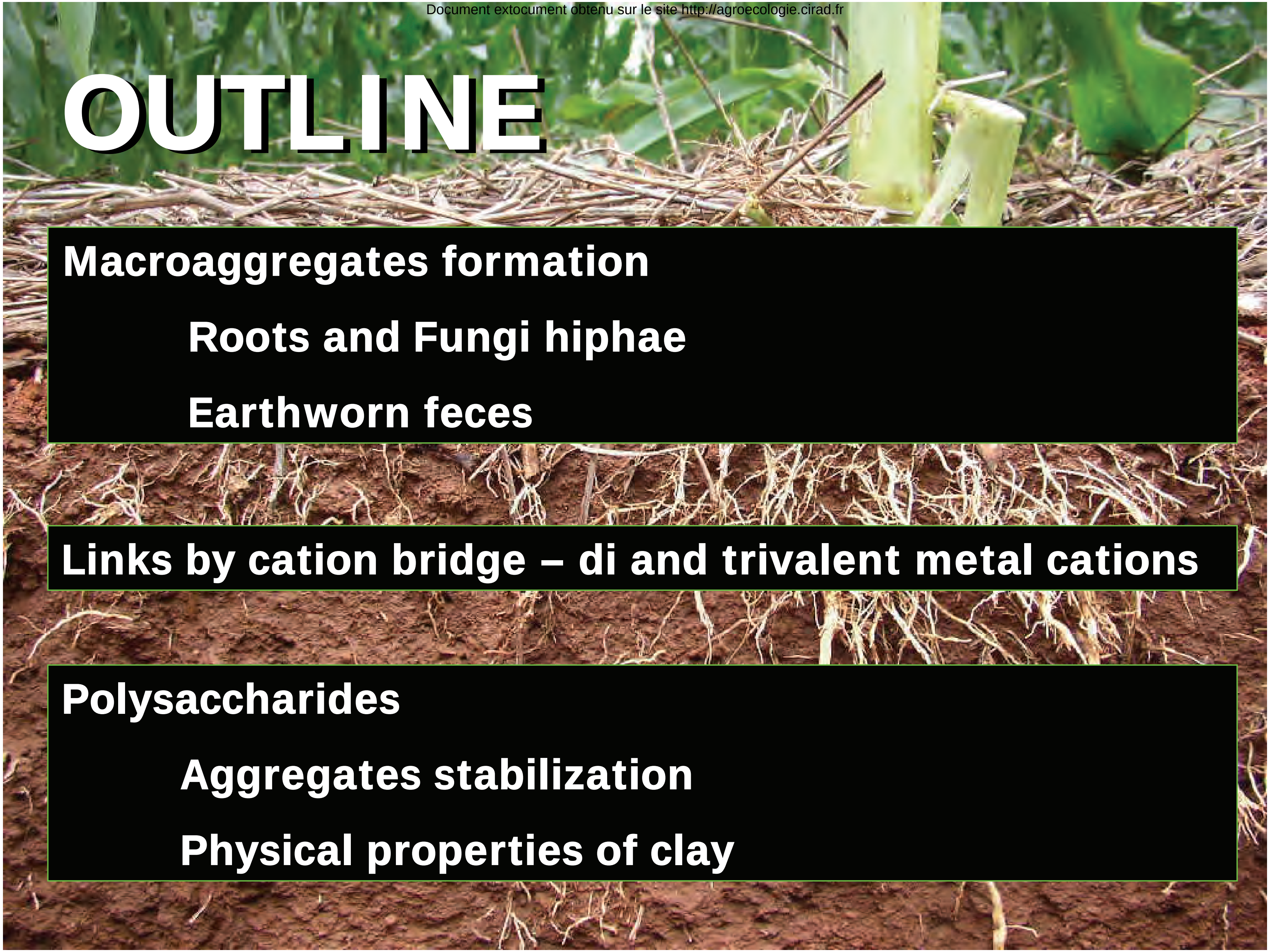
Biological interactions with aggregates formation



