial configuration of agricultural parcels is also closely linked to soil degradation processes. Horn and Fleige (2000), Botta et al. (2006), Berisso et al. (2012), and Hamza and Anderson (2005) demonstrated that machinery traffic substantially contributes to soil compaction, which often persists over extended periods and adversely affects water infiltration, nutrient cycling, and crop productivity. Soil compaction is associated with reduced infiltration capacity and increased erosion risk, while wheel tracks aligned with the slope may function as preferential pathways for surface runoff. Consequently, irregular field geometry, inappropriate travel direction, extensive headlands, and repeated manoeuvring around obstacles should be regarded not only as operational constraints but also as factors increasing the susceptibility of agricultural soils to degradation.

Apart from the field boundaries, the internal structure of a field is another important factor, particularly the presence of enclaves and other internal obstacles. Energy infrastructure, technical facilities, isolated trees, woody patches, wetlands, and other landscape elements complicate machinery guidance, increase repeated passes, reduce field coverage continuity, and may lead to localised yield losses as well as increased consumption of seed, fertilisers, and fuel. Al-Amin et al. (2023) demonstrated that field geometry has a substantial effect on field management efficiency and production costs while also emphasising that

internal field elements are often underestimated when evaluating operational impacts.

Planning the routes of farm machinery in agricultural fields is essential to efficiently complete agricultural tasks. The travelled distances directly affect economic and environmental aspects such as fuel consumption and soil compaction (Hamza and Anderson, 2005; Conesa-Muñoz et al., 2016; Seyyedhasani et al., 2019). Beyond operational efficiency, field and route optimisation contribute directly to environmental sustainability. Reduced overlap decreases fuel consumption and greenhouse gas emissions. Optimised turning patterns lower soil compaction, preserving soil structure, improving water infiltration (Hamza and Anderson, 2005), and increasing yields (Arvidsson and Håkansson, 2014; Sunoj et al., 2021). There are many approaches to optimise the routing of machinery in agricultural fields. The primary task is to select the optimum angle of parallel paths to minimise the non-working distance travelled by machines operating in a headland (Bochtis and Vougioukas, 2008), and to avoid short corner tracks (Spekken and Molin, 2012).

Despite significant advances over the past two decades, numerous research challenges remain. Most optimisation algorithms assume static field conditions, whereas real agricultural environments involve dynamic obstacles, varying soil moisture, weather uncertainties, and machinery failures. Furthermore, field shape optimisation and machinery route optimisation are often investigated separately, although they represent strongly interconnected problems the integrated optimisation of which could yield substantially greater economic and environmental benefits (Seyyedhasani et al., 2019). In the context of changing CAP measures, it gradually becomes effective for farmers to simplify the shape of fields even at the cost of decreased size of the productive part of the field (production areas). Low-productive or difficult-to-cultivate parts of agricultural parcels may be excluded from intensive farming (environmentally-technical areas). This allows for increasing the effectiveness of agricultural operations while simultaneously improving the sustainability of the use of agricultural parcels and meeting CAP requirements on non-productive areas (Czech Republic, 2023a).

Field shape optimisation, together with crop selection, may have a significant impact on meeting requirements for preventing soil erosion covered by GAEC 5 standard in the EU. In the Czech Republic, GAEC 5 (DZES 5) is implemented

through the land parcel identification system (LPIS) erosion assessment framework, where spatial erosion risk differentiation is represented by internally delineated erosion areas (VEPs). The final assessment combines the spatial distribution of erosion risk areas with declared crops and their protective functions (Czech Republic, 2023b; Ministry of Agriculture of the Czech Republic, 2025; Ministry of Agriculture of the Czech Republic, 2026).

In the present study, optimisation of the internal spatial arrangement of agricultural field parcels is used as an overarching concept the main operational principle of which is the optimisation of field geometry and machinery trajectories through the spatial allocation of production areas (PA) and environmentally-technical areas (ETA). The preceding discussion demonstrates that the suitability of an agricultural parcel for optimisation cannot be evaluated using a single parameter. Instead, field geometry, terrain, accessibility, internal obstacles, and soil sensitivity must be integrated within a unified assessment framework. To address this need, a nationwide multi-criteria analysis (MCA) of agricultural parcels was originally developed and described in the methodological framework proposed by Kapička et al. (2017). The MCA integrated several spatial and operational factors affecting the suitability of agricultural parcels for optimisation interventions. Since its original development, substantial changes have occurred in the availability, structure, and quality of national geospatial datasets. Therefore, the present study builds upon the original MCA framework, updates its data inputs, and revises selected methodological components to reflect the current data conditions and contemporary requirements for agricultural land optimisation.

The objectives of this study were to (i) describe the structure of the nationwide classification of agricultural parcels based on MCA, (ii) interpret the spatial and operational characteristics of the individual classes, and (iii) discuss the practical implications of this classification for agricultural management and public administration.

METHODOLOGY

Study area and analytical framework

The analysis was conducted for the entire territory of the Czech Republic using the national

land parcel identification system structure. The agricultural parcel (DPB in the Czech LPIS) was used as the basic spatial assessment unit. The objective was to identify agricultural parcels with the highest potential for spatial optimisation to improve operational efficiency while maintaining compliance with environmental requirements for sustainable agricultural land management.

