

# Polymer Chemistry: Soil Treatment

The current and future use of Polyacrylamide (PAM) and other polymers  
in treating topsoil for water retention and erosion control

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CHEM-420 - Dr. Franklin Chen

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# Overview

- ▶ What is Topsoil?
  - ▶ How is it formed?
  - ▶ How is it lost?
- ▶ Current Erosion-control Techniques
  - ▶ Polyacrylamide (PAM) additive
  - ▶ The chemistry of hydrogels
- ▶ The Future of Polymer-based Soil Treatment
  - ▶ Modification of Naturally-occurring polymers (e.g. cellulose)
  - ▶ Other methods of modification

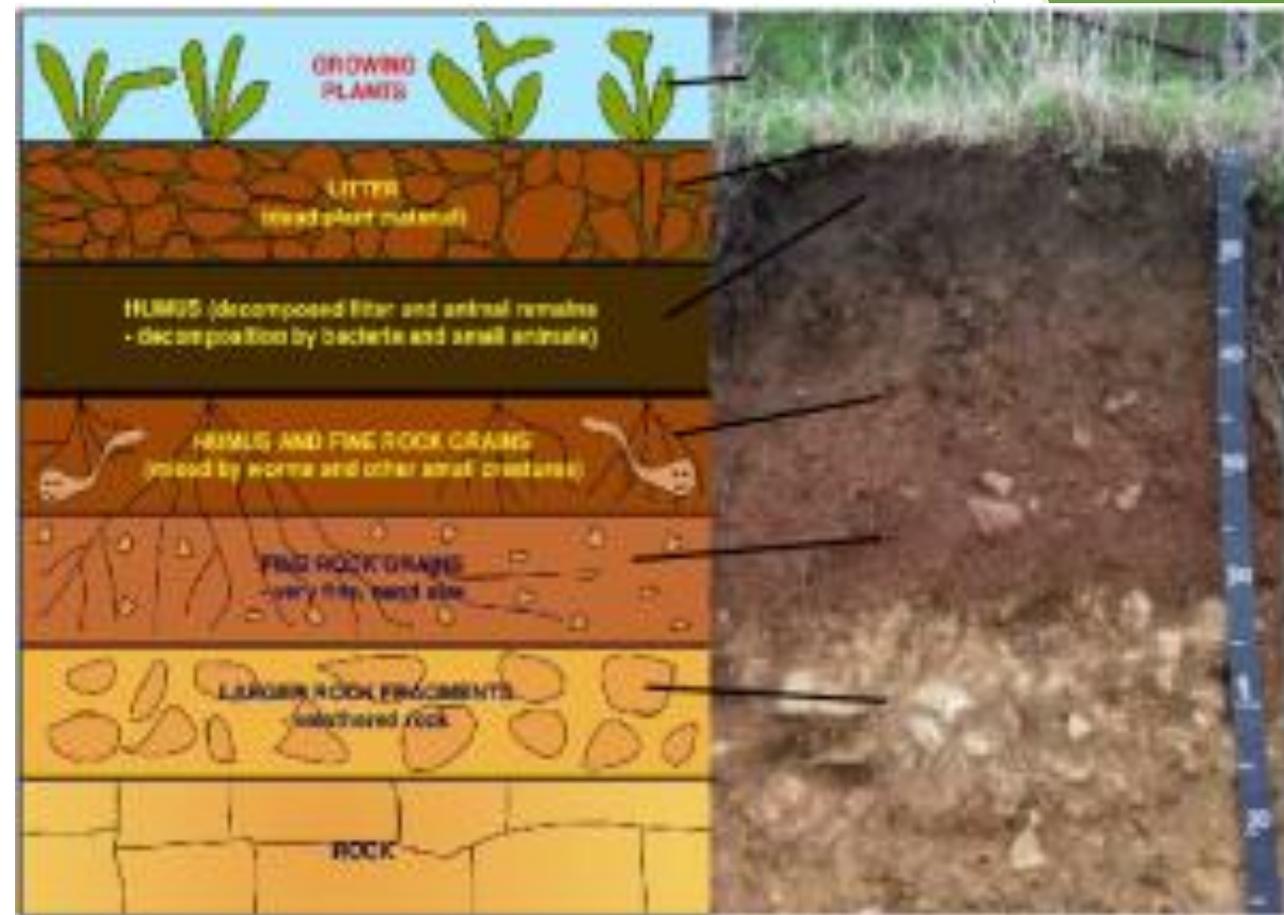
# What is topsoil?

