Using enzyme activities to assess soil health for sustainable land management

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The Industrial revolution at the end of the 19th century and the beginning of the 20th century brought about a profound transformation in agriculture

Mechanisation of agricultural work:

The introduction of machines such as the mechanical plough, reaper, thresher, and later the tractor replaced manual and animal labour.







Use of fertilisers and chemical products: Chemical fertilisers, particularly nitrates, and pesticides began to be used, significantly increasing crop yields.









Improvements in transport: The development of the railway and other infrastructure enabled faster food transportation and connected rural areas with urban markets.





Development of large-scale intensive agriculture: The availability of machinery and chemical products supported the development of more intensive and large-scale farming.







Increase in productivity

Intensive farming makes agricultural soils highly vulnerable to degradation.













Intensive farming has caused significant degradation of agricultural soils

- **Loss of organic matter:** Intensive tillage and lack of organic inputs reduce soil carbon content, affecting fertility and structure.
- **Soil erosion:** Excessive land use without conservation practices leads to the loss of the nutrient-rich topsoil layer.



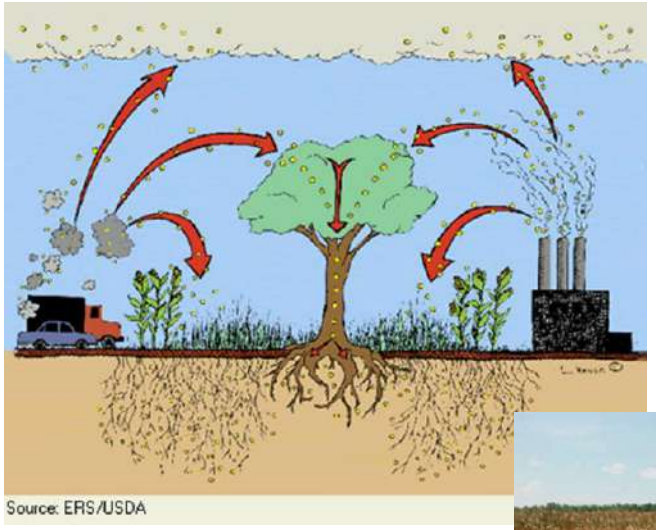




- **Compaction:** Frequent passage of heavy machinery decreases porosity, limits water infiltration, and reduces aeration.

Intensive farming has caused significant degradation of agricultural soils

- **Salinisation:** Inadequate irrigation and excessive fertiliser use can lead to salt accumulation, impacting productivity.
- **Chemical contamination:** Overuse of pesticides and fertilisers results in the build-up of pollutants and leaching into groundwater.


Source: ERS/USDA







Intensive farming has caused significant degradation of agricultural soils

- **Loss of soil biodiversity:** Crop simplification and agrochemical use reduce the diversity of soil microorganisms and fauna.
- **Acidification:** Continuous use of nitrogen fertilisers acidifies the soil, disrupting its chemical balance.







Soil is a fundamental component of the environment and, together with water, represents one of the most important and finite natural resources.

Currently, around 33% of global soils are degraded

There is an urgent need to transform management systems and agricultural practices







Climatic Change



Growing global awareness:

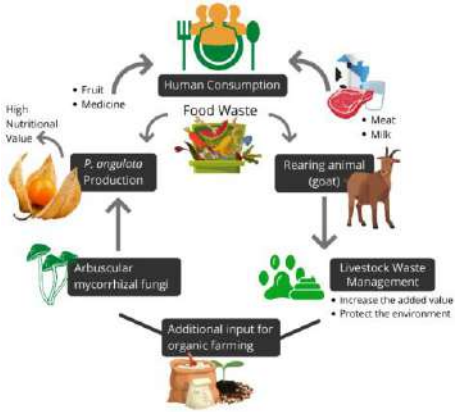
- Soil degradation and loss processes
- Importance of soil for human well-being
- Need to maintain healthy soils for future generations







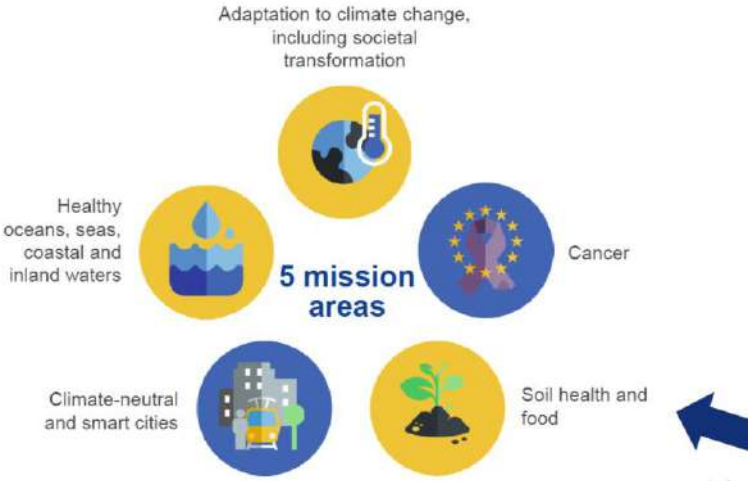






New European agricultural policies pay special attention to soil protection and the need to restore biodiversity, safeguard soil resources, and implement a circular economy.













EU Mission *"A Soil Deal for Europe"*
(Mission Soil)



- Create 100 Living Labs and Lighthouses in rural and urban areas to experiment with and demonstrate good practices in sustainable soil management.
- Reduce desertification, preserve soil organic carbon, curb urban soil sealing, and restore polluted soils.
- Promote citizen engagement and raise awareness about the importance of soil for human health, food security, and the environment.
- Establish a European framework for monitoring soil health.

Establish a European framework for monitoring SOIL HEALTH.

SEVERAL QUESTIONS AND PROBLEMS ASSOCIATED WITH MEASURING SOIL QUALITY

- ✓ WHAT IS SOIL QUALITY?
- ✓ WHICH SOILS ARE CONSIDERED HIGH QUALITY?
- ✓ HOW CAN WE COMPARE THE QUALITY OF TWO AGRICULTURAL SOILS?
- ✓ WHAT ARE THE BEST INDICATORS OF SOIL QUALITY? HOW CAN WE SELECT A GOOD INDICATOR OF SOIL QUALITY? WHICH CHARACTERISTICS SHOULD A SOIL QUALITY INDICATOR HAVE?
- ✓ PRE-EXISTING ASSUMPTIONS WHEN DECIDING WHICH MANAGEMENT PRACTICES HELP MAINTAINING OR IMPROVING SOIL QUALITY.

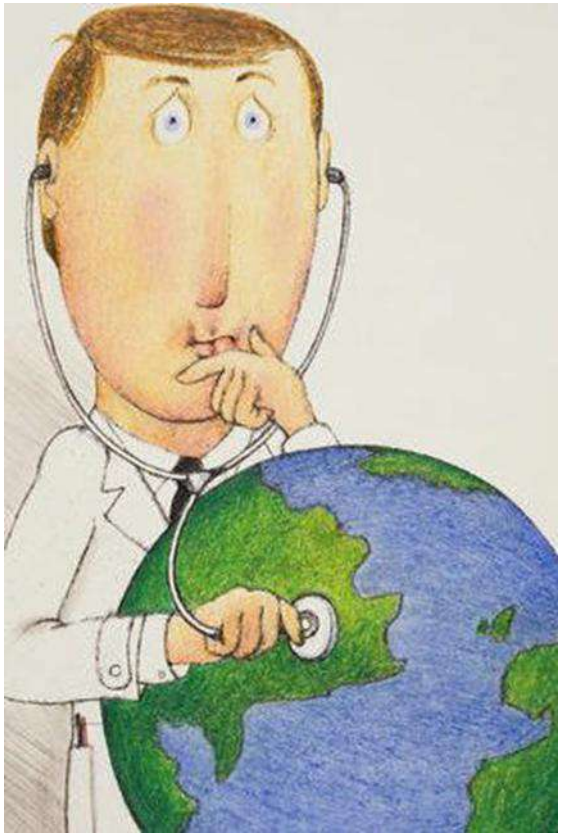
WHAT IS SOIL QUALITY?