The methodological framework consisted of a multi-stage geospatial analysis. First, nationwide spatial datasets describing terrain morphology, soil properties, parcel geometry, and transport accessibility were compiled and harmonised. Subsequently, a set of spatial indicators characterising each agricultural parcel was derived from these datasets. Finally, all indicators were integrated within an updated multi-criteria analysis framework derived from the methodology proposed by Kapička et al. (2017), enabling the classification of agricultural parcels according to their suitability for subsequent shape optimisation.

Compared with the original framework proposed by Kapička et al. (2017), the present study introduced several updates reflecting changes in the structure and availability of national geospatial data. The assessment was adapted to the current LPIS parcel structure, allowing a more detailed representation of agricultural land management units. In addition, the analysis was based on updated nationwide spatial datasets, and selected MCA criteria were revised to better correspond to current data conditions and contemporary requirements for agricultural land management. These modifications preserve the conceptual basis of the original framework while improving its applicability for the present nationwide assessment. The resulting classification served as a screening tool for selecting representative sites for detailed investigation. Parcels with the highest optimisation potential were subsequently subjected to detailed analyses of field configuration, shape optimisation design, and simulation of agricultural machinery traffic.

Spatial data sources

The analysis integrated several nationwide geospatial datasets describing terrain morphology, soil conditions, parcel geometry, and transport accessibility (Table 1). Raster-based analyses were performed at a spatial resolution of 5×5 m, whereas vector datasets were processed using their original spatial accuracy. A Digital Terrain

Model (DTM – DTM4g 2024/8) was used to derive terrain morphometric variables, including mean slope, elevation range, proportion of steep areas, and terrain variability. Boundaries of LPIS (LPIS DPB 2025/4) agricultural parcels constituted the primary spatial units for analysis and were additionally used to assess parcel shape complexity and identify internal enclaves. The Czech Evaluated Soil Ecological Units (BPEJ – 2025/4) database provided information on soil susceptibility to machinery-induced compaction, while the national ZABAGED (2025/1) database was used to evaluate transport accessibility based on the distance to the road network. Additional thematic layers provided by the Ministry of Agriculture of the Czech Republic (MZe) were used to identify the landscape features influencing agricultural management. Spatial analyses were conducted in ArcMap 10.6.1 using the S-JTSK / Krovak East North coordinate reference system (EPSG:5514), the official national coordinate system of the Czech Republic. The initial dataset consisted of 669 876 LPIS agricultural parcels across all agricultural land-use categories. However, only arable land categories (R, U, and G) were selected for further analysis, resulting in a final dataset of 301 558 parcels and 2 492 104 ha.

Prior to analysis, all spatial datasets were transformed into a common coordinate reference system, spatially harmonised, and preprocessed to ensure consistency among analytical layers. The construction of the MCA and the integration of individual evaluation criteria are described in the following section.

Principle of the multi-criteria analysis

The multi-criteria analysis applied in this study builds upon a methodological framework originally developed and described by Kapička et al. (2017). The original approach was designed as a nationwide screening tool for identifying agricultural parcels suitable for spatial optimisation. For the purposes of the present study, the methodology was updated and revised to reflect changes in the availability, structure, and quality of national geospatial datasets, while preserving the original conceptual framework and evaluation principles.

A multi-criteria analysis was developed to systematically evaluate the suitability of agricultural land parcels for subsequent spatial optimisation. Unlike conventional approaches that primarily assess parcel geometry or individual

terrain characteristics, the proposed method integrates multiple factors influencing the operational efficiency of agricultural management into a single evaluation framework. The underlying assumption is that the optimisation potential of a land parcel is determined by the combined effects of terrain morphology, parcel geometry, transport accessibility, and soil properties, rather than by any single characteristic.

MCA was designed as a screening tool to identify LPIS agricultural parcels with the greatest potential to benefit from shape optimisation. It does not represent an optimisation algorithm itself, but serves as a decision-support framework for selecting candidate parcels for subsequent detailed analyses. By restricting computationally intensive optimisation procedures to the most suitable parcels, the approach substantially reduces computational demands while enabling nationwide application.

The exclusive use of standardised national datasets ensures methodological reproducibility and facilitates application across the entire territory of the Czech Republic.

Each criterion was classified into ordinal categories representing increasing levels of management complexity. The categories were subsequently assigned weighted scores reflecting the relative importance of individual criteria for parcel optimisation. The aggregated score represents an overall suitability index, which was used to classify each agricultural parcel into one of four suitability classes ranging from parcels with minimal optimisation potential to parcels requiring comprehensive spatial reconfiguration.

The criteria of MCA

The multi-criteria analysis comprised ten evaluation criteria grouped into four categories representing the principal factors affecting the operational efficiency of agricultural land management: (i) terrain characteristics (C1–C5), (ii) parcel geometry (C6–C7), (iii) accessibility and spatial constraints (C8–C9), and (iv) soil susceptibility to machinery-induced compaction (C10). The rationale for the selection of individual criteria, their classification thresholds, and the weighting scheme is described in detail by Kapička et al. (2017), on which the present study builds. All criteria were derived from nationwide geospatial datasets described in the Spatial Data Sources chapter. The original weighting scheme was retained

to ensure methodological consistency and comparability with the previous nationwide assessment. The weights were established through expert consultation involving specialists in agricultural engineering, soil conservation, and land management. Maintaining this weighting structure enables direct comparison between the original classification and its present nationwide update.