OUTLINE

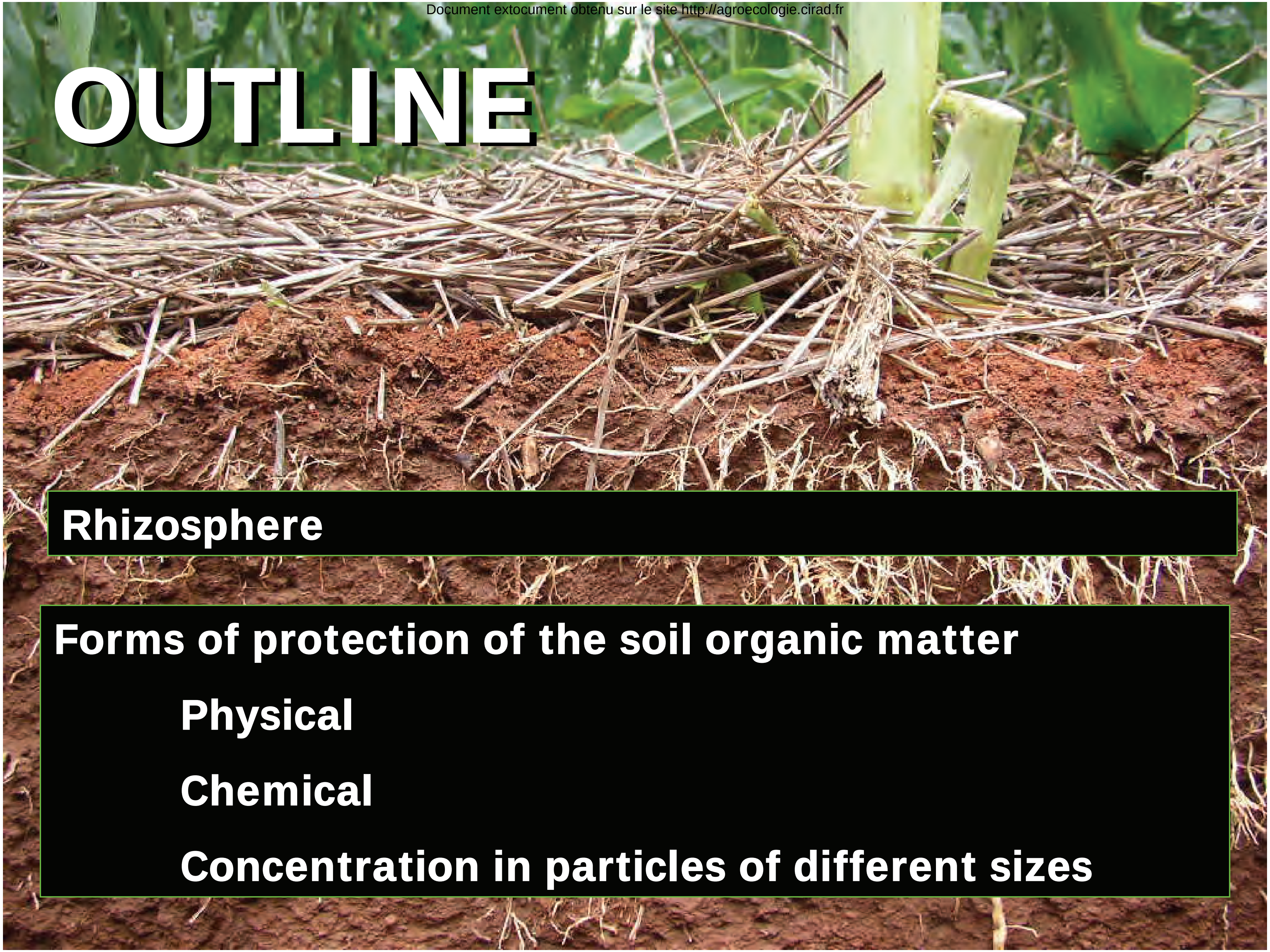
Macroaggregates formation

- Roots and Fungi hiphae
- Earthworn feces

Links by cation bridge – di and trivalent metal cations

Polysaccharides

- Aggregates stabilization
- Physical properties of clay

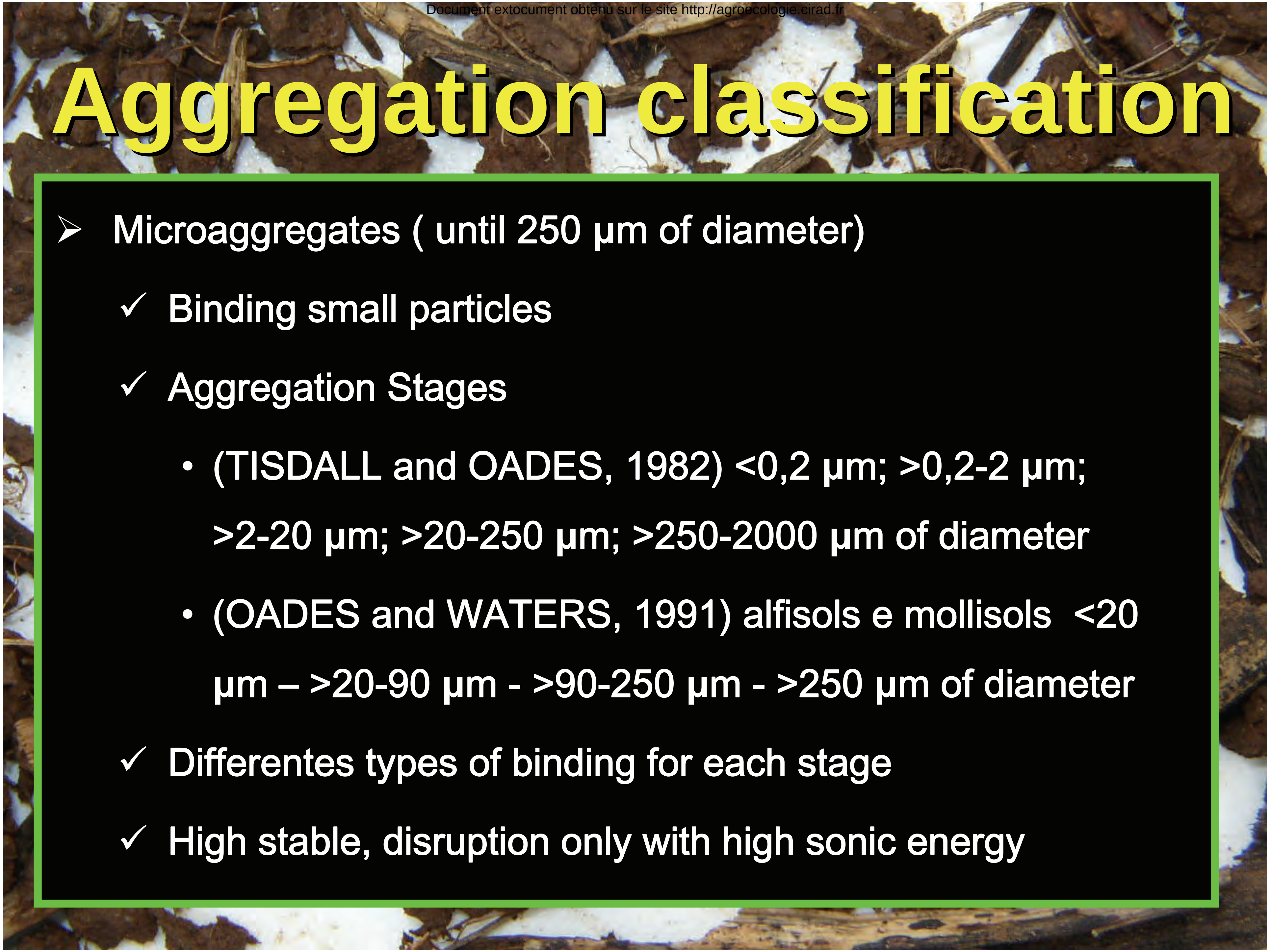


OUTLINE

Rhizosphere

Forms of protection of the soil organic matter

- Physical
- Chemical
- Concentration in particles of different sizes



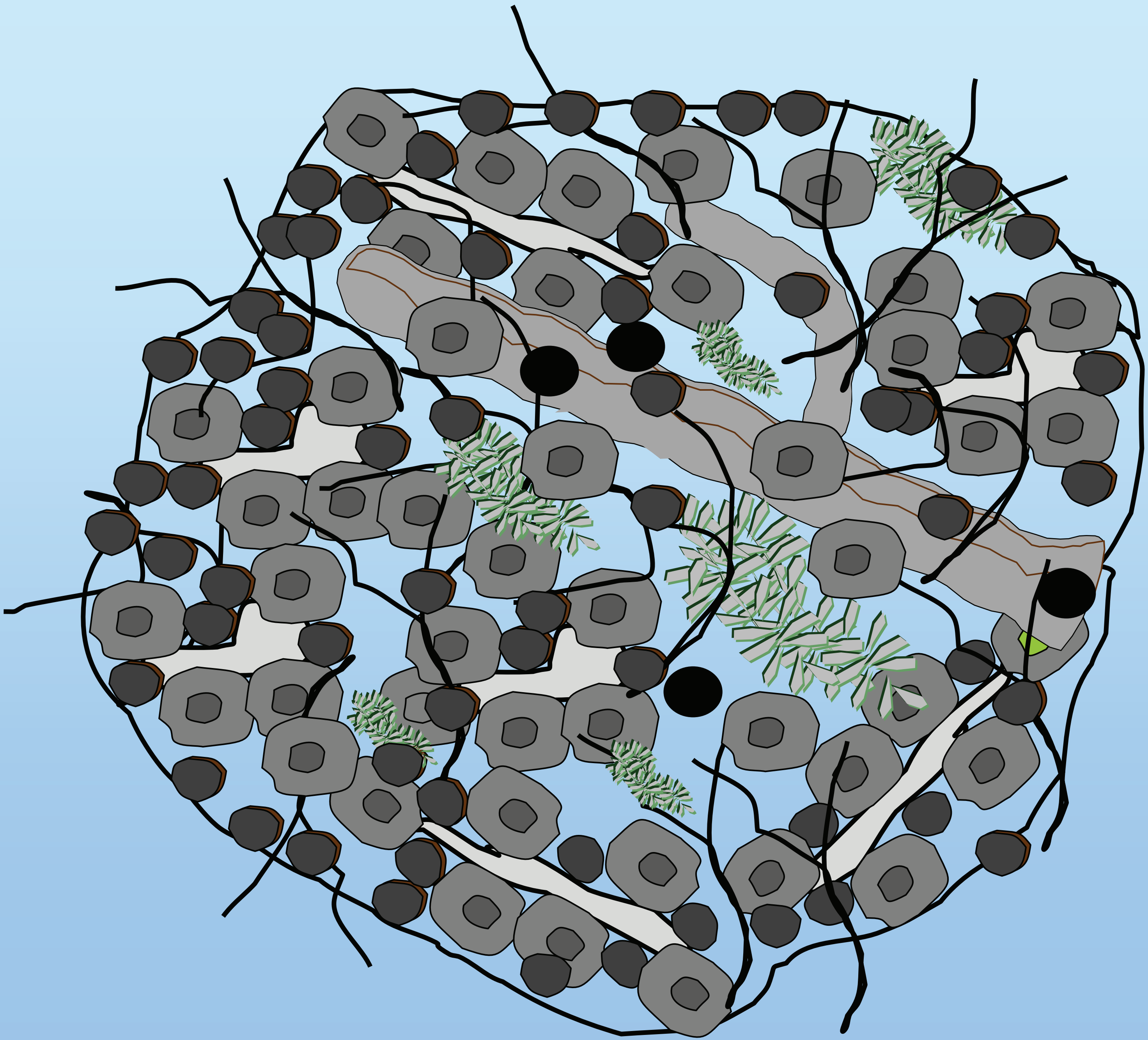
Aggregation classification

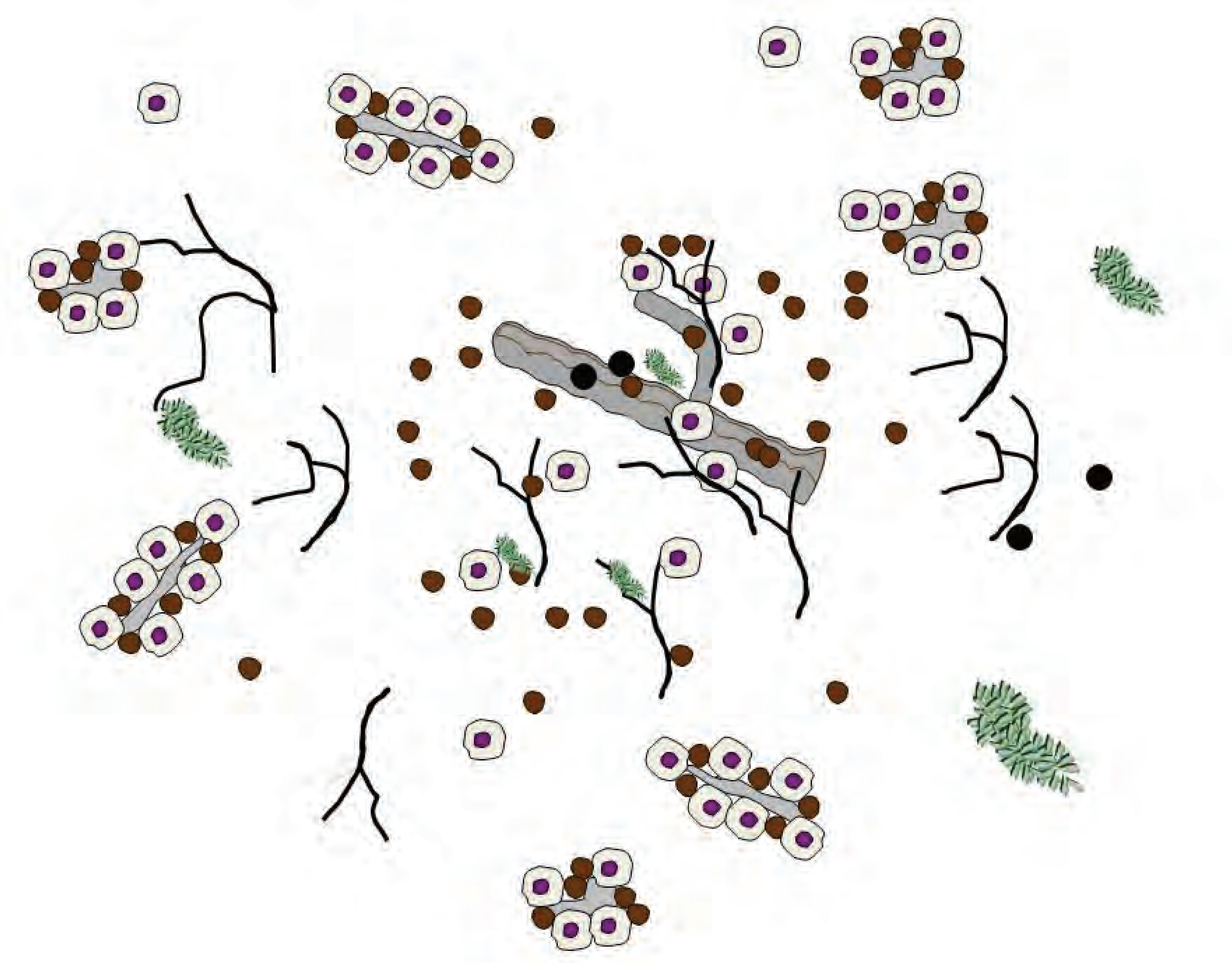
- ➢ Microaggregates (until 250 µm of diameter)
  - ✓ Binding small particles
  - ✓ Aggregation Stages
    - (TISDALL and OADES, 1982) <0,2 µm; >0,2-2 µm; >2-20 µm; >20-250 µm; >250-2000 µm of diameter
    - (OADES and WATERS, 1991) alfisols e mollisols <20 µm – >20-90 µm - >90-250 µm - >250 µm of diameter
  - ✓ Differentes types of binding for each stage
  - ✓ High stable, disruption only with high sonic energy

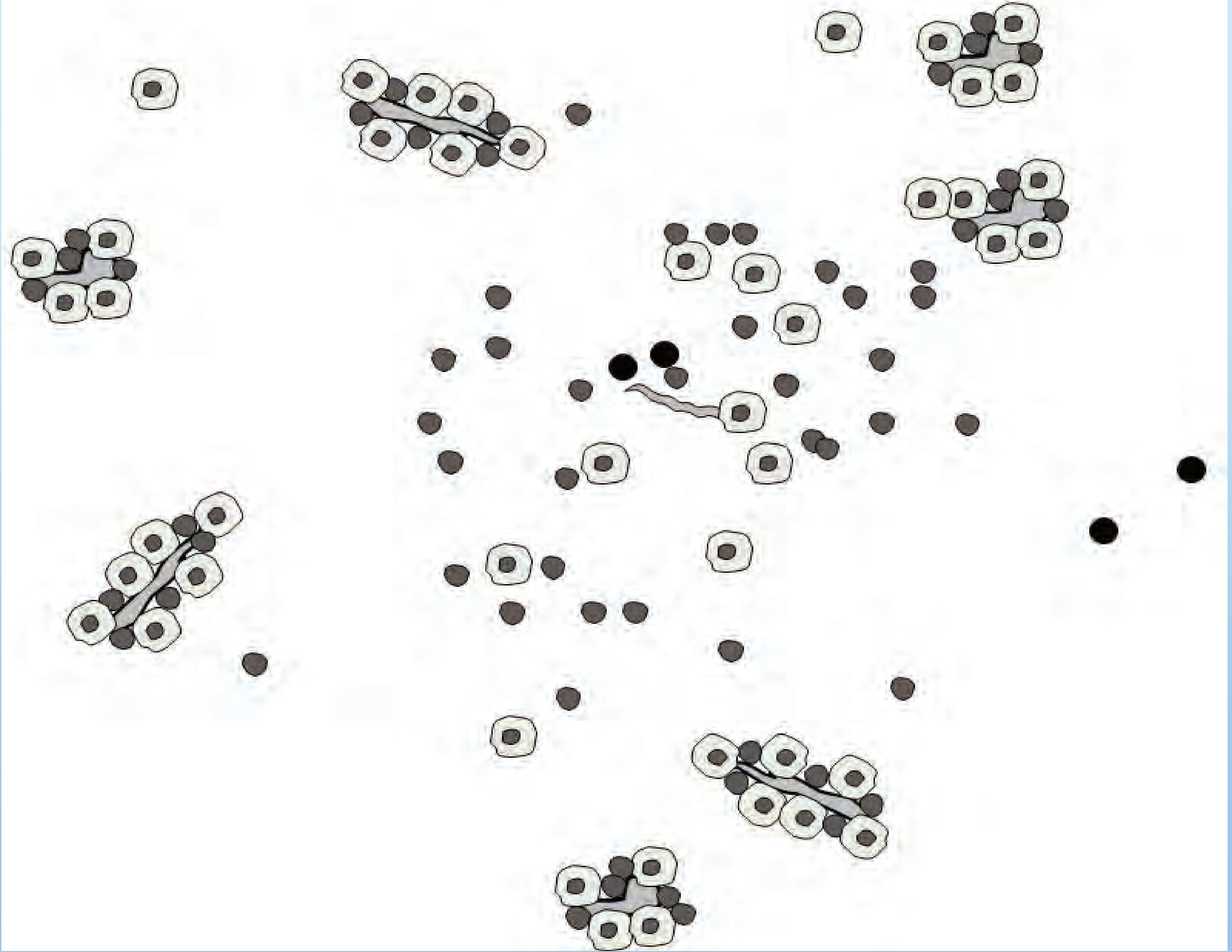
Aggregation model

- Macroaggregates
  - Binding between microaggregates
  - Weak binding than microaggregates
  - Easily disrupted
  - On the field are affected by soil management system

Document extocument obtenu sur le site http://agroecologie.cirad.fr







Stabilizer agents in the aggregates types

Soil Type	Stablizer agent	Aggregation Stage (µm)	Source
Oxisol	Oxidos (Fe and Al)	<20->20-90	Oades & Waters, 1991
Oxisol	Óxidos (Fe and Al)	<2->100-500	Robert & Chenu, 1992
Vertisol	Soil organic matter	20-35->>250	Collis-George & Lal, 1970
Andosols	Allophanes and amorphous aluminosilicates	0,001-0,01->0,1-1	Robert & Chenu, 1992

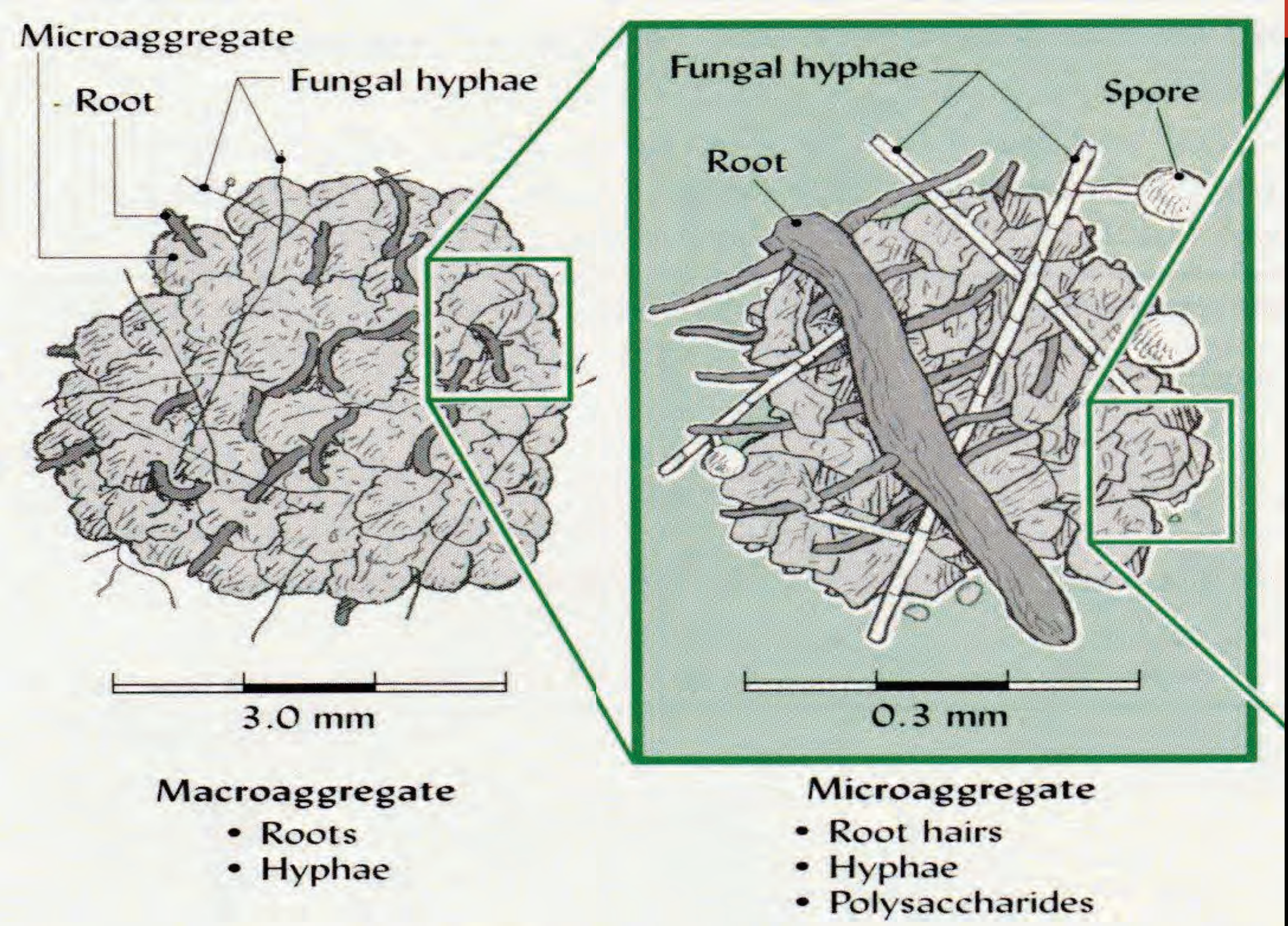
Stabilizer agents in the aggregates types