"the capacity (of soil) to function"

“Soil quality is the capacity of a specific kind of 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” Karlen et al. (1997)

SOIL QUALITY ⟷ SOIL HEALTH

QUALITY refers to the suitability of the soil to perform a specific function, while HEALTH refers to its general condition (Doran and Safley, 1997; Doran, 2002).



WHICH SOILS ARE CONSIDERED HIGH QUALITY

- **When environmental conservation is the priority:**

  Higher quality soil ➔ **Natural soil developed under *climax vegetation***

  - ✓ **In balance with other components of the environment**
  - ✓ **Developed without human intervention**

- **When soil productivity is the priority:**

  Higher quality soil ➔ **More productive soil**

  - ✓ **Being able to maintain high and sustainable productivity**
  - ✓ **Achieving high levels of environmental, human and animal health protection.**



GOOD QUALITY SOIL



POOR QUALITY SOILS









HOW CAN WE COMPARE THE QUALITY OF DIFFERENT AGRICULTURAL SOILS

CHARACTERISTICS OF A GOOD INDICATOR OF SOIL QUALITY

The selected indicators must meet certain requirements. A good indicator should:

a) **Measure one or more functions of the soil**

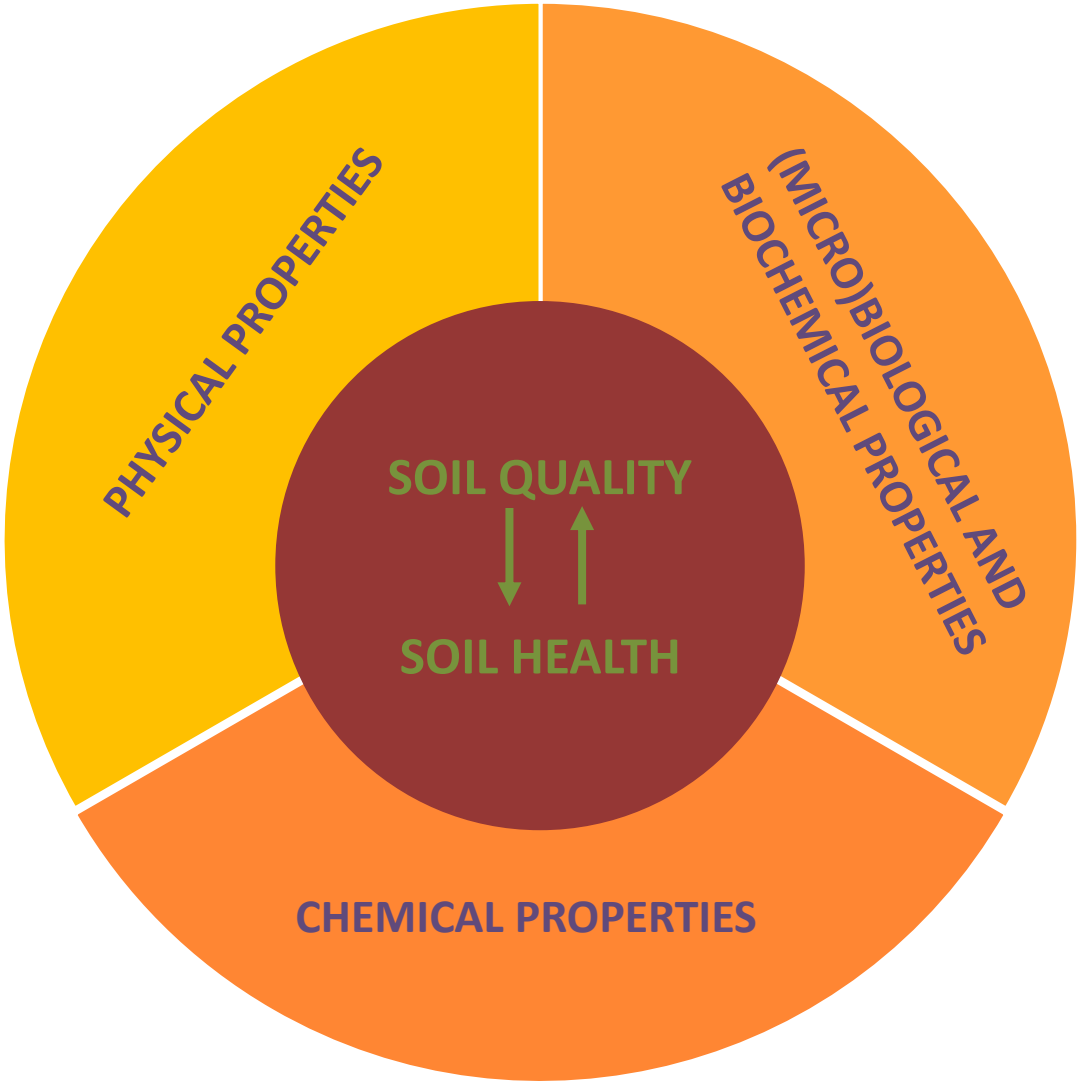
b) **Be sensitive enough to detect changes caused by management, disturbance, or restoration, and respond quickly to external stressors.**

c) **Provide reference values, as well as critical or threshold limits.**

d) **Be easily interpretable**

e) **Cost-effective: should not require expensive equipment, reagents, or specialised tools that are hard to obtain in standard analytical laboratories.**

WHICH PROPERTIES ARE MOST SUITABLE FOR AN INDICATOR?



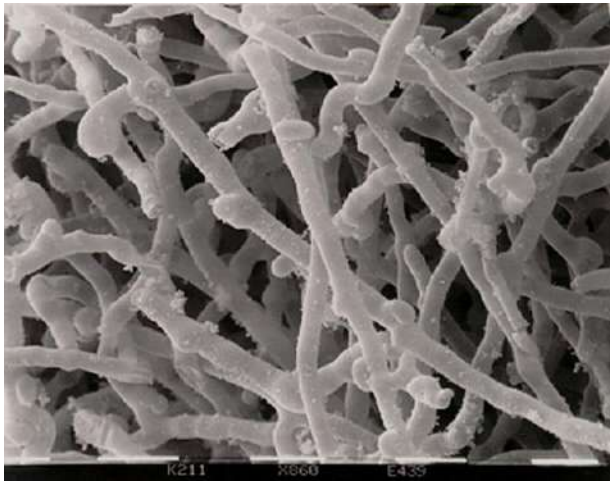
WHICH PROPERTIES ARE MOST SUITABLE FOR AN INDICATOR?

Physical and physico-chemical properties are of limited use because they change only very slowly, or only when the soil undergoes a drastic alteration, making them not very suitable for monitoring purposes.



Biological and biochemical properties are:

- ✓ **Sensitive: respond quickly to external disturbances**
- ✓ **Cost-effective: do not require expensive or hard-to-obtain equipment, reagents, or tools, and can be easily implemented in common soil laboratories**



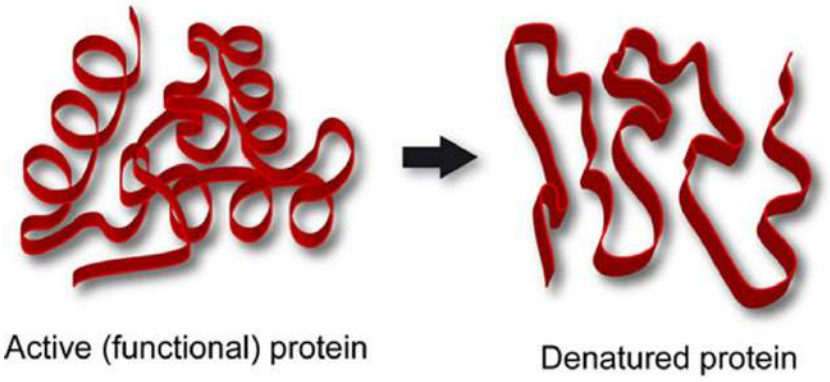
SOIL ENZYMES

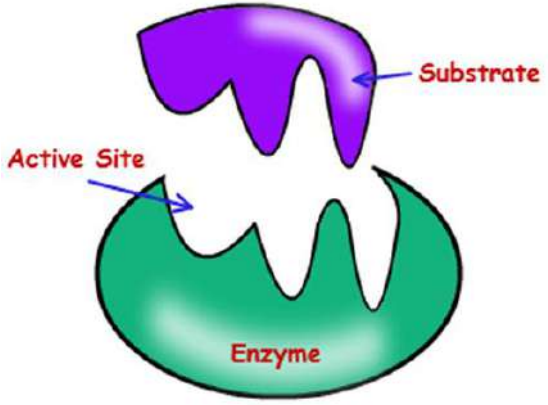
Although soil enzymes are produced by plants and animals, they are mainly produced by bacteria and fungi.

