Soil hydrophysical quality in relation to organic matter in Mediterranean ecosystems of central Spain

Lorena Recio Vázquez

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Thesis Supervisors:
Dra. Pilar Carral González (UAM)
Dr. Gonzalo Almendros Martín (CSIC)

CSIC Consejo Superior de Investigaciones Científicas
UAM Universidad Autónoma de Madrid

Departamento de Biología Ambiental del Museo Nacional de Ciencias Naturales (CSIC)
Departamento de Geología y Geoquímica de la Universidad Autónoma de Madrid (UAM)

Presentation Outline

Introduction

The concept of soil quality

Soil quality

- ecological and socio-economic functions
- non-renewable resource
- soil degradation problems

"The capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health" (Doran et al., 1996).

Studies on soil quality

- Can the soil perform all these functions
  What are its weaknesses?
- What is the soil response to specific management practices?

How to assess soil quality?

The assessment of soil quality

Function → Processes → Attributes/ Properties → Indicators → Methodology

Function: Physical dimension

Physical support

Air movement and exchange

Water supply and storage

Water flow regulation

Processes: Flows of matter and energy

Attributes/ Properties:
- Soil structure
- Soil texture
- Soil porosity
- Water holding capacity
- Infiltration capacity

Indicators: An indirect quantifiable measure of the attribute

'minimum data set'

A number of properties that provide practical assessment of the soil processes of importance for a specific function

Methodology:
- Attribute monitoring
- Comparison of different soil systems

The role of organic matter in soil quality

Soil organic matter improves → **Soil Quality**

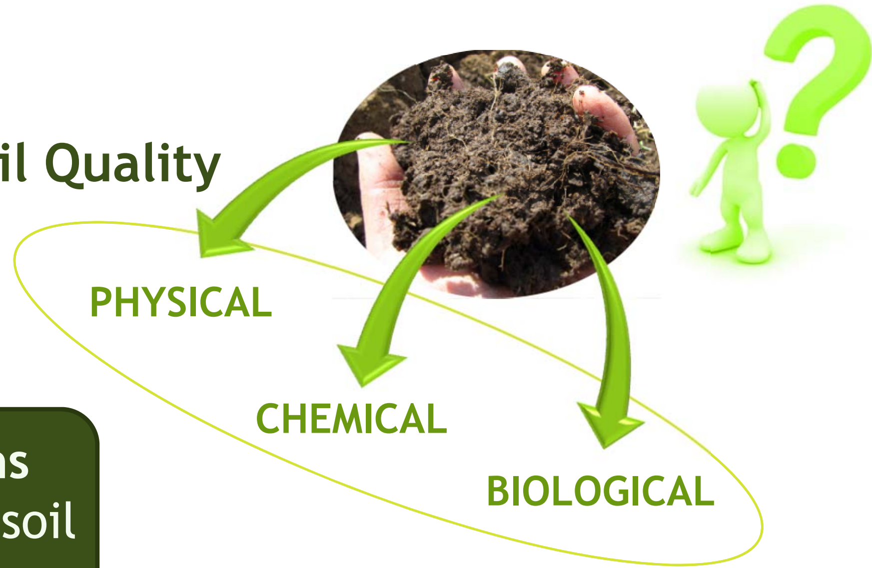
Quantity

Organic carbon concentration

Quality

Stability of carbon forms in the ecosystem

Interactions with other soil constituents



The role of organic matter in soil quality

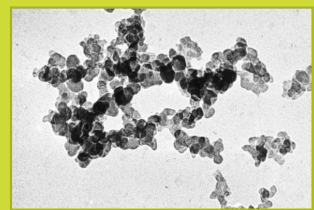
Soil organic matter —improves→ **Soil Quality**

Quantity | **Quality**

Continuum of materials

Physical & Chemical dynamics

Turnover rates



Soil properties can be affected by specific pools of soil organic matter in a different manner

Mediterranean soils

Objectives

Objectives

General objective

To study the interactions between different soil properties

- Provide empirical knowledge of the soil **properties** that can be used as quality **indicators**
- Quantify the importance of **organic matter** in the soil **hydrophysical response**

Specific objectives

Descriptive approach

1st Objective

- Description of hydrophysical parameters
- Identification of degradation problems

2nd Objective

- SOM quantity
  - Organic carbon content
- SOM quality
  - Composition, structure, stability and transformation mechanisms

Statistical analyses

3rd Objective

- Which variables can be used to explain soil hydrophysical quality?
- Relation between the different variables?
  - SOM