Soil Type	Stabilizer agent	Aggregation stage (µm)	Source
Alfissol	Inorganic material, polymeric organic, electrostatic links, coagulation.	< 0,2	Tisdall & Oades, 1982
	Plant debris and microorganism	0,2-2->2-20	
	Plant debris and fungus	2-20->20–250	
	Roots and hyphae or/and polysaccharides[b]	20-250->>2000	
Alfissol, Mollisol	Microorganism debris	< 20	Oades & Waters, 1991
	Inorganic material's and plant debris	20->20-90	
	Plant debris	20-90->90-250	
	Roots and Hyphae	20-250->>2000	

[A] *– soils with total organic carbon >2%*

[B] *– soils with total organic carbon <1%*

Macroaggregate Hierarchy



Macroaggregate

- Roots
- Hyphae

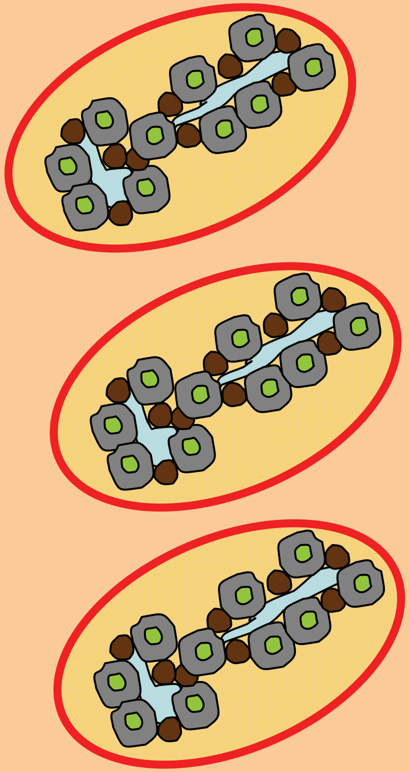
Microaggregate

- Root hairs
- Hyphae
- Polysaccharides

(Tisdall & Oades, 1982)

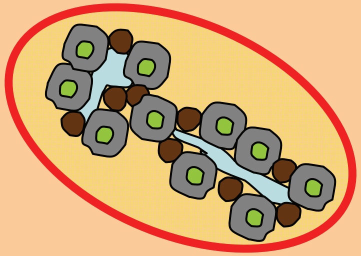
Macroaggregates (> 250 µm)

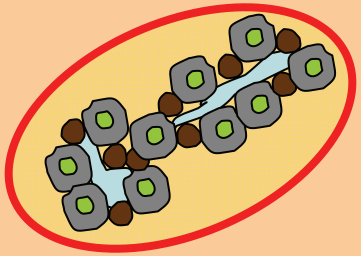
They are less stable in water, except when linked by iron and aluminum oxides



They are linked mainly for fungi hyphae, roots fibers and polysaccharides

Macroaggregates (> 250 µm)





To test the hypothesis, they stabilized the pores of the soil cultivated with polivinil alcohol (PVA), and they verified that the wetting rate of the pores between 15 and 50 µm was similar the virgin soil for the 0,2 kPa suction. Supporting the hypothesis that microaggregates of 20-250 µm are stabilized by organic material

Source: Quirk & Williams, 1974

Roots and fungi hyphae

The roots exudates stimulate the fungi hyphae development and forming an extensive *“root-hyphae-net”* in the soil. The aggregates are covered by the polysaccharides that glues firmly them.

Roots and fungi hyphae

That *"root-hyphae-net"* holds intact the aggregates

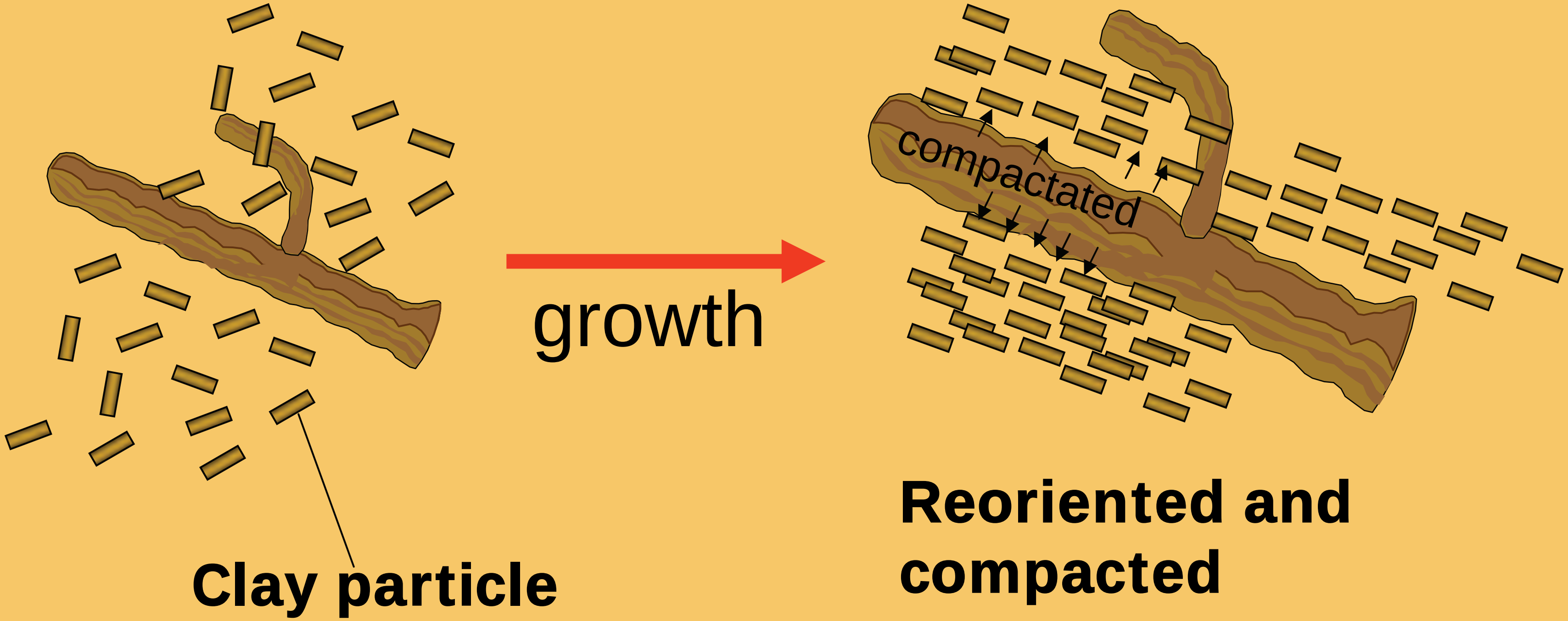
The clay in the surface protects the roots and hiphae of the microorganisms attack

The stability in many soils is associated with the organic matter

Photo by C. Rice

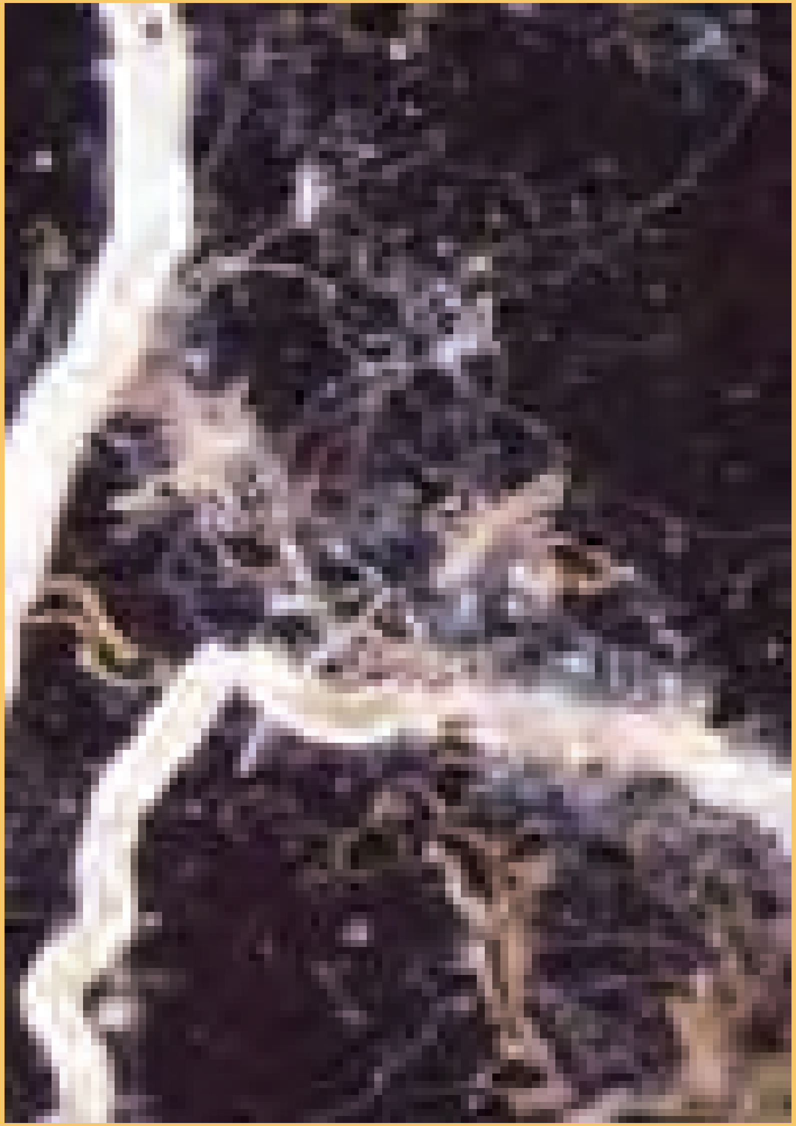
Roots and fungi hyphae

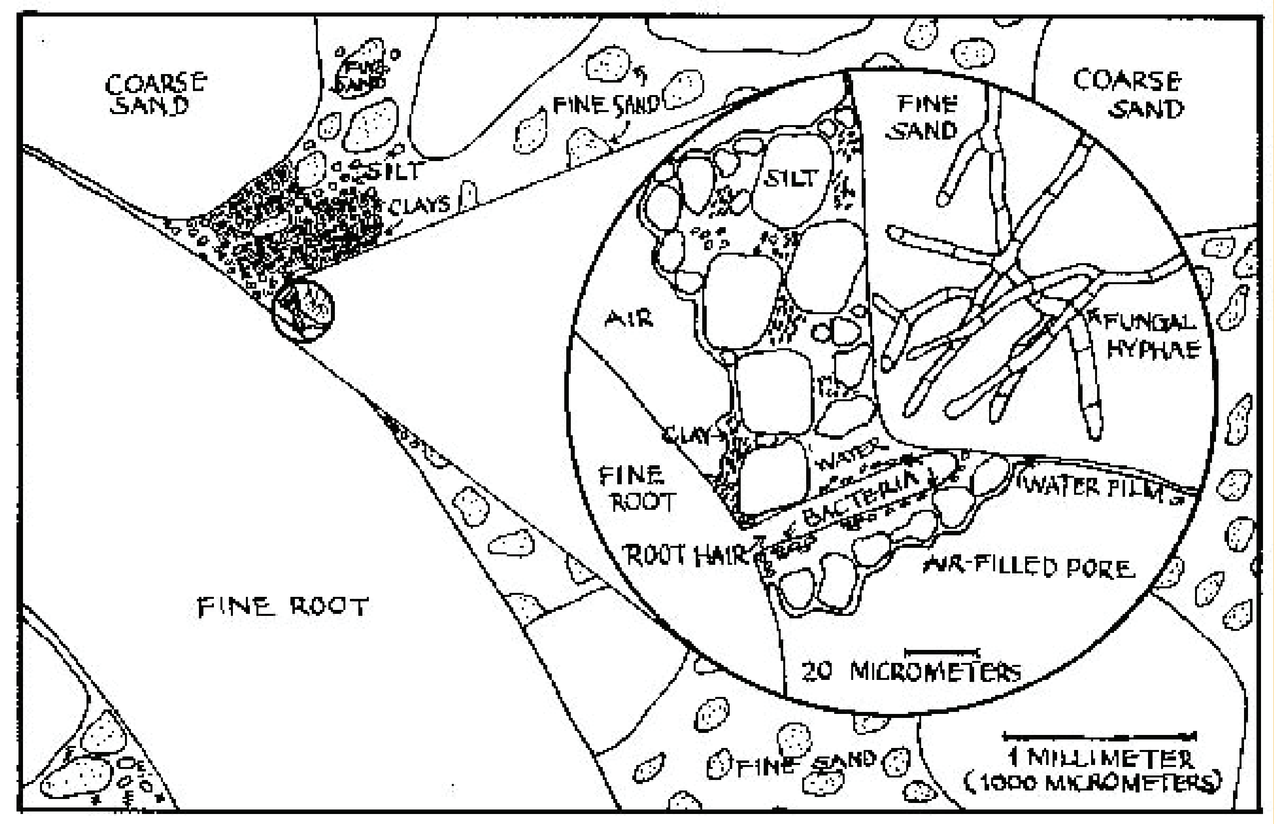
Fine roots goes through the soipores and drying around the place and compressing to form the aggregates that will be stabilized by polysaccharides excreted by microorganisms (Allison, 1968)



Roots and fungi hyphae

The fungi reorganize the particles inside of the aggregates, which are stabilized by polysaccharides excreted (Mc Lean, 1966)





A tiny bit of soil shown at two enlargements. The background is enlarged approximately 30 times. At this scale, an earthworm would be about as wide as the entire drawing. The isolated portion is enlarged approximately 500 times. At this scale, that earthworm would be about 17 times wider than the pages of this magazine. Note the tremendous range of sizes, and how the sizes of pores and the "necks" that connect them constrain the movement of water, air, and organisms.
(Composited and redrawn from figures in *Soil Science: Methods & Applications* by D.L. Rowell.)