As proteins, enzymes are sensitive to pH, temperature, and other environmental conditions.

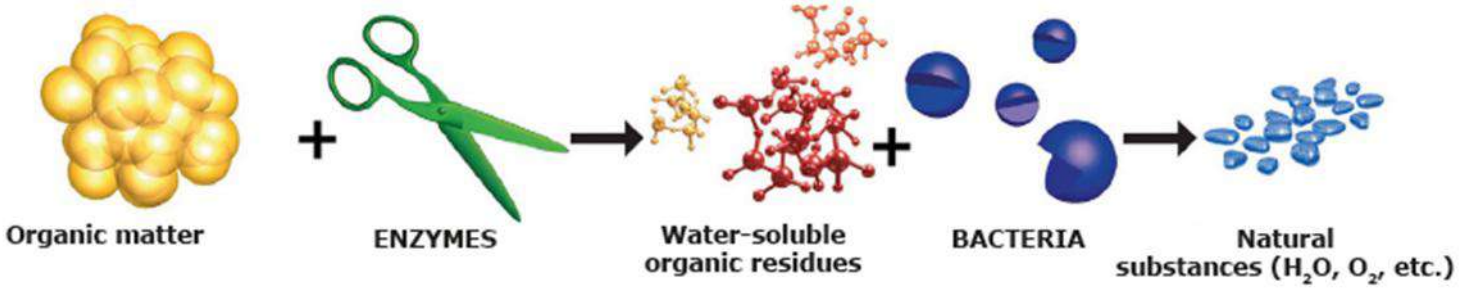
Enzyme production and activity are influenced by multiple biotic and abiotic factors, such as:

- ✓ Microbial community composition and structure
- ✓ Nutrient availability
- ✓ Quality and quantity of organic matter
- ✓ Temperature, moisture, and other environmental conditions

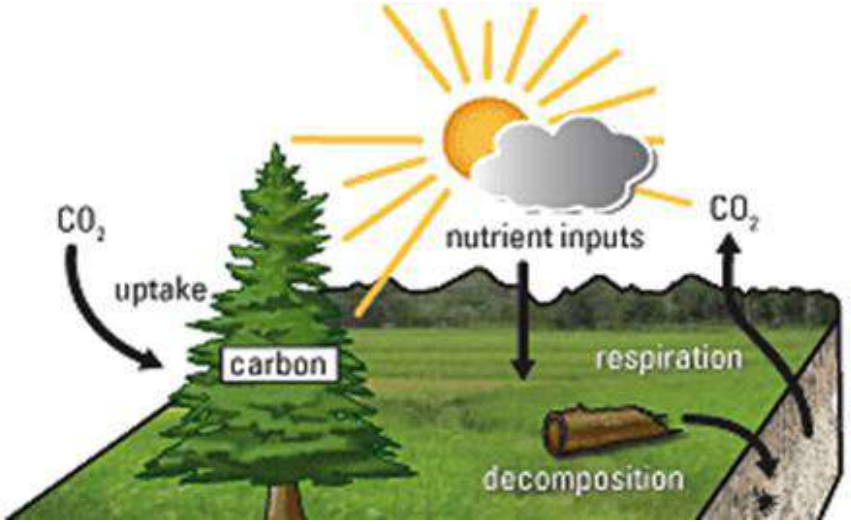




Microbial communities drive the decomposition of soil organic matter by producing a variety of enzymes, mainly oxidative and hydrolytic.

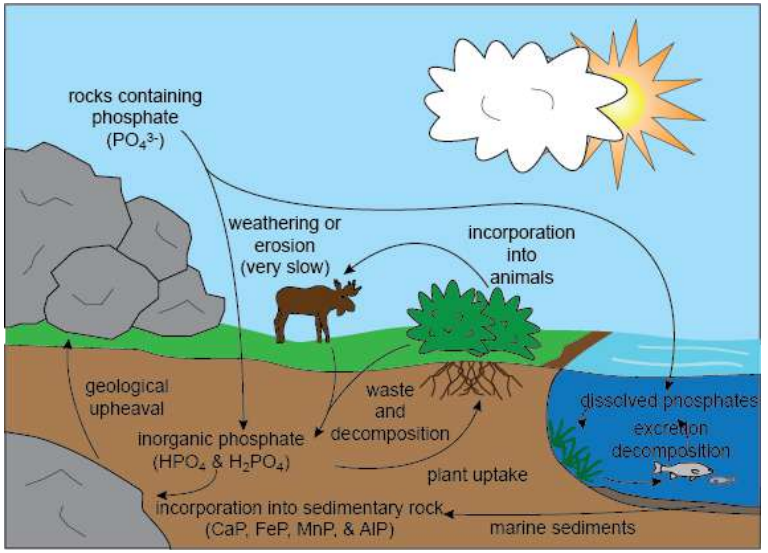


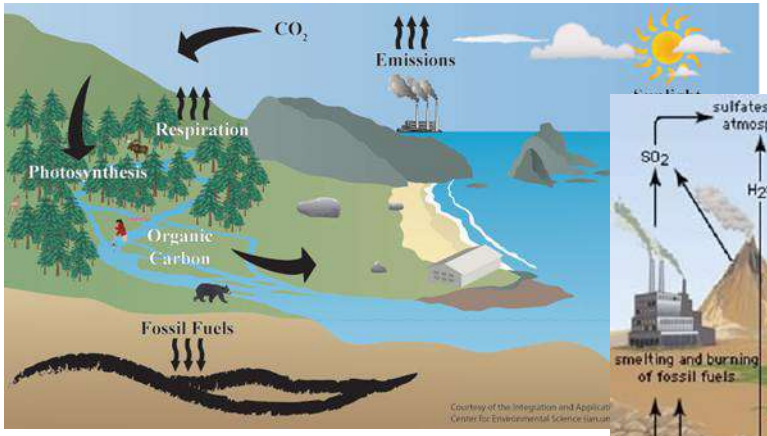
Human activities, including agricultural management, affect soil microbial communities and enzyme processes, thereby altering soil functioning and entire ecosystems.

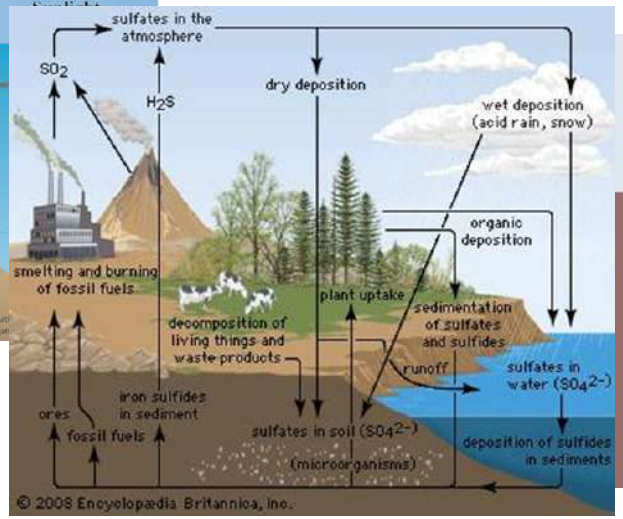


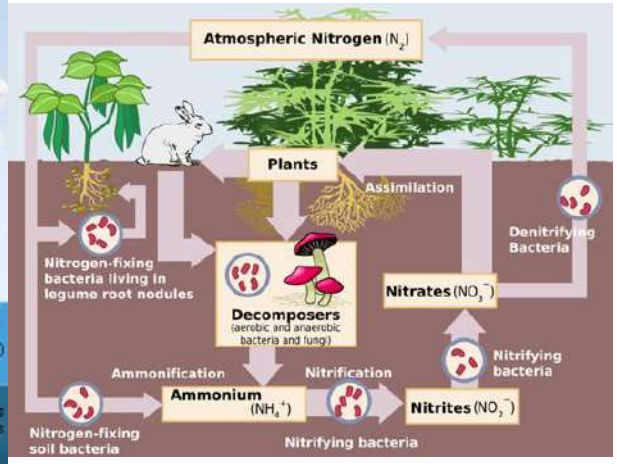
Soil enzymes are widely used as indicators of soil degradation and pollution, and therefore of soil quality loss.