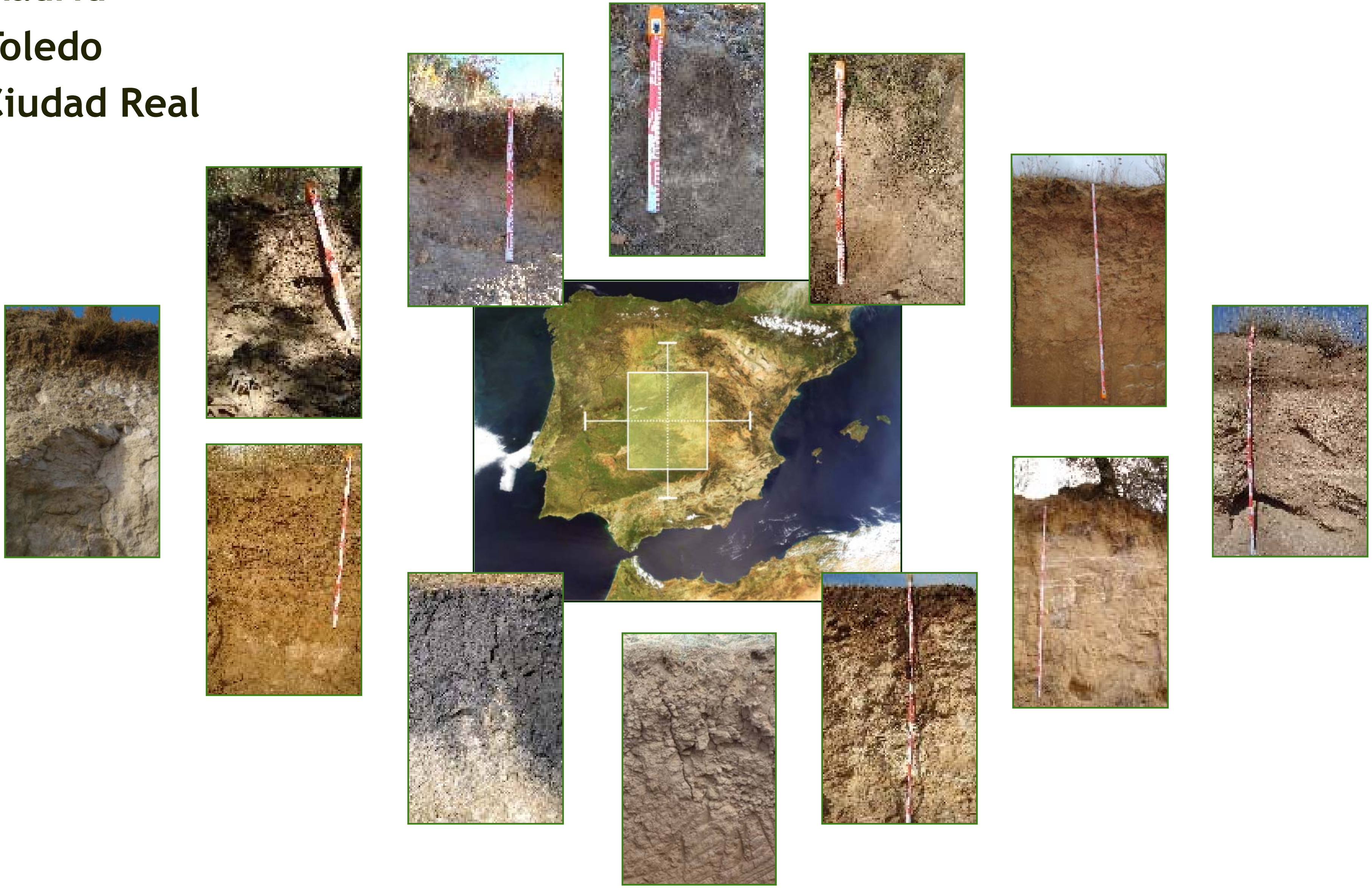
Study area

Study area

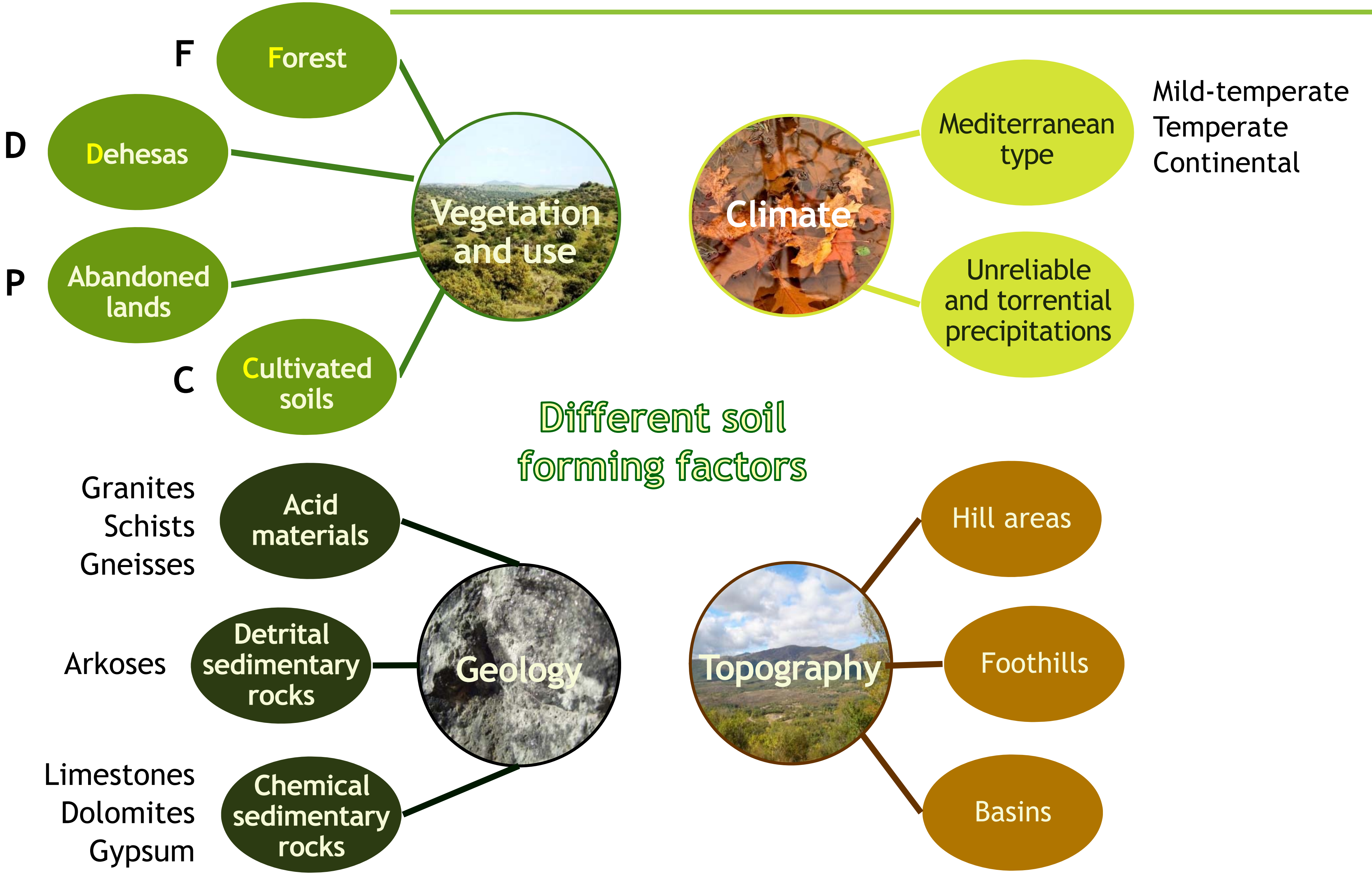
Madrid

Toledo

Ciudad Real

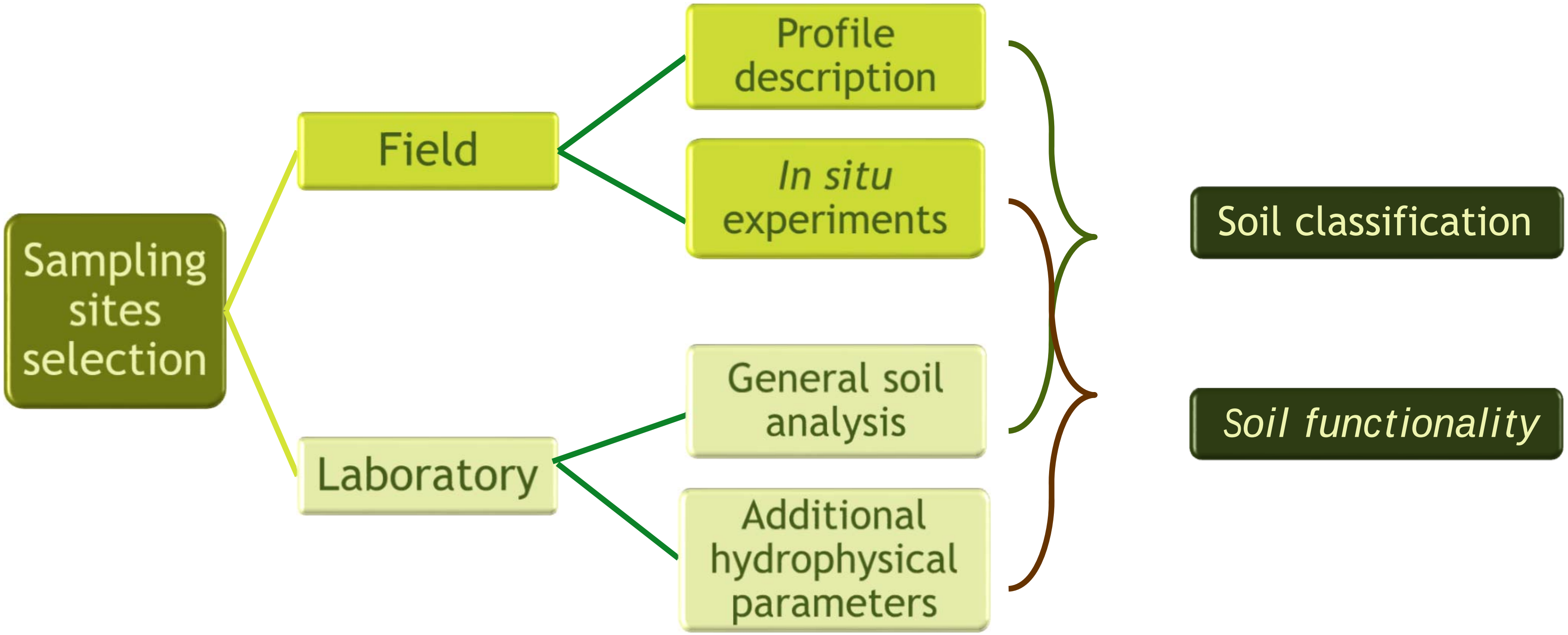


Study area

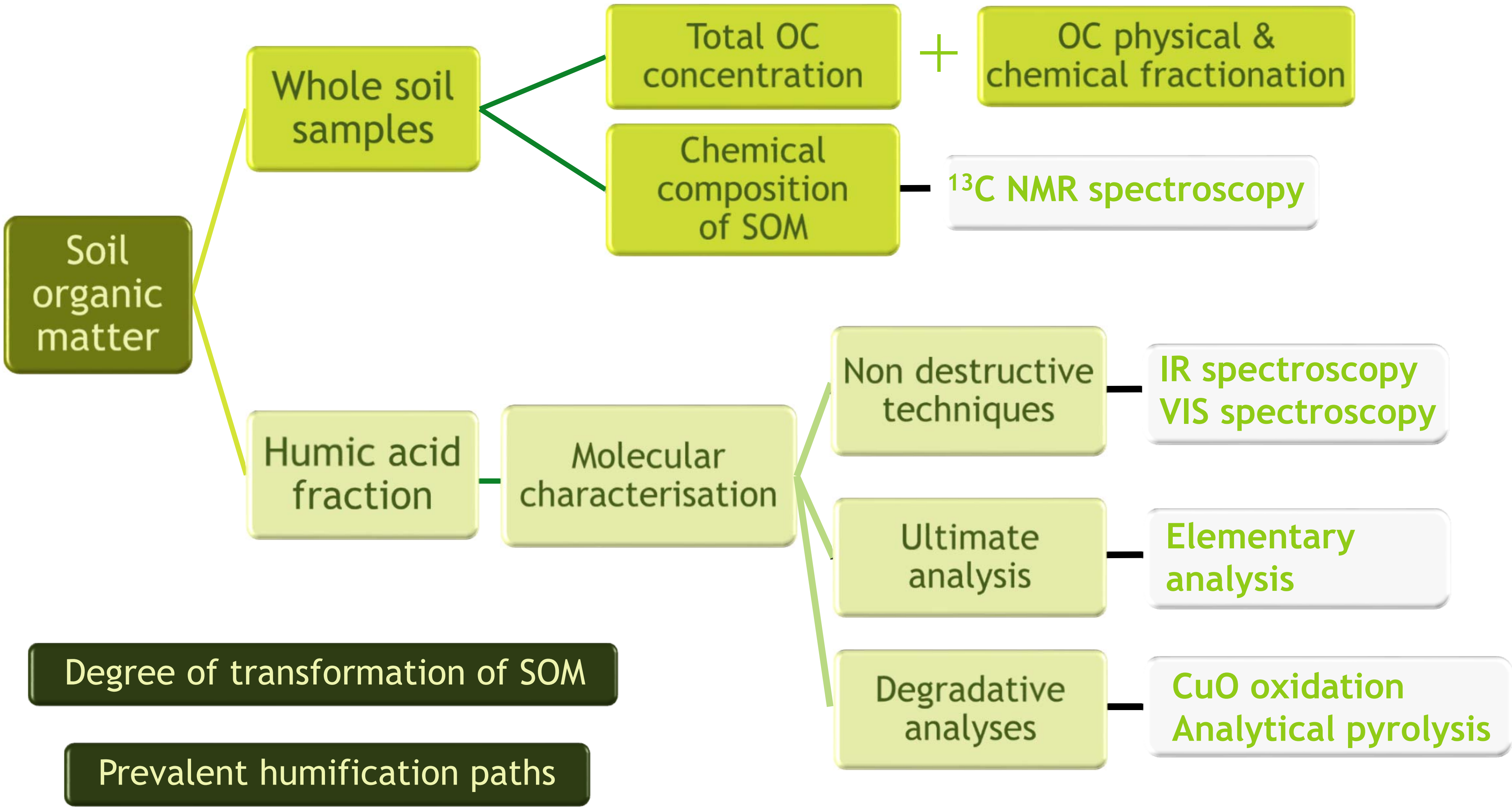

F
Forest
D
Dehesas
P
Abandoned lands
C
Cultivated soils
Vegetation and use
Climate
Mediterranean type
Mild-temperate
Temperate
Continental
Unreliable and torrential precipitations
Different soil forming factors
Granites
Schists
Gneisses
Acid materials
Arkoses
Detrital sedimentary rocks
Limestones
Dolomites
Gypsum
Chemical sedimentary rocks
Geology
Topography
Hill areas
Foothills
Basins

Materials and Methods

1st Objective

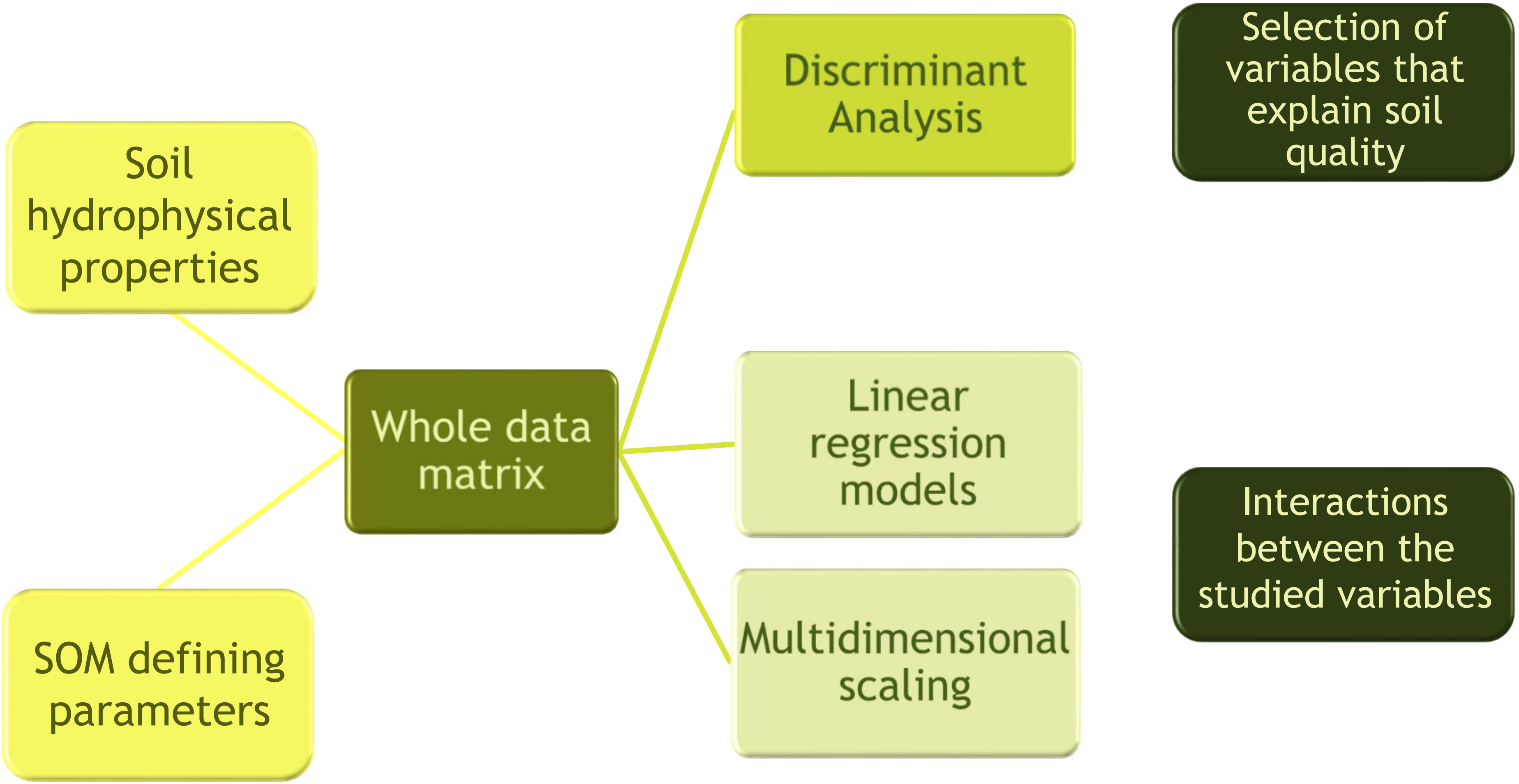


2nd Objective



Materials and Methods

3rd Objective



Results and Discussion

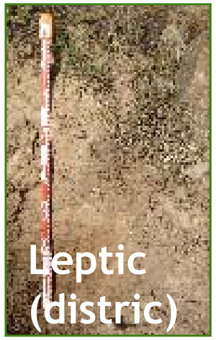
- Objective 1

Objective 1

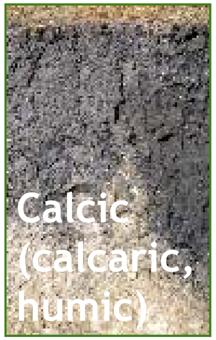
Results and Discussion

Soil classification (FAO, 2006)

Cambisols

