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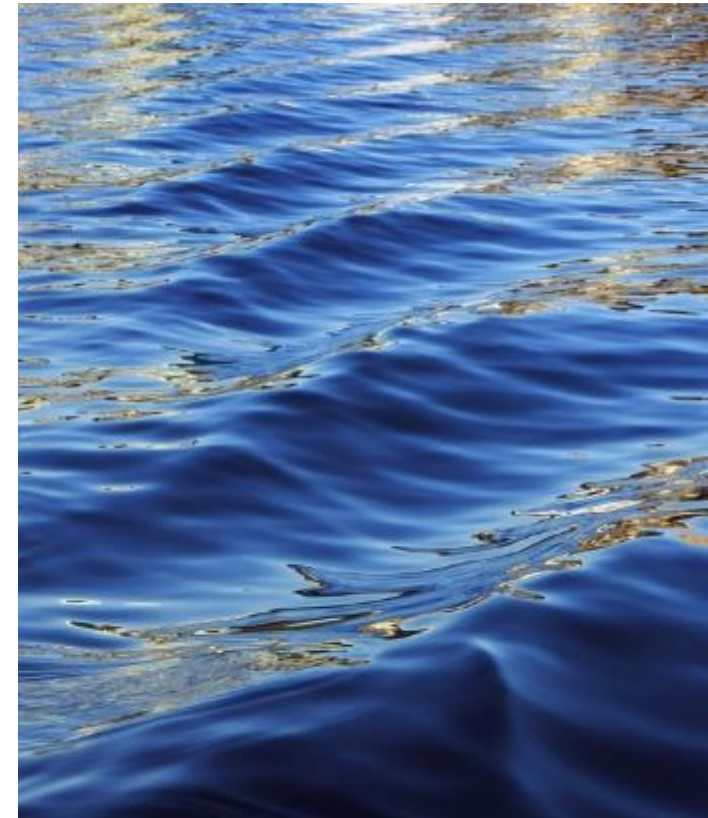
Assessment and Quantification of Soil Quality

Prof. Konstantinos Mattas

Dr. George Bilas

Training in Italy

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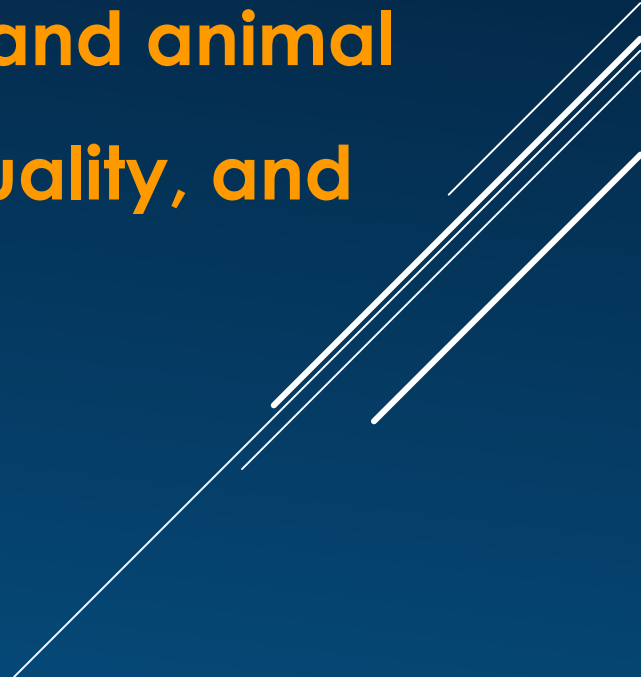
ASSESSMENT AND QUANTIFICATION OF SOIL QUALITY