The hyphae effect is indirect and favoring the roots growth

Thomas, 1986

Direct and indirect effects of roots and VA mycorrhizal hyphae on the geometric mean diameter of aggregates of several silt loams and silt clay loams, as show by path analysis

Variável (comprimento)	Coeficiente de correlação	
	Efeito direto	Efeito indireto
Hifas externas	0,54**	-
Raízes finas colonizadas	-	0,36**
Raízes muito finas colonizadas	-	0,13
Raízes finas	0,37**	0,40*
Raízes muito finas	-	0,12

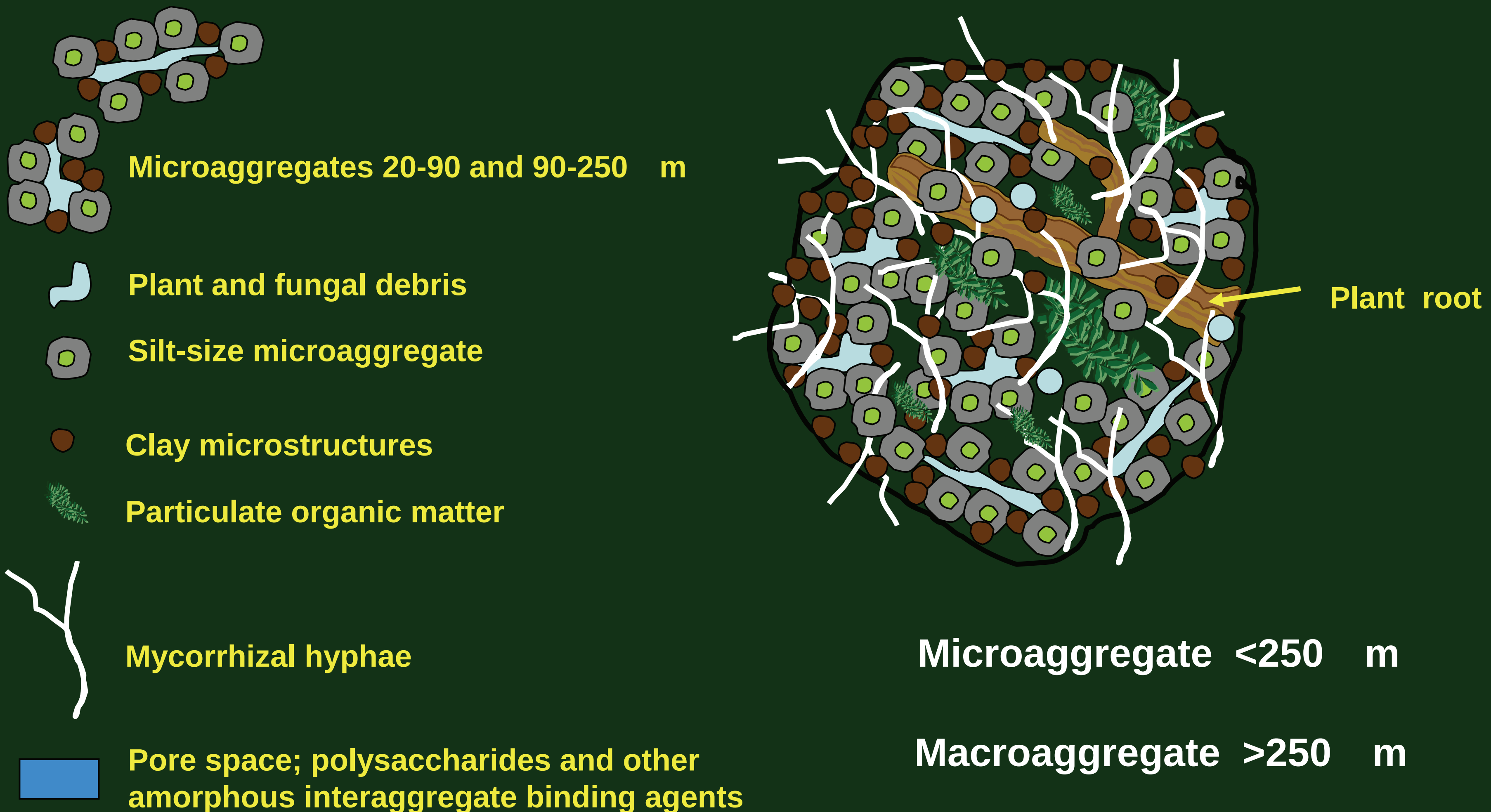
Miller e Jastrow 1990

Aggregation pathway in a Oxisol under long term in no-tillage – Study “in situ”

Cover crops effect in the aggregation

Cover crops effect in the aggregation

Microaggregates-macroaggregates model



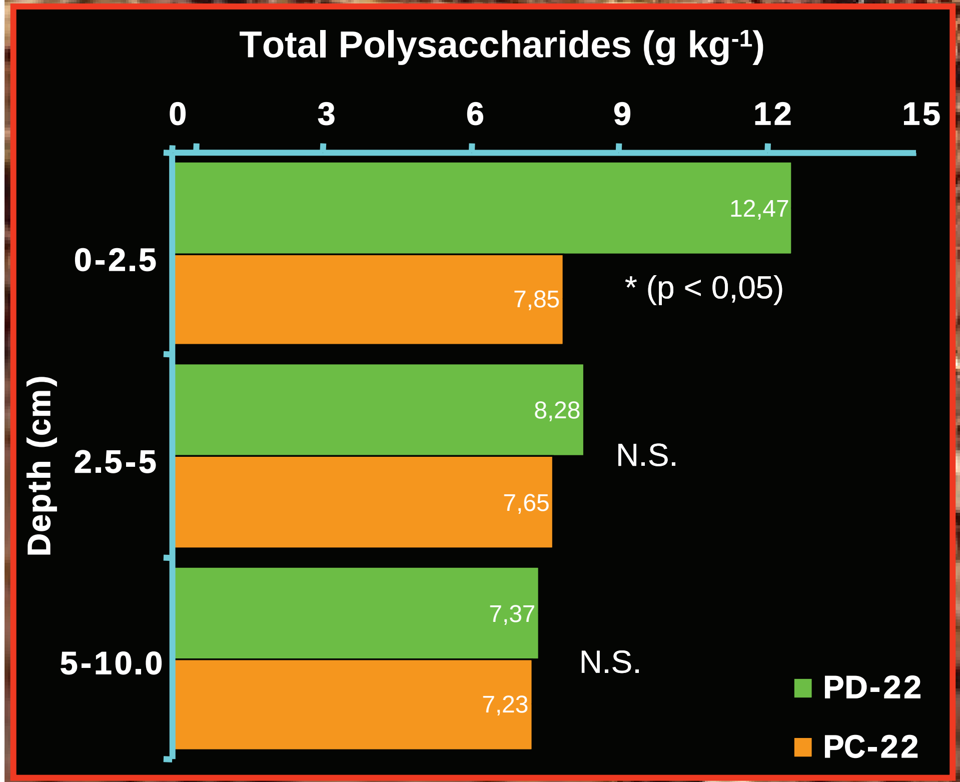
Microaggregate <250 μm

Macroaggregate >250 μm

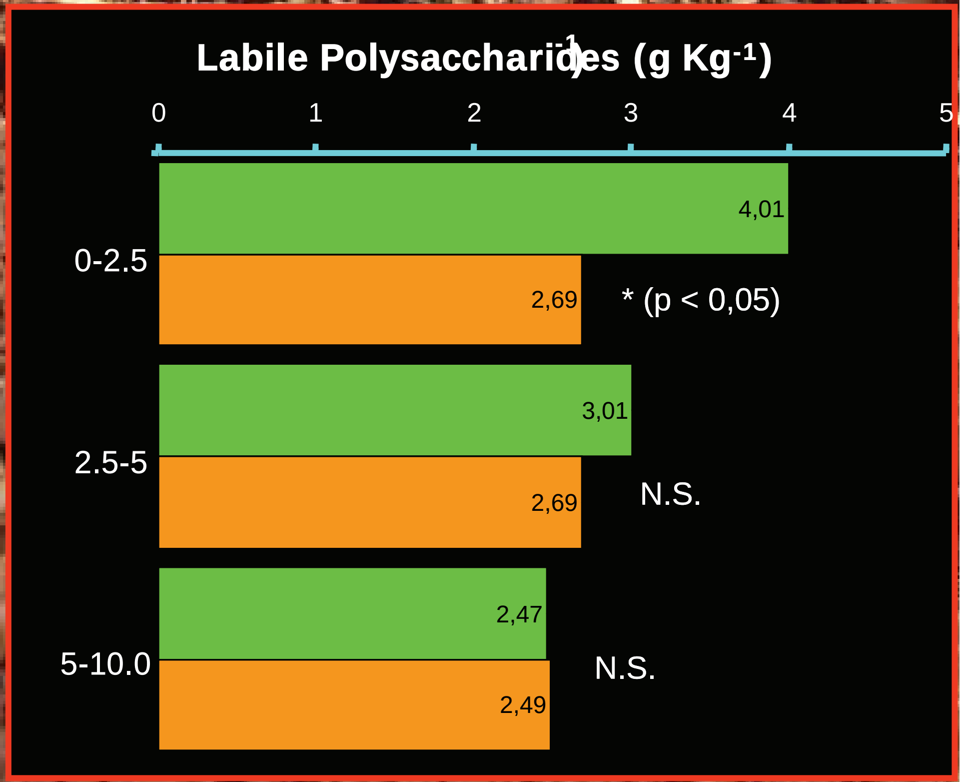
Adapted from Jastrow and Miller, 1997

Slide from Dr. Charles Rice Presentation - Argentine

Soil Polysaccharides



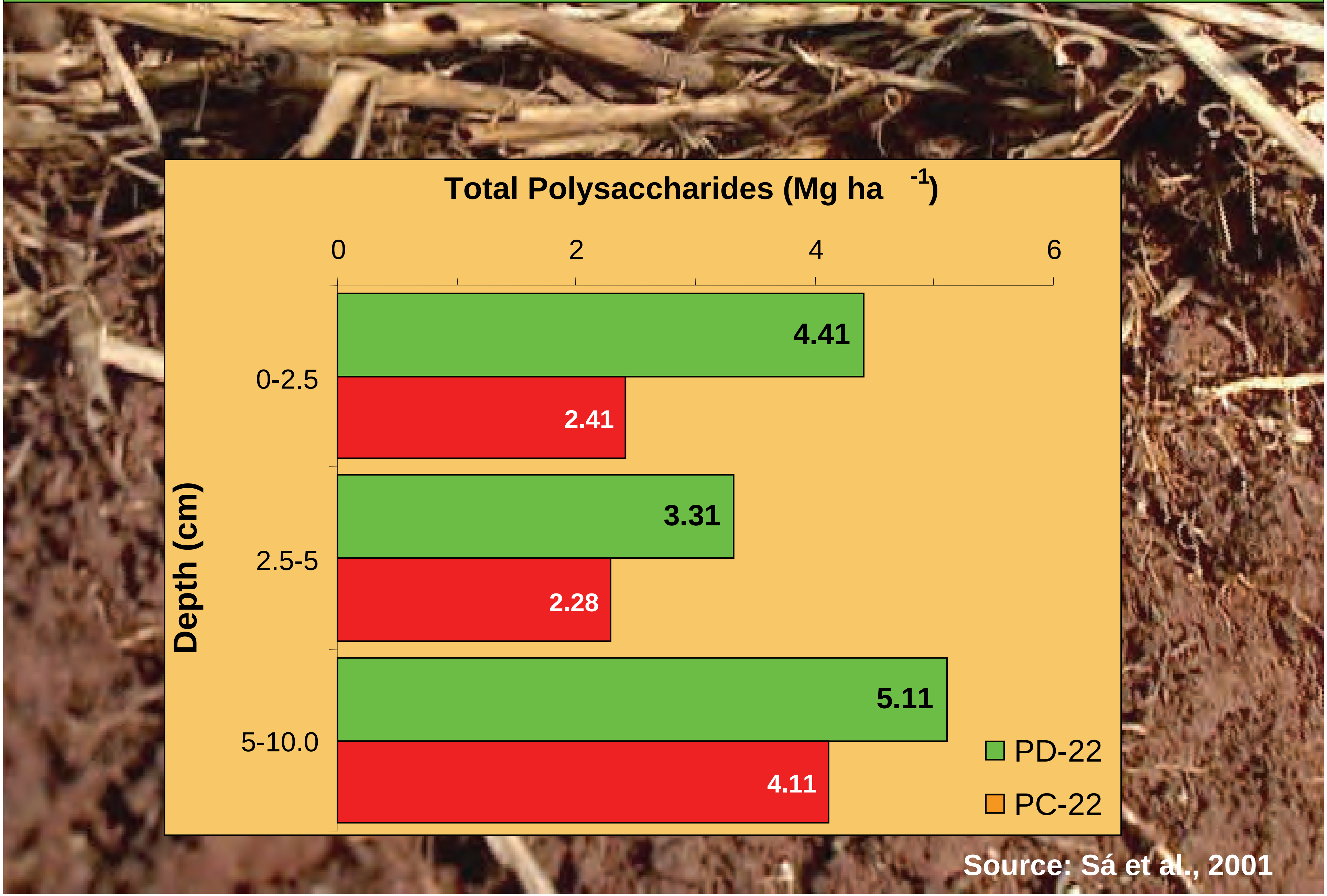
Total Polysaccharides (g kg^{-1})



