Supplementary Table S2. Summary of Findings of Included Studies on Soil Fertility, Land Use, and Monitoring in Hungary (2000 – 2020)

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
1	Takács et al., 2021	Soil quality changes under long-term agriculture in Hungary	Soil quality indicators SOM, nutrients	Field assessment, longitudinal analysis	Agricultural activities led to measurable changes in soil quality, with declines in organic matter in intensively managed areas.
2	Mesele et al., 2024a	Soil organic matter trends under ecological change	Soil organic matter, soil quality indicators	Comparative ecological analysis	Soil organic matter dynamics are strongly influenced by environmental and land-use changes.
3	Kocsis et al., 2025	Effects of forest restoration on sandy soils in Hungary	Soil chemistry, biological activity	Field experiments, soil analysis	Forest restoration significantly improves soil biological and chemical properties in degraded sandy soils.
4	Shojaeezadeh et al., 2024a	Climate and land-use impacts on soil erosion	Soil erosion, land use, climate variables	Remote sensing, modelling	Land-use change and climate variability significantly increase erosion risk.
5	Mesele et al., 2024b	Anthropogenic soil improvement in forest ecosystems	Soil nutrients, mineralogy	Comparative soil analysis	Human activities can enhance soil fertility in certain ecosystems.
6	Kovács et al., 2025	Seasonal dynamics of soil microbiome under different management practices on Chernozem soils (Hungary)	Soil microbiome composition, seasonal variation, tillage, fertilisation, cropping system	Field experiment, microbiological analysis (sequencing), statistical analysis	Soil microbial composition varies seasonally and is strongly influenced by tillage, fertilisation, and cropping systems; sustainable management practices can enhance soil biological activity and ecosystem resilience
7	Thiébeau & Bertrand, 2020	Biomass production and nutrient immobilisation on marginal soils	Biomass yield, carbon and nitrogen dynamics	Field experiment, soil analysis	Short rotation coppices enhance carbon and nitrogen immobilisation even without fertilisation.
8	Szalai et al., 2016	Soil organic carbon redistribution via erosion	SOC, erosion processes	Field-scale monitoring	Erosion redistributes SOC, reducing fertility in upper slopes.
9	Kocsis et al., 2020	Soil drought sensitivity in Hungary	Soil moisture, yield response	Modelling, yield analysis	Hungarian soils show variable drought sensitivity affecting productivity.

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
10	Nagy & Soos, 2025	Agricultural land use	Land-use patterns	Policy and conceptual analysis	Land-sharing and sparing approaches influence sustainability outcomes.
11	Kotroczó et al., 2023	Long-term soil organic matter and moisture dynamics	SOM, soil moisture	Long-term field experiment	Soil organic matter and moisture strongly regulate soil respiration.
12	Batjes, 2002	Soil carbon and nitrogen stocks in Europe	SOC, nitrogen stocks	Database analysis	Central and Eastern Europe soils store significant carbon reserves.
13	Benedek et al., 2012	Effects of compost application on soil fertility in a Hungarian Luvisol	SOC, N, P, K, pH, soil fertility indicators	Field experiment, soil sampling, laboratory chemical analysis	Compost application enhanced soil fertility by improving nutrient availability and soil chemical properties.
14	Jakab et al., 2016	Changes in soil organic matter due to erosion	Organic carbon aggregates	Laboratory and field analysis	Erosion alters both quantity and quality of soil organic matter.
15	Shojaeezadeh et al., 2024b	Future projections of soil erosion	Soil erosion, climate scenarios	Predictive modelling	Soil erosion is expected to increase under future climate scenarios.
16	Harta et al., 2021	Soil biological quality and collembolan communities in forest plantations on former agricultural land (Hungary)	Collembola (soil biota) diversity and abundance, soil properties (e.g., moisture, organic matter)	Field sampling, soil biological analysis, statistical comparison	Forest plantations established on agricultural land improve soil biological quality; Collembola communities reflect changes in soil conditions and can serve as bioindicators of soil recovery and ecosystem restoration.
17	Nyandi et al., 2025	Relationship between canopy reflectance and maize productivity under nitrogen treatments	Chlorophyll indices, canopy reflectance indices, grain yield, protein and starch content	Field experiment, spectral analysis	Strong relationships were found between spectral indices and crop performance, indicating that remote sensing can effectively monitor nitrogen status and predict yield and quality traits in maize to guarantee the use of land.
18	Ocwa et al., 2023	Climate and fertilisation impacts on maize yield	Yield, fertilisation, climate	Literature review	Fertilisation and climate jointly determine crop productivity.
19	Maqsoom et al.,	Soil erosion and sediment	Soil erosion,	RUSLE model, GIS,	Identified high spatial variability in