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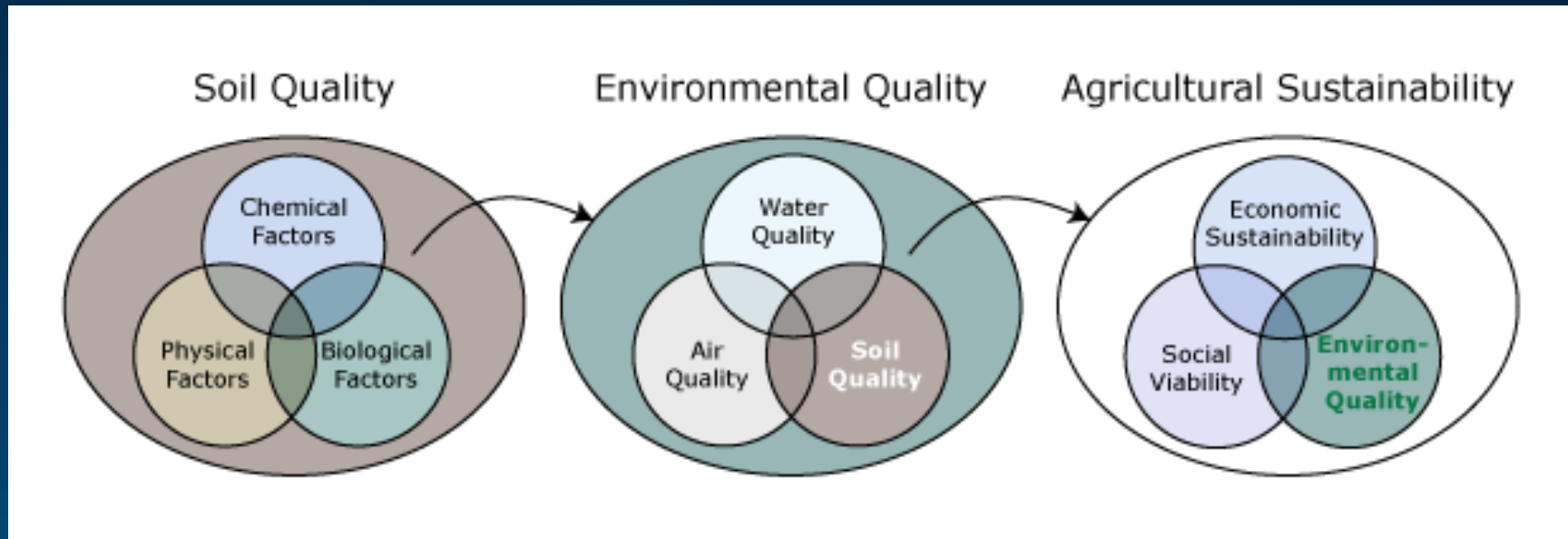
SOIL QUALITY

“the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation”

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SOIL QUALITY

Soil quality is one aspect of sustainable agroecosystem management



(Harwood, R.R., 1990; Miller F.P. and M.K. Wali, 1995)

SOIL QUALITY

- ▶ **SOIL QUALITY IS LINKED TO SUSTAINABILITY**
- ▶ Understanding soil quality means assessing and managing soil so that it functions optimally now and is not degraded for future use
- ▶ By monitoring changes in soil quality, a land manager can determine if a set of practices are sustainable



SOIL QUALITY

- ▶ Soil quality cannot be measured directly because it is a broad, integrative, context-dependent concept. Instead, we analyze a variety of proxy measurements that together provide clues about how the soil is functioning as viewed from one or more soil-use perspectives
- ▶ These measurements are called soil quality indicators
- ▶ A set of low-cost readily measured indicators that accurately predict soil functions of interest is called an efficient indicator set
- ▶ Indicators of soil quality may include characteristics of soil solids, soil solutions, soil atmospheres, vegetation, and other soil biota, and possibly even economic analyses of land-uses or ecosystem services

SOIL QUALITY

- ▶ Although the quantity and quality of data may differ, the process of soil quality evaluation follows the same basic steps regardless of the method used: identification of soil use issues followed by indicator selection and interpretation
- ▶ More specifically, in order to select appropriate indicators, one must first determine the land-use objectives, and then indicators must be proposed, measured and assessed across a representative set of lands and management practices
- ▶ An efficient indicator set should be used to inform land management decisions at specific sites and then be used to monitor trends in soil function after changing practices and over time

SOIL QUALITY

For people active in production agriculture,

- ▶ it may mean highly productive land,
- ▶ sustaining or enhancing productivity,
- ▶ maximizing profits, or
- ▶ maintaining the soil resource for future generations;

For consumers,

- ▶ it may mean plentiful, healthful, and inexpensive food;

For naturalists,

- ▶ it may mean soil in harmony with the landscape and its surroundings;

For the environmentalist,

- ▶ it may mean soil functioning at its potential in an ecosystem with respect to maintenance or enhancement of biodiversity, water quality, nutrient cycling, and biomass production.

SOIL QUALITY

WHAT DOES SOIL DO?

- ▶ **Regulating water.** Soil helps control where rain, snowmelt, and irrigation water goes. Water and dissolved solutes flow over the land or into and through the soil.
- ▶ **Sustaining plant and animal life.** The diversity and productivity of living things depends on soil.
- ▶ **Filtering potential pollutants.** The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits.
- ▶ **Cycling nutrients.** Carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled through soil.
- ▶ **Supporting structures.** Buildings need stable soil for support, and archeological treasures associated with human habitation are protected in soils.