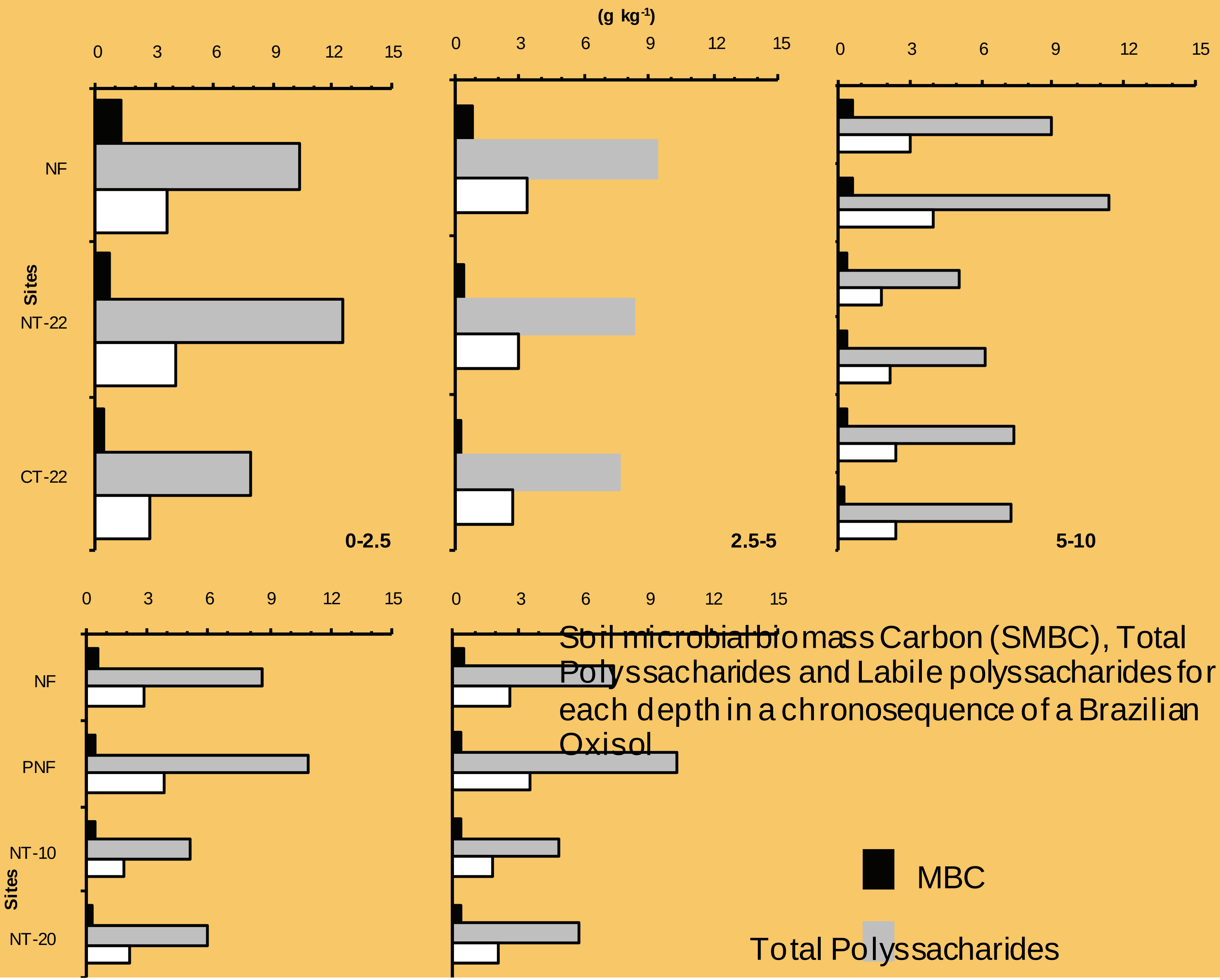
Labile Polysaccharides (g Kg^{-1})

Fonte: Sá et al., 2001

Soil polysaccharides stock in surface layers



Source: Sá et al., 2001



Soil microbial biomass Carbon (SMBC), Total Polyssacharides and Labile polyssacharides for each depth in a chronosequence of a Brazilian Oxisol

The contribuition of VA Mycorrhizal fungi to aggregation is on three simultâneos process

They form an entangled with primary soil particle

Protected physically the clays and OM that forming microaggregates

Glue microaggregates and some macroaggregates to form large macraggregates

Miller & Jastrow, 1992

The fungi polysaccharides stabilize the soil macroaggregates

Roots and fungi hyphae

Correlation among roots, external hyphae and % of water stable aggregates greater than 2 mm diameter

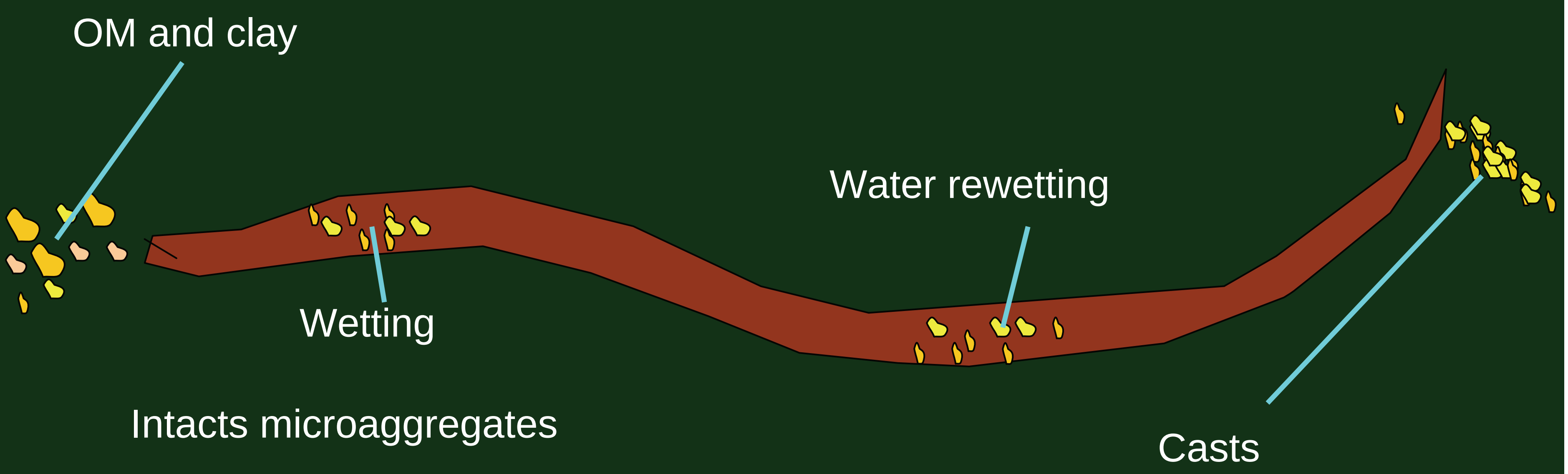
Source	Soil	Attribute correlated	**r^2**
Thomas et al. (1986)	Silty Clay loams	Root biomass External hyphae length	**0,54** **0,20**
Tisdall & oades, (1980)	Fine sandy loams	Root length Root length	**0,93** **0,77**
Miller & Jastrow, (1992)	Silt loams e silty clay loams	Root length Hyphae length	**0,81** **0,74**

The effect of plant species, grown in artificial aggregates of an Alfisol, on root length, organic carbon and water stable aggregates > 250 µm

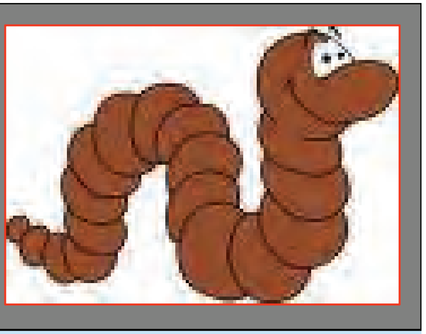
Plant species	Root length ($cm\ cm^{-3}$)	Organic carbon (%)	% WSA
Control	-	1.25	31.4
Pea	3.9	1.51	49.5
Rye	81.6	1.73	64.4
Wheat	27.8	1.54	55.6

Materechera et al., 1992

Earthworm casts

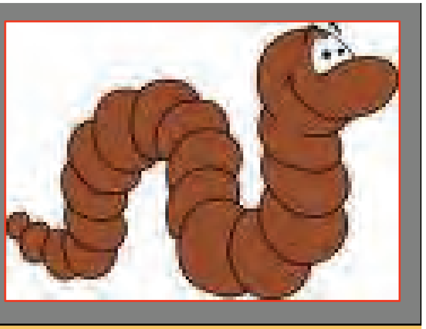


Earthworm casts



The earthworms ingest a mix of minerals and organic matter and they deposit this material as CASTS or MACROAGGREGATES on the soil or in the subsurface, depending of the species

Earthworm Casts



The soil is destabilized when passing trough for the earthworm, due to the wetting and crush

The microaggregates are not physically modified

The material initially is moistened and later part of the water is reabsorbed inside the earthworm, and liberated with larger humidity than soil before passing trough her

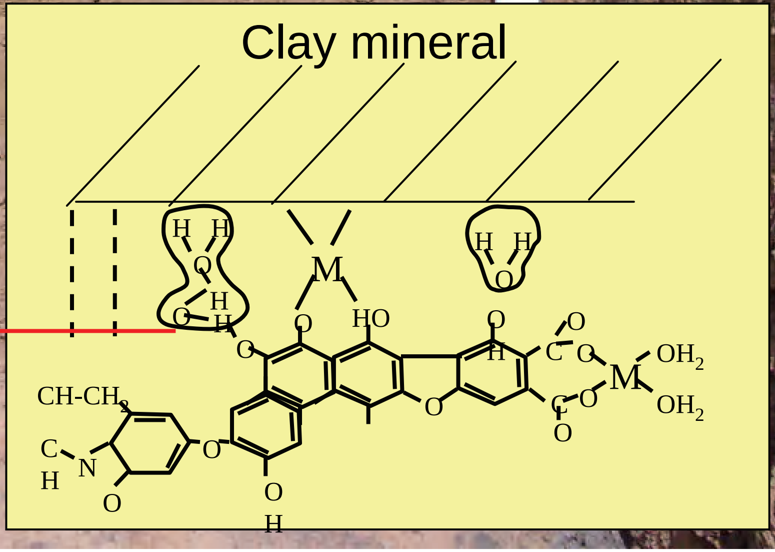
Cool casts are more disperse than the soil around, but with the time become stable

Polyvalent cation bridges

Polysaccharides form H^+ bridges with water molecules in the H-shell of an exchangeable cation

Individual H-bonds are weak

Many Hydroxil groups along its length may form many H-bonds and may be bounded strongly to the surface of a clay particle