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
	2020	yield assessment	sediment yield, topography	remote sensing	erosion risk; land management practices significantly influence erosion intensity.
20	Falloon et al., 1998	Carbon sequestration potential in soils	Soil carbon	Modelling, GIS	Soils have significant potential for carbon sequestration.
21	Nabayi et al., 2023	Fertiliser and organic amendments on soil fertility	Nutrients, soil fertility	Field trials	Combined organic and mineral fertilisers improve soil fertility.
22	Morgan et al., 2025	Soil classification using satellite data	Soil properties, remote sensing indices	Data fusion, remote sensing	Advanced remote sensing improves soil classification accuracy.
23	Zhang et al., 2023	Soil reclamation in saline soils	Soil salinity, microbial communities	Field experiment	Soil amendments improve microbial activity and soil recovery.
24	Alsafadi et al., 2020	Soil suitability for viticulture	Soil, climate, topography	GIS-based multi-criteria analysis	Integrated indicators improve land suitability assessment.
25	Kabato et al., 2025b	Climate-smart agriculture strategies	Soil fertility, GHG emissions	Review	Sustainability practices enhance soil fertility and reduce emissions.
26	Tölgyesi et al., 2020	Impact of woody species on soil moisture and nutrients in sandy drylands	Soil moisture, SOC, N, P, organic matter, depth-wise soil nutrient distribution	Field soil sampling under vegetation patches, laboratory chemical analysis, statistical comparison	Woody species form surface fertility islands but desiccate lower soil layers, reducing soil water availability and affecting nutrient distribution in sandy drylands.
27	Tomchuk et al., 2018	Agricultural environmental management	Environmental indicators	Economic and analytical methods	Better management improves environmental sustainability.
28	Eldridge et al., 2024	Soil processes in drylands	Soil biogeochemistry	Global dataset analysis	Soil function hotspots depend on vegetation and aridity.
29	Bouzouidja et al., 2021	Soil quality assessment of nature-based solutions	SOC, N, P, K, soil structure, soil quality indices	Field soil sampling, laboratory analysis, simplified performance assessment	Introduced a practical framework to evaluate soil quality under nature-based solutions, showing maintenance or improvement of soil fertility.

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
				methodology	
30	Meena et al., 2025	Effects of land use on soil organic carbon fractions and carbon management	SOC fractions, total SOC stocks, carbon management index, land-use types	Field soil sampling, laboratory SOC fractionation, carbon stock estimation, comparative land-use analysis	Land-use systems strongly influence SOC fractions and carbon stocks, with improved carbon management and stability under less intensive and natural land-use systems.
31	Nagy, 2007	Fertilisation effects on crop yield	Yield, fertilisation	Field trials	Fertilisation significantly increases maize yield.
32	Abd Ghani et al., 2023	Soilless agriculture and crop development	Nutrient supply	Experimental study	Soilless systems enhance early crop growth.
33	Schils et al., 2018	Yield gaps in European agriculture	Crop yield, management	Modelling, comparative analysis	Yield gaps persist due to management and environmental factors.
34	Süle et al., 2024	Status of agricultural irrigation in Hungary	Irrigation systems, water use	Conference analysis, national overview	Irrigation remains limited but increasingly important under climate change pressures.
35	Bankó et al., 2021	Soil carbon indicators for sustainability targets (4p1000)	Soil C, soil N	Long-term field experiment, laboratory analysis	Labile carbon and nitrogen indicators are effective tools for monitoring soil health improvements. Indicators useful for monitoring soil fertility changes / soil health.
36	Kocsis et al., 2021	Soil-specific drought sensitivity in Hungarian agroecosystems	Soil moisture crop yield	Modelling, yield response analysis	Soil properties strongly influence drought resilience and crop productivity.
37	Németh, 1995	Nitrogen management in Hungarian soils and groundwater protection	Nitrogen, groundwater contamination	Soil chemistry analysis, policy context	Inefficient nitrogen management contributes to groundwater pollution.
38	Tóth, 2001	Soil productivity assessment methods in Hungary	Soil productivity indices	Integrated land evaluation modelling	Soil productivity indices provide reliable tools for land evaluation.
39	Szilassi, 2017	Land cover variability and landscape patterns	Land cover, spatial patterns	GIS, landscape analysis	Significant land cover changes influence landscape structure and ecological