Terrain-related criteria (C1–C5)

Terrain characteristics were derived from the digital terrain model (DTM; 5×5 m resolution) and describe the topographic conditions affecting machinery operation, field accessibility, and the potential for parcel shape optimisation.

- C1 Mean slope. Mean slope was calculated as the average slope of all DTM cells within each agricultural parcel and represents the overall terrain steepness affecting field operations. Higher slope values indicate increased operational difficulty, fuel consumption, and erosion risk. The analysis was performed using the Zonal Statistics as Table tool with the mean statistic.
- C2 Elevation range. Elevation range was calculated as the difference between the maximum and minimum elevation within each agricultural parcel. This criterion characterises the overall vertical relief and complements the mean slope by describing terrain ruggedness. The analysis was performed using the Zonal Statistics as Table tool with the range statistic.
- C3 Share of slopes steeper than 6° . The proportion of parcel area exceeding a slope of 6° was calculated as the percentage of cells in the slope layer derived from the DTM that exceeded this threshold. The criterion reflects the extent of areas where field operations become increasingly constrained and erosion risk increases. The areas exceeding the 6° slope threshold were identified using the Reclassify tool and subsequently quantified using the Tabulate Area function.
- C4 Share of slopes steeper than 11° . This criterion represents the proportion of parcel area exceeding 11° slope, identifying locations with substantial limitations for mechanised field operations and elevated erosion susceptibility. The analysis was performed analogously to criterion C3.
- C5 Terrain aspect variability. Terrain heterogeneity was quantified using an aspect-based

heterogeneity index derived from the spatial distribution of terrain orientation within each parcel. Greater variability indicates more heterogeneous terrain conditions that reduce the efficiency of machinery trajectories. Aspect values were derived using the Aspect tool and subsequently reclassified into eight cardinal and intercardinal direction classes (N, NE, E, SE, S, SW, W, NW). The index was calculated as the ratio between the sum of absolute area differences of opposite aspect classes and the total parcel area:

$$\text{Terrain aspect variability} = \frac{|A_1 - A_5| + |A_2 - A_6| + |A_3 - A_7| + |A_4 - A_8|}{\sum_{i=1}^8 A_i} \quad (1)$$

where: A_i – area of the i -th aspect class,
 $A_1 - A_8$ represent the eight aspect classes.

Lower values indicate a greater variability of terrain orientation within the parcel.

Parcel geometry criteria (C6–C7)

Parcel geometry directly influences machinery efficiency by affecting working path length, turning frequency, overlap, and field accessibility. Both criteria were derived from LPIS parcel boundaries.

- C6 Shape complexity. Shape complexity was quantified using a geometric complexity index calculated from the parcel polygon geometry. Parcels with irregular outlines, narrow sections, or pronounced indentations received higher scores because such configurations reduce operational efficiency and offer greater potential for spatial optimisation. Owing to its direct influence on machinery movement, this criterion received the highest weighting within MCA.

$$\text{Shape complexity} = \frac{P}{4\sqrt{A}} \quad (2)$$

where: P – perimeter [m], A – area [m²]

- C7 Presence of enclaves. Enclaves were identified as non-managed areas enclosed within an agricultural parcel that interrupt continuous field operations. The criterion was classified according to the presence and size of enclosed areas, with larger enclaves receiving higher scores. Enclaves were identified by removing internal polygon parts using the Eliminate Polygon

Parts tool. Their area was subsequently determined as the difference between the original parcel geometry and the geometry after enclave removal using the Erase tool.

Accessibility-related criteria (C8–C9)

Accessibility criteria describe spatial constraints affecting field management and the feasibility of subsequent parcel reconfiguration.

- C8 Presence of landscape features. Landscape features were identified using the Ministry of Agriculture database. Parcels were classified according to the presence and type of landscape features that constrain field operations or influence future spatial reorganisation. The analysis was performed using a spatial query (Select by Location) to identify the presence of landscape features within agricultural parcels.
- C9 Distance to the nearest access road. Accessibility was evaluated as the shortest distance from the parcel boundary to the nearest road contained in the ZABAGED® database. Greater distances indicate reduced logistical accessibility and potentially lower operational efficiency. The analysis was performed using the Near tool, which determines the distance to the nearest feature.

Soil-related criterion (C10)

C10 Soil susceptibility to compaction. Soil susceptibility to machinery-induced compaction was derived from the BPEJ database. Parcels were classified into four susceptibility classes ranging from

low to very high. Higher susceptibility indicates a greater need for optimised machinery movement and controlled traffic to minimise soil degradation. The predominant soil susceptibility class for each parcel was determined using the Zonal Statistics as Table tool with the majority statistic.

For all criteria, continuous values were classified into ordinal categories representing increasing levels of management complexity. Category thresholds were established using agronomic practice, terrain characteristics, and expert knowledge. The assigned category scores were subsequently combined using the weighting scheme described in the chapter Classification of LPIS agricultural parcels to calculate the overall MCA suitability index.