- ▶ Topsoil is the upper layer of soil that contains most of the available plant nutrients and in which most of the biological activity takes place. The soil's organic matter is concentrated in the topsoil, making it noticeably darker than the subsoil. The topsoil is the primary home of the vast “soil food web”—the amazingly complex community of microorganisms, earthworms, insects, and small vertebrates that is the only proper home for the roots of crop plants.

# What makes up topsoil?

A soil profile is the side view of soil, from the uppermost layer to the bottom layer.

- ▶ The topmost layer of the soil is composed mainly of fresh soil and decaying organic matter. The color ranges from brown to black.
- ▶ The second layer of the soil consists of highly decomposing organic matter. The color ranges from brown to gray.
- ▶ The third layer of soil is composed of sand and silt. It has lost most of its nutrients. The color of this layer is light brown.
- ▶ The fourth layer consists of clay and large rocks and bedrock. The color ranges from rust to tan.
- ▶ The fifth layer of soil is bedrock. The color is gray.



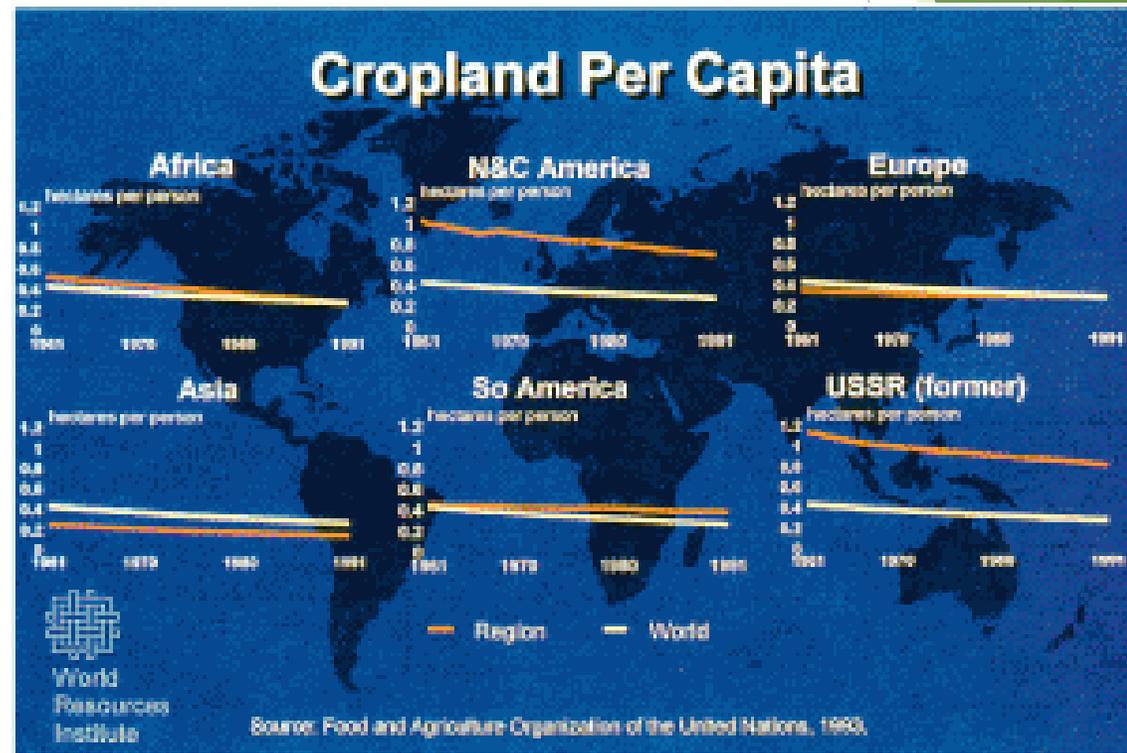
Erosion...