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
					processes.
40	Kocsis et al., 2016	Improving land quality indices using soil and yield data	Soil properties, yield data	GIS, statistical modelling	Integration of soil maps and yield data improves land evaluation accuracy.
41	Lóczy et al., 2020	Land evaluation of floodplains under aridification	Soil properties, ecosystem services	GIS-based assessment, ecosystem service evaluation	Aridification alters floodplain functions, requiring adaptive land-use strategies.
42	Mics et al., 2013	Ecosystem dynamics and soil processes	Soil processes, ecosystem functions	Ecological analysis	Ecosystem structure influences soil functioning and nutrient cycling.
43	Al-Graiti et al., 2022	Effects of soil management on dissolved organic matter	Dissolved organic matter	Laboratory and field analysis	Soil management practices significantly affect DOM composition and dynamics.
44	Szesztay, 2001	Water management and regional development	Water resources, land development	Policy environmental analysis	Water management is a critical factor in sustainable regional development.
45	Várallya, 1989	Soil degradation processes in Hungary	Soil degradation, erosion	Field observations, conceptual analysis	Soil degradation is widespread and requires integrated management strategies.
46	Fokom et al., 2013	Land-use effects on soil structure and nutrients	Soil C, N, aggregate stability	Field experiment	Land-use change significantly affects soil structure and nutrient dynamics.
47	Gábor, 1998	Landscape characteristics and land-use patterns	Landscape features, land use	Geographical analysis	Landscape structure strongly influences land-use patterns and soil processes.
48	Csomós et al., 2024	Land take and land-use change drivers in Hungary	Land-use change, urban expansion	Spatial analysis, statistical modelling	Urbanisation and infrastructure development are key drivers of land take, reducing agricultural land.
49	Kassai & Tóth, 2020	Spatial variability of soil phosphorus	Soil P, soil properties, socioeconomic factors	Digital soil mapping, GIS	High spatial variability in soil P influenced by fertilisation practices and soil type.
50	Henits et al., 2022	Monitoring agricultural subsidies using satellite	Crop cover, vegetation indices	Sentinel-2 remote sensing	Remote sensing effectively monitors agricultural land management and

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
		data			subsidy compliance.
51	Magda, 2007	Post-transition land utilisation changes	Agricultural land use	Statistical analysis	Land-use restructuring occurred after economic transition, affecting agricultural production patterns.
52	Szabó et al., 2016	Satellite image comparison in Tisza-tó region	Land cover	Landsat image analysis	Satellite datasets provide reliable land cover monitoring over time.
53	Nagy et al., 2021	Soil moisture estimation in agricultural lands	Soil moisture	Field measurements, remote sensing indices	Soil moisture indices correlate moderately with field measurements.
54	Gelencsér et al., 2010	Soil erosion modelling	Soil loss	WEPP and USLE models	Soil erosion risk varies across slope and land management practices.
55	Pásztor et al., 2018	National soil-type mapping	Soil types	Sequential classification, digital soil mapping	Produced a national soil-type map supporting soil resource assessment.
56	Szabó et al., 2002	Farm-level soil information systems	Soil fertility indicators	Database compilation	Integrated soil data systems improve farm management decisions.
57	Pinke et al., 2024	Climate sensitivity of crop yields	Crop yields, climate variables	Statistical modelling	Climate variability increases vulnerability of crop production.
58	Deszső et al., 2020	Carbon sequestration in vineyards	SOC, erosion	Field sampling, modelling	Organic vineyards can increase SOC and reduce erosion
59	Keller et al., 2006	Anthropogenic impacts on loess sediments	Soil chemistry	Geochemical analysis	Anthropogenic activities influence carbonate reactions in soils.
60	Keller et al., 2020	Land-use intensity and erosion susceptibility	Soil erosion	Field observation	Higher land-use intensity increases erosion risk.
61	Gulacsi & Kovács, 2018	Drought monitoring in forests	NDVI, drought indices	MODIS remote sensing	Remote sensing effectively detects drought stress patterns.
62	Government of Hungary, 2020	Climate reporting	Environmental indicators	National reporting framework	Climate change affects agricultural productivity and soil conditions.
63	Szatmári et al., 2020	Salt-affected soils mapping	Soil salinity	Digital soil mapping	Identified spatial distribution of salt-affected soils in Hungary.
64	Kocsis et al.,	Drought sensitivity of soils	Crop yields, soil	Statistical analysis	Sandy and clay soils show higher