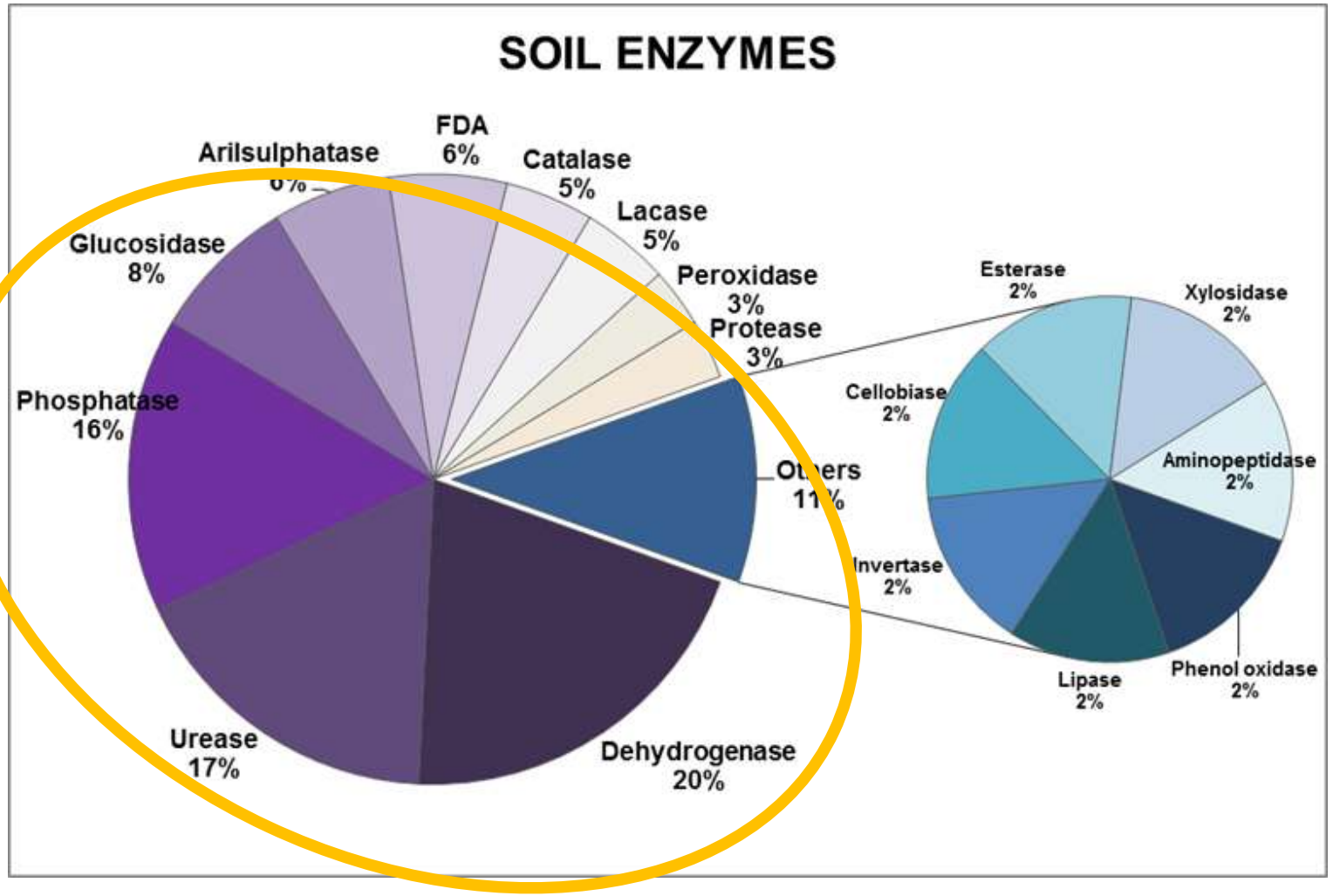
- ❖ Oxidoreductases
- ❖ Hydrolases:
  - ✓ Carbon cycle
  - ✓ Nitrogen cycle
  - ✓ Phosphorus cycle
  - ✓ Sulphur cycle