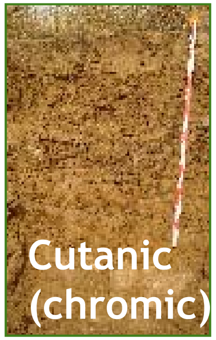


Vertisols

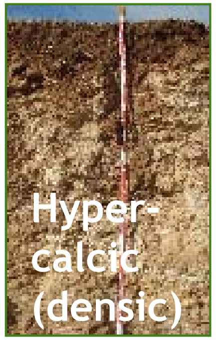


Kastanozem

Luvisols



Calcisols



Leptosol

Results and Discussion

Assessment of specific hydrophysical parameters

Profile	F1	F2	F3	D1	D2	D3	P1	P2	P3	C1	C2	C3
Bulk density ($kg \cdot m^{-3}$)	1.0	1.0	1.4	1.2	1.0	0.9	1.4	1.3	1.4	1.5	1.7	1.6
Porosity (%)	52	56	39	46	58	61	38	35	41	39	24	31
Structural resilience (*Irs*, %)	21	14	7	12	21	18	13	6	12	2	3	3
Structural stability (*Ies*, %)	98	98	63	96	97	99	92	97	84	61	89	34
Water holding capacity ($g \cdot 100\ g^{-1}$)	9.5	7.9	6.2	8.5	13.8	17.8	4.8	7.0	9.6	12.1	5.9	6.2
Air availability (%, v:v)	67	79	70	67	53	33	74	8	47	0	26	29
Ks ($mm \cdot min^{-1}$)	0.9	2.3	3.2	9.1	0.9	1.3	9.5	2.5	1.1	0.3	5.0	0.3
Par. *a* ($mm \cdot min^{-1}$)	7.1	20.4	5.5	4.1	2.8	5.8	29.9	9.5	7.2	7.0	10.7	7.9
Par. *b*	0.53	0.27	0.33	0.35	0.55	0.69	0.49	0.37	0.58	0.22	0.16	0.36
Hydrophobicity (WDPT, s)	2.6	4.5	0.3	0.2	341	7.7	4.8	1.4	1.4	0.0	0.4	0.5