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
	2020		properties		drought sensitivity.
65	Balogh et al., 2025	Land-use change and biological invasion	Land cover change	GIS and historical analysis	Land-use change promotes biological invasions in ecosystems.
66	Tóth et al., 2021	Land quality and productivity	Soil fertility indicators	Statistical modelling	Soil quality strongly influences land productivity.
67	Lemenkova, 2012	Climate impacts on landscapes	Climate, land cover	GIS analysis	Climate change contributes to landscape transformation.
68	Szilassi et al., 2006	Historical land-use impacts on soil	Soil properties, erosion	Field sampling	Land-use changes altered soil erosion patterns.
69	Kertész, 2016	Desertification risk	Soil degradation	Environmental analysis	Desertification risk exists in vulnerable Hungarian regions.
70	Chen et al., 2012	Land cover change in Hungary and China	Land cover	Remote sensing, GIS	Demonstrated applicability of RS for land-cover monitoring.
71	Joshi & Nagare, 2009	Land-use change detection	Land cover	Remote sensing	Land-use changes detected using satellite imagery.
72	Lászlók, 2012	Energy crop production impacts	Land use	Policy and spatial analysis	Energy crop expansion affects agricultural land allocation.
73	Erdei et al., 2022	Riparian landscape change	Land cover	GIS	Riparian ecosystems experienced significant land-use transitions.
74	Nagy et al., 2020	Landscape degradation	Soil degradation	Spatial analysis	Anthropogenic pressure accelerates landscape degradation.
75	Csorba et al., 2004	Landscape research review	Landscape processes	Literature review	Highlights importance of landscape studies in environmental planning.
76	Németh et al., 2021	Marshland landscape change	Land use	Remote sensing	Wetland landscapes show long-term land-use changes.
77	IIASA, 2012	Land-use change datasets	Land-use data	Database development	Provided metadata tools for kland-use research.
78	Wojtaszek, 2019	Field variability mapping	Soil properties	Remote sensing	Spatial variability can be mapped effectively with RS.
79	Lennert et al., 2020	Land cover changes in Budapest	Urban land cover	GIS modelling	Urban expansion alters surrounding land-use patterns.

