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Towards a unifying approach of land degradation in Europe

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- ***General objective****: exploring the geospatial convergence of multiple land degradative conditions (land multi-degradation) across the European agricultural environments, for a unifying modelling of land degradation on this continent;*

- ***Structure:***

  - *the concepts of land degradation and land multi-degradation and their environmental importance;*
  - *the methodological framework of the present research;*
  - *the geospatial results of land multi-degradation in European agricultural landscapes;*
  - *conclusions;*
  - *references.*

❑ *Land degradation – key concepts:*

- ***land degradation**: "reduction or loss of biological or economic productivity of lands, due to many degradation processes, such as water/eolian soil erosion, physical/chemical/biological/economic land deterioration, or long-term loss of vegetation" (UNCCD, 1994);*

- *land degradation – multiple degradative pathways (processes) that cause a decline in land productivity (Prăvălie et al., 2021) (Fig. 1);*

- *land degradation = **desertification** if it occurs in dryland systems (except for hyper-arid areas) (UNCCD, 1994; Reynolds et al., 2007; Cherlet et al., 2018) (Fig. 2);*

- ***land multi-degradation** – land degradation occurring through multiple concurrent (convergent) processes (Prăvălie et al., 2024).*

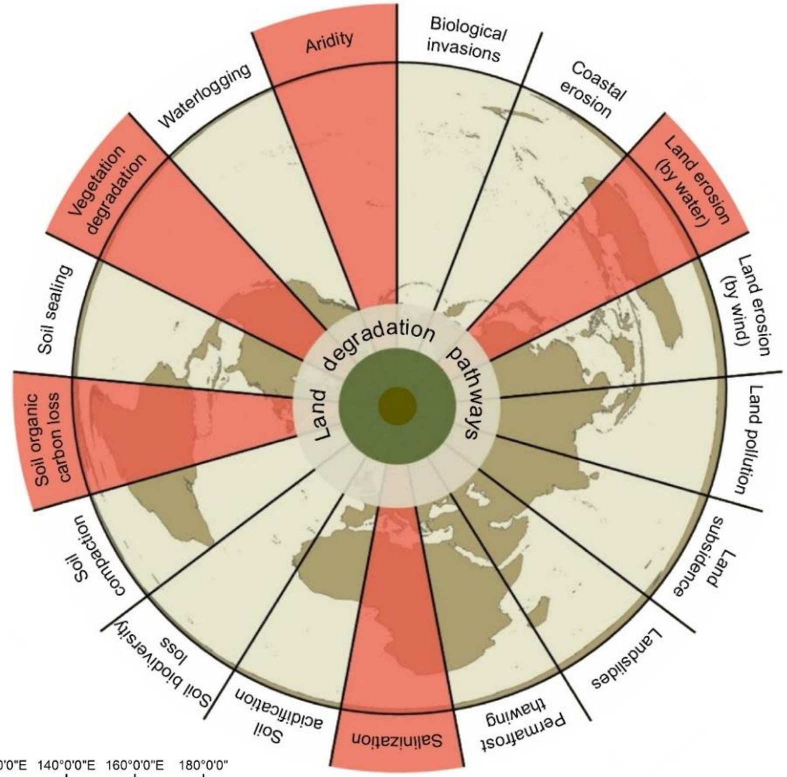

***Fig. 1.** Schematic approach to land degradation pathways currently occurring globally (after Prăvălie, 2021).*

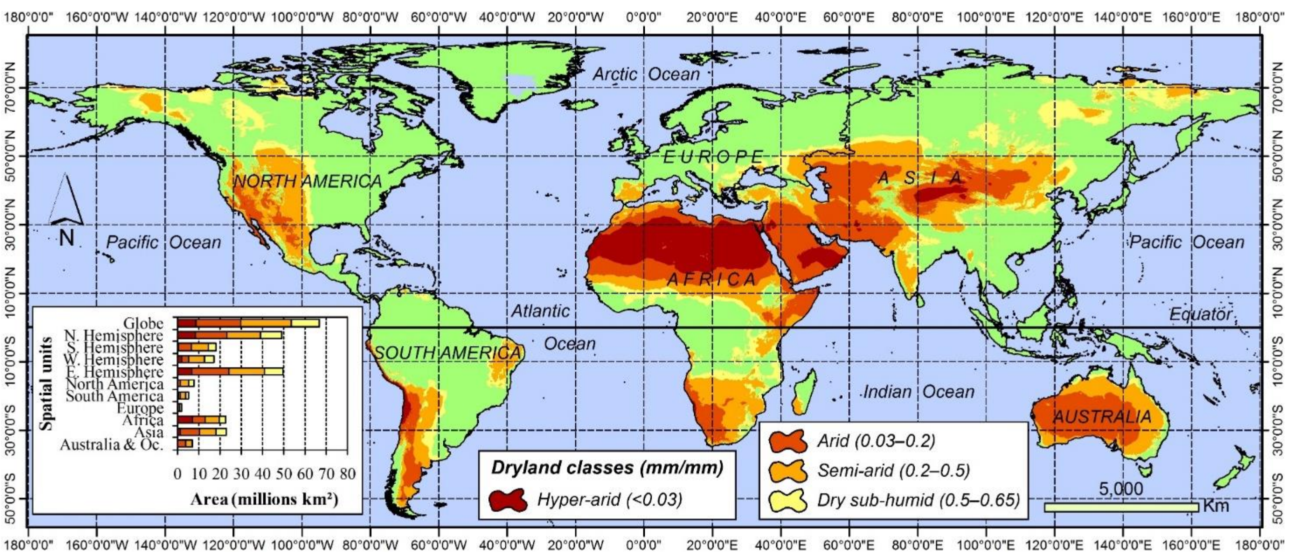

***Fig. 2.** Spatial representation of the global dryland systems (after Prăvălie, 2016).*

❑ *Environmental relevance:*

- *land degradation / land multi-degradation – various negative environmental consequences, like the reduction / collapse of soil functions (Fig. 3);*

- *for example, the disruption of the climate regulation capacity (Fig. 3) – soil is the second carbon pool at the entire planetary scale and the first carbon pool at global terrestrial scale (Fig. 4).*

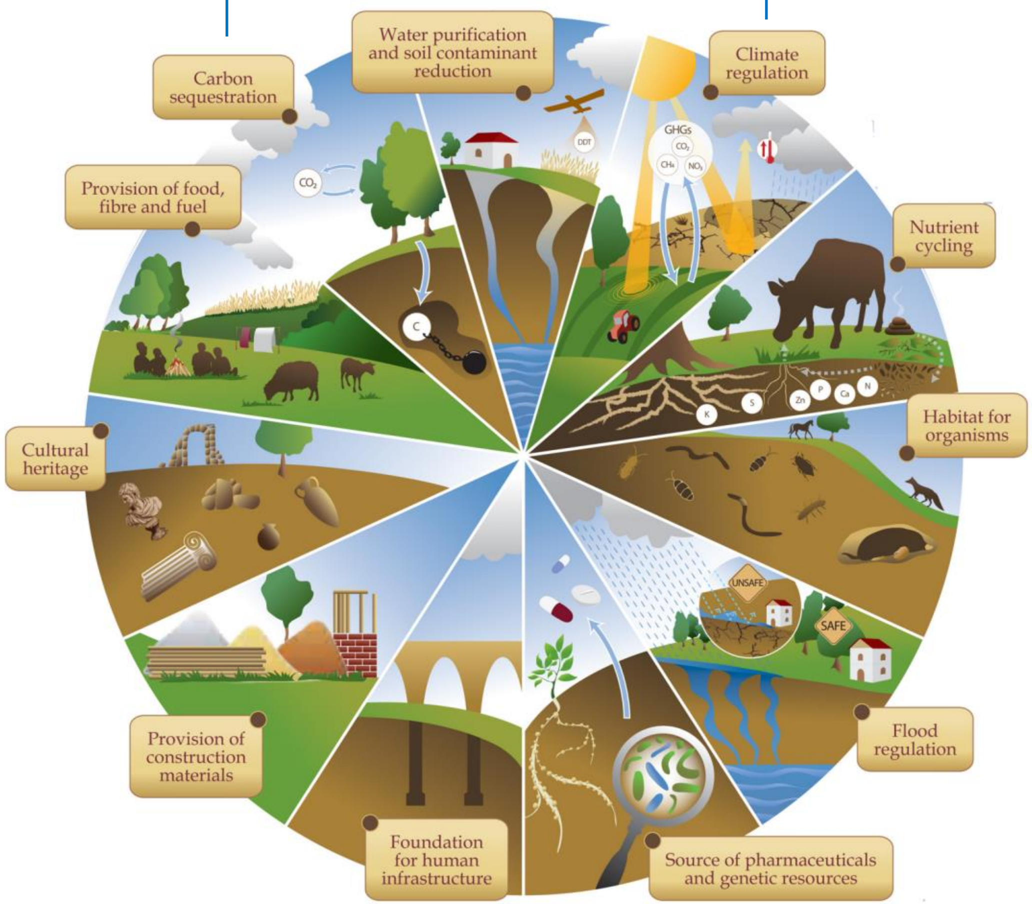

Fig. 3. *Schematic approach to various soil functions (after Baveye et al., 2020).*

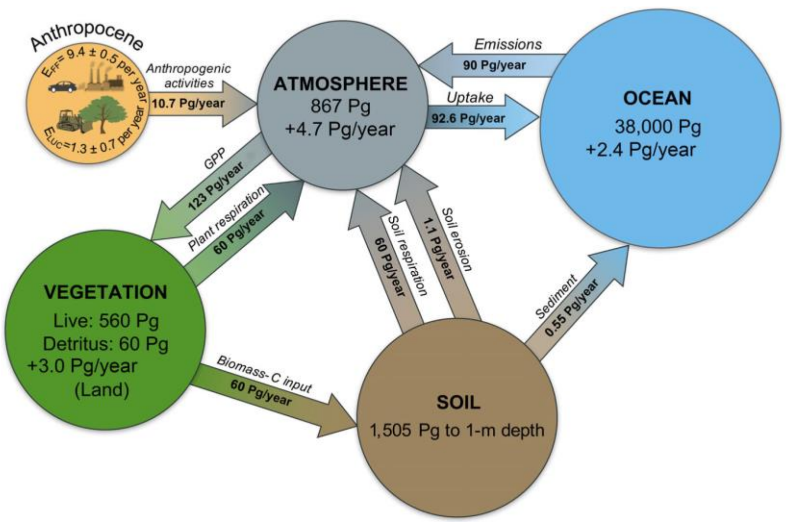

Fig. 4. *Carbon cycle at the global scale (Source: Lal, 2018). Notes: arrows – carbon fluxes, circles – carbon stocks, E_{FF} – emissions by fossil fuel, E_{LUC} – emissions by land use conversion; 1 Pg C – one billion tons of carbon.*