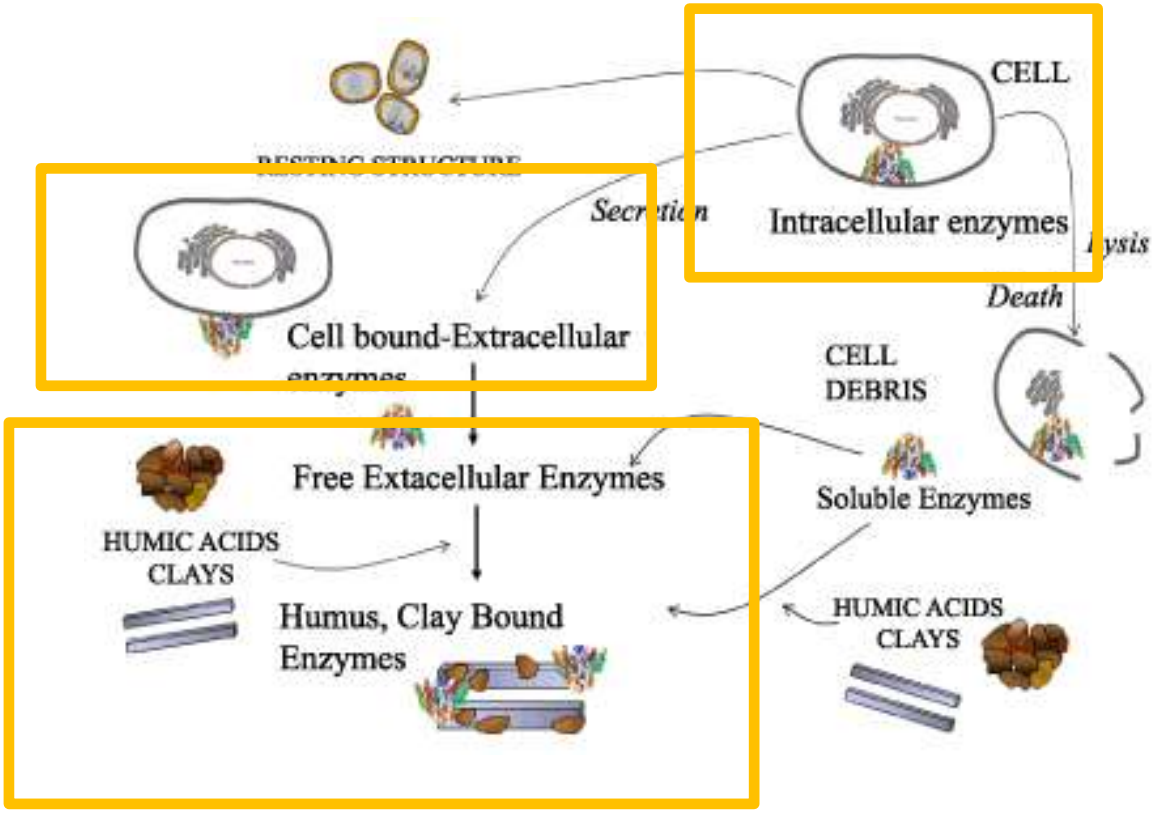






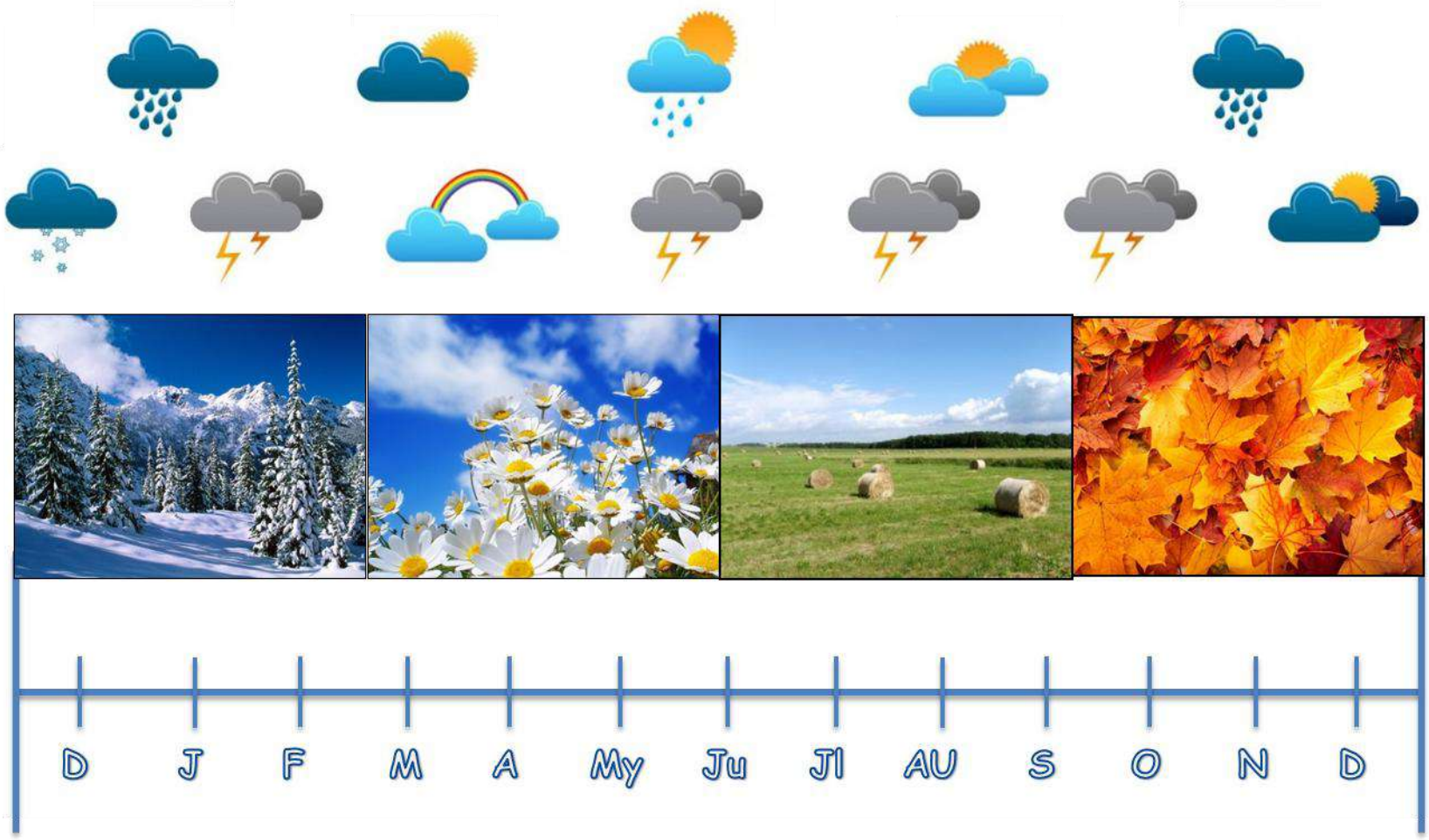



SOIL ENZYMES
FDA
6%
Arilsulphatase
Catalase
5%
Lacase
5%
Glucosidase
8%
Peroxidase
3%
Protease
3%
Phosphatase
16%
Urease
17%
Dehydrogenase
20%
Esterase
2%
Xylosidase
2%
Cellobiase
2%
Aminopeptidase
2%
Invertase
2%
Lipase
2%
Phenol oxidase
2%



- It is not possible to distinguish between extracellular, cell-bound (exocellular), and intracellular enzymes.
- The measured activity reflects potential rather than actual activity under field conditions.
- Lack of standardised methods and frequent modifications, which are not always applied correctly.

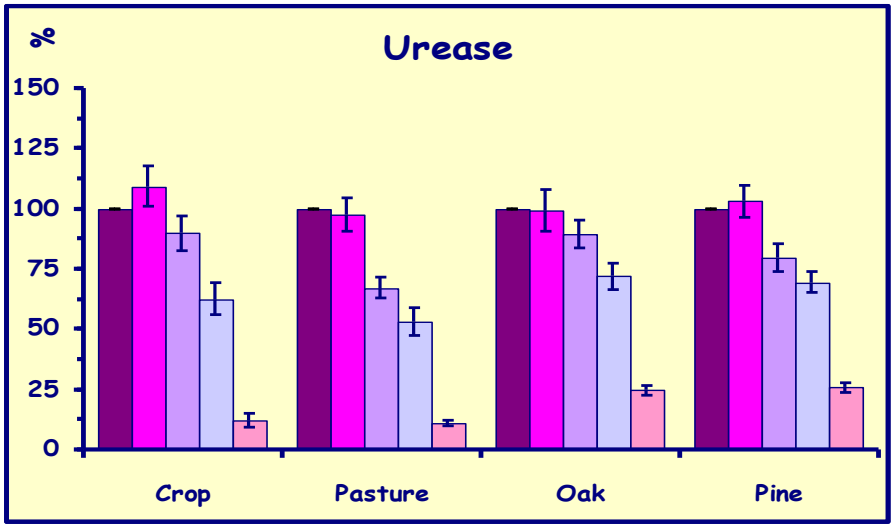
Seasonal variation can exceed the variation caused by disturbance

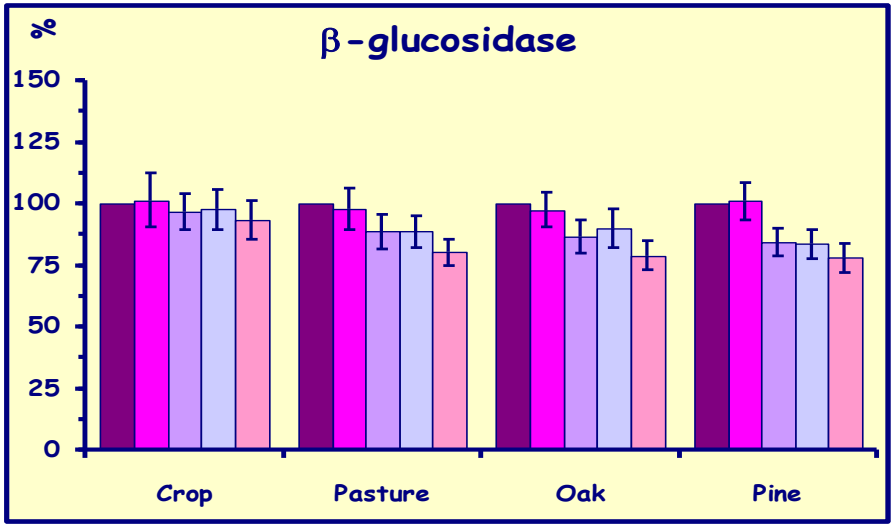


A SINGLE ENZYME CANNOT BE USED AS AN INDICATOR OF SOIL QUALITY

It is incorrect to assume that a single enzymatic activity, reflecting one specific soil reaction, can indicate complex functions such as total microbial activity, soil fertility, or soil quality, which depend on many reactions and processes.

The behaviour of one enzyme does not necessarily reflect that of other enzymes, as enzymes involved in different cycles and stages of degradation may respond differently.