The selected criteria collectively represent the principal factors influencing the operational efficiency of agricultural land management. Terrain-related criteria describe natural constraints affecting field operations, parcel geometry reflects the efficiency of mechanised fieldwork, accessibility criteria characterise logistical limitations, and the soil criterion accounts for long-term sustainability associated with the risk of machinery-induced compaction. Their combined evaluation provides a comprehensive assessment of the suitability of individual LPIS agricultural parcels for subsequent shape optimisation.

Classification of LPIS agricultural parcels

The output of the multi-criteria analysis was an overall suitability score assigned to each agricultural parcel representing its spatial complexity

Table 1. List of the criteria used in MCA

Code	Criterion	Weight	Category	Scores	Data source
C1	Mean slope	8	< 1°; 1–2°; 2–4°; 4–6°; 6–11°; > 11°	8; 16; 24; 32; 36; 40	DTM
C2	Elevation range	6	< 5 m; 5–10 m; 10–20 m; 20–50 m; 50–100 m; > 100 m	6; 12; 18; 21; 24; 30	DTM
C3	Share of slopes steeper than 6°	6	0%; 0–<10%; 10–35%; 35–70%; > 70%	6; 12; 18; 24; 30	DTM
C4	Share of slopes steeper than 11°	7	0%; 0–<10%; 10–35%; 35–70%; > 70%	7; 14; 21; 28; 35	DTM
C5	Terrain aspect variability	5	1.0000; 0.9999–0.9997; 0.9997–0.8000; 0.8000–0.6000; ≤ 0.6000	5; 10; 15; 20; 25	DTM
C6	Shape complexity	10	< 1.0; 1.0–1.3; 1.3–2.0; 2.0–3.0; > 3.0	10; 20; 30; 40; 50	LPIS
C7	Presence of enclaves	3	Not present; ≤ 40 m ² ; > 40 m ²	3; 9; 15	LPIS
C8	Presence of landscape features	3	Not present; agricultural; non-agricultural	3; 9; 15	MZe
C9	Distance to the nearest access road	5	Direct access; 0.1–10 m; 10–30 m; 30–50 m; > 50 m	5; 10; 15; 20; 25	ZABAGED
C10	Soil susceptibility to compaction	4	Low; medium; high; very high	4; 12; 16; 20	BPEJ

and potential for shape optimisation. The final score was calculated by aggregating the weighted scores of all ten evaluation criteria.

$$MCA = \sum_{i=1}^{10} S_i \quad (3)$$

where: S_i – represents the score assigned to the category of criterion.

To facilitate interpretation and the selection of candidate sites for detailed analysis, all agricultural parcels were classified into four suitability classes representing increasing optimisation potential. Class boundaries were defined according to the final aggregated suitability score (Table 2). Parcels assigned to the lowest class exhibited favourable spatial characteristics requiring little or no intervention, whereas parcels in the highest class were characterised by combinations of terrain, geometric, accessibility, and soil constraints, indicating the greatest potential benefit from spatial reconfiguration.

Interpretation of suitability classes

The four suitability classes represent increasing levels of spatial complexity and the corresponding potential benefits of parcel shape optimisation (Table 2).

Class I comprises parcels with regular geometry, low terrain variability, and favourable accessibility, where only limited optimisation is expected to improve operational efficiency. Class II includes parcels with moderate spatial complexity resulting from either irregular geometry or the combined influence of several minor constraints. These parcels remain suitable for relatively simple adjustments to field configuration or machinery operating patterns.

Classes III and IV represent parcels with high and very high spatial complexity, respectively. These parcels are typically characterised by irregular shapes, heterogeneous terrain, limited accessibility, internal obstacles, or combinations of multiple limiting factors. Consequently, they offer the greatest potential for improving operational efficiency through parcel reconfiguration, optimisation of machinery traffic, and the incorporation of environmental engineering measures.

In the present study, only parcels classified into Classes III and IV were selected for subsequent optimisation and simulation analyses, as these categories were expected to provide the greatest operational benefits.

RESULTS

Spatial distribution of MCA classes in the Czech Republic

The results show that the spatial distribution of individual MCA classes in the Czech Republic is strongly dependent on the topographic conditions of the site. It is evident from the map in Figure 1 that categories I and II predominate in the lowlands, whereas a higher proportion of categories III and IV is found in mid-mountain and higher altitudes. The share of individual classes in the total arable land area is visible from Figure 2. Classes III and IV, which are particularly suitable for optimisation, together account for 39.3% of the arable land registered in the LPIS. The resulting MCA classification layer has been published as a publicly accessible web map application (Lang et al., 2026), allowing users to explore and query the classification results throughout the Czech Republic.

Effect of parcel size on the distribution of MCA classes

An analysis of the distribution of MCA classes by LPIS parcel size area revealed that the proportion of operationally more complex classes (Classes III and IV) increases significantly with growing LPIS parcel size (Figure 3). In size categories up to 2 ha, Classes I and II predominate, whereas in larger areas, the share of Class III and subsequently Class IV progressively increases. In the category exceeding 100 ha, Class III becomes dominant (51.0%) and Class IV reaches 10.0%, confirming that large arable LPIS agricultural parcels represent the most critical group suitable for optimisation in terms of geometric and operational complexity.

The distribution of MCA classes across area categories suggests that optimisation potential is associated not only with small or irregular parcels but also with large agricultural parcels, where operational constraints become increasingly pronounced.