❑ *The methodological approach of land multi-degradation in Europe:*

- *most / all land degradation processes – so far* ***analyzed in a singular manner (the "uni-degradation" perspective)*** *across the globe and in Europe;*

- *this continental analysis focuses on modelling 12 concurrent processes in Europe –* ***water erosion, wind erosion, soil organic carbon loss, soil salinization, soil acidification, soil compaction, soil nutrient imbalances, soil pollution via pesticides, soil pollution via heavy metals, vegetation degradation, groundwater decline*** *and* ***aridity****) (Table 1);*

- *these land degradation processes are highly relevant for highlighting the agricultural land degradation in Europe and worldwide (Table 1);*

Table 1. *The 12 processes selected for this continental analysis, considering their general negative ecological effects for agricultural land productivity (after Prăvălie et al., 2024).*

No.	Land degradation processes	Examples of negative effects on agricultural land productivity
1	Water erosion	*Degrading soil structure, reducing soil depth or decreasing / losing the soil nutrient content*
2	Wind erosion	*Accelerating dust emission, damaging crops by abrasion or reducing the organic matter content*
3	Soil organic carbon loss	*Disrupting structural stability and water holding capacity of soils or decreasing soil fertility*
4	Soil salinization	*Limiting plant growth due to phytotoxicity, water uptake difficulty or soil organic carbon losses*
5	Soil acidification	*Threatening soil bacterial diversity, increasing toxicity for plants or limiting soil nutrient availability*
6	Soil compaction	*Reducing soil porosity, shrinking oxygen and water supply to plants or restricting root penetration*
7	Soil nutrient imbalances	*Amplifying acidity and micronutrient deficiencies in soils, due to N or P excess, or inhibiting plant growth, due to N or P deficit*
8	Soil pollution via pesticides	*Exerting stress on soil health via toxicity and decline in microbial community or earthworm activity*
9	Soil pollution via heavy metals	*Poisoning the soil, injuring plants via chlorosis and necrosis or hindering root growth and crop yields*
10	Vegetation degradation	*Decreasing soil productivity via soil organic carbon losses or through increased land exposure to water and wind erosion*
11	Groundwater decline	*Depleting groundwater resources, inducing soil water stress or inhibiting plant development*
12	Aridity	*Generating surface low water availability and constant soil water deficit or triggering desertification*

- *6 databases available internationally were directly used – water erosion (Borrelli et al., 2017), soil organic carbon (SOC) loss (Prăvălie et al., 2021), soil salinization (Toth et al., 2008), soil acidification (Ballabio et al., 2019), soil compaction (EC, 2008) and soil pollution via pesticides (Tang et al., 2021) (Fig. 5);*

- *for the other layers (wind erosion, soil nutrient imbalances, soil pollution via heavy metals, vegetation degradation, groundwater decline and aridity), various pre-existent data from other sources were collected, in order to model the geospatial data for the remaining 6 processes (Prăvălie et al., 2024) (Table 2, Fig. 5);*

- *the 12 rasters, with various features (Table 2), were structured into **2 classes – Critical** and Non-critical (Fig. 5);*

- *by intersecting the Critical classes of the 12 datasets, a **Land Multi-degradation Index (LMI)** was obtained (Prăvălie et al., 2024).*

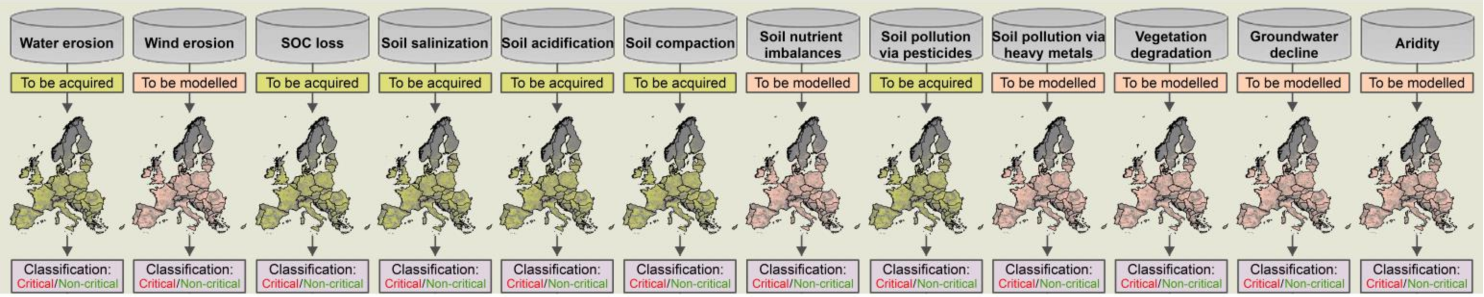

Fig. 5. *Schematic approach to geospatial database processing in Europe.*

Table 2. *Characteristics of land degradation data that were used in this continental approach (after Prăvălie et al., 2024).*