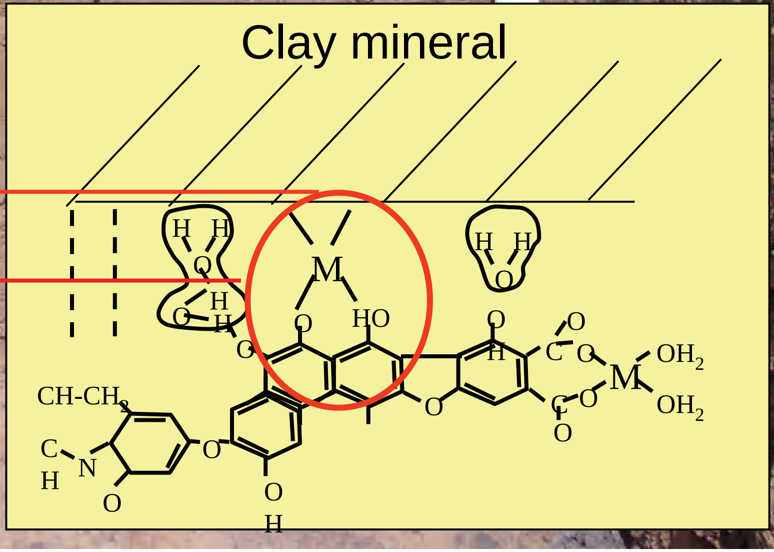
H^+ Bonds Bridges

Tisdall, 1996

Polyvalent cation bridges

Polysaccharides in the rhizosphere are negatively charged

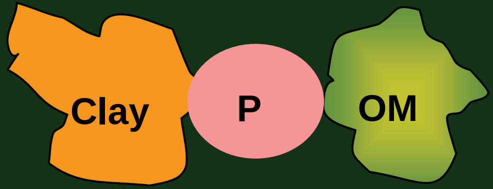
Polysaccharides negatively charged can be adsorbed onto surface of clay by polyvalent cations such as Ca^{2+}, Fe^{3+}, Al^{3+}, aluminosilicates and hydroxialuminium



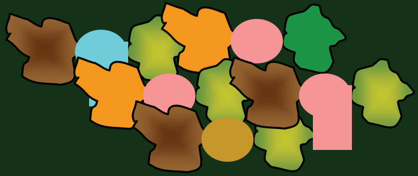
The cation bridge are strengthened with time

Foster, 1982

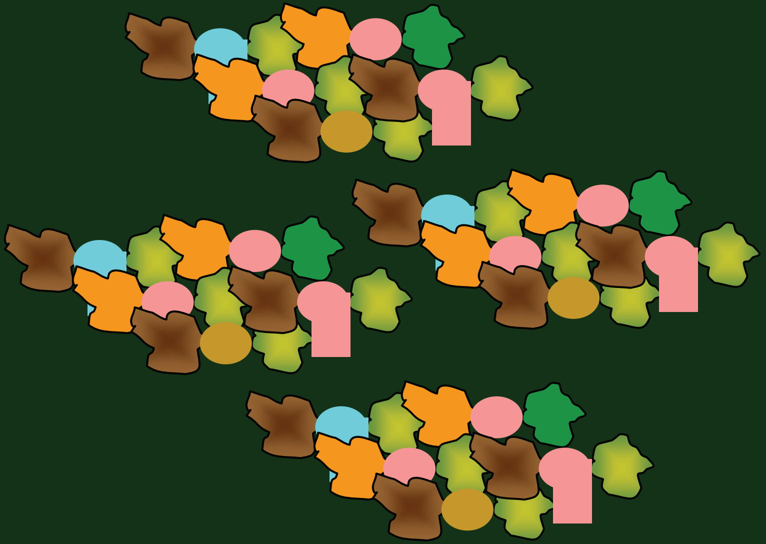
The polyvalent cation form strong bridges between clay and OM, and probably stabilize the OM before the microbial degradation



Clay-P-OM



$(\text{Clay-P-OM})_x$



$((\text{Clay-P-OM})_x)_y$

The macroaggregates stabilization is also associated with the polyvalent cations excreted by root exudates and forming strengthening bridges between OM and clay

Polysaccharides and aggregates stabilization

Mucilage

Polysaccharides
Poligalaturonic acid
Amino component

↓

Easily decomposed by microorganisms

↓

Replaced by microbial polysaccharides

Negative charge

↓

Adsorbed with clay

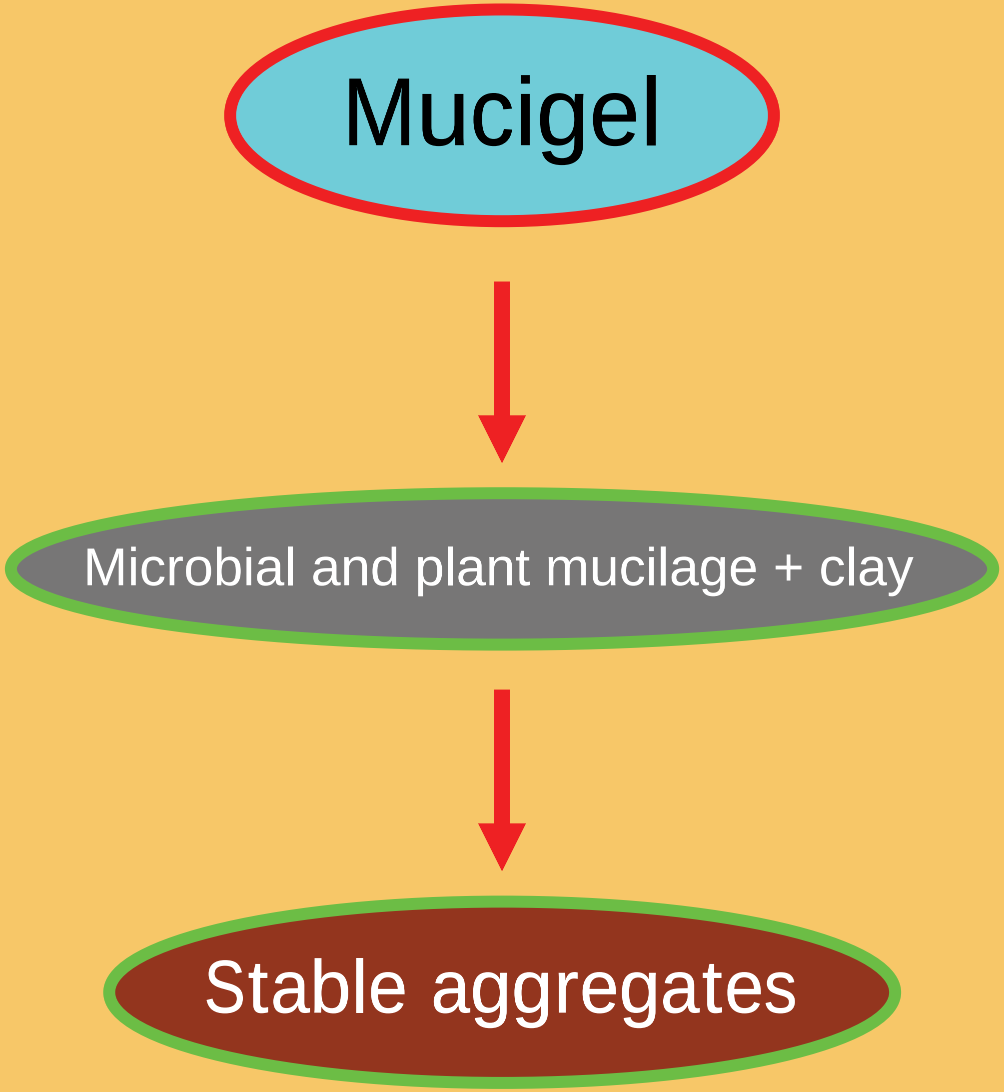
↓

Low mobility in the soil

↓

Aggregates are formed when silt and clay particles are deposited in soil solution

Polysaccharides and aggregates stabilization



Mucigel

↓

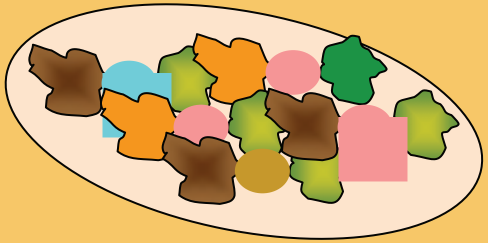
Microbial and plant mucilage + clay

↓

Stable aggregates

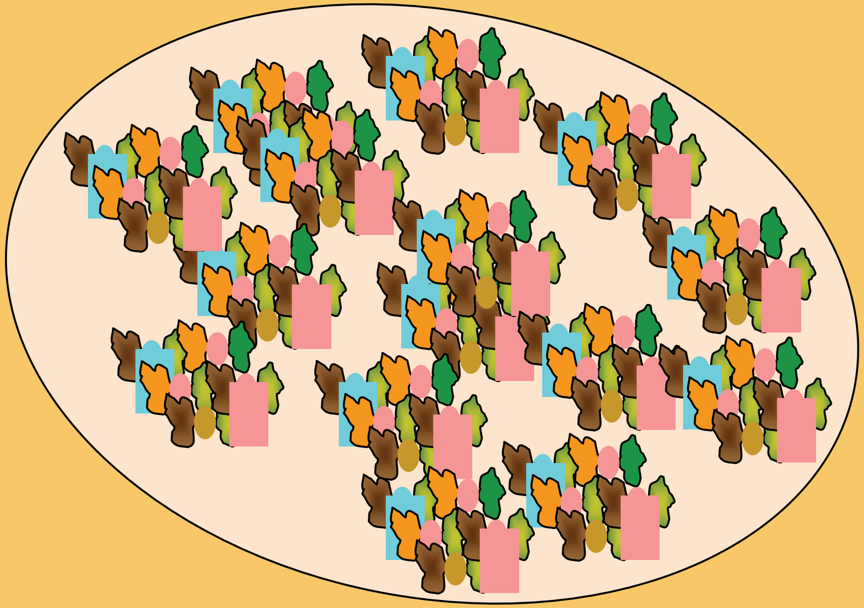
Polysaccharides and aggregates stabilization

Aggregates de 2-20µm



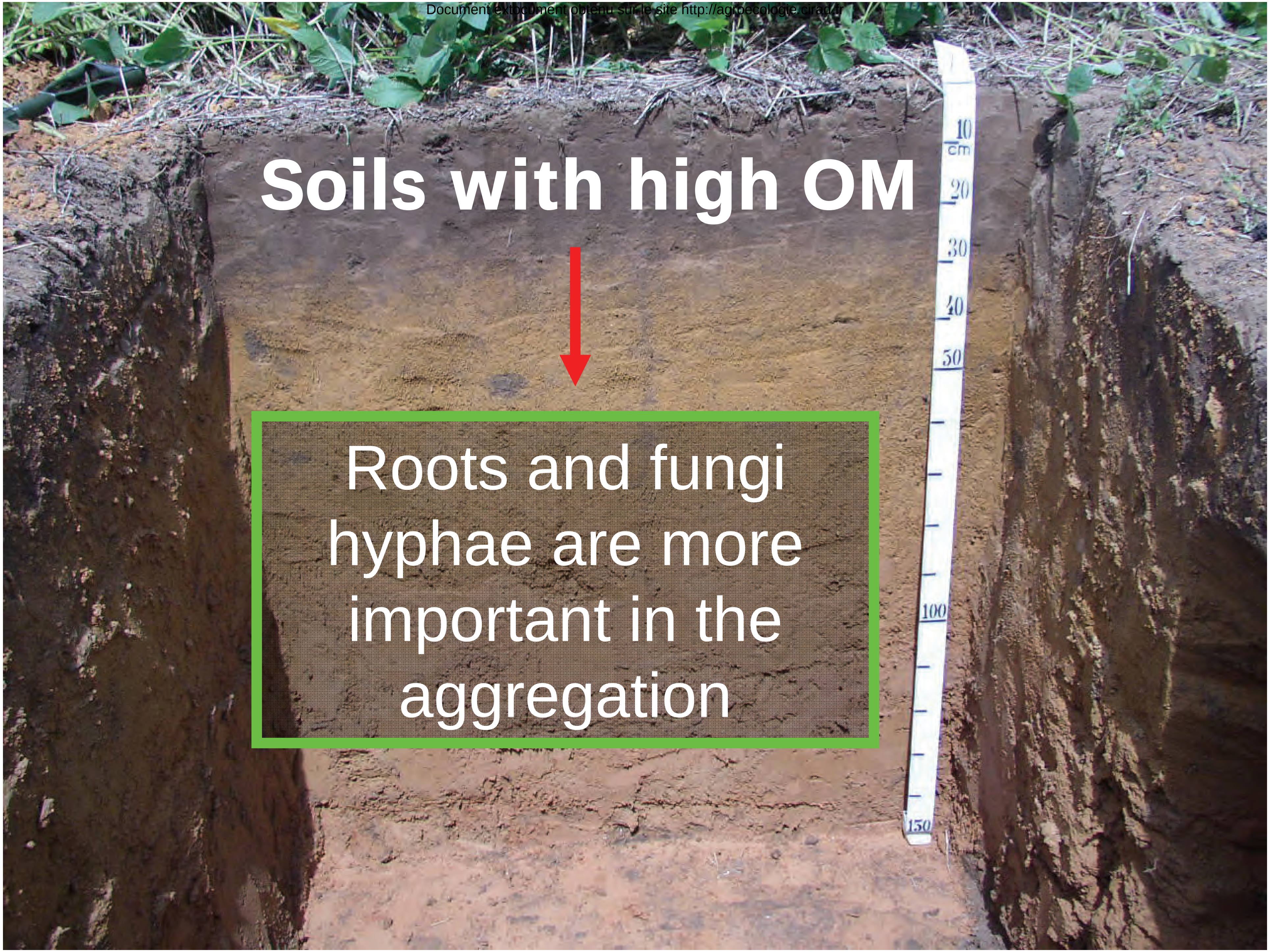
Microbial
recalcitrant
polysaccharides

Agregados de 20-250 µm



Roots
polysaccharides

Soils with high OM



Roots and fungi hyphae are more important in the aggregation

Polysaccharides and aggregates stabilization

Microbial polysaccharides have cellulose fibril comprising a mucigel layer around the organism

↓

Low molecular weight

↓

Small amount have high capacity to stabilize the microaggregates

Polysaccharides and physical properties of clay

Effect of the fungal polysaccharide, scleroglucan, on the tensile strength of kaolinite

Scleroglucan (mg g^{-1} Clay)	Tensile strength (10^5 Pa)
0	1
1	2
5	[illegible]
13	14
21	18
24	21
30	19

Increase the water retention in the clay

Chenu & Guérif, 1991

Polysaccharides and physical properties of clay

The kaolinite has few points of contact with the particles, as little as 0.1% polysaccharide nearly doubled the strength of kaolinite.