How Topsoil is lost to weathering



# Is soil really in danger of running out?

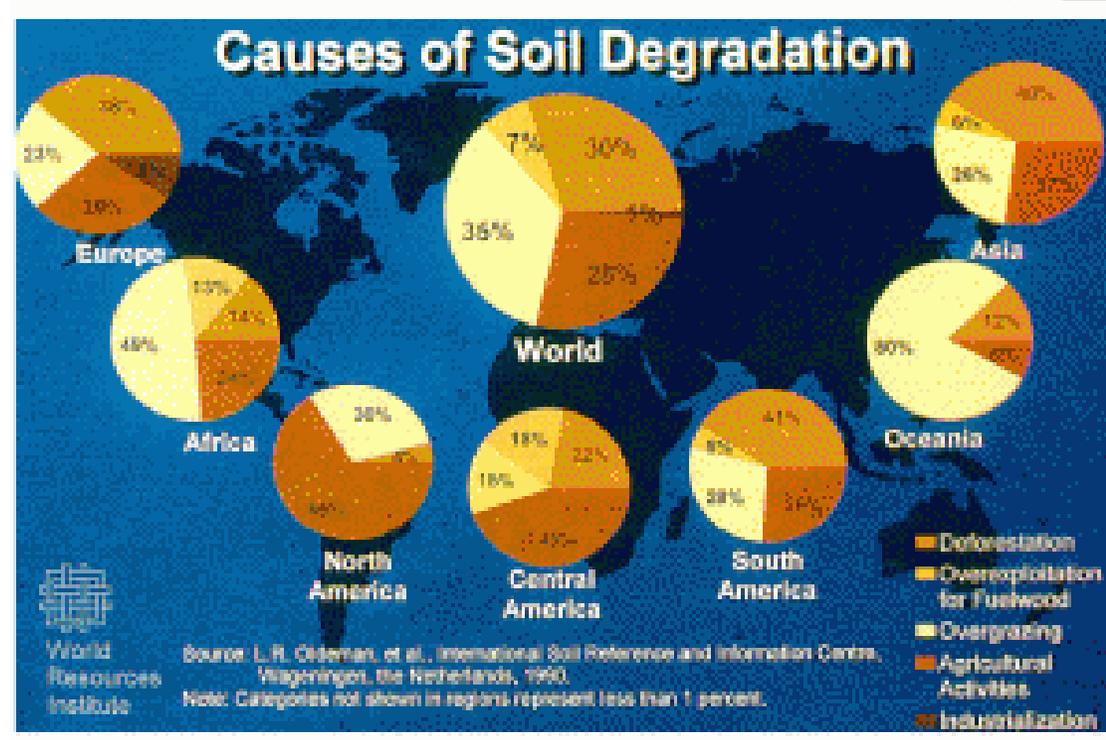
- ▶ About 60 years of topsoil left
- ▶ Some 40% of soil used for agriculture around the world is degraded or seriously degraded
- ▶ 70% of the topsoil, the layer allowing plants to grow, is gone