Table 2. Classification of agricultural parcels based on the sum of scores

Class	Sum of scores
I	< 112
II	112–141
III	142–174
IV	> 174

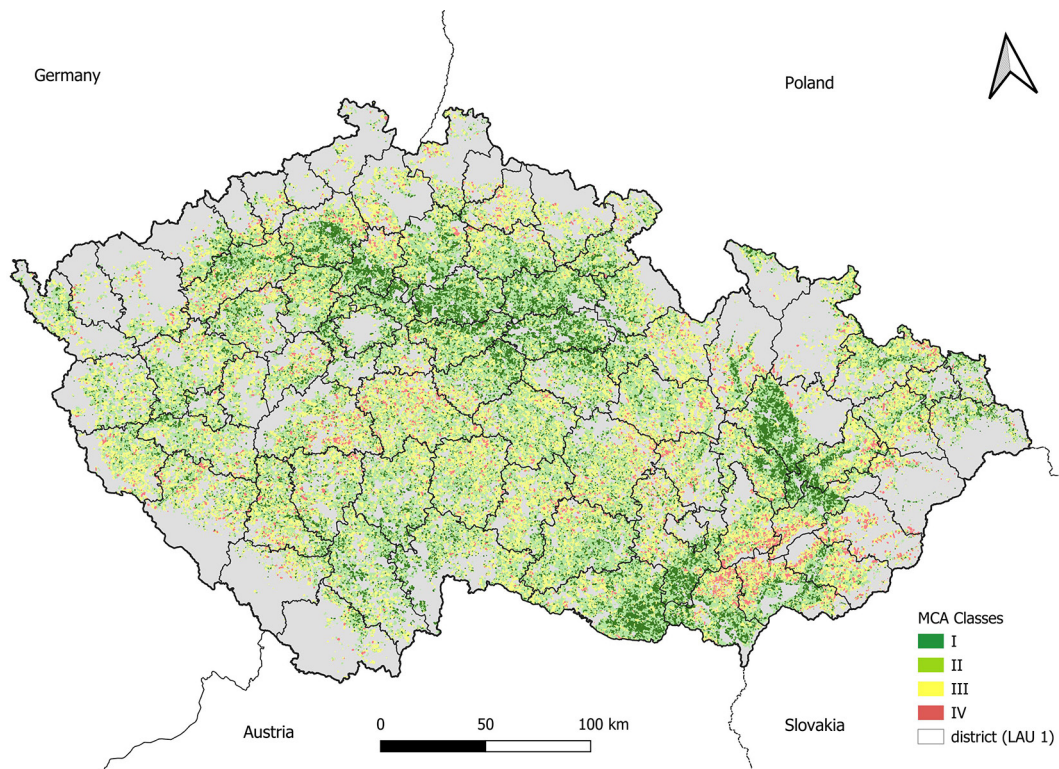


Figure 1. Distribution of MCA classes in the Czech Republic for arable land registered in LPIS

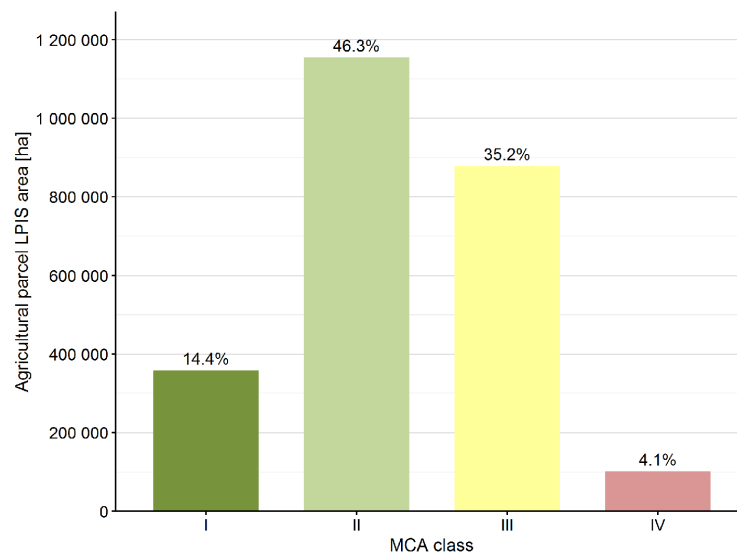


Figure 2. Areal representation of individual MCA classes in the Czech Republic (LPIS arable land only)

Relationship between MCA class and erosion risk categories

Figure 4 illustrates the distribution of individual MCA classes across erosion-risk categories defined under GAEC 5, using the official erosion-risk layer applicable from 1 July 2025. Agricultural parcels classified within MCA Classes III and IV predominantly fall into erosion-prone categories,

whereas Classes I and II are less represented in these categories. This finding indicates that the MCA approach identifies the parcels that are not only problematic in terms of farming efficiency but also exhibit a higher susceptibility to soil erosion. Therefore, the optimisation of agricultural parcel configuration and management may provide a comprehensive solution addressing both operational inefficiencies and erosion-related risks.