Results and Discussion

Soil capacity to perform its hydrophysical functions ➡ Soil functionality

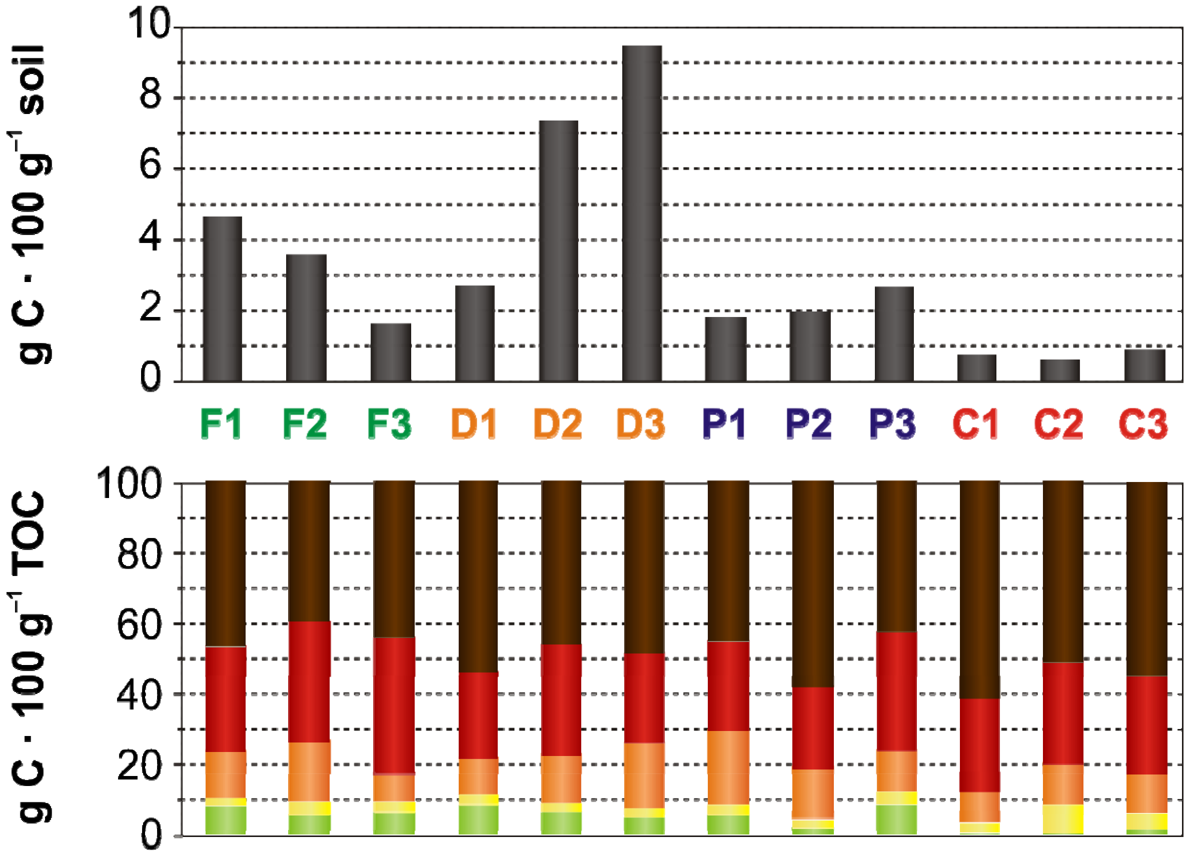
Soil function	F1	F2	F3	D1	D2	D3	P1	P2	P3	C1	C2	C3
Physical support	+ + + +	+ + +	-	+ + +	+ + + +	+ + + +	+	+	+	- - -	- -	- - - -
Aeration	+ + + +	+ + + +	+	+ + +	+ + +	+ +	+ +	- - -	+	- -	- - -	- -
Water supply & storage	+	-	- - -	+	+ +	+ + +	- - - -	- -	+	+ +	- - -	- - -
Water transmission (topsoil)	+	+	+ +	- - - -	- - -	+	- - -	+ + +	+ +	- -	-	- -
Water transmission (profile)	+	+ + + +	-	- -	- - -	- -	+ + + +	+ +	+	+	+ + +	+

Results and Discussion

- Objective 2

Results and Discussion

Soil organic matter characterisation → Quantitative → Qualitative



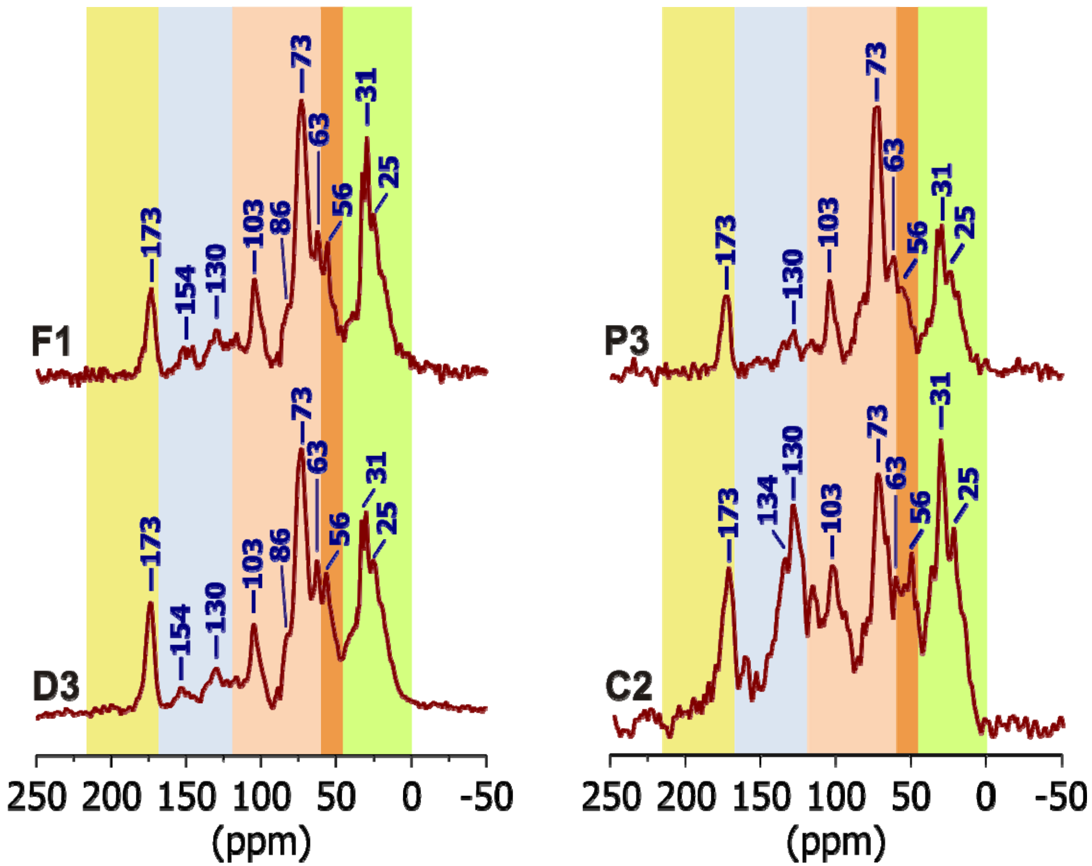
0.7 - 9.5 g C·100 g^{-1} soil

- Free organic matter < 9%
- Free fulvic acids < 8%
- Lipids < 1%
- Fulvic acids } > 40%
- Humic acids } > 40%
- Humin > 50%

Results and Discussion

Soil organic matter characterisation → Qualitative

^{13}C NMR spectroscopy



Alkyl C → 25-36%
- Alkanes
- Fatty acids
- Waxes
- Cutans…

***O*-Alkyl C** → 31-47%
- Carbohydrates
- Tannin-like structures

Methoxyl / *N*-Alkyl C → 10-13%
- Methoxyl groups in lignins
- Cα aminoacids

Carbonyl C → 6-8%
- Carboxyl /amide/ester groups

Aromatic C → 9-26%

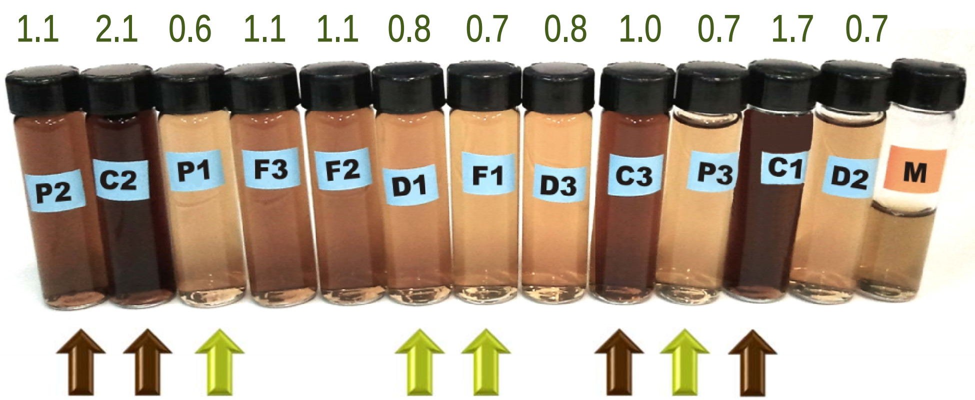
Isolated humic acids → Spectroscopic techniques

