# Rainwater harvesting and greywater recovery
## - Part 3-

**Prof. Patrice CANNAVO**

AGROCAMPUS OUEST / Agreenium, France

Department of Physical Environment, Landscape Architecture
Environmental Physics and Horticulture research Laboratory

***Module 2: Resource use from a challenge perspective***

*Urban Agriculture for resource efficiency and waste management*

# Course outline

**1. Urban water hydrology**
- 1.1 Specificities of the urban context
- 1.2 Impacts of the vegetation on water regulation
- 1.3 Soil properties (reminder)

**2. Green roof potential for water runoff control**
- 2.1 Roles and constitution
- 2.2 Performance

**3. Greywater**
- 3.1 Origin, collection, treatment
- 3.2 Greywater reuse for irrigation

**4. Stormwater basin for road water runoff**
- 4.1 Operation
- 4.2 Infiltration performance and clogging process