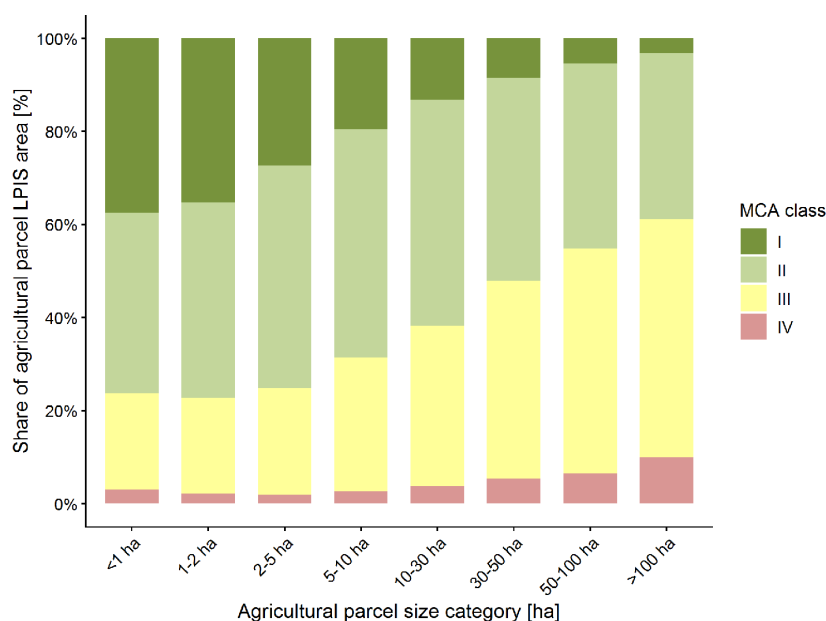


Figure 3. Representation of MCA classes by LPIS area on arable land in the Czech Republic
LPIS parcels classified into classes III and IV are characterized by a more complex shape and a higher need for optimisation

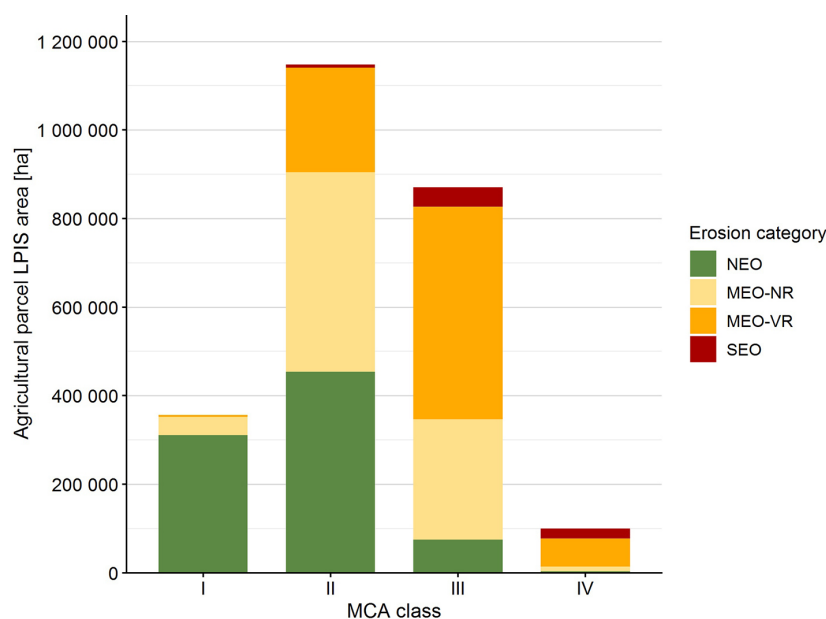


Figure 4. Erosion risk categories for individual MCA classes

Relationship between MCA class and climatic region categories

Climatic regions are defined according to Decree No. 327/1998 Coll. (Czech Republic, 1998) and are used within the BPEJ system to characterise the climatic conditions of agricultural land in the Czech Republic. The classification comprises ten categories ranging from very warm, dry regions (category 0) to cold, very

humid regions (category 9). Figure 5 illustrates the distribution of MCA classes across climatic regions of the Czech Republic. A gradual shift in class representation can be observed from lower to higher climatic region categories. While parcels classified as MCA class I are more frequent in warmer regions, the proportion of classes III and IV progressively increases towards colder and generally more topographically diverse regions. This trend suggests that the agricultural