No.	LD data	Original resolution [a]	Time period	Metric
1	Water erosion	250 × 250 m	2012	t ha^{-1} yr^{-1}
2	Wind erosion	500 × 500 m	2001–2021	t ha^{-1} yr^{-1}
3	SOC loss	1 × 1 km	2001–2015	t C km^2 yr^{-1}
4	Soil salinization	1 × 1 km	2008	%
5	Soil acidification	500 × 500 m	2019	pH units
6	Soil compaction	1 × 1 km	2008	Susceptibility
7	Soil nutrient imbalances	1 × 1 km (N) 100 ×100 m (P)	2010–2019	kg/ha (N) mg/kg (P)
8	Soil pollution via pesticides	10 × 10 km	2015	Risk score
9	Soil pollution via heavy metals	1 × 1 km (As, Cd, Cr, Co, Pb, Sb, Ni) 500 × 500 m (Cu) 250 × 250 m (Hg)	2009	mg/kg
10	Vegetation degradation	500 × 500 m	2000–2015	NDVI units
11	Groundwater decline	1 × 1 km	2004–2013	GTD (m yr^{-1})
12	Aridity	1 × 1 km	1981–2018	AI (mm/mm)

Notes: m – meter, km – kilometer, ha – hectare, t – ton, C – carbon, N – Nitrogen, P – Phosphorous; NDVI – Normalized Difference Vegetation Index; GTD – Groundwater Table Depth; AI – Aridity Index; As – Arsenic; Cd – Cadmium; Cr – Chrome; Co – Cobalt; Pb – Lead; Sb – Antimony; Ni – Nickel; Cu – Copper; Hg – Mercury; a – spatial resolution of the originally collected data, which were processed at an intermediate resolution of 500 × 500 m.

❑ The geospatial results of multiple land degradation processes in Europe:

- *different spatial patterns of land (uni-) degradation processes across Europe (Figs. 6, 7);*
- *each driver of degradation – examined according to some specific critical classes (Figs. 6, 7);*