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
80	Ministry of Agriculture, 2017	National landscape strategy	Landscape indicators	Policy framework	Strategy aims to manage landscape sustainability.
81	Szabó et al., 2019	NDVI trends in Hungary	NDVI	Remote sensing	Vegetation dynamics linked to climate variables.
82	Negovanović et al., 2020	NDVI and soil test integration	NDVI, soil nutrients	GIS analysis	Combining RS and soil data improves monitoring.
83	Mika et al., 2002	NDVI correlation with crop yields	NDVI, crop yields	Statistical analysis	NDVI correlates with maize and wheat yield variability.
84	Centeri et al., 2010	Phosphorus loss in slopes	Soil P	Field measurements	P loss influenced by land management and slope.
85	Bozsik & Koncz, 2018	Regional land-use differences	Land use	Statistical analysis	Regional differences reflect socioeconomic drivers.
86	Mustafa, 2016	Land-use optimisation	Soil fertility capability	GIS analysis	Land capability classification supports
87	Laborczi et al., 2016	Topsoil texture mapping	Soil texture	Classification trees	Produced national texture maps for Hungary.
88	Várallyay, 2006	Soil degradation processes	Soil moisture regime	Environmental analysis	Extreme moisture regimes contribute to degradation.
89	Centeri et al., 2001	Soil erosion sustainability	Soil loss	Field experiments	Soil erosion threatens sustainable land management.
90	Bidló et al., 2012	Soil investigation in urban areas	Soil chemistry	Field sampling	Urban soils show altered chemical properties.
91	Pásztor & Fodor, 2010	Agro-ecological potential	Soil fertility indicators	GIS modelling	Agro-ecological zoning supports sustainable agriculture.
92	Rieder et al., 2018	SOM alteration from land-use change	SOM	Experimental plots	Land-use changes affect SOM decomposition rates.
93	Birkás et al., 2012	Soil quality and land use	Soil quality indicators	Field analysis	Land management practices influence soil quality.
94	Velmurugan & Garcia, 2009	Soil resource mapping	Soil properties	Remote sensing, GIS	RS useful for soil resource inventory.

No.	Authors / Year	Study focus	Parameters analysed	Methodological approach	Main findings
95	Ács et al., 2015	Soil-atmosphere relationships	Soil moisture climate	Modelling	Soil processes strongly linked to atmospheric conditions.
96	Szatmári et al., 2024	SOC stock modelling	SOC	Space-time modelling	SOC stocks show spatial variability across Hungary.
97	Kovács et al., 2022	Grassland changes	Grassland extent	Spatial analysis	Grassland areas declined due to land-use changes.
98	Pásztor et al., 2007	Soil information systems in SE Europe	Soil databases	Database review	Regional soil databases support environmental research.
99	Opršal et al., 2016	Drivers of land-use change	Biophysical factors	GIS modelling	Land-use change driven by environmental and socioeconomic factors.
100	Waltner et al., 2020	Land cover change and erosion	Soil erosion	GIS analysis	Land cover conversion increases erosion susceptibility.
101	O'Donnell & Manier, 2022	Soil moisture estimation	Soil moisture	Modelling	Soil moisture influences ecological productivity.
102	Csikós et al., 2023	Cropland productivity assessment	Crop productivity	Earth observation	Satellite data enable national cropland monitoring.
103	Szilassi et al., 2010	Relationship between soil quality and agricultural land-use change in the Lake Balaton catchment (Hungary)	Soil quality indicators (e.g., organic matter, nutrients), land-use patterns	GIS-based spatial analysis, field data integration, case study approach	Agricultural land-use change significantly influences soil quality; intensification and conversion of land lead to soil degradation, emphasising the importance of sustainable land-use planning and management.
104	Matasov et al., 2020	Spatial determinants and drivers of long-term land-use transitions in European Russia	Land-use change, socio-economic drivers, environmental factors	Historical data analysis, spatial modelling, GIS-based analysis	Land-use transitions are driven by a combination of socio-economic changes and environmental conditions; long-term patterns reflect shifts in agricultural practices, population dynamics, and policy influences.
105	Vári et al., 2022	National ecosystem services assessment framework in Hungary	Ecosystem services, land use, socio-economic	Conceptual framework development,	Provides a comprehensive framework for assessing ecosystem and land-use services in Hungary; highlights the

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			ecological indicators	national-scale assessment, stakeholder engagement	importance of integrating ecological, social, and economic dimensions into land-use planning and policy-making.
106	Dadgar, 2018	Effects of land types and land use on soil organic carbon in the Damavand region (Iran)	Soil organic carbon (SOC), total nitrogen, soil texture, pH, $CaCO_3$	Field sampling, laboratory soil analysis, regression modelling	Soil organic carbon varies significantly across land-use types and geomorphological units; higher SOC is associated with alluvial and cultivated areas, while lower values occur in rangelands and plateau soils. SOC shows strong positive correlation with total nitrogen and is influenced by land management and environmental factors.

Gábor, 1998 – Translation from Hungarian: “A Borsodi-dombság tájföldrajzi jellemzése”