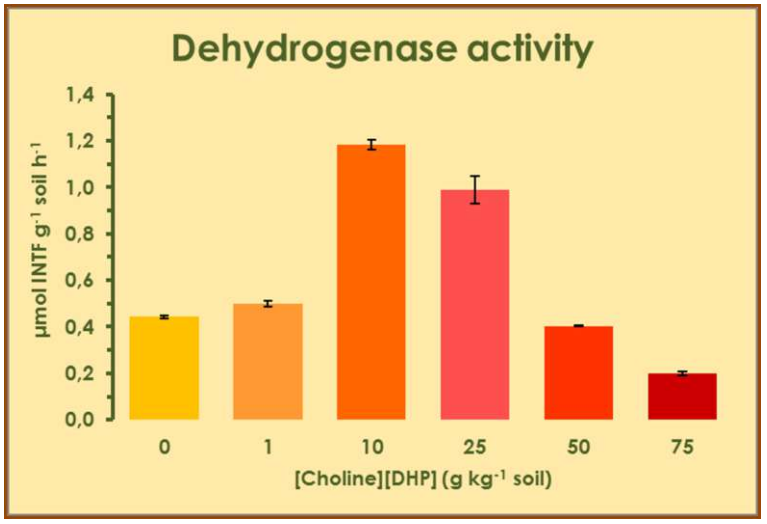


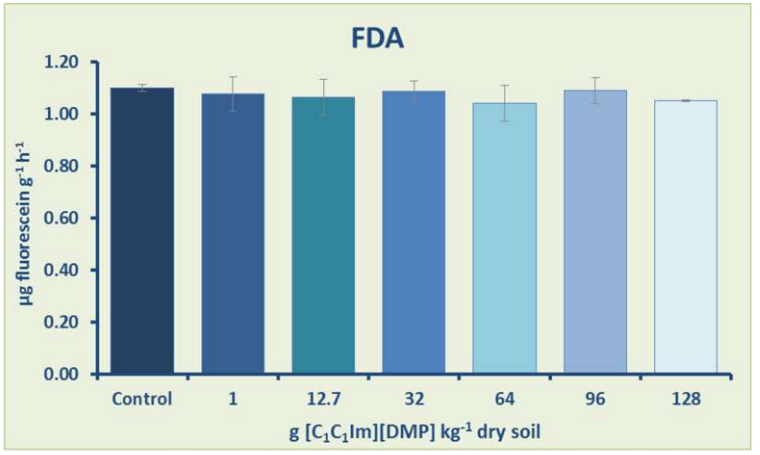
LABORATORY EXPERIMENTS

Enzyme activities in soils under different land uses, artificially contaminated with varying levels of 2,4,5-trichlorophenol.

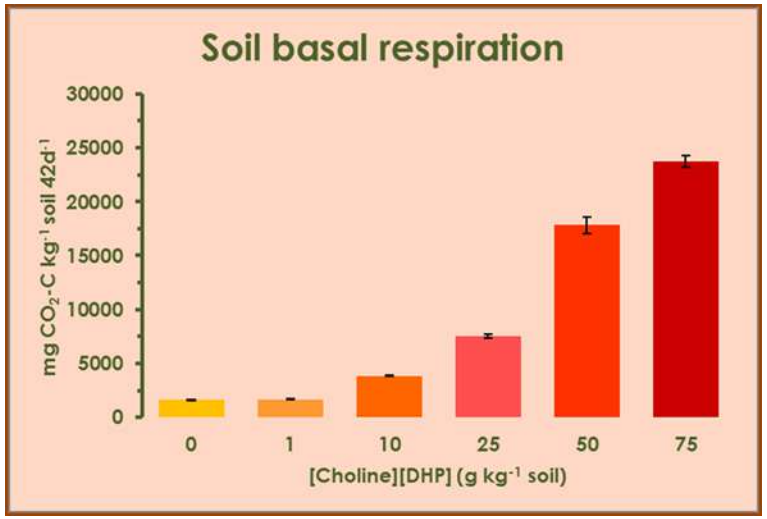
Percentage of enzyme activity compared with an uncontaminated control soil.

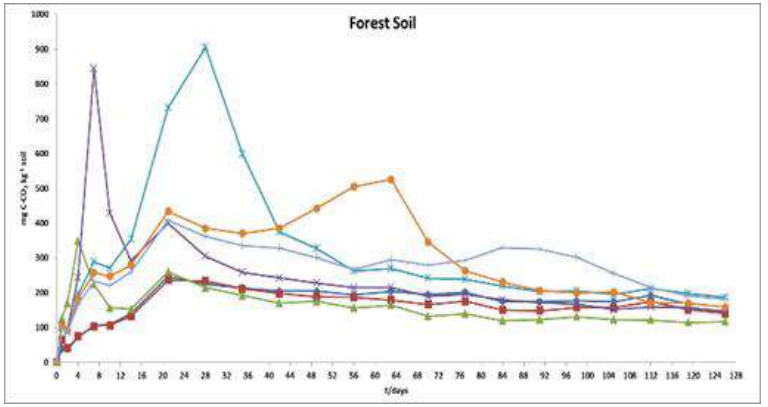
More is not always better





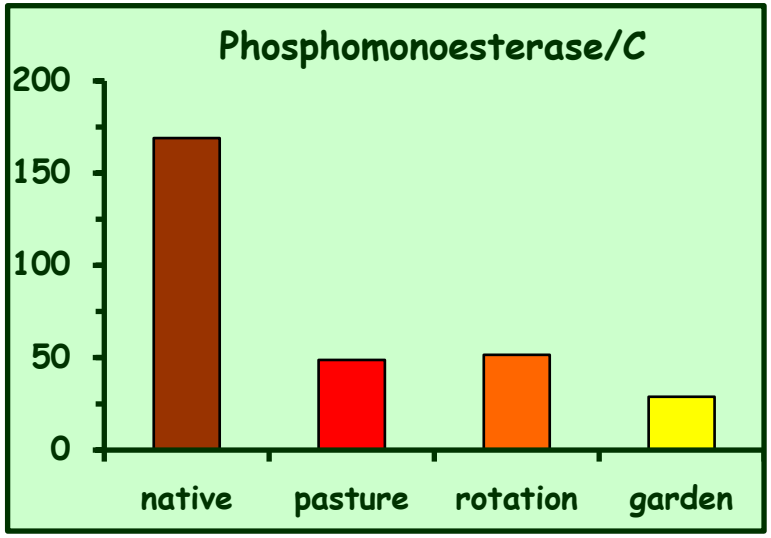
Fluorescein diacetate hydrolysis in the soil spiked with increasing doses of $[C_1C_1Im][DMP]$.

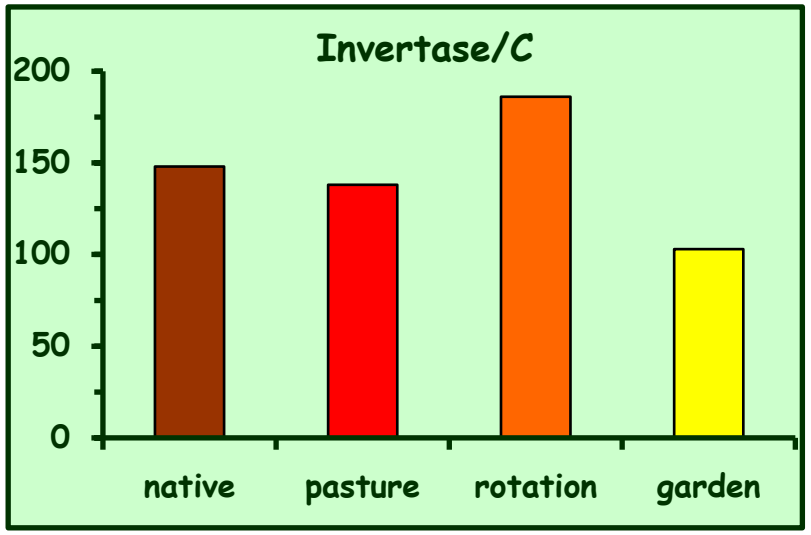




INDICES BASED ON SIMPLE RATIOS OF TWO PROPERTIES.