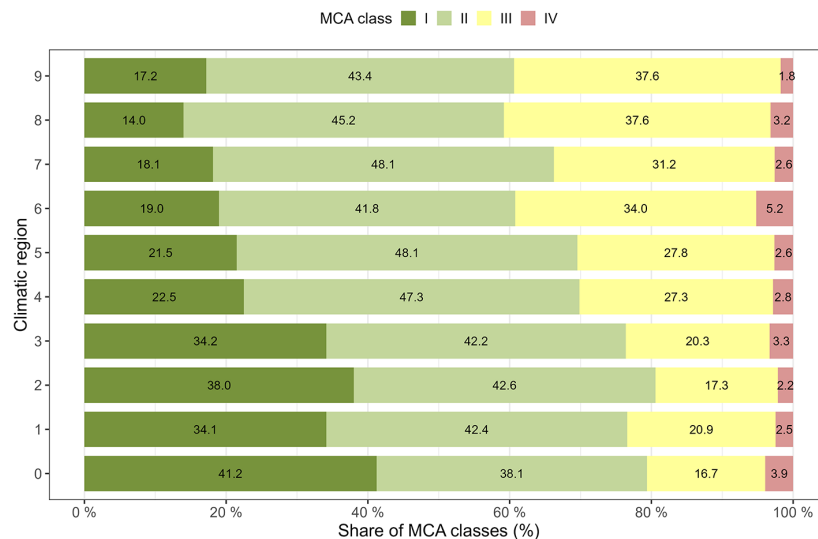


Figure 5. Representation of MCA classes by climatic region

parcels located in higher climatic regions are more likely to exhibit spatial characteristics associated with greater optimisation potential. The relationship is further supported by a positive, although relatively weak, Spearman rank correlation between climatic region and MCA class ($\rho = 0.18$), indicating that climatic conditions are associated with the resulting classification but represent only one of several contributing factors.

Despite this trend, class II remains the dominant category across all climatic regions, indicating that the influence of climatic region alone is limited and that the final MCA classification results from the combined effect of terrain, parcel geometry, accessibility, and soil-related characteristics.

Figure 6 presents boxplots showing the distribution of point scores for individual MCA criteria across the four MCA classes. Several criteria exhibit a clear relationship with the resulting classification. For example, the scores for C1 (Mean slope) progressively increase from class I to class IV, indicating that steeper parcels are more frequently classified as requiring optimisation. Another trend is observed for C4 (Share of slopes steeper than 11°), where classes I and II contain predominantly parcels with little or no steep terrain, whereas class IV is characterised by a substantially higher representation of steep areas. In contrast, C10 (Soil susceptibility to compaction) shows a relatively even distribution across all MCA classes, suggesting that this factor alone does not determine the overall classification, but contributes in combination with the remaining criteria.

DISCUSSION

The importance of MCA as a tool for assessing the operational suitability of LPIS parcels

The presented results show that the developed multi-criteria analysis provides a structured and reproducible basis for the nationwide classification of LPIS parcels according to their shape-optimisation potential. Rather than representing a direct validation of optimisation benefits, the classification should be interpreted as a screening tool for identifying the parcels where detailed field-level assessment may be most justified. The main advantage of this approach lies in the fact that it does not merely quantify a single, isolated parameter, such as geometric complexity, but integrates multiple factors that are mutually dependent in practice, specifically topography, accessibility, in-field obstacles, and soil compaction sensitivity. Consequently, MCA reflects the real conditions of agricultural practice more accurately than a one-dimensional assessment based solely on a single morphological indicator.

From a methodological perspective, the resulting classification should not be interpreted as an abstract spatial zonation, but as an assessment of the relationship between the spatial structure of LPIS parcels and their potential operational complexity. This relationship gives the MCA framework practical relevance, as it enables the identification of parcels where operational constraints and potential corrective measures can be considered within a single decision-support output.