*Decline in worldwide the amount of cropland per capita*

# How does soil erosion happen?

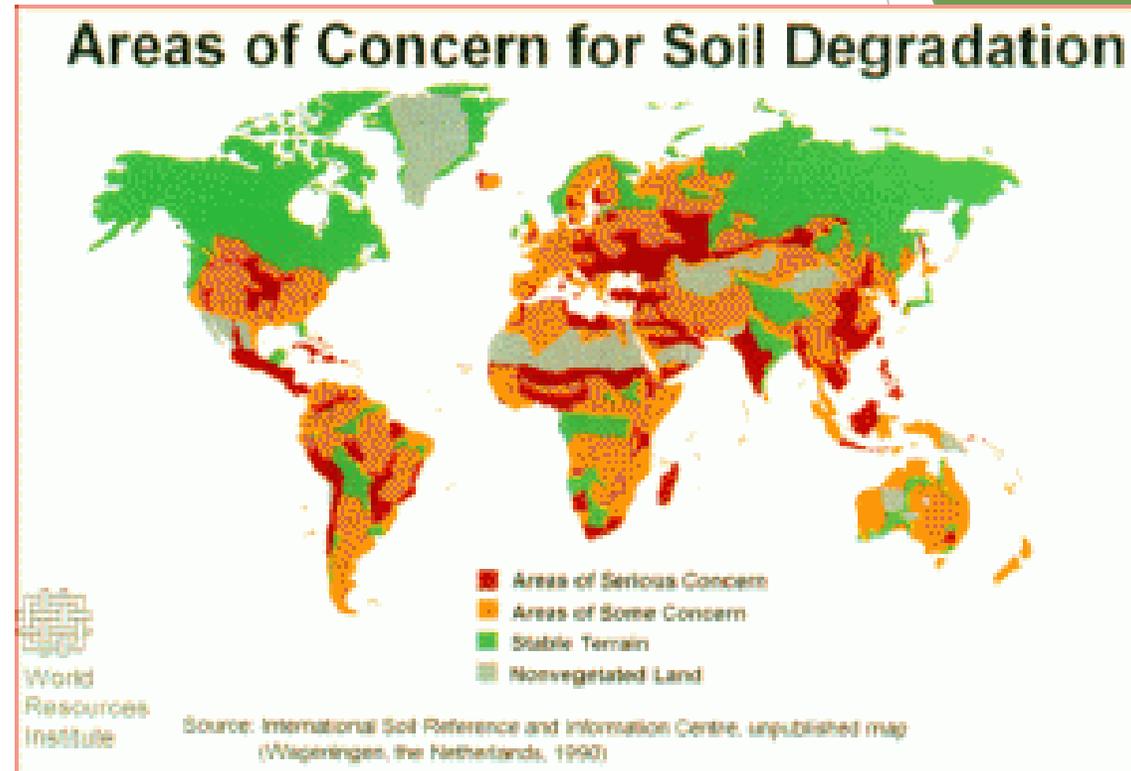
- ▶ Deforestation
- ▶ Overexploitation for fuel wood
- ▶ Overgrazing
- ▶ Agricultural activities and industrialization



*The above figure illustrates the relative sizes of the causal mechanisms as a function of region.*

# Who will be impacted the most?

- ▶ No continent is free from the problem. Areas of serious concern include zones where up to 75% of the topsoil has been lost already. The central portion of the United States is an area of particular local concern. Soil erosion is most serious in China, India and parts of South America. If the food supply goes down, then obviously, the price goes up. The crisis point will hit the poorest countries hardest, in particular those who rely on imports. The capacity of the planet to produce food is already causing conflict.



*Of the world's 1.2 billion hectares with moderate to severe soil degradation, the largest areas are in Asia and Africa. Central America has the highest percentage and worst degrees of soil degradation*