The tensile strength increase linearly up to 20 times that the original

The amount of polysaccharides increase the water retained in the small pores in kaolinite

Rhizosphere

Living roots release many types of organic materials into the rhizosphere within 50 µm of the surface of the root

Rhizosphere

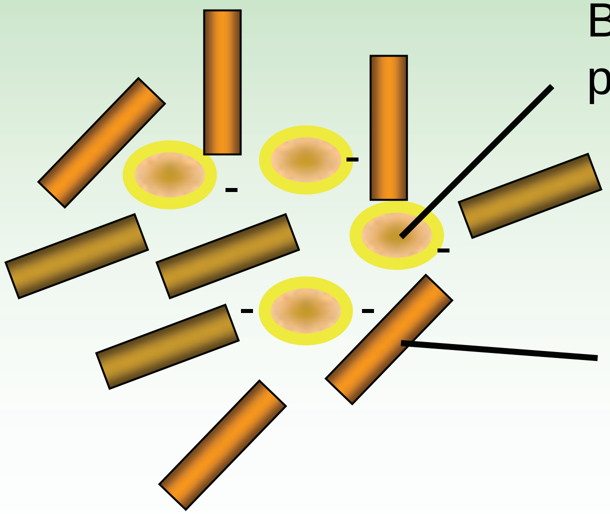
Larger C/N ratio

Bacteria proliferation of with larger capacity of Nitrogen uptake (negative gram)

The number of bacteria negative gram in the rizosfera is from 5 to 2000 times larger than in the soil

Rhizosphere

Layer of extracel polysaccharides, neutral or negatively charged interact with clay particles stabilizing the aggregates < 20 µm

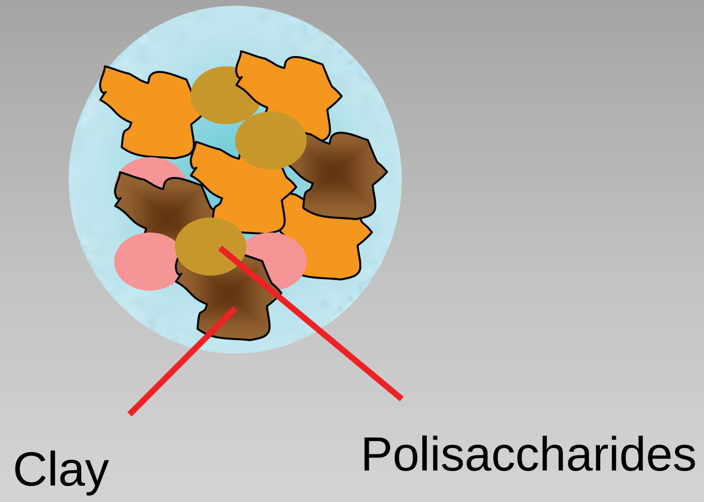


Bactérias surrounded by polysaccharides

Clay particles

Wetting and drying cicles

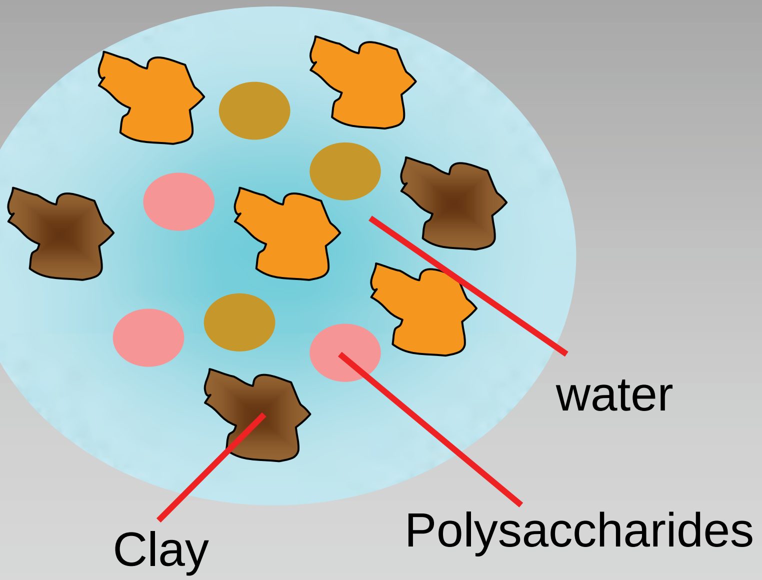
The water content affects the bonds which form between the particles of clay, and OM and clay, and hence the formation and stabilization of aggregates of differente sizes



As a soil dries, particles of clay, organic colloids and salts are deposited at points of contact, strengthening bonds between larger particles

Dry soil

Wetting and drying cicles

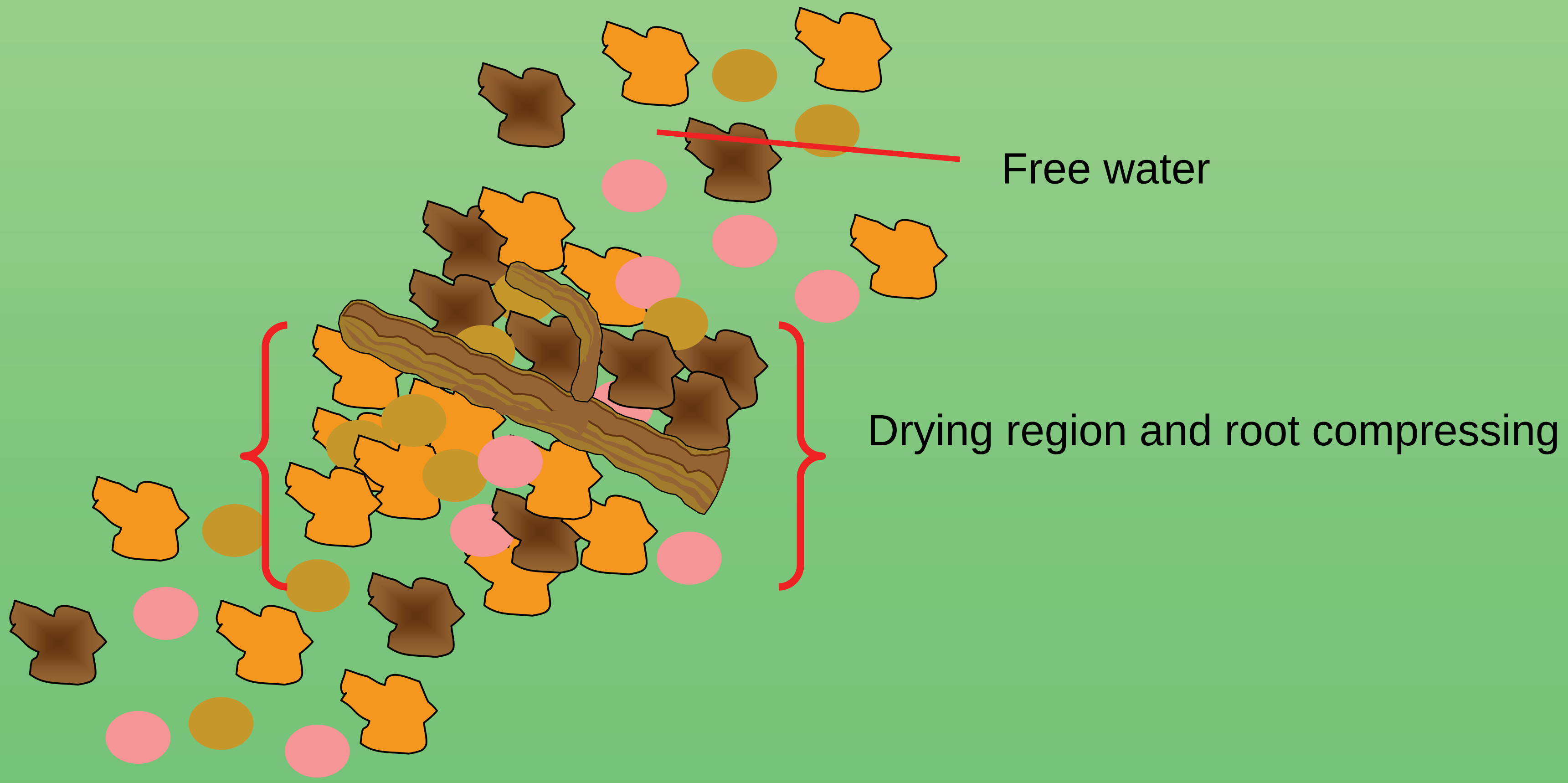


Wet Soil

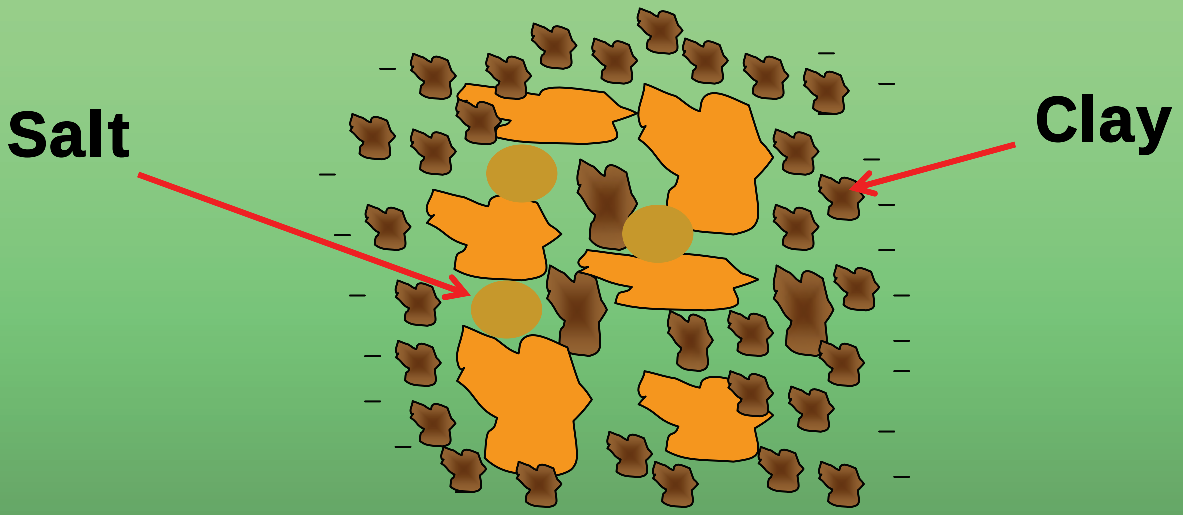
At the constant water content, specaily at the plastic limit, particles of clay are rearranged to positions of minimum energy and are chemically bound together at points of contact

Wetting and drying cicles

The roots can have effect in the aggregation due drying the soil around the local

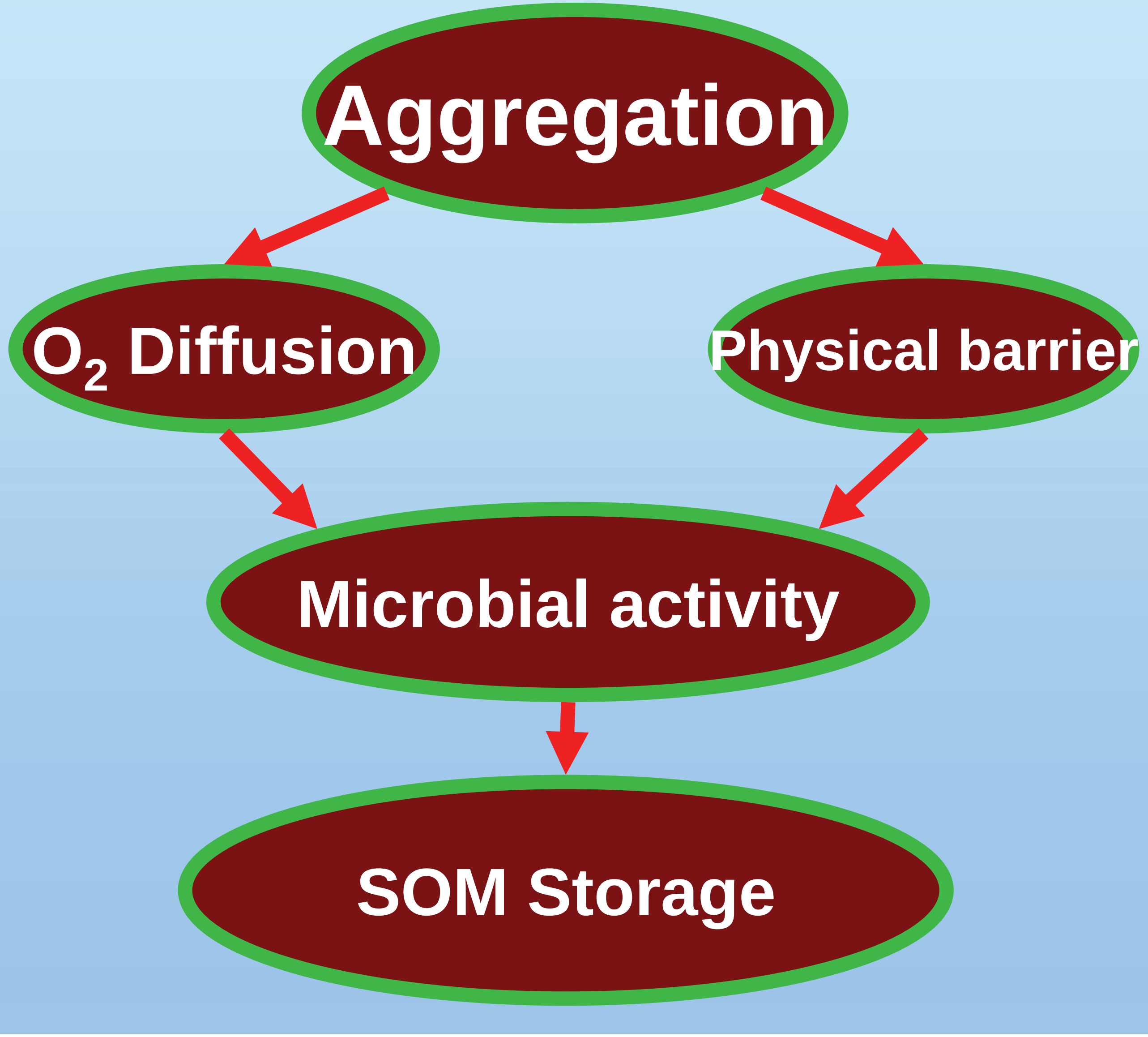


Wetting and drying cicles



Fine layer, more compacted and rich in clay and salts surrounded of the aggregates. More reactiviy than the internal part of the aggregates and prompt combined with organic colloids