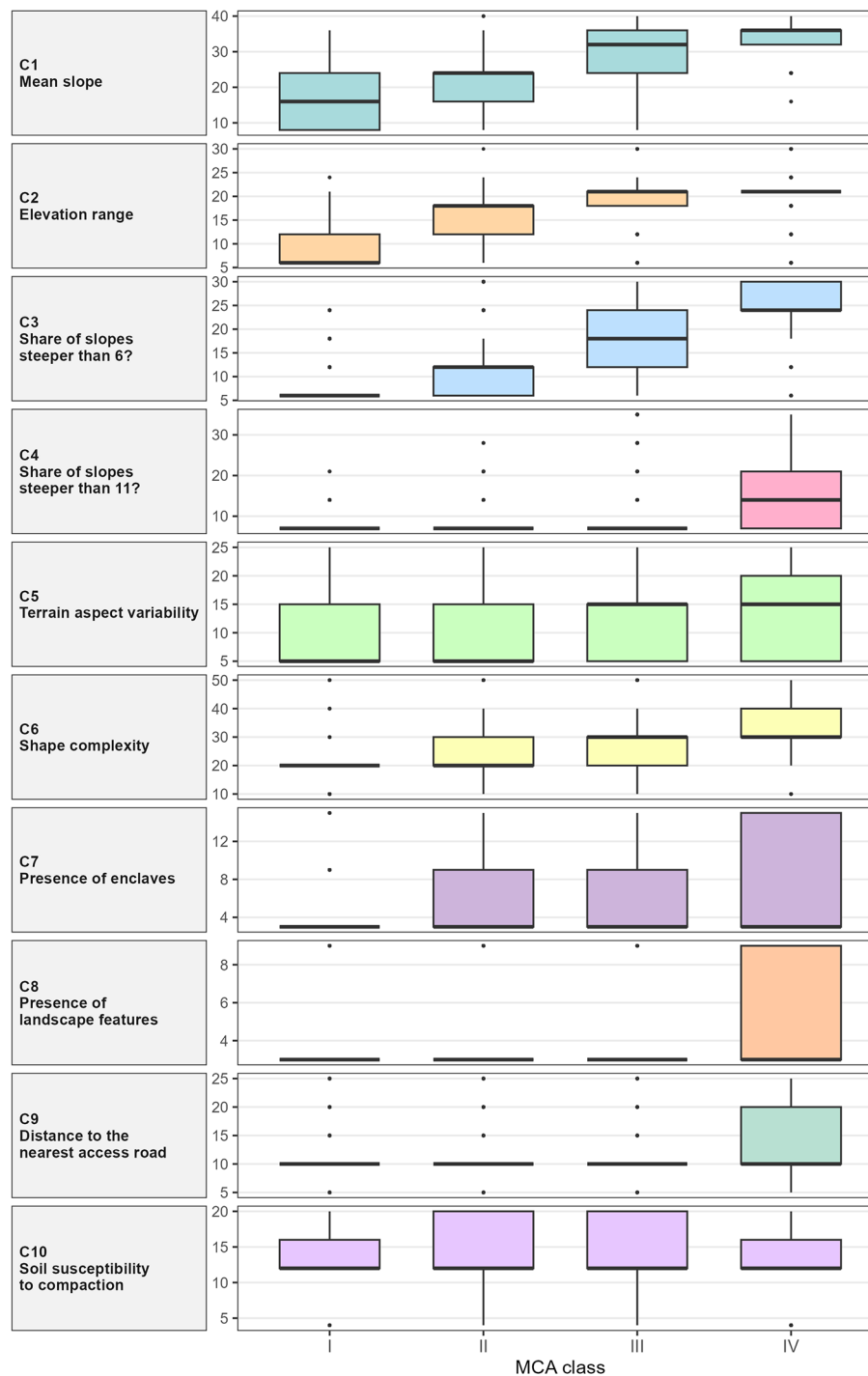


Figure 6. Distribution box-plots of score values for individual MCA criteria over MCA classes

This practical relevance corresponds to the current methodological concept of optimising the internal spatial arrangement of agricultural parcels, in which parcel reconfiguration is understood as a means of combining efficient machinery operation with soil and water protection and broader environmental functions (Groot et al., 2007; Saggau et al., 2023). In this context, the MCA classification can support the preliminary

identification of the parcels where detailed design of production areas and environmentally technical areas may be most relevant. Such a follow-up design may consider the technical requirements of agricultural machinery, crop rotation principles, economic efficiency, protection of soil and water resources, and the enhancement of ecosystem services. Thus, the nationwide classification provides an intermediate decision-support layer

between national geospatial screening and parcel-level optimisation planning for farmers, advisors, and public authorities.

Classes III and IV as priority targets for optimisation interventions

The most significant practical outcome is the identification of Classes III and IV as the LPIS parcel groups with the highest need for optimisation. These classes are associated not only with higher operational demands but also with increased economic costs arising from irregular working trajectories, a greater number of headland turns, a larger extent of overlaps and double-sowing, and a higher risk of technogenic soil compaction. From an agronomic perspective, these are therefore the land parcels where the greatest benefits can be expected from modifying machinery traffic organisation, internal restructuring of production areas, and the targeted utilisation of environmentally-technical areas.

This conclusion aligns with the more broadly defined framework of agricultural land optimisation, according to which unsuitable shapes, higher slope gradients, longer slope lengths, and complicated accessibility limit the potential for efficient machinery working width utilisation and increase operational losses (Zhou et al., 2014; Al-Amin et al., 2023). On arable land, this trend is even more pronounced in large LPIS parcels, where the proportion of Classes III and IV increases. Here, MCA serves as a prioritisation filter, enabling more detailed design procedures to be focused on those parcels where the anticipated effect of changing traffic lines or spatial restructuring will be highest.

CONCLUSIONS

The nationwide classification of agricultural parcels according to their suitability for shape optimisation provides a methodologically consistent and practically applicable tool for evaluating the operational and environmental demands of agricultural land in the Czech Republic. A multi-criteria analysis based on ten criteria translates complex spatial characteristics of agricultural parcels into four interpretable classes with direct implications for machinery traffic organisation, the design of environmentally-technical areas, and soil protection.

A key finding is that nearly 40% of the arable land area in the Czech Republic exhibits a degree of morphological complexity associated with high suitability for optimisation interventions. Classes III and IV are of particular significance, as they are associated with higher operational costs, increased input consumption, a greater frequency of irregular field traffic patterns, elevated risks of anthropogenic soil compaction, and a more adverse relationship with soil erosion vulnerability.

Furthermore, the results demonstrate that the need for optimisation increases with parcel size, and that a higher proportion of classes III and IV is predominantly characteristic of higher-altitude and topographically diverse climatic regions. This suggests that optimisation of agricultural parcels is not merely a technical-operational issue for individual farms but also carries a substantial regional dimension and significance for the spatial prioritisation of conservation measures.

The practical value of the resulting map layer lies in its ability to identify the agricultural parcels where subsequent detailed assessment may consider adjustments to field-operation direction, internal subdivision into production areas and environmentally-technical areas, and other spatial reconfiguration measures. These measures may support more efficient machinery operation while contributing to soil and water protection, non-production requirements and broader environmental functions of the agricultural landscape. From the perspective of public administration, the map layer provides a spatially consistent basis for defining the priority areas where conservation-oriented land-management measures may be targeted.

Although the presented classification does not replace a detailed design of specific optimisation measures at the individual parcel level, it provides a robust and standardised basis for their prioritisation. In this sense, it serves as an important bridge between precision agriculture, economic management efficiency, and agricultural land protection.

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