SOIL QUALITY

ASSESSING SOIL QUALITY

- ▶ Soil quality is an assessment of how well soil performs all of its functions.
- ▶ It cannot be determined by measuring only crop yield, water quality, or any other single outcome
- ▶ The quality of a soil is an assessment of how it performs all of its functions now and how those functions are being preserved for future use
- ▶ Soil quality cannot be measured directly, so we evaluate indicators.
- ▶ Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. Indicators can be physical, chemical, and biological characteristics.

SOIL QUALITY

According to Doran and Parkin, 1996

Ideal indicators should:

- correlate well with ecosystem processes
 - integrate soil physical, chemical, and biological properties & processes
 - be accessible to many users
 - be sensitive to management & climate
 - be components of existing databases
 - be interpretable
- Indicators can be assessed by qualitative or quantitative techniques. After measurements are collected, they can be evaluated by looking for patterns, and comparing results to measurements taken at a different time or field.

SOIL QUALITY

While there is no dispute that soils provides very important and useful services, there is no one way to categorize these services. Scientists have grouped these services in various ways, some of which are listed below.

Larson and Pierce, 1991

- ▶ Provide a medium for plant growth and biological activity
- ▶ Regulate and partition water flow and storage in the environment
- ▶ Serve as an environmental filter and buffer in the immobilization and degradation of environmentally hazardous compounds

Seybold et al., 1997

- ▶ Sustain biological activity, diversity, & productivity
- ▶ Providing support for socioeconomic structures
- ▶ Protection of archeological treasures associated with human habitation
- ▶ Water and solute flow
- ▶ Filtering & buffering of contaminants
- ▶ Nutrient cycling

SOIL QUALITY

Karlen et al., 1994

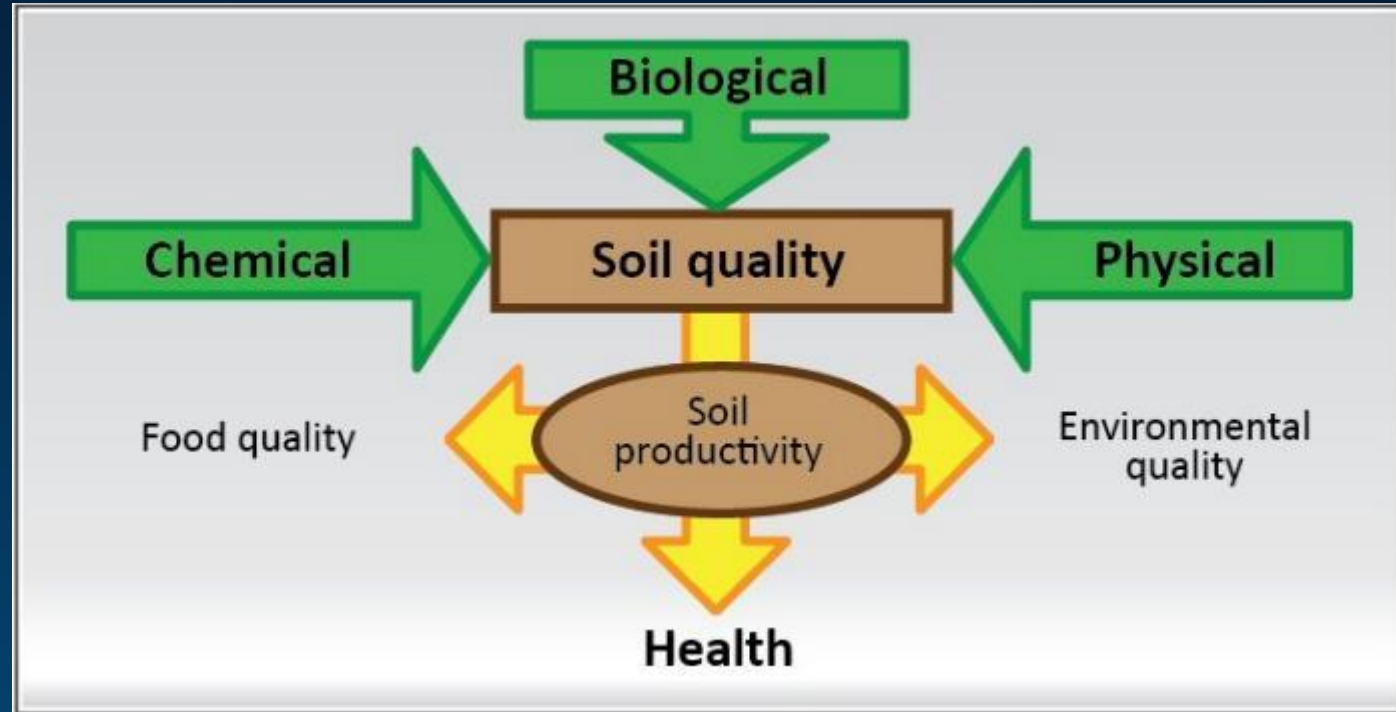
- ▶ Water entry, retention and supply
- ▶ Resistance to stress and disturbance
- ▶ Plant growth