Enzyme activity expressed per unit of organic carbon or microbial biomass.





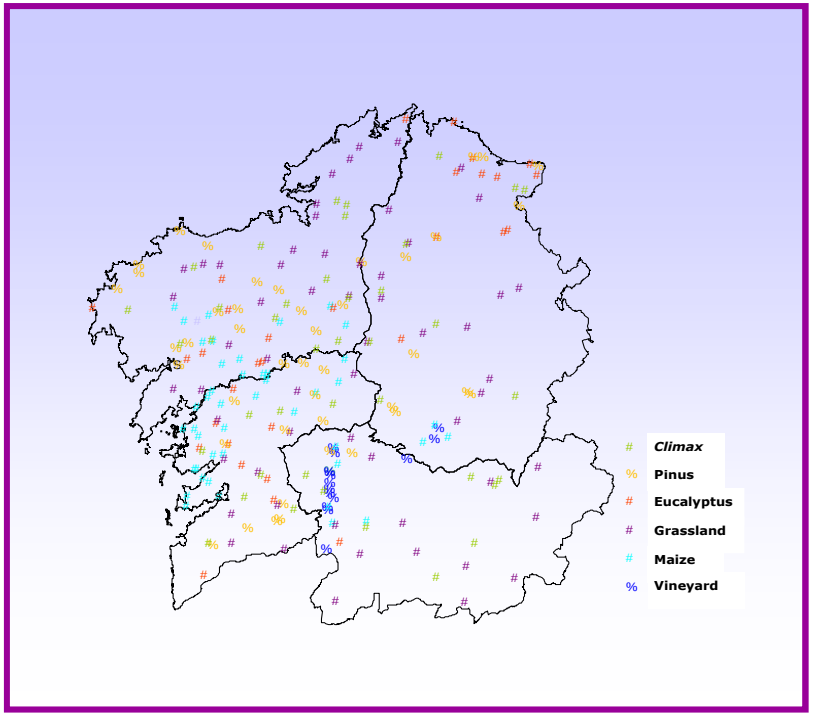
Different soil uses (and varying organic matter content):

- Undisturbed forest soil
- Permanent pasture
- Pasture-maize rotation
- Garden soil

COMBINING ENZYME ACTIVITIES AND BIOCHEMICAL PROPERTIES IN COMPLEX EQUATIONS

- ✓ Enzyme Activity Number (Beck, 1984)
- ✓ Biological Index of Fertility (Stefanic et al., 1984)
- ✓ Lignocellulosic Factor (Sinsabaugh te al., 1994)
- ✓ Star Diagramas (Blume and Dilly, 1998)
- ✓ Equation of Biochemical Equilibrium (Trasar-Cepeda et al., 1998)
- ✓ AI 1, AI 2 and AI 3 (Puglisi et al., 2006)
- ✓ Quality Index SQI for Mollisols and Inceptisols (Zornoza et al., 2007)
- ✓ Quality Index for Pasture Soils (Paz-Ferreiro et al., 2007)
- ✓ Biological Quality Index (Armas et al., 2007)
- ✓ Quality Index Cp/Cm (Chaer et al., 2009)
- ✓ Rhizosphere Soil Microbial Index (Sinha et al., 2009)

COMBINING ENZYME ACTIVITIES AND BIOCHEMICAL PROPERTIES IN COMPLEX EQUATIONS

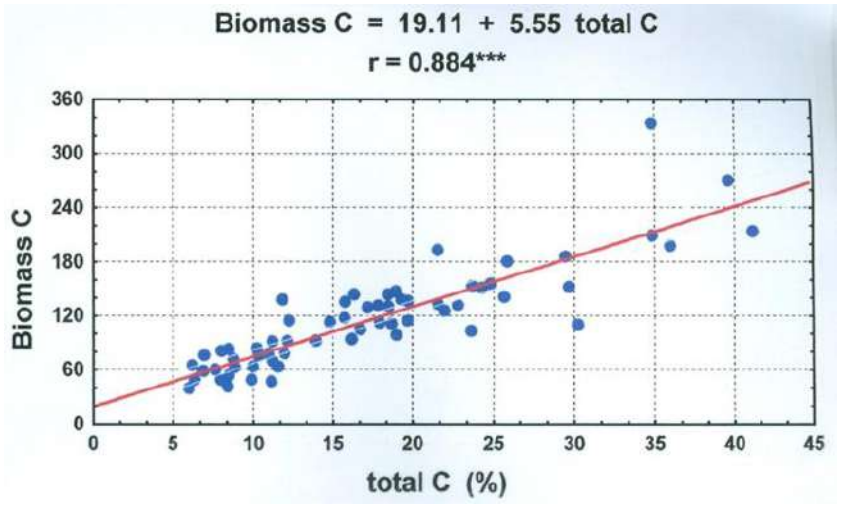


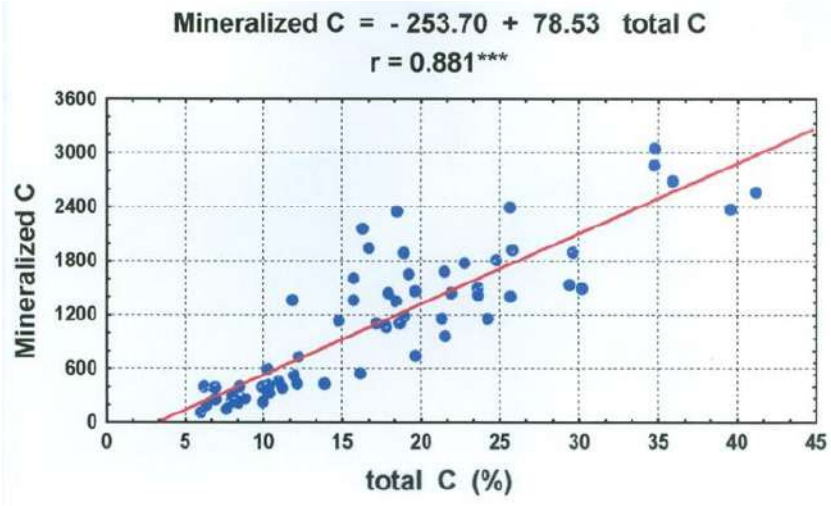


Many Umbrisols under climax Atlantic oakwood vegetation (O and Ah horizons).

WOODLAND SOILS UNDER *CLIMAX* VEGETATION

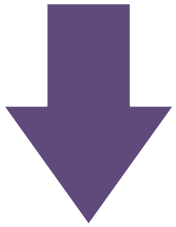
High-quality soils maintain a biochemical balance between organic matter and biochemical activity.





Total N (Nk) = (0.38×10^{-3}) microbial biomass-C+ (1.4×10^{-3}) N mineralized + (13.6×10^{-3}) phosphomonoesterase + (8.9×10^{-3}) ß-glucosidase + (1.6×10^{-3}) urease

For these *climax* soils: N calculated (Nc)/N measured(Nk) = 1



When a soil becomes degraded (for any reason), this balance is disrupted, and the Nc/Nk ratio can indicate the degree of soil degradation.