Physical protection



Aggregation

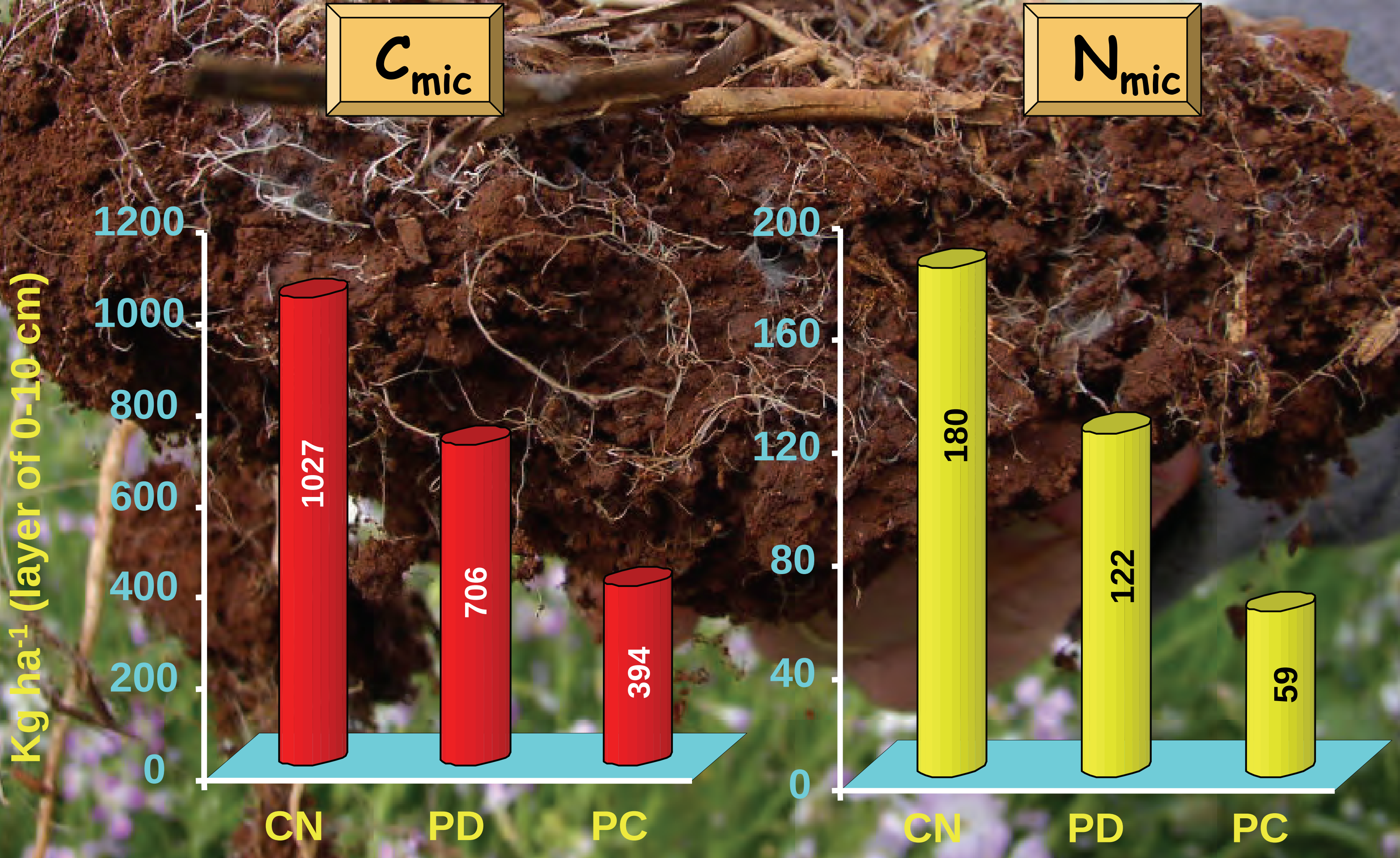
O_2 Diffusion

Physical barrier

Microbial activity

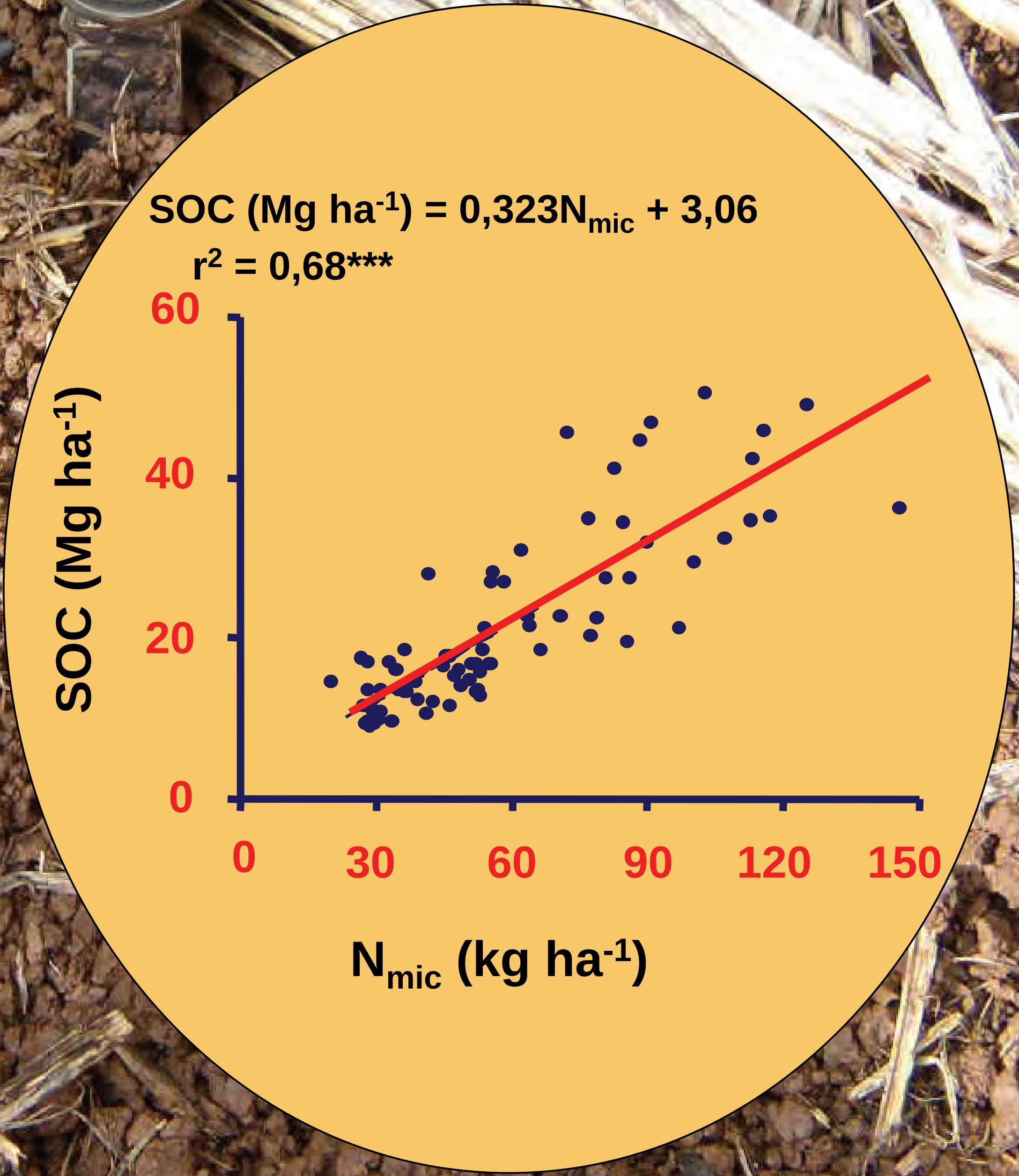
SOM Storage

C_{mic} and N_{mic} Stock (0-10 cm)



Source: Sá et al., 2001

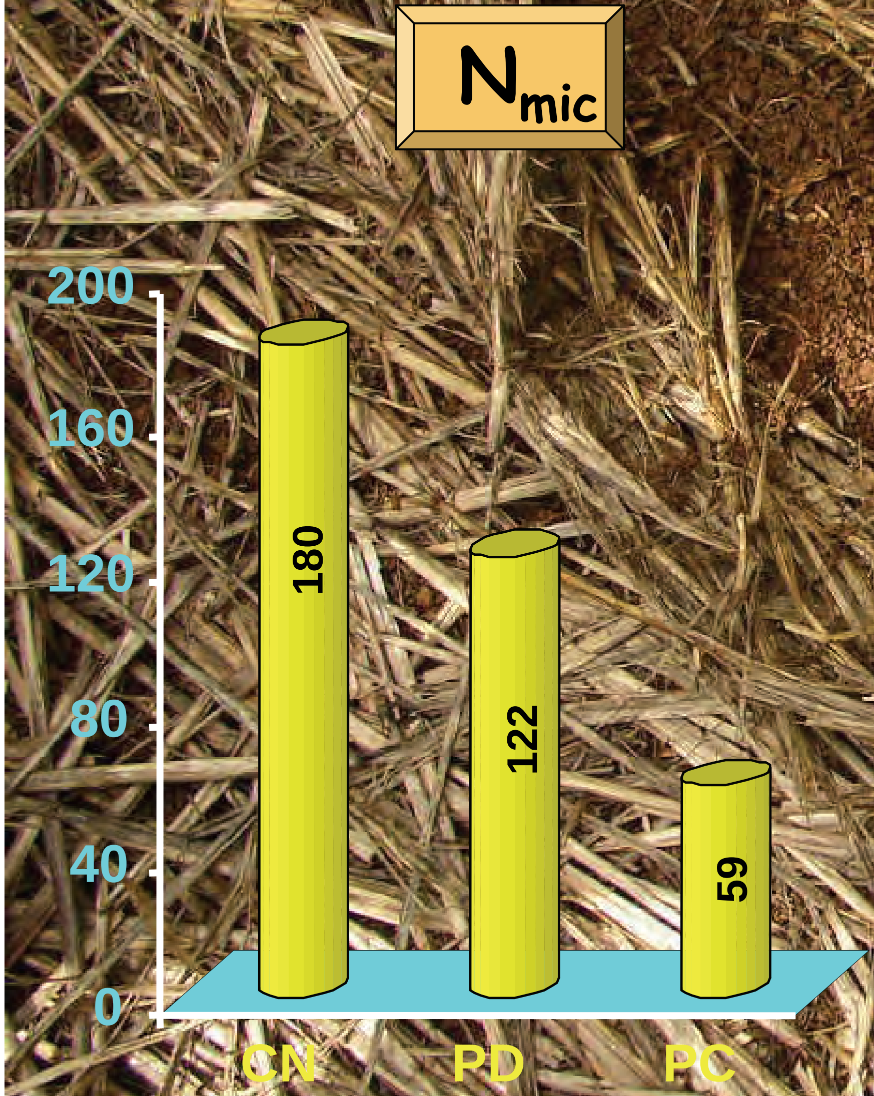
SOC x N_{mic}



SOC (Mg ha^{-1}) = 0,323N_{mic} + 3,06

r^2 = 0,68***

C_{mic} and N_{mic} (0-10 cm)



Source: Sá et al., 2001

MBN Half life

0,25 a 0,3 years

↓

At 3 to 4 months ± 60 /ha N are cycled and available to plants uptake

Total amount of N cycled in a 3 to 9 months period (LF + MBN) ≈ 210 kg ha^{-1}