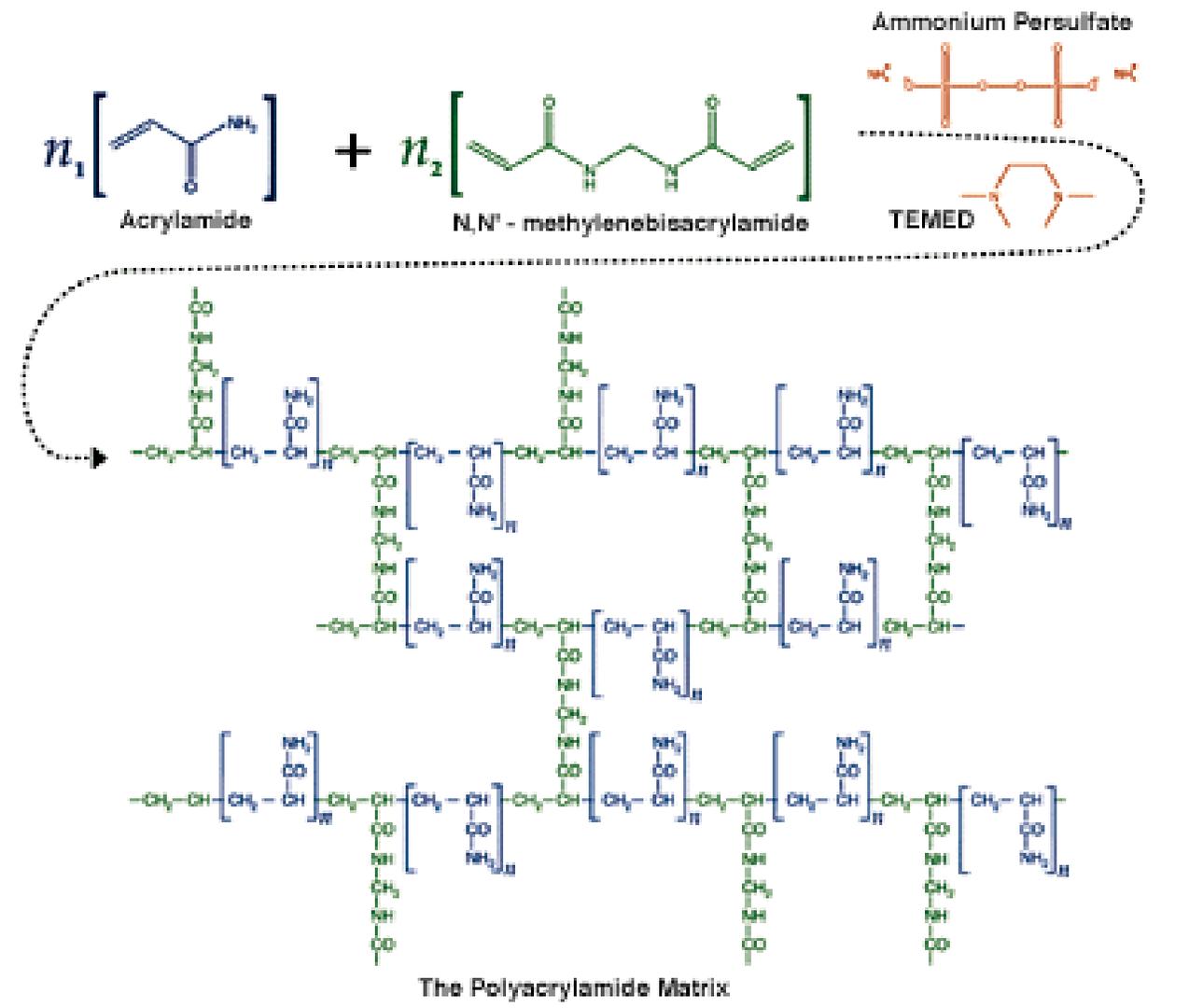
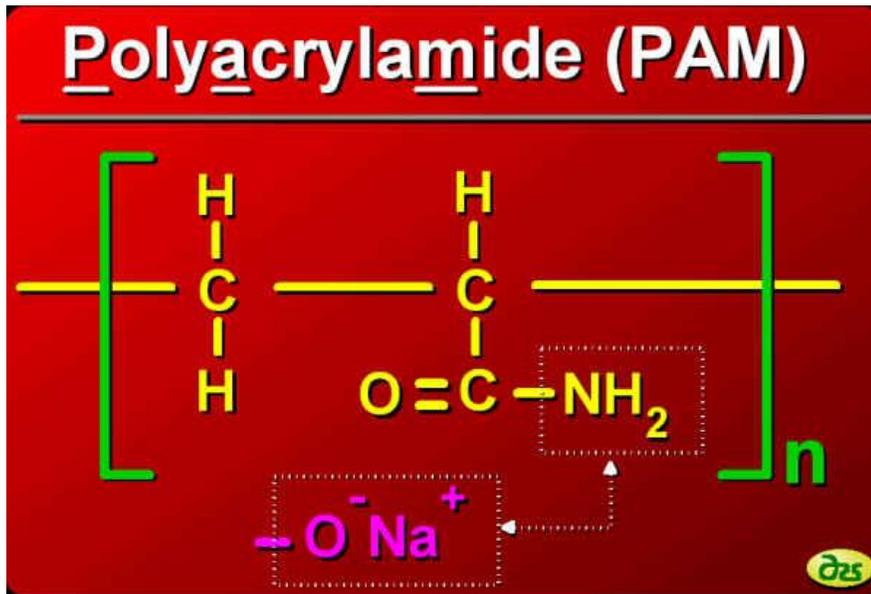
# Erosion Control Polyacrylamide (PAM)