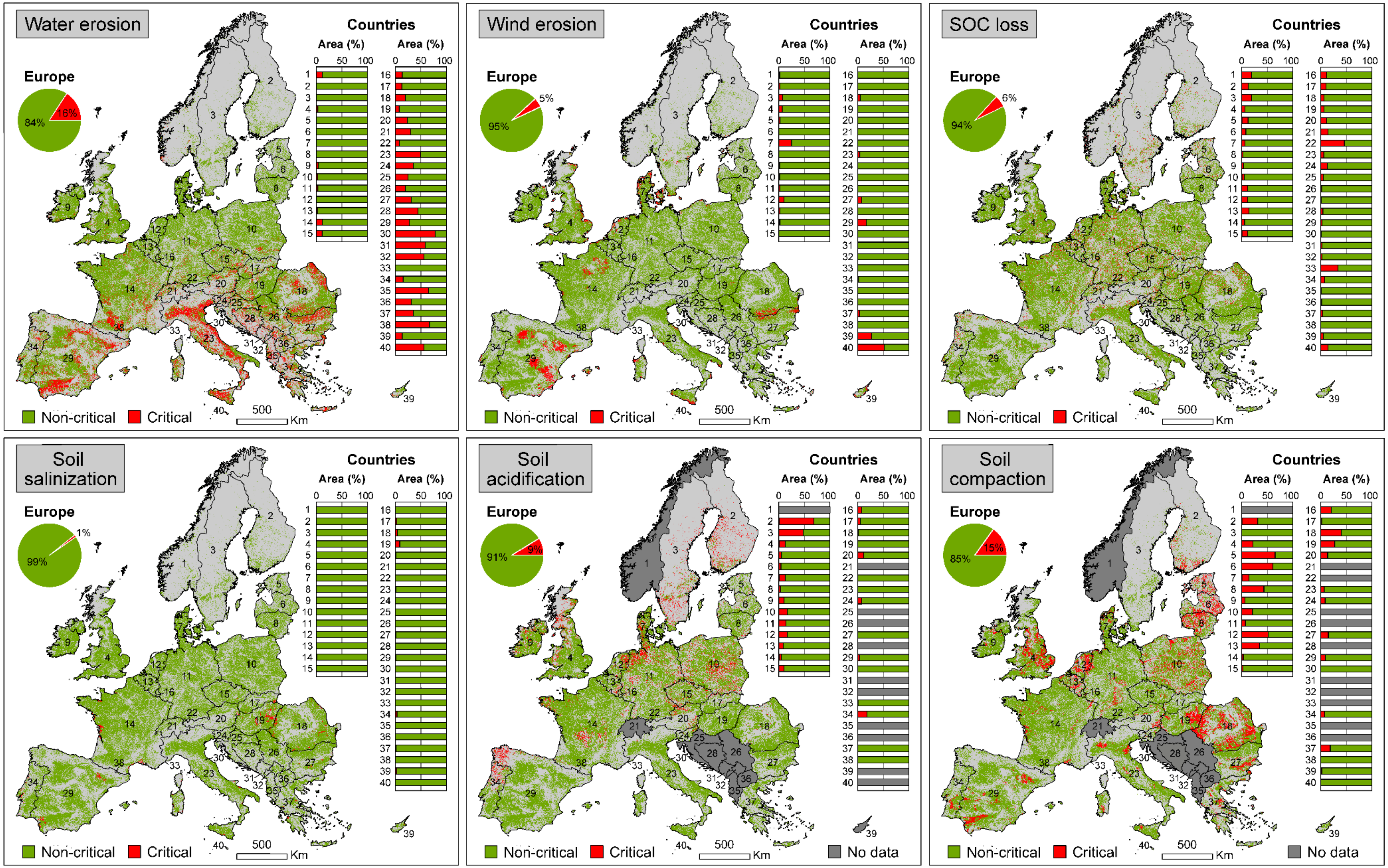

Fig. 6. *Mapping of water erosion, wind erosion, SOC loss, soil salinization, soil acidification and soil compaction in European agricultural areas (after Prăvălie et al., 2024).*

- *soil pollution via pesticides – the largest spatial footprint at continental level (52% of the cumulated agricultural area of 40 investigated countries) (Fig. 7);*

- *followed by soil nutrient imbalances (39%), soil pollution via heavy metals (31%) and aridity (26%) (Fig. 7);*

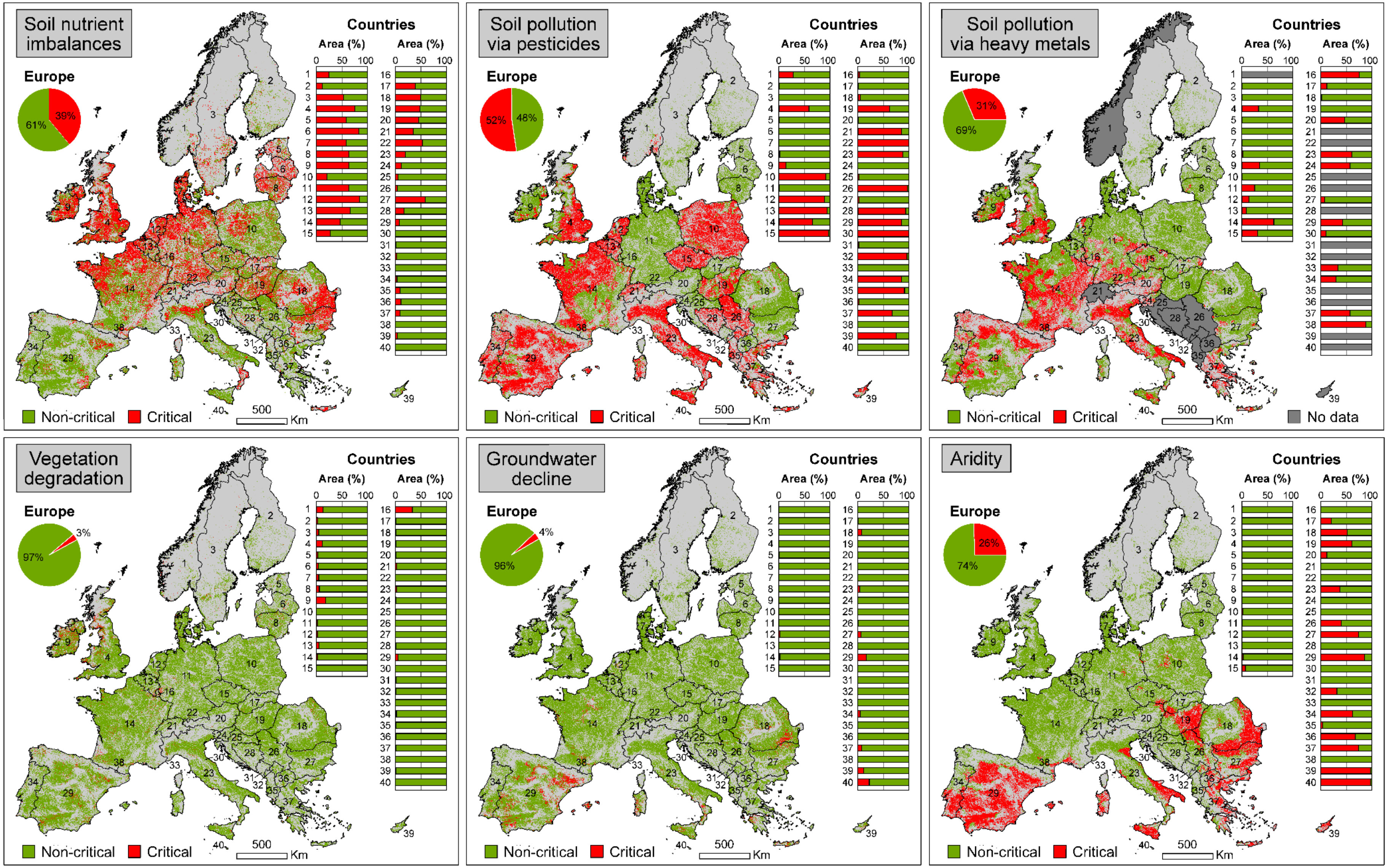

Fig. 7. *Mapping of soil nutrient imbalances, soil pollution via pesticides, soil pollution via heavy metals, vegetation degradation, groundwater decline and aridity in European agricultural areas (after Prăvălie et al., 2024).*