SOILS IMPACTED BY ANTHROPOGENIC ACTIVITIES:

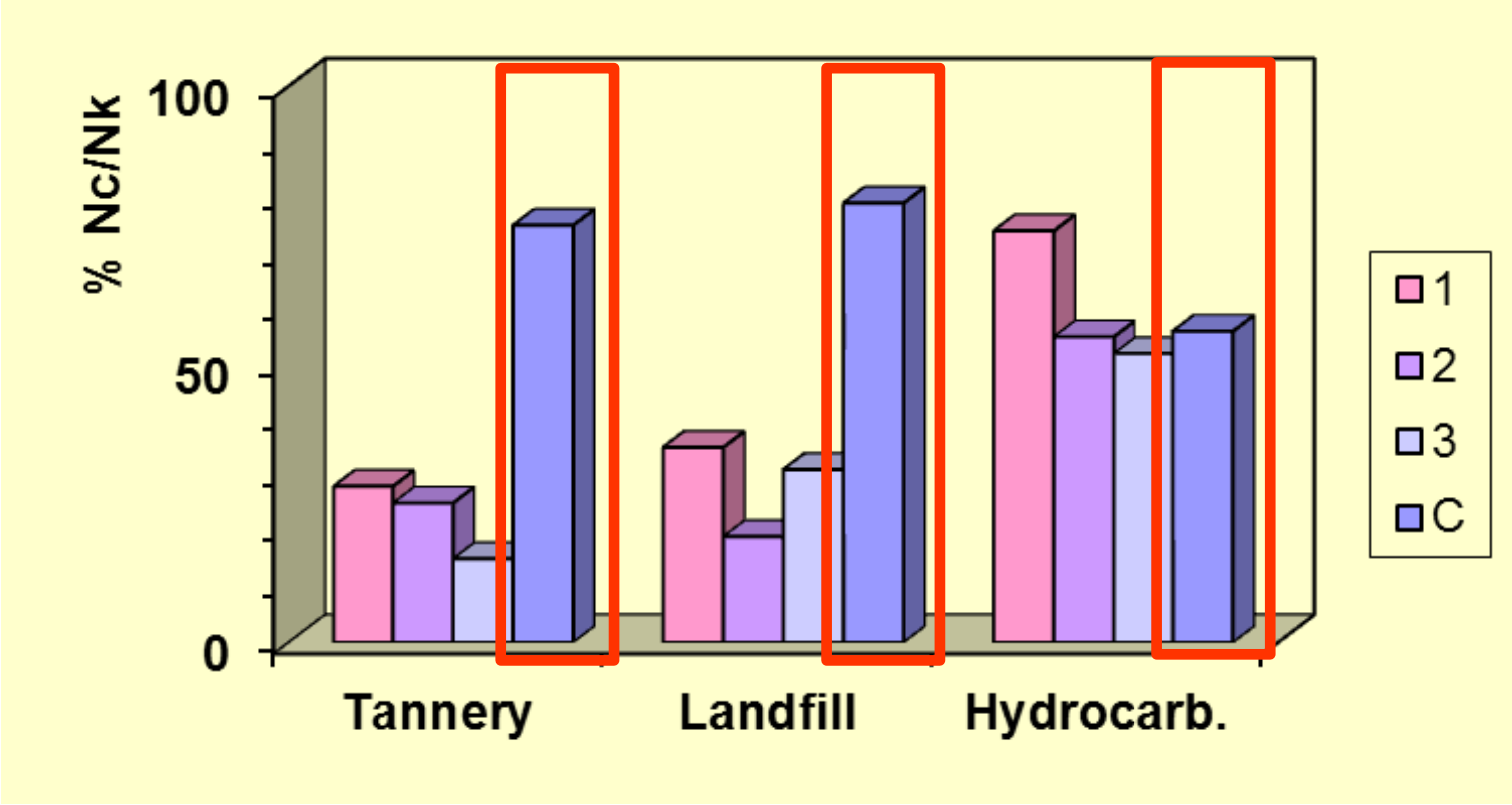
DIFFERENT CONTAMINATION SCENARIOS

A grassland area affected by TANNERY EFFLUENT

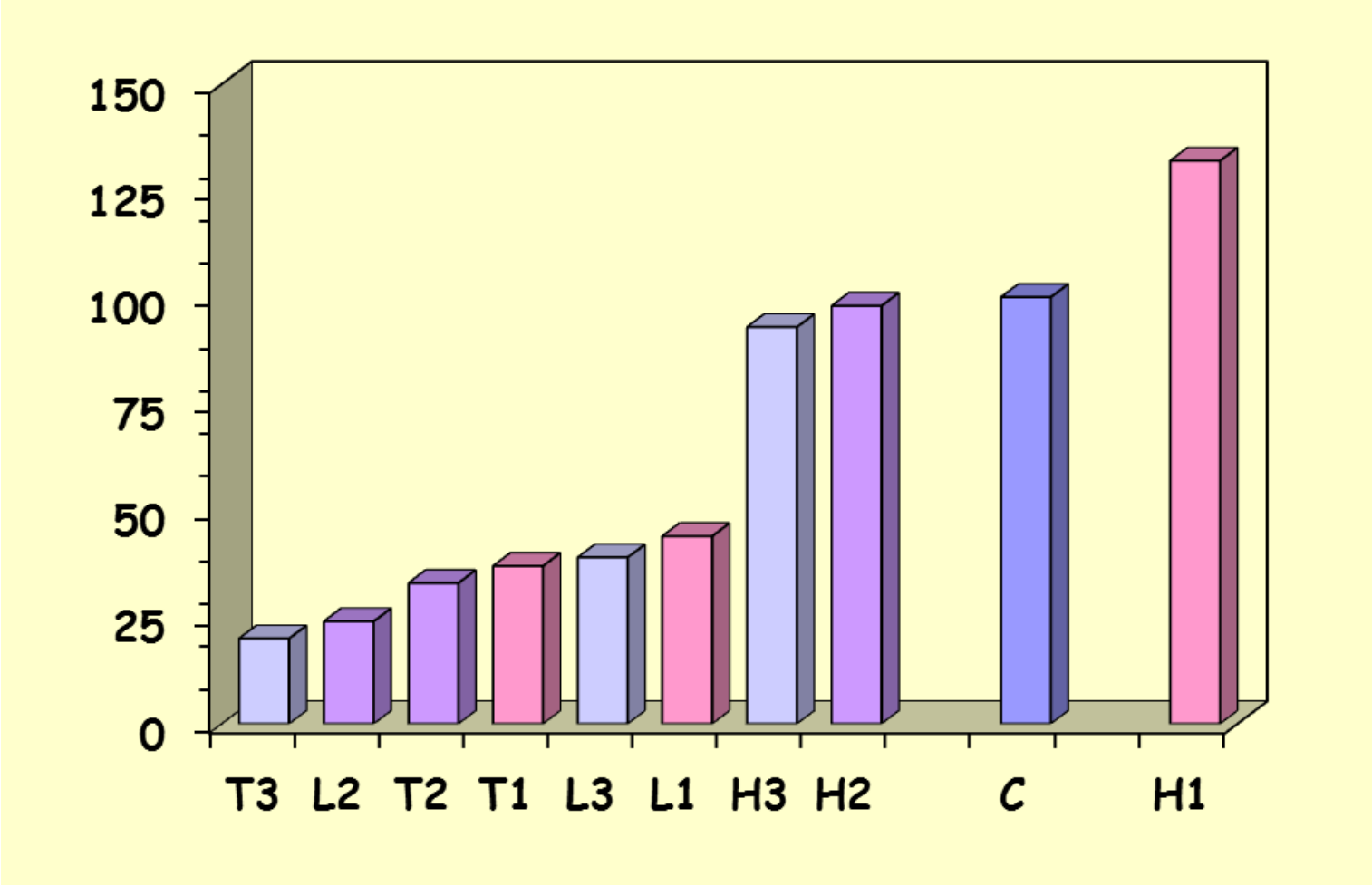
A grassland area affected by EFFLUENT FROM AN URBAN WASTE LANDFILL

A grassland area affected by FUEL OIL SPILLS

- ✓ **Accidental contamination**
- ✓ **Different (unknown) levels of contaminants: one unaffected control (C) and three sites affected to varying degrees**



Previous degradation level of the control soil



Rank them according to pollution level and detect possible stress

In summary, enzyme activities are useful indicators of soil quality, as long as certain precautions are taken. The following points are especially important:

- ✓ Do not rely on just one enzyme activity; use a range of activities, ideally combined with other biochemical indicators.
- ✓ A suitable reference soil is essential for conducting the investigation.
- ✓ Seasonal variation should be taken into account, particularly in agricultural soils.
- ✓ Remember that measurements indicate potential activity, not actual activity in the field.
- ✓ The varying locations of enzymes in soil must be taken into account; therefore, enzyme activities cannot serve as indicators of microbial activity.


THANK YOU FOR
YOUR ATTENTION!!!!