- ▶ Used as a water retention aid
- ▶ Also shown to help prevent soil erosion
- ▶ Agricultural and domestic applications
- ▶ Can be produced and sold in various chain lengths to suit different applications
- ▶ Does not break down in the environment

# Polyacrylamide and Water Retention

The acrylamide chain segments are replaced by acrylic acid groups that are capable of forming hydrogen bonds with water thus allowing polyacrylamide to retain water at a level greater than it's own molecular weight.



# Environmental Pros and Cons

## Cons

- ▶ Polyacrylamide is made from non-renewable fossil fuels.
- ▶ Polyacrylamide itself is not hazardous but it often contains traces of its starting material, acrylamide, which is a known neurotoxin.
- ▶ Polyacrylamide does not readily biodegrade.

## Pros

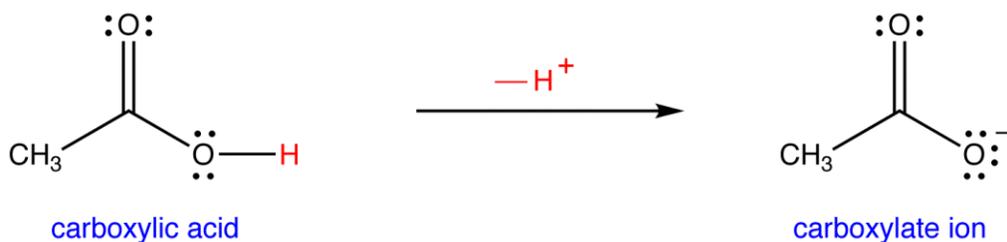
- ▶ Important in conserving water resources. From the USDA website, agriculture accounts for 80-90% of the country's water usage.
- ▶ The gel like consistency of polyacrylamide helps to prevent soil erosion.