Visible spectroscopy

Diagenetic transformation of the SOM

Dark colour = High aromaticity and molecular complexity

E_4 = 0.66 – 2.07 UA



Results and Discussion

Isolated humic acids → Spectroscopic techniques

Infrared spectroscopy

Forest soils
***Dehesa* soils**

Biomolecules preservation

Aliphaticity

Marked lignin pattern

Direct humification pathway

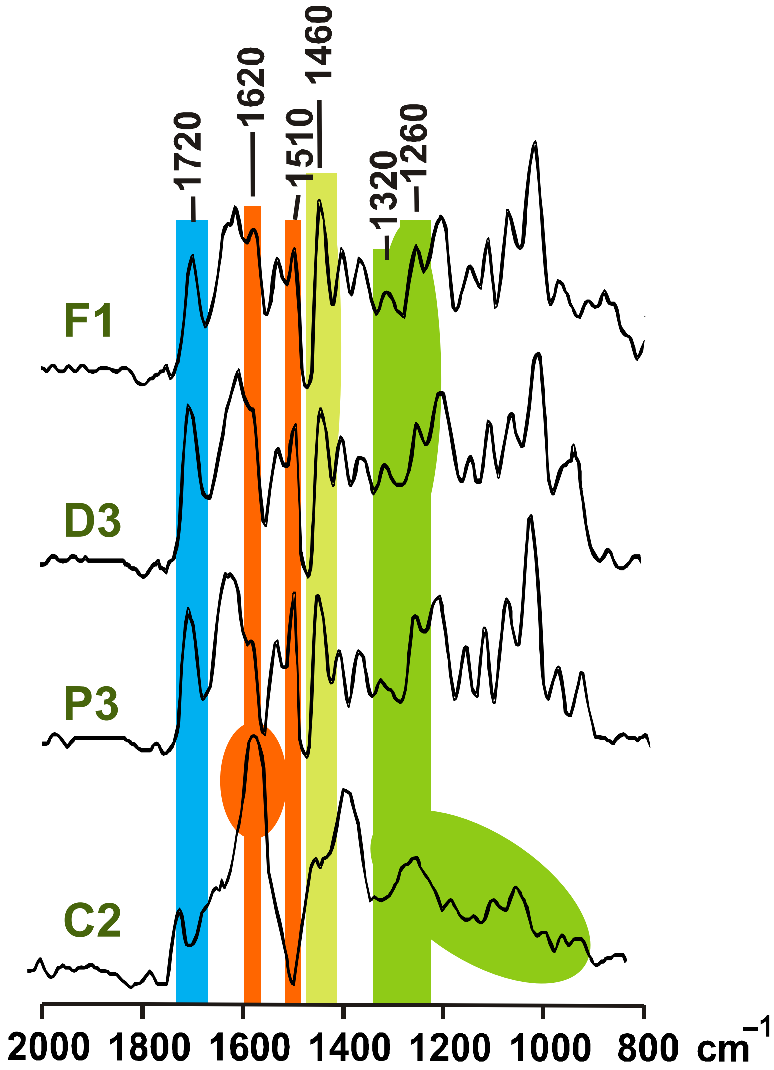
Cultivated soils

High macromolecular complexity

Unrecognisable band pattern

Marked aromatic bands

Indirect humification pathway



Results and Discussion

Isolated humic acids → **Degradative techniques** → **GC/FID GC/MS**

Thermal degradation → Analytical pyrolysis + GC/MS

Molecular composition of humic acids

- **Lipids** → 20-48%
- **Carbohydrate derivatives** → 4-8%
  Cellulose and related macromolecules from plant and microbial origin
- **Phenols** → 4-23%
- **Methoxyphenols** → 0.2-16%

  (Phenols and Methoxyphenols: Lignins, Polysaccharides, Proteins)
- **Aromatics** → 16-43%
  High degree of organic matter transformation
- **N-compounds** → 8-18%
  Plant and microbial origin
  - Long-chain alkanenitriles: specific from humified soil organic matter

Results and Discussion

- Objective 3

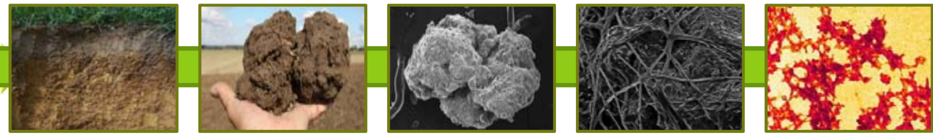
Statistical analysis

Which variables can be used to explain soil hydrophysical quality?

Discriminant analysis

Backward stepwise option

- *Soil physical functionality* → **Classification factor**
  - Very good/ Good
  - Normal
  - Deficient/ Very deficient
- Dimensions of *soil functionality* → **Physical functions**
  - Support
  - Aeration
  - Water supply and storage
  - Water transmission
- Variables for the data matrix

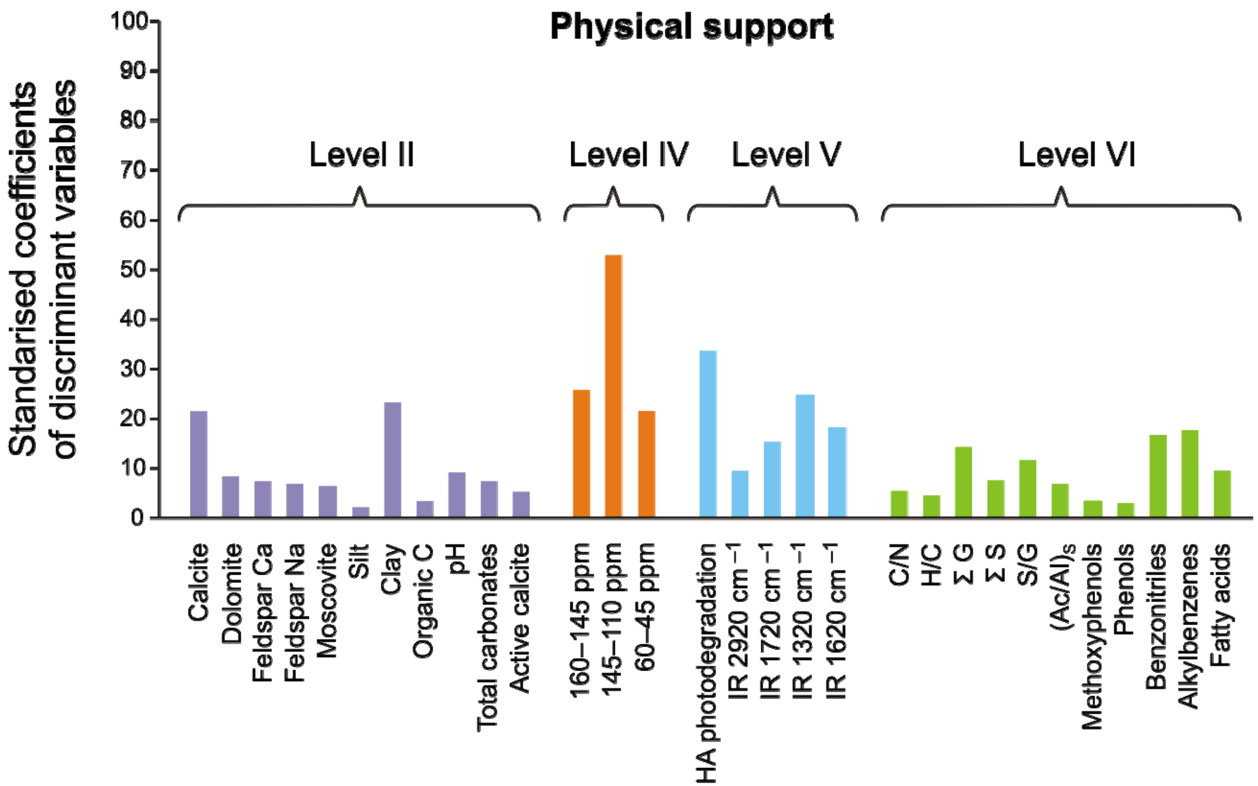


  - I: Macroscopic features of soil profile
  - II: Mineralogy, texture and chemical fertility
  - III: Soil organic matter fractions
  - IV: Chemical structure soil organic matter
  - V: Spectroscopic features of humic acids
  - VI: Molecular composition of humic acids