- ***Land Multi-degradation Index (LMI)*** *– obtained by fusing the 12 land degradation (the critical classes) databases (Fig. 8);*
- *LMI results – between one and ten converging (co-occurring) processes in Europe (Fig. 8);*
- *~10% of agricultural/arable lands are cumulatively affected by 4 and ≥ 5 concurrent processes (Table 3).*

Table 3. *Spatial extent (in km² and %) of LMI classes in agricultural/arable environments of Europe (after Prăvălie et al., 2023).*

No.	LMI classes (number of co-occurring processes)	Agricultural lands		Arable lands	
		km²	%	km²	%
1	No degradation (0)	143,626	6.84	71,196	6.23
2	Very low degradation (1)	577,279	27.50	304,105	26.60
3	Low degradation (2)	727,147	34.65	395,940	34.64
4	Medium degradation (3)	451,213	21.50	249,178	21.80
5	High degradation (4)	156,170	7.44	95,169	8.33
6	Very high degradation (≥ 5)	43,473	2.07	27,562	2.40

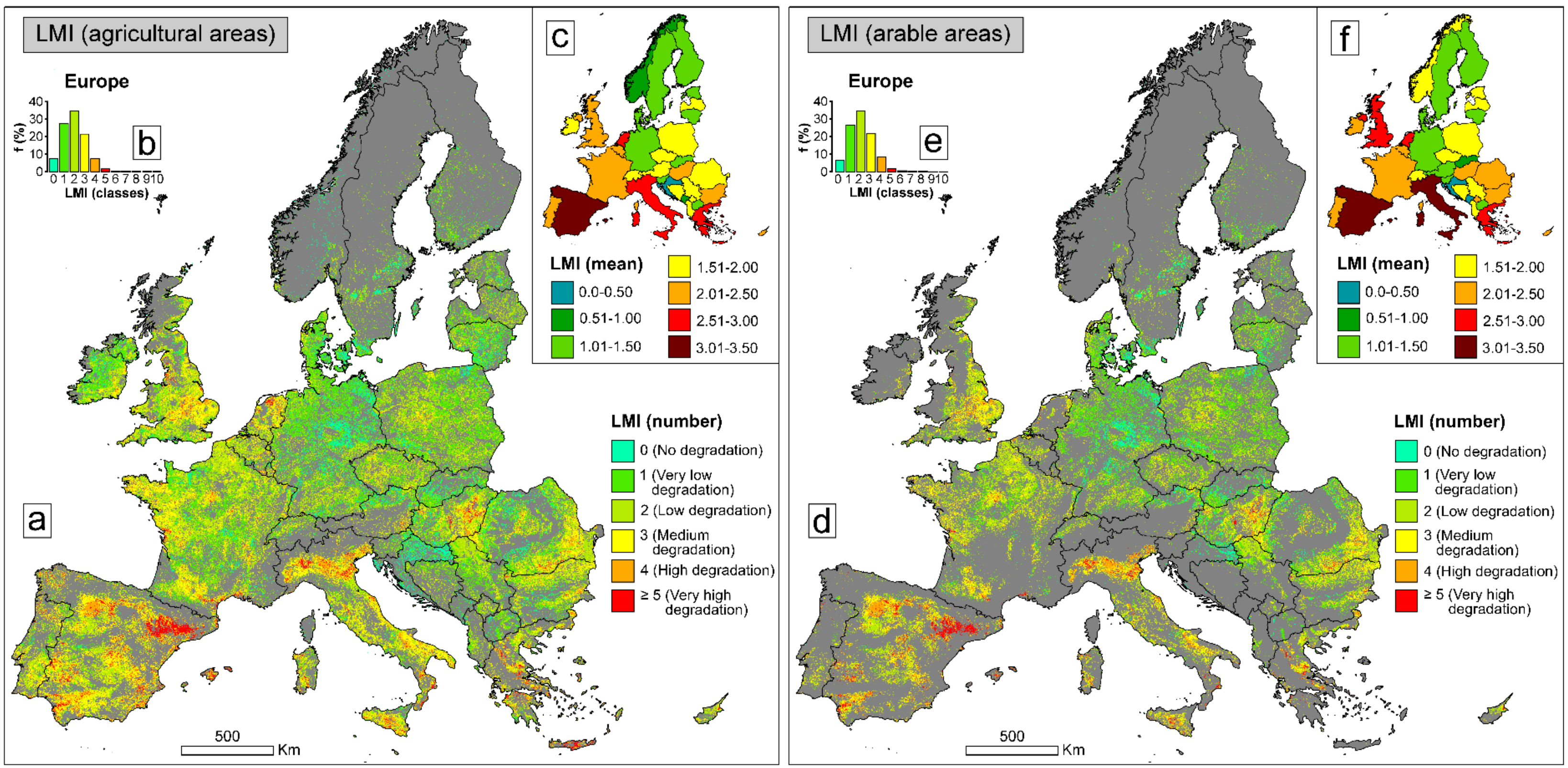

Fig. 8. *Land multi-degradation (LMI) in Europe.* ***a,d*** *Spatial distribution of LMI values in agricultural / arable landscapes.* ***b,e*** *Histogram of LMI values for European agricultural /arable lands.* ***c,f*** *Average number of co-occurring processes in agricultural / arable environments of Europe.*