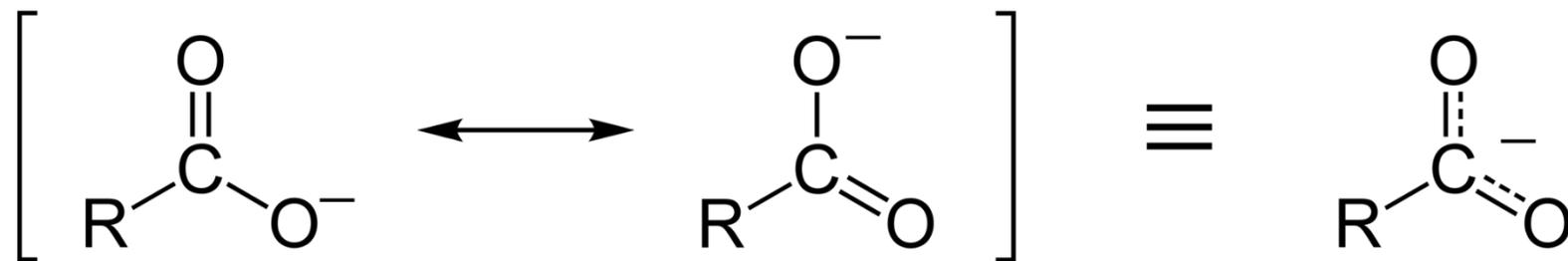
# Background on Resonance

## Carboxylate / Sulfonate Anions

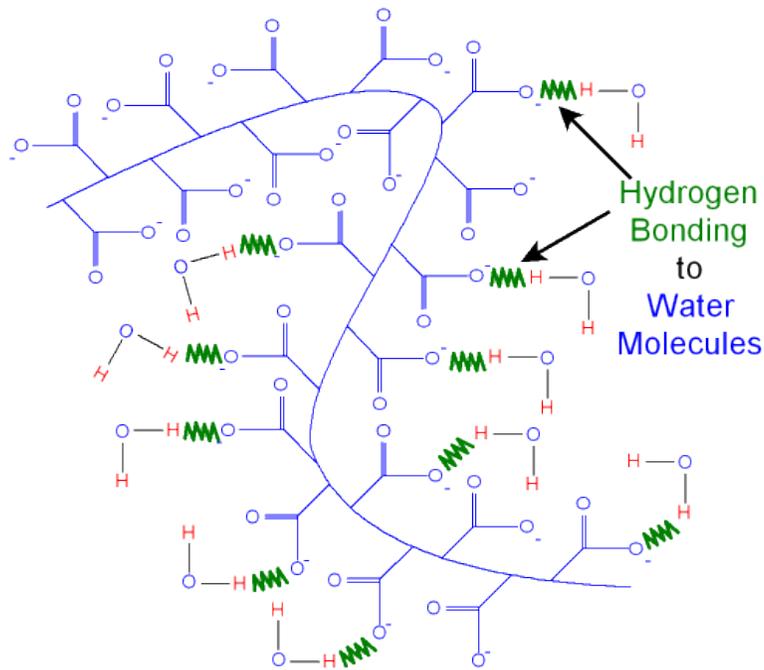
Recall from Organic Chemistry that when the carboxylic acid is neutralized, a negatively-charged Carboxylate Ion results:



The double-bond between the chain carbon becomes shared with both oxygens in a resonance-stabilized anion:

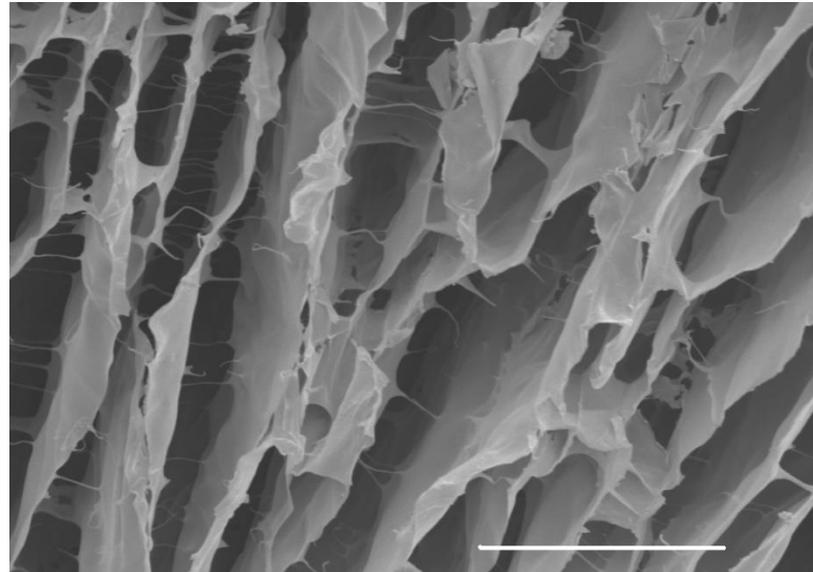


# Anionic Groups and Hydrogen Bonding Hydrogel Chemistry



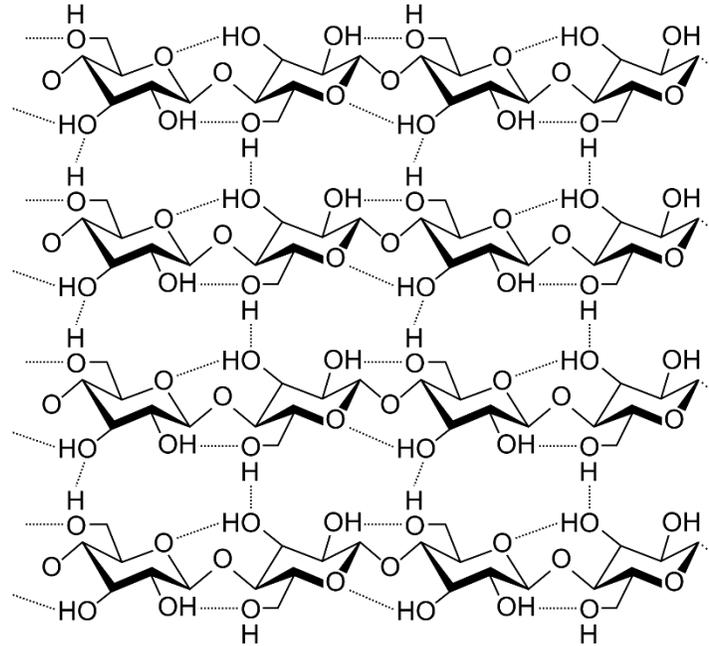
Anionic (above, Carboxylate) groups allow hydrogen-bonding within network