Statistical analysis. Discriminant analysis

Physical support

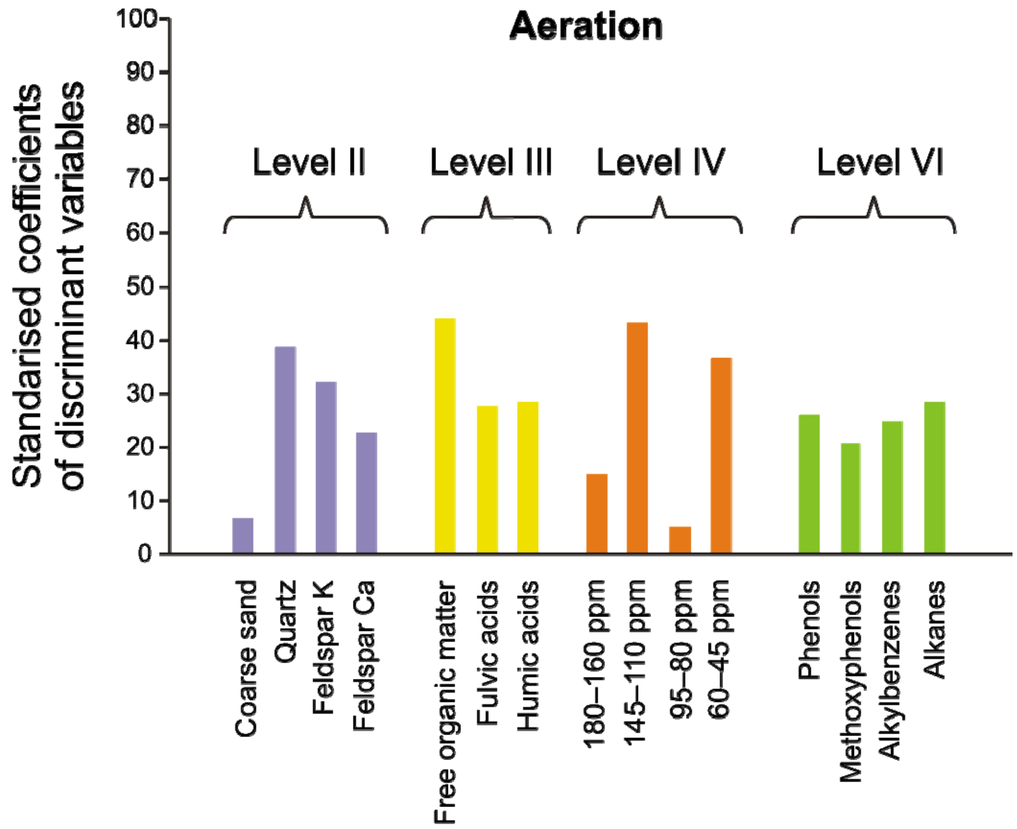
I	n.s.
II	Calcite Clay
III	n.s.
IV	Aromatic C *O*/*N*-Substituted aromatic C
V	Aromatic band Syringyl units
VI	Alkylbenzenes Benzonitriles Lignin units



Statistical analysis. Discriminant function analysis

Aeration

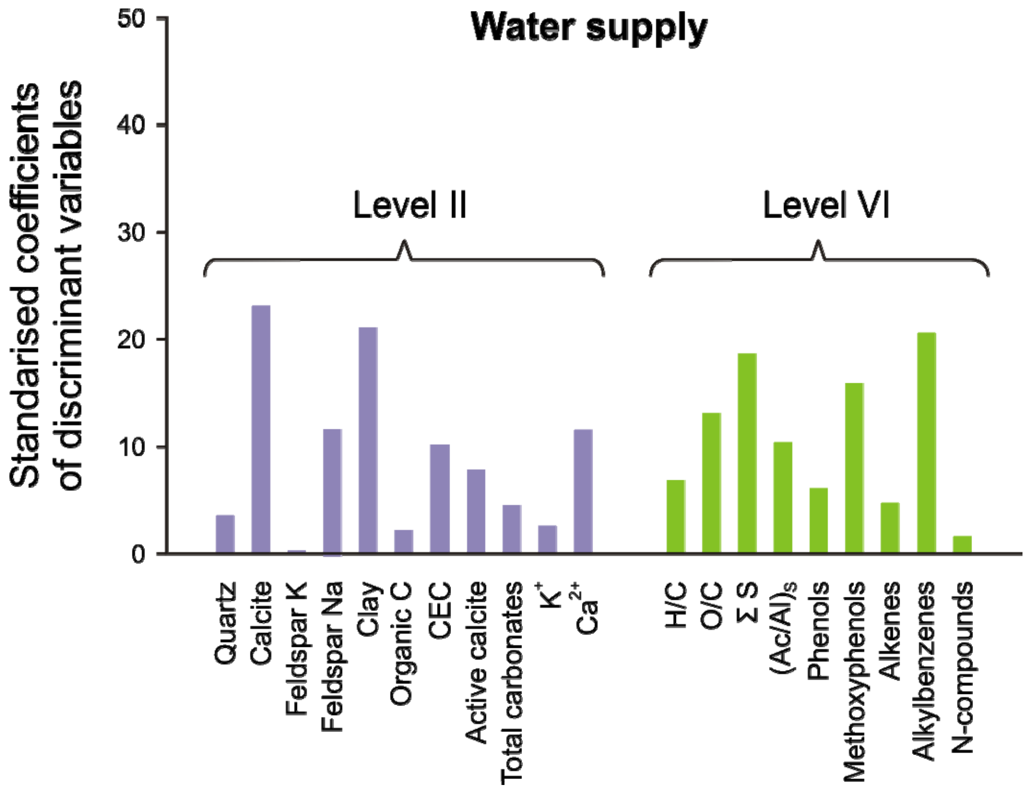
I	n.s.
II	Quartz, feldspar Sand
III	Free organic matter Humic acids Fulvic acids
IV	Aromatic C Methoxyl/ N-alkyl C
V	n.s.
VI	Alkylbenzenes Phenols Methoxyphenols



Statistical analysis. Discriminant function analysis

Water supply

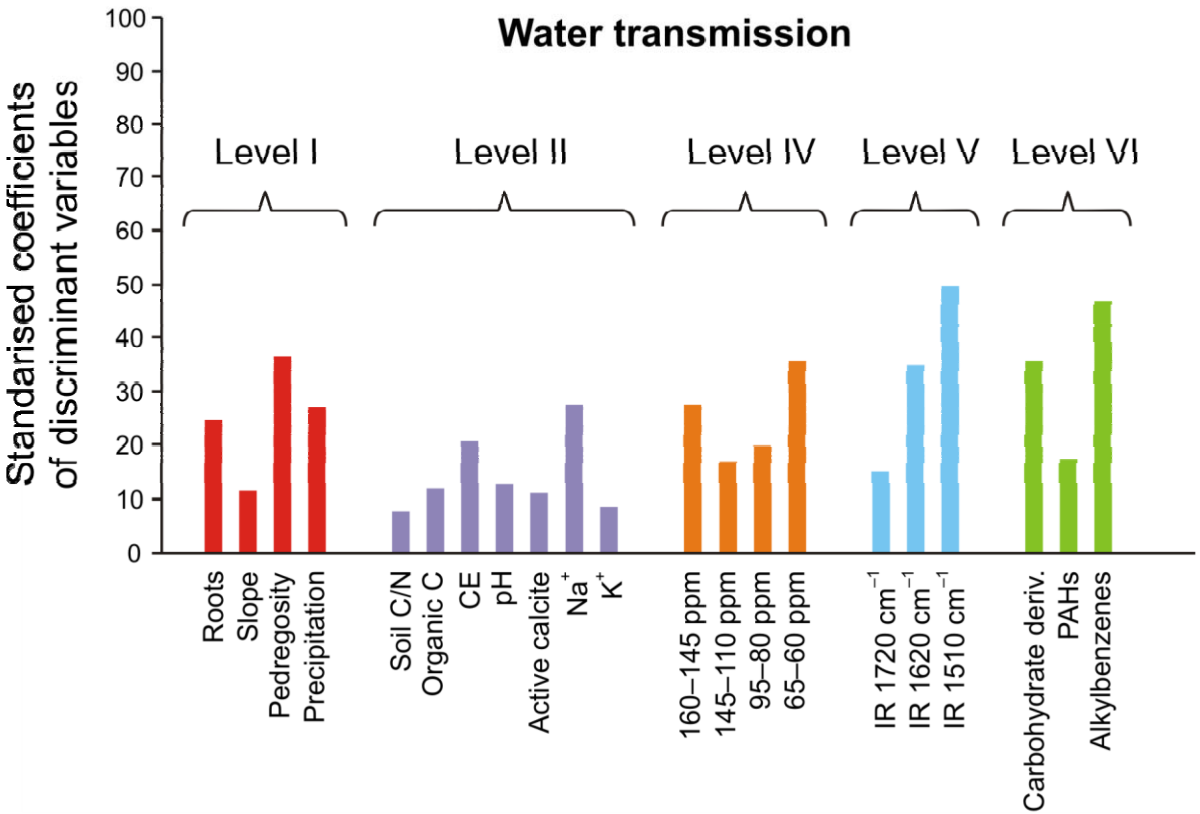
I	n.s.
II	Calcite, Carbonates, Ca^{2+}, Active calcite Clay
III	n.s.
IV	n.s.
V	n.s.
VI	O/C atomic ratio Phenols Methoxyphenols