- *besides the number (LMI), a complex pattern of interacting land degradation pathways was detected in Europe (Figs. 9, 10).*

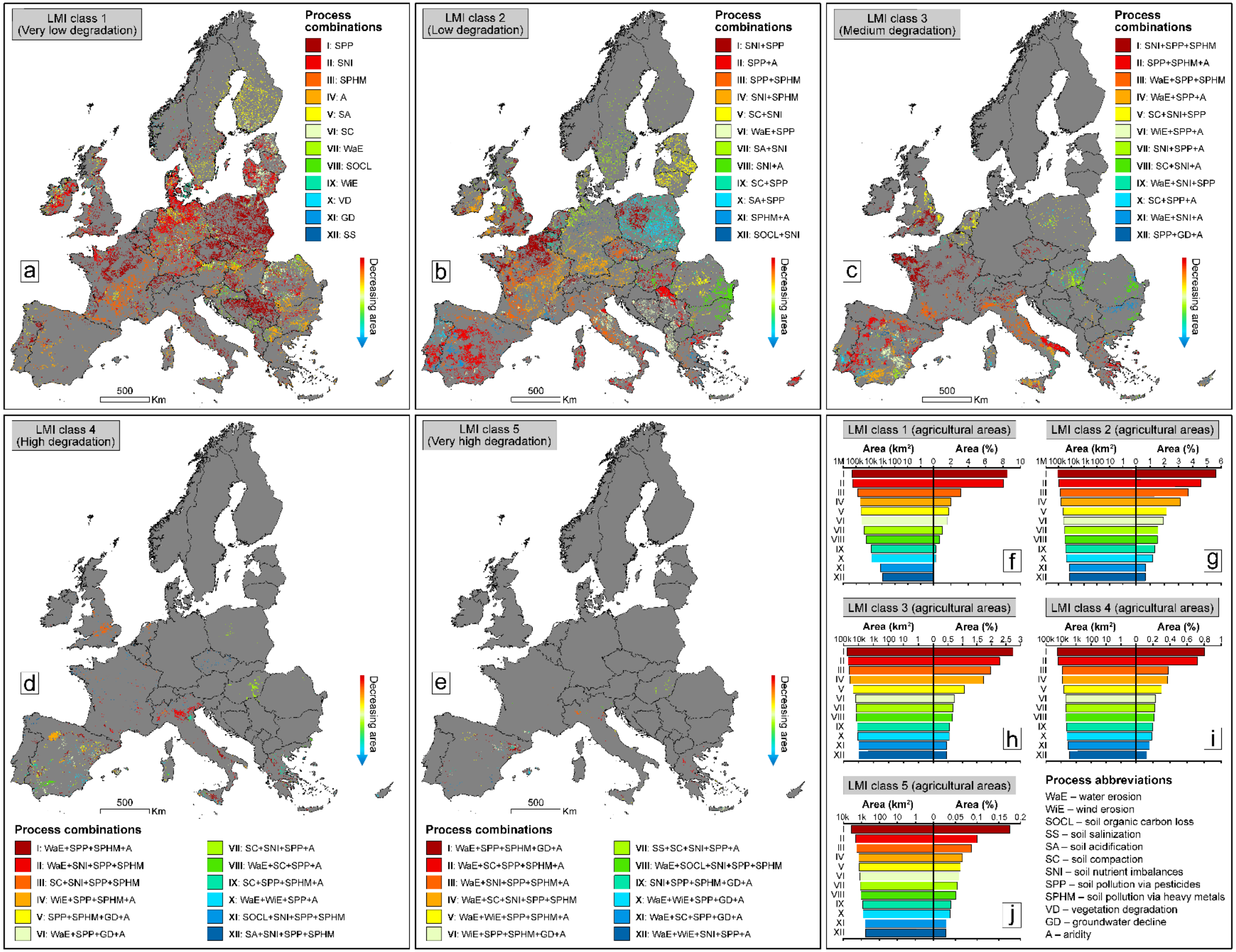

Fig. 9. *Spatial pattern of interacting convergent processes in agricultural environments of Europe.* ***a–e****, Spatial distribution of the dominant (most frequent) co-occurring process types (combinations) in LMI agricultural classes 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e).* ***f–j****, Absolute and percentage-based (% of the total continental agricultural lands) spatial footprint of the dominant co-occurring process types in LMI agricultural classes 1 (f), 2 (g), 3 (h), 4 (i) and 5 (j) (after Prăvălie et al., 2024).*