Chemically cross-linked networks allow hydrogen bonding to absorb water into scaffold:



# Modifying Cellulose

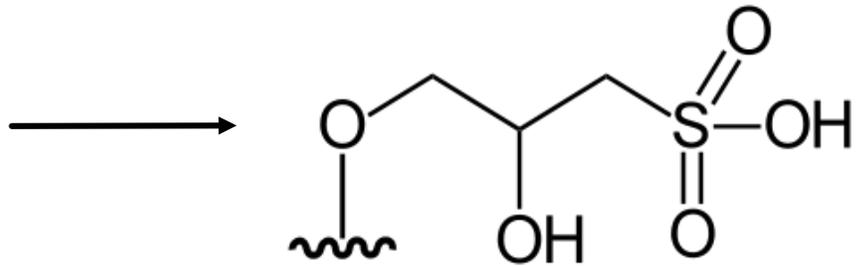
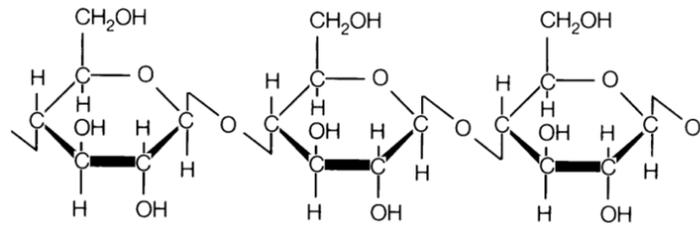
Dr. Chen's grant proposal seeks to use already existing cellulose (wood fiber) waste from paper mills:



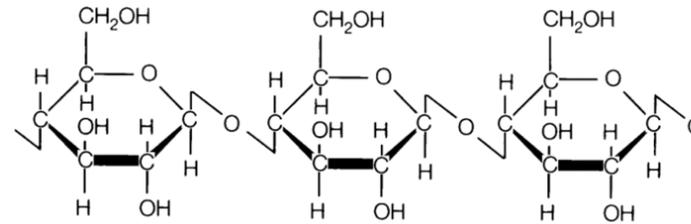
The network polymer structure of this plant matter is plentiful in this region. Chemically, it already has the OH leaving groups necessary for simple modification into a substance with hydrogel-like properties.

# Methods of Modification

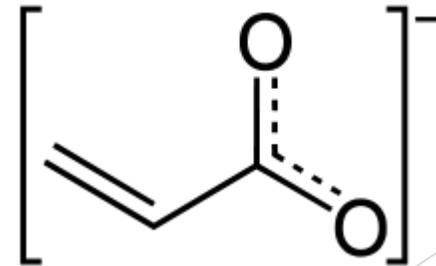
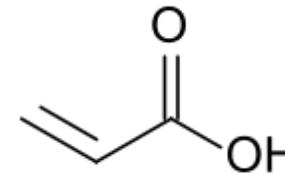
## ► Sulfonation



## ► Graft with Acrylic Acid



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# The Future: Other Possible Methods of Modification

## Enzyme-catalyzed carboxylation:

- ▶ Several known biochemical mechanisms achieve carboxylate anion end-products. Could these be mimicked to meet our needs?
  - ▶ Biochemical reaction of Rubisco (ribulose biphosphate) is carbon-fixing
  - ▶ Vitamin K-dependent Carboxylase mechanism

## Other naturally-produced polymers:

- ▶ Recall that Polymer Chemistry got it's start by chemists coming up with ways to modify already known natural linen polymer!
- ▶ Other than cellulose, there are many other known natural polymers:
  - ▶ Polysaccharides
  - ▶ Protiens and polynucleotides

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