Statistical analysis. Discriminant function analysis

Water transmission

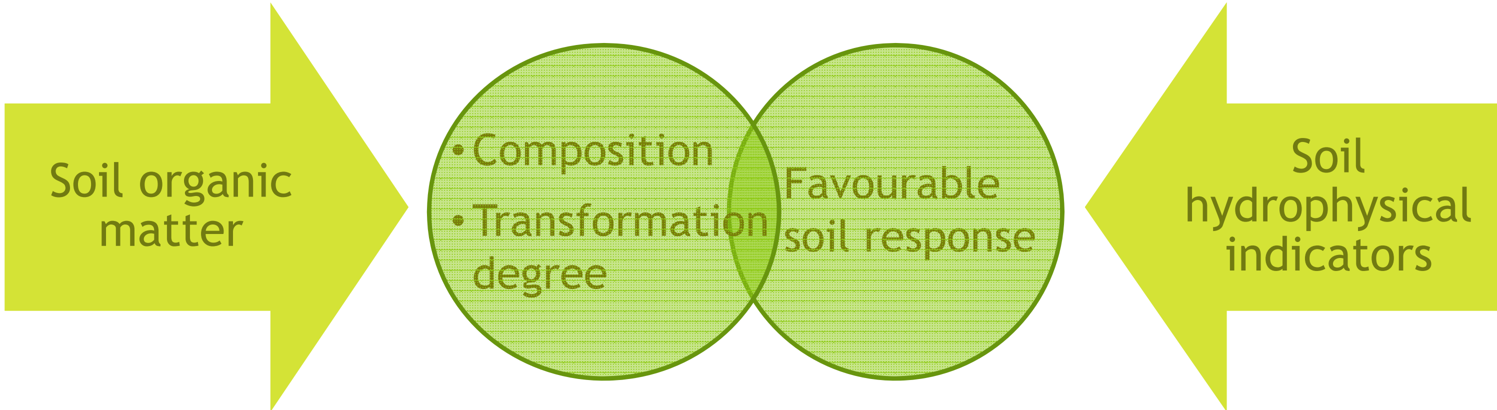
I	Pedregosity Precipitation Root content
II	Na⁺, CIC, pH Active calcite Organic C
III	n.s.
IV	Aromatic C *O*/*N*-Substituted aromatic C *O*-Alkyl C
V	Aromatic bands Carboxyl band
VI	Alkylbenzenes PAHs Carbohydrate derivatives



Statistical analysis

How do these variables correlate with hydrophysical indicators?

Linear correlation models → Multi-dimensional scaling analysis → 2-D scatter plot → To identify groups of variables directly correlated to each other

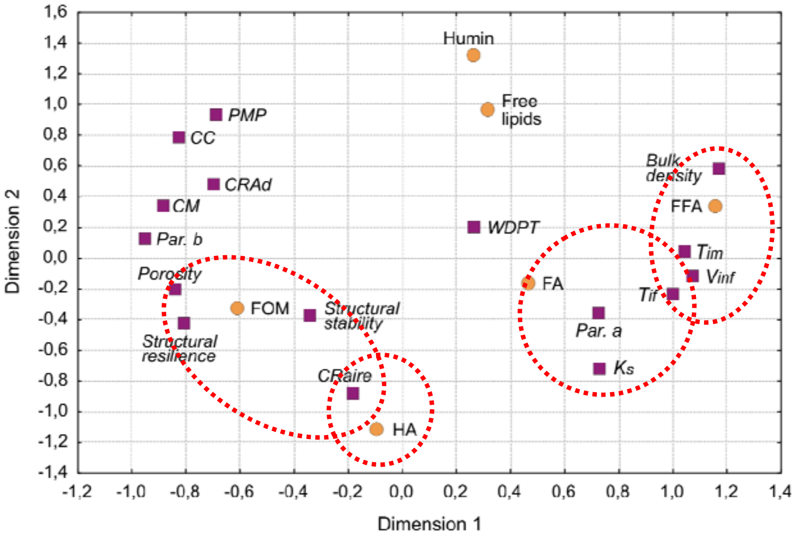


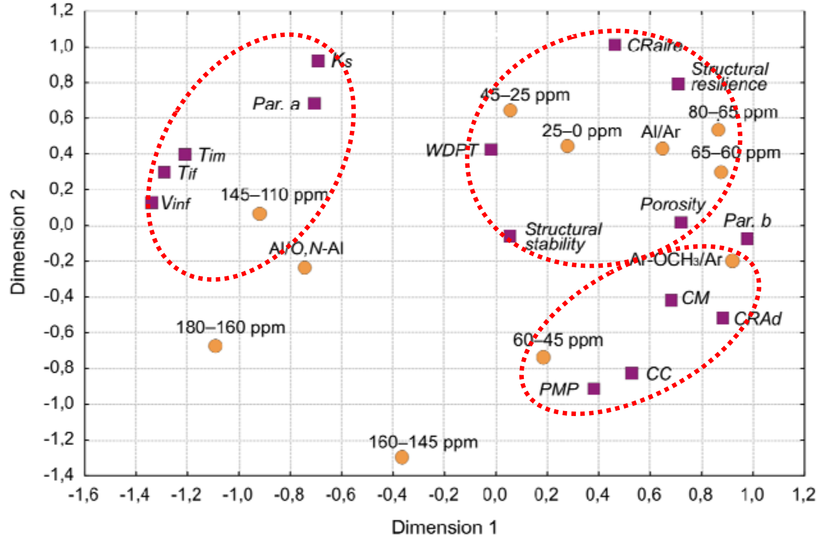
- Support
- Aeration
- Water supply
- Water transmission