- *the main combinations of 4 and 5 concurrent processes – the major hotspots of land degradation in Europe (Figs. 9, 10).*

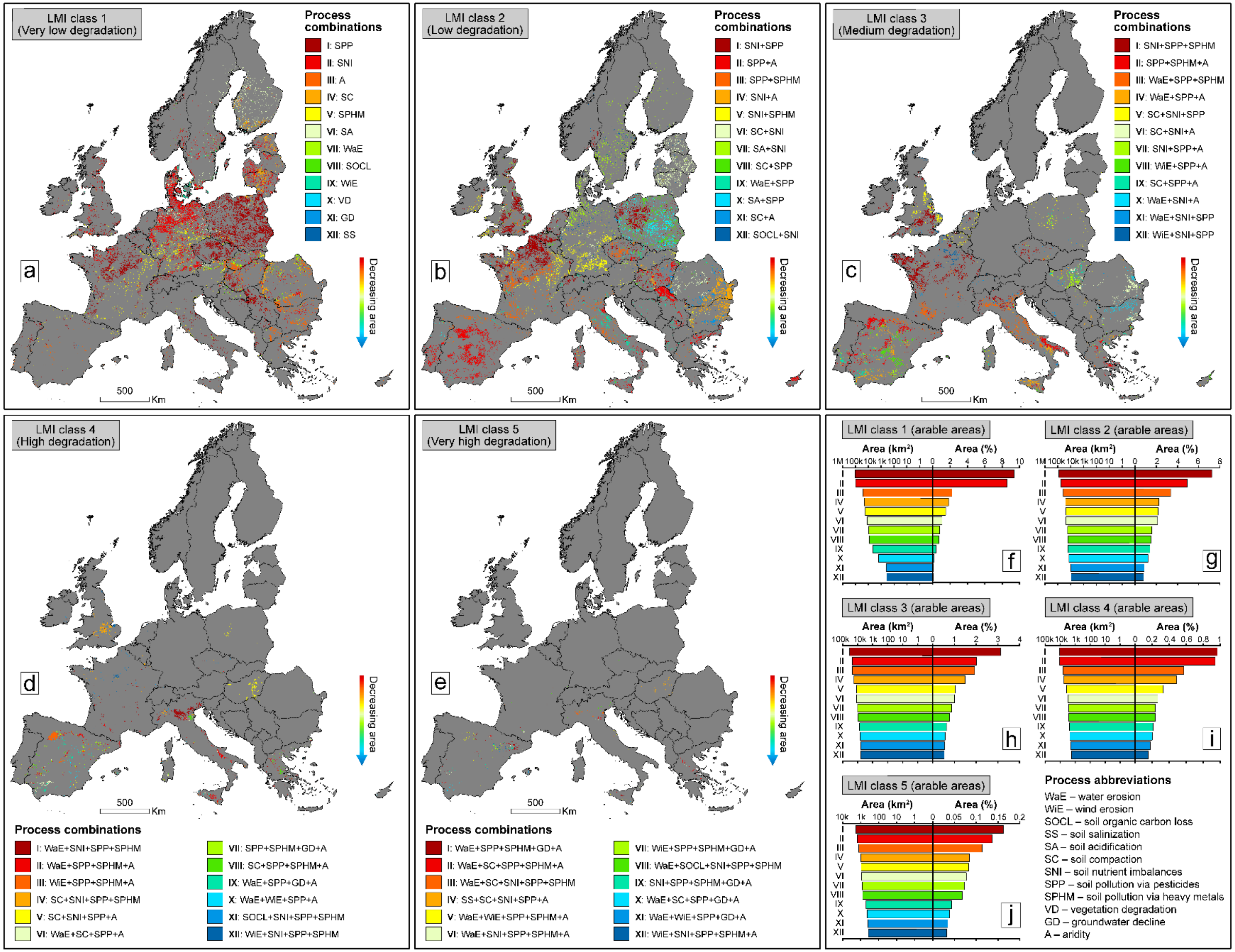

Fig. 10. *Spatial pattern of interacting convergent processes in arable environments of Europe.* ***a–e****, Spatial distribution of the dominant (most frequent) co-occurring process types (combinations) in LMI arable classes 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e).* ***f–j****, Absolute and percentage-based (% of the total continental arable lands) spatial footprint of the dominant co-occurring process types in LMI classes 1 (f), 2 (g), 3 (h), 4 (i) and 5 (j) (after Prăvălie et al., 2024).*

❑ *Conclusions:*

- ✓ *European agricultural systems – under the pressure of various land degradative conditions;*

- ✓ *the convergent (unified) analysis of multiple land degradation processes – addressed continentally in this study, using large-scale geospatial data and complex methods;*

- ✓ *about 10% of agricultural/arable lands of Europe are cumulatively affected by 4 (high degradation) and ≥ 5 (very high degradation) concurrent processes;*

- ✓ *our findings will enable policy makers to develop knowledge-based strategies for land degradation mitigation and other critical European sustainable development goals;*

- ✓ *the findings obtained in this research are important for some key land degradation policies, like Land Degradation Neutrality, the 2030 Agenda for Sustainable Development or Paris Agreement.*

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