Harris et al., 1996

- ▶ nutrient relations
- ▶ water relations
- ▶ toxicant relations
- ▶ pathogen relations
- ▶ rooting relations
- ▶ aesthetic relations
- ▶ physical stability

Doran & Parkin, 1994

- ▶ Sustain plant & animal productivity
- ▶ Maintain or enhance water & air quality
- ▶ Support human health & habitation



SOIL QUALITY

Soil Quality Monitoring

- ▶ Soil quality across space
- ▶ Soil quality across time
- ▶ Benchmark soil quality sites



QUANTIFICATION OF SOIL QUALITY

- **Soil Quality Index** is calculated as a function of Soil Functions performance

$$\text{SQI} = f(\text{SF}_1, \text{SF}_2, \text{SF}_3, \text{SF}_4, \text{SF}_5)$$

- **Soil Functions** performance is calculated as a function of Soil Indicators

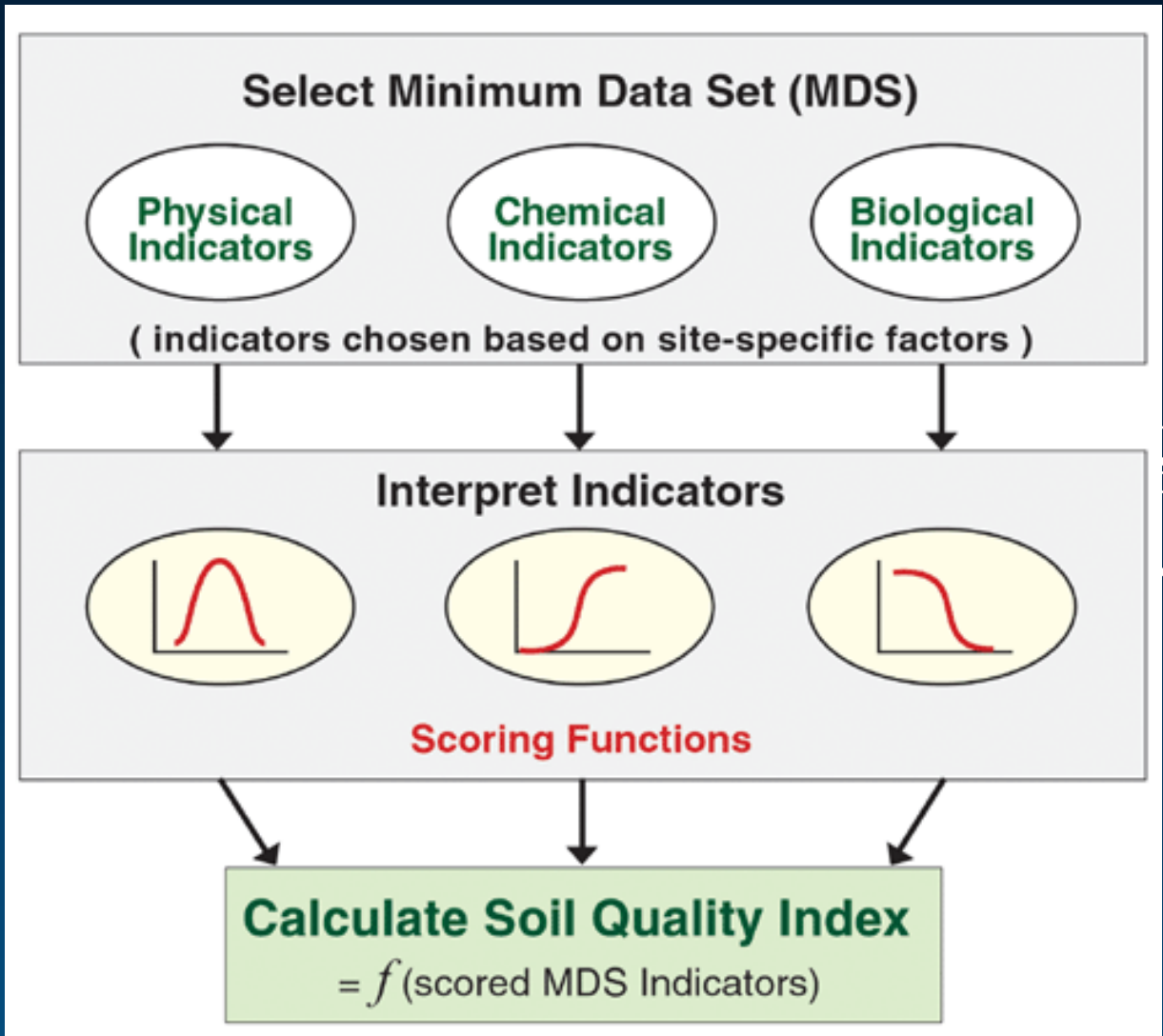
$$\text{SF1} = f(\text{SI}_1, \text{SI}_2, \dots, \text{SI}_n)$$

$$\text{SF2} = f(\text{SI}_1, \text{SI}_2, \dots, \text{SI}_n)$$

$$\text{SF3} = f(\text{SI}_1, \text{SI}_2, \dots, \text{SI}_n)$$

$$\text{SF4} = f(\text{SI}_1, \text{SI}_2, \dots, \text{SI}_n)$$

$$\text{SF5} = f(\text{SI}_1, \text{SI}_2, \dots, \text{SI}_n)$$



QUANTIFICATION OF SOIL QUALITY

Steps for quantifying soil quality (SQI) for a specific goal and site

1. Define management goal – Select soil quality component
2. Select appropriate soil functions for management goal (SF)
3. Select appropriate soil indicators for each soil function (SI)
4. Determine weighing factor of each soil function for calculating soil quality index (W)
5. Determine weighing factor of each soil indicator for calculating each soil function (w) performance
6. Standardize-score soil indicator values (all soil indicators values are transformed to a range 0-1)
7. Calculate SQI using the following equations:

QUANTIFICATION OF SOIL QUALITY

- ▶ **SQL** = $W_1 \cdot SF_1 + W_2 \cdot SF_2 + W_3 \cdot SF_3 + W_4 \cdot SF_4 + W_5 \cdot SF_5$
- ▶ **SF₍₁₋₅₎** = $w_1 \cdot SI_1 + w_2 \cdot SI_2 + w_3 \cdot SI_3 + w_4 \cdot SI_4 + w_5 \cdot SI_5$
- ▶ **Soil indicators'** values have been scored-standardized in the range of **0-1**
- ▶ **Weighing factors** have values in the range of **0-1**
- ▶ The equations are linear of first degree
- ▶ Therefore **soil functions** will have values in the range of **0-1**
- ▶ And consequently **SQL** will get values in the range of **0-1**
- ▶ Usually we multiply SQL by 100 so that we get percentages of SQL outcomes

ASSESSING THE IMPACTS OF WASTEWATER REUSE FOR IRRIGATION USING SOIL QUALITY INDEX



G. BILAS¹, G. GALANIS¹, G. ZALIDIS¹, A. PANORAS², N. MISOPOLINOS¹ and V. TAKAVAKOGLOY¹

¹ Laboratory of Applied Soil Science, School of Agronomy, Aristotle University of Thessaloniki,
54124 Thessaloniki, Greece, misopoli@agro.auth.gr

² NAGREF – LRI, 57400 Sindos-Thessaloniki, Greece, panoras.lri@nagref.gr

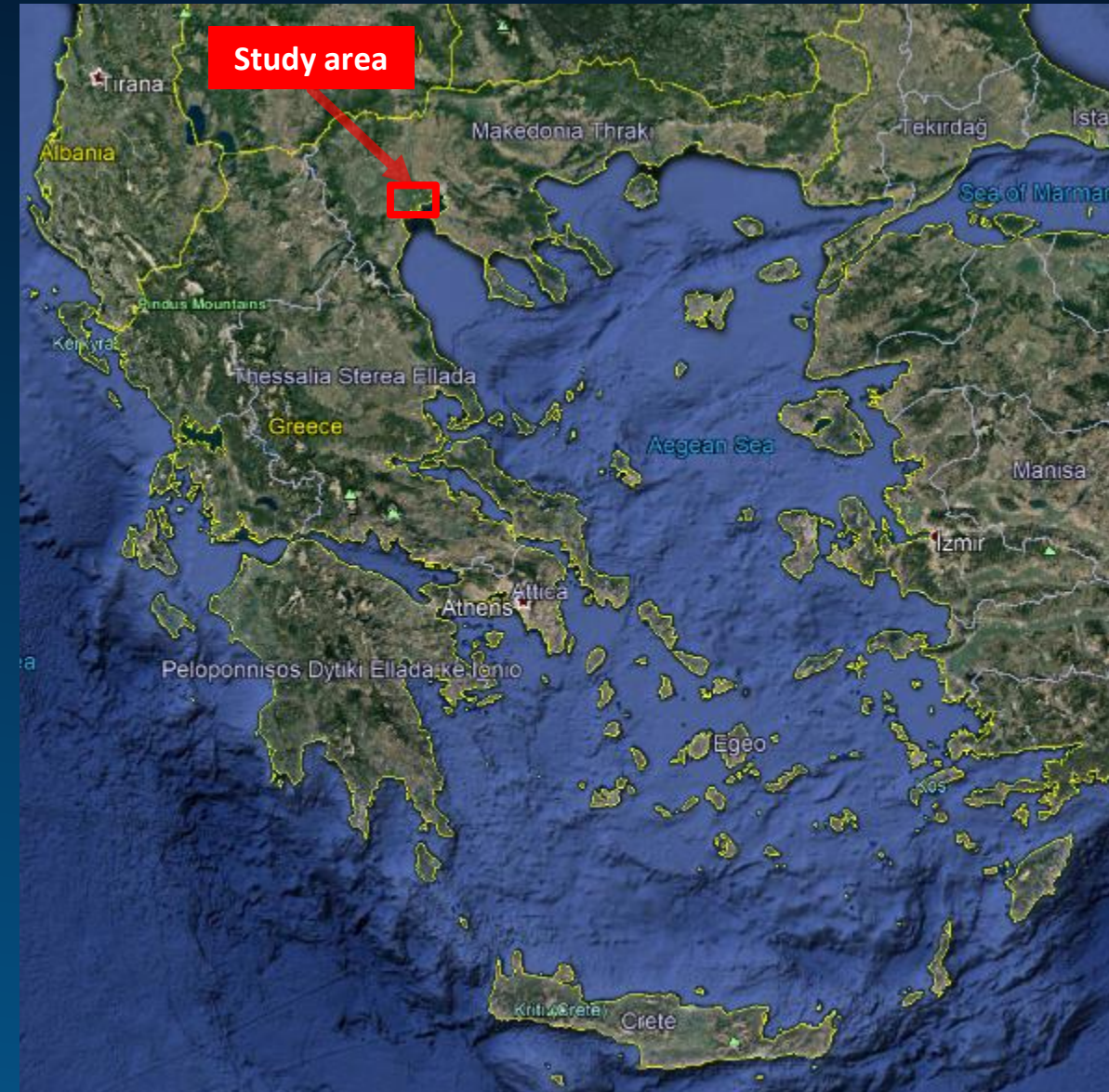
OBJECTIVES

The overall objective of this work was to quantify soil quality using SQI in order to comparatively assess the impact of wastewater reuse for irrigation. Specific objectives were:

- a) to assess the impacts of different irrigation wastewater qualities on soil quality, and
 - b) to quantify soil quality using a procedure consisting of a simple normalizing method to assign scores to treatment values of the most relevant indicators of local ecological conditions.
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MATERIALS AND METHODS

- 6-year experimental field under conventional farming located near Gallikos River in northern Greece
- Crop rotation included sugar beets (*Beta vulgaris*), cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* ssp. *Mays*)
- Wastewater was applied by a drip irrigation system
- Experimental design was completely randomized, with six replicates per treatment.



WATER QUALITIES APPLIED

- Fresh water provided by an irrigation well (**Tf**)
- Wastewater that received a secondary biological treatment and disinfection of the outflow (**Tp**)
- Wastewater that received a secondary treatment in a series of lagoons without disinfection of the outflow (**TI**)

	Tf	Tp	TI
pH	7.58 (0.12)	7.69 (0.21)	7.99 (0.18)
EC (dS/m)	1.07 (0.05)	4.00 (0.23)	5.88 (0.32)
K ⁺ (cmoles/L)	0.09 (0.01)	1.02 (0.12)	1.39 (0.34)
Na ⁺ (cmoles/L)	2.56 (0.25)	29.89 (3.46)	41.45 (7.22)
Ca ⁺⁺ (cmoles/L)	5.15 (0.45)	4.79 (0.98)	5.44 (1.12)
Mg ⁺⁺ (cmoles/L)	4.07 (0.95)	6.99 (2.77)	10.60 (1.67)
SAR	1.19 (0.17)	12.22 (2.16)	14.66 (3.45)
BOD ₅ (mg/L)	1.0 (0.01)	20.0 (3.28)	31.5 (5.32)



RESULTS

Indicator	Treatment		
	Tf	Tp	Tl
Bulk density (g/cm ³)	1.28 (0.05)	1.28 (0.05)	1.24 (2.28)
Infiltration rate (mm/hr)	61.1 (38.6) a	14.1 (8.0) b	13.7 (11.4) b
Water filled pore space (%)	30.1 (1.4) c	41.4 (5.7) b	42.9 (9.1) a
pH	7.72 (0.31) b	8.30 (0.19) a	8.50 (0.28) a
EC (dS/m)	1.15 (0.09) c	3.99 (0.86) b	5.22 (1.36) a
TOC (Mg/ha)	9.98 (0.07)	9.98 (0.09)	9.30 (0.24)
SAR	1.74 (0.40) c	8.74 (1.23) b	10.59 (2.40) a
Soil respiration (kg C/ha/d)	2.70 (1.02) b	7.58 (1.51) a	7.79 (1.55) a

Values within a row for an indicator followed by a different letter are significantly different at $p \leq 0.05$ using the Fisher's protected LSD



QUANTIFICATION METHOD

SQI = **Nutrient Relations** x W_1

+

Water Relations x W_2

+

Rooting Environment x W_3

where W_1 , W_2 , W_3 are the weighting factors of soil functions and $W_1+W_2+W_3 = 1$

QUANTIFICATION METHOD

$$\text{Nutrient Relations (NR)} = \text{pH} \times w_1 + \text{EC} \times w_2 + \text{TOC} \times w_3 + \text{Soil respiration} \times w_4$$

$$\text{Water Relations (WR)} = \text{Bulk density} \times w_1 + \text{Infiltration rate} \times w_2 + \text{Water filled pore space} \times w_3$$

$$\text{Rooting Environment (RE)} = \text{Bulk density} \times w_1 + \text{pH} \times w_2 + \text{EC} \times w_3 + \text{SAR} \times w_4 + \text{Soil respiration} \times w_5$$

where w_1, w_2, \dots, w_n are weighting factors and for each function $w_1 + w_2 + \dots + w_n = 1$.

SELECTED THRESHOLD VALUES AND RULES OF CHANGE

Indicator	Lower threshold	Optimum	Upper threshold	Rules of change
Bulk density (g/cm ³)		1.24	2.00†	Less is better
Infiltration rate (mm/hr)	0†	61.1		More is better
Water filled pore space (%)	15.0†	42.9		More is better
pH		7.72	8.50‡	Less is better
EC (dS/m)		1.15	2.00†	Less is better
TOC (Mg/ha)	0.00†	9.98		More is better
SAR		1.74	13.00§	Less is better
Soil respiration (kg C/ha/d)	0.00#	7.79		More is better

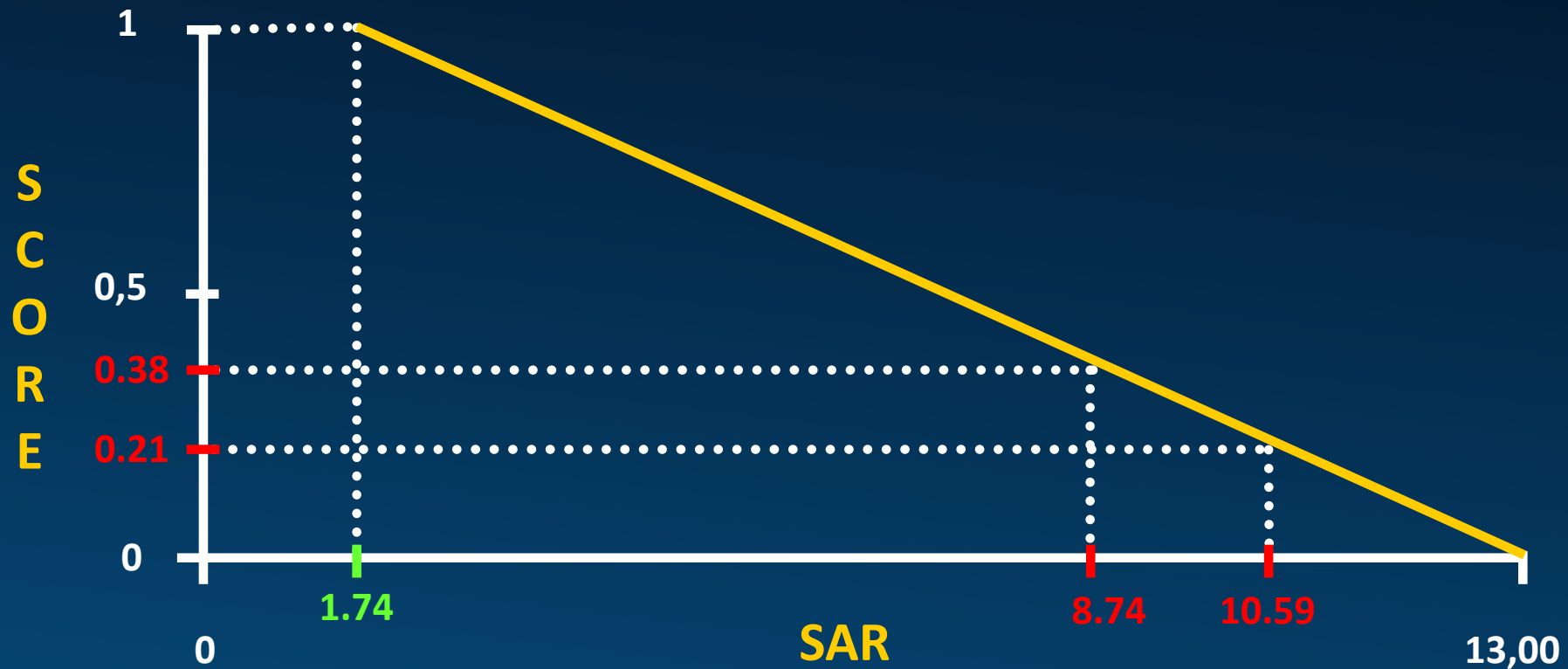
†Values adopted after Glover et al. (2000)

‡ pH values greater than 8.5 denote that the soil is sodic (USDA, 1954)

§ SAR values greater than 13 denote that the soil is saline (USDA, 1954)

Soil respiration 0 value denotes no microbial activity (Parkin et al., 1996)

Normalizing procedure - Scoring



Treatment			
Indicator	Tf	TP	TI
SAR	1.74 (0.40) c	8.74 (1.23) b	10.59 (2.40) a

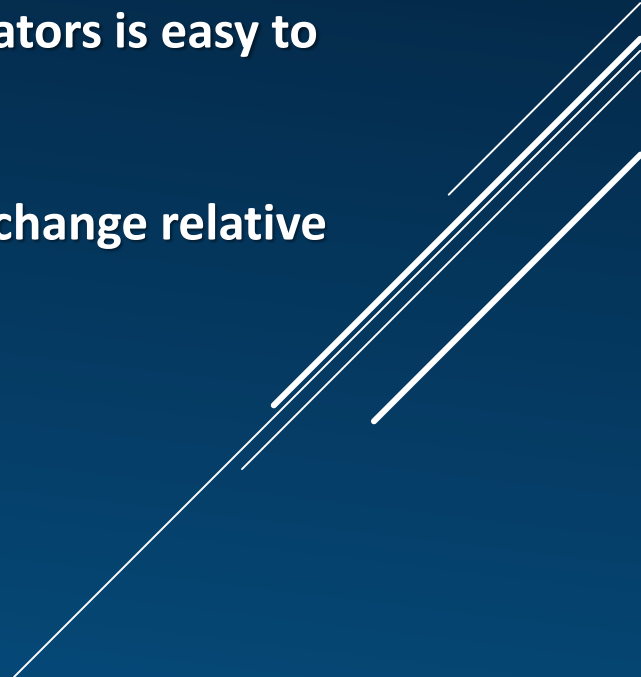
CALCULATED NORMALIZED VALUES

Indicator	Tf	Tp	Tl
Bulk density (g/cm ³)	1.00	1.00	1.00
Infiltration rate (mm/hr)	1.00	0.23	0.22
Water filled pore space (%)	0.54	0.95	1.00
pH	1.00	0.00	0.00
EC (dS/m)	1.00	0.00	0.00
TOC (Mg/ha)	1.00	1.00	1.00
SAR	1.00	0.38	0.21
Soil respiration (kg C/ha/d)	0.35	0.97	1.00


SCORES OF SOIL FUNCTIONS AND SQI

Soil Functions				
Treatment	Nutrient Relations	Water Relations	Rooting Environment	SQI
Tf	0.84	0.85	0.87	0.85
Tp	0.56	0.73	0.52	0.60
Tl	0.50	0.74	0.44	0.56

CONCLUSIONS

- The SQI for the three treatments indicated that there was an impact on soil quality when wastewater was reused for irrigation.
 - The proposed method for calculating normalized values for measured soil indicators is easy to use and requires selection of threshold values that should not be exceeded.
 - Optimum values have been assigned to indicators based on the desired rule of change relative to the reference treatment, since quantification of soil quality is comparative.
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CONCLUSIONS

- The scoring procedure described was effective at quantifying soil quality for different treatments. The proposed procedure amplifies differences when measured values are close to selected threshold levels, thus making it able to assess impacts that can possibly degrade soil quality.
 - The indicators to be measured must be carefully selected to represent local ecological conditions.
 - Caution has to be exercised when applying wastewater for irrigation and site specific adaptive soil management has to be taken into consideration to avoid soil degradation.
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**THANK YOU
FOR YOUR ATTENTION**