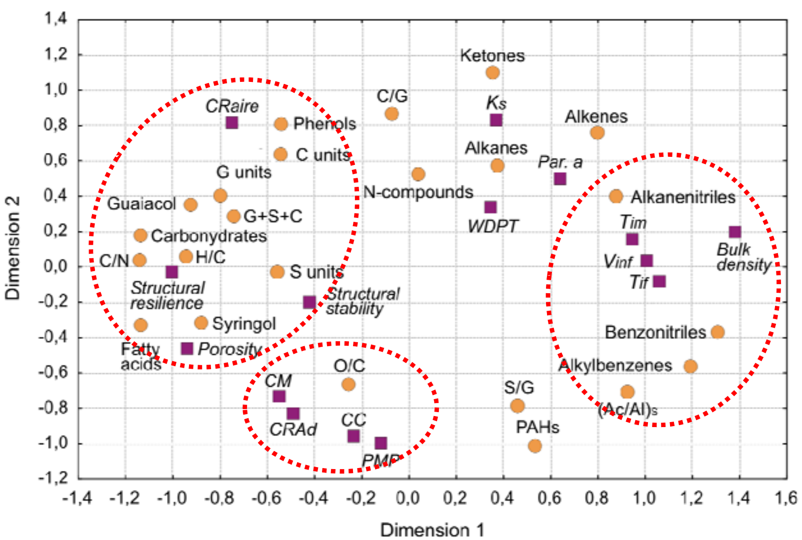
Objective 3

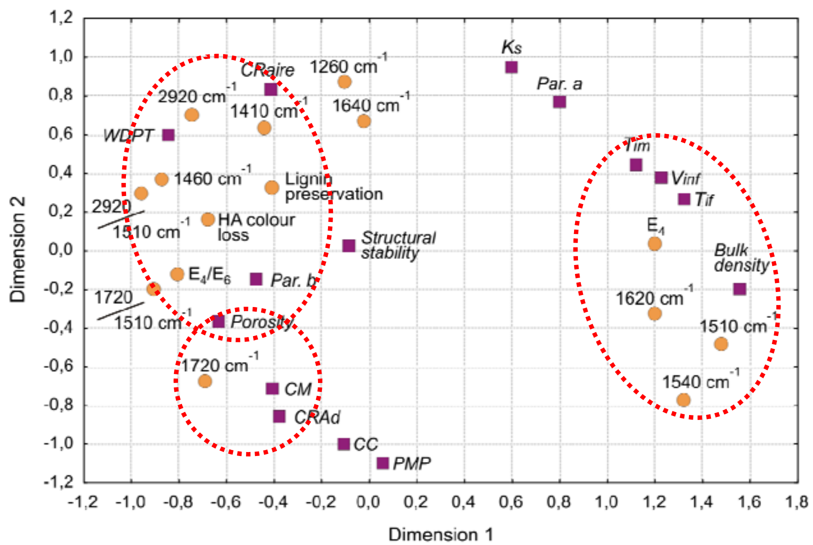
Results and Discussion

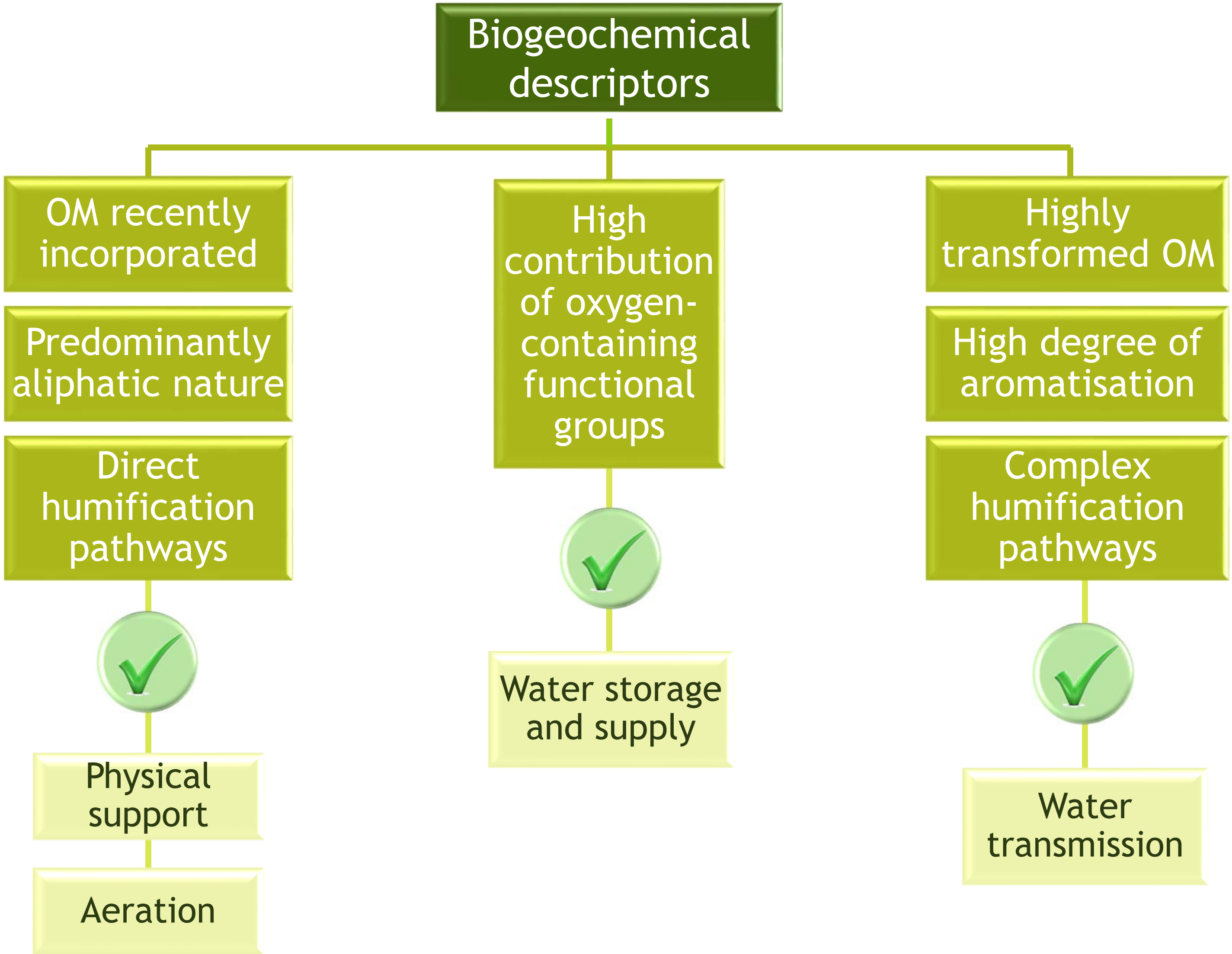
Statistical analysis. Correlation models. MDS










Biogeochemical descriptors
OM recently incorporated
Predominantly aliphatic nature
Direct humification pathways
Physical support
Aeration
High contribution of oxygen-containing functional groups
Water storage and supply
Highly transformed OM
High degree of aromatisation
Complex humification pathways
Water transmission

Conclusions

Objective 1

- **Se identifican una serie de parámetros que permiten evaluar la respuesta hidrofísica de los suelos en los ecosistemas mediterráneos: textura, ii) porosidad, iii) estabilidad estructural, iv) agua útil v) volumen de poros ocupado por aire a capacidad de campo, vi) tasa de infiltración final y vii) volumen de agua infiltrada por el suelo después de una hora del inicio de la infiltración.**

- **La principal amenaza a la que se enfrentan los suelos en la región estudiada responde al desequilibrio existente entre la capacidad de almacenamiento de agua y la capacidad de infiltración del agua de las precipitaciones, lo que deriva en problemas de aireación y un alto riesgo de erosión hídrica por escorrentía superficial.**

Objective 2

- En los ecosistemas estudiados, la materia orgánica del suelo se encuentra fundamentalmente acumulada en formas de carbono estables .
- Entre los constituyentes de la materia orgánica, las estructuras alifáticas prevalecen sobre las aromáticas, apuntado a una estabilización efectiva del dominio alifático en los procesos de humificación.
- Por otra parte, los procesos de humificación directa prevalecen en los suelos bajo bosque y dehesa, mientras que los suelos cultivados muestran indicios de procesos humificación indirecta con una elevada interacción de la fracción mineral.

Objective 3.

- Las variables macromorfológicas más significativas (porcentaje de raíces, cobertura rocosa y pendiente), explican un elevado porcentaje de la variabilidad hidrofísica de los suelos, especialmente en lo referido a la infiltración hídrica, por lo que no deben ser obviadas en los modelos predictivos.

- En todas las funciones hidrofísicas de los suelos evaluadas, la granulometría del suelo y su composición y concentración en carbonato cálcico y carbonato activo, representan un segundo grupo de variables muy relevantes a la hora de identificar posibles problemas de degradación en los ecosistemas mediterráneos.

- Respecto al papel de la materia orgánica, el contenido total de carbono orgánico es menos discriminante a la hora de explicar la funcionalidad física de los suelos que su composición estructural, su complejidad molecular y su grado de asociación entre las fracciones orgánicas y la matriz mineral.

- Sobre esta base, pueden proponerse una serie de indicadores alternativos a la concentración de carbono orgánico total para describir la funcionalidad hidrofísica de los suelos en estos ecosistemas: i) la densidad óptica E4 ii) las intensidades de las bandas del espectro IR a 1510 cm^{-1} y 1460 cm^{-1} iii) la concentración de unidades estructurales derivadas de la lignina tras la oxidación de los ácidos húmicos con CuO y; iv) la proporción de determinados compuestos de pirólisis (alquilbencenos, benzonitrilos y alcanonitrilos).

Gracias por su atención!

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Multivariate statistical assessment of functional relationships between soil physical descriptors and structural features of soil organic matter in Mediterranean ecosystems

Lorena Recio-Vazquez [a,*], Gonzalo Almendros [a], Heike Knicker [b], Pilar Carral [c], Ana-María Álvarez [c]

[a] National Museum of Natural Sciences (CSIC), Serrano 115B, 28006 Madrid, Spain
[b] Institute for Natural Resources and Agrobiology (CSIC), Reina Mercedes 10, 41012 Seville, Spain
[c] Department of Geology and Geochemistry, Faculty of Sciences, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain

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ABSTRACT

Current environmental research is paying increasing attention to reliable analytical surrogates of soil quality. In this work a series of molecular features of soil organic matter were studied in different soil types from Central Spain with the purpose of identifying the soil functions most closely correlated with specific pools of soil organic matter and their structural characteristics. Soil physical variables—including bulk density, total porosity, aggregate stability, available water capacity and water infiltration parameters (Kostiakov's equation coefficients)—were determined. The major soil organic fractions (lipids, particulate free organic matter, fulvic acids, humic acids and humin) were quantified using standard procedures and the soil organic matter was characterised by spectroscopic techniques. Statistical data treatments including simple regression, canonical correlation models and multidimensional scaling suggested two well-defined groups of physical properties in the studied soils: (i) those associated with organic matter of predominantly aromatic character (e.g., water infiltration descriptors), and (ii) soil physical variables related to organic matter with marked aliphatic character and comparatively low degree of humification (e.g., porosity, aggregate stability, available water capacity and field air capacity). From the practical viewpoint, the results support the idea that the detailed structural study of the soil organic matter is useful for accurately monitoring soil physical status. The only determination of total soil organic carbon ought to be complemented with qualitative analyses of the organic matter fractions, at least at the spectroscopic level, which to large extent help to explain the origin of the variability in soil physical properties and can be used for the early diagnosis of possible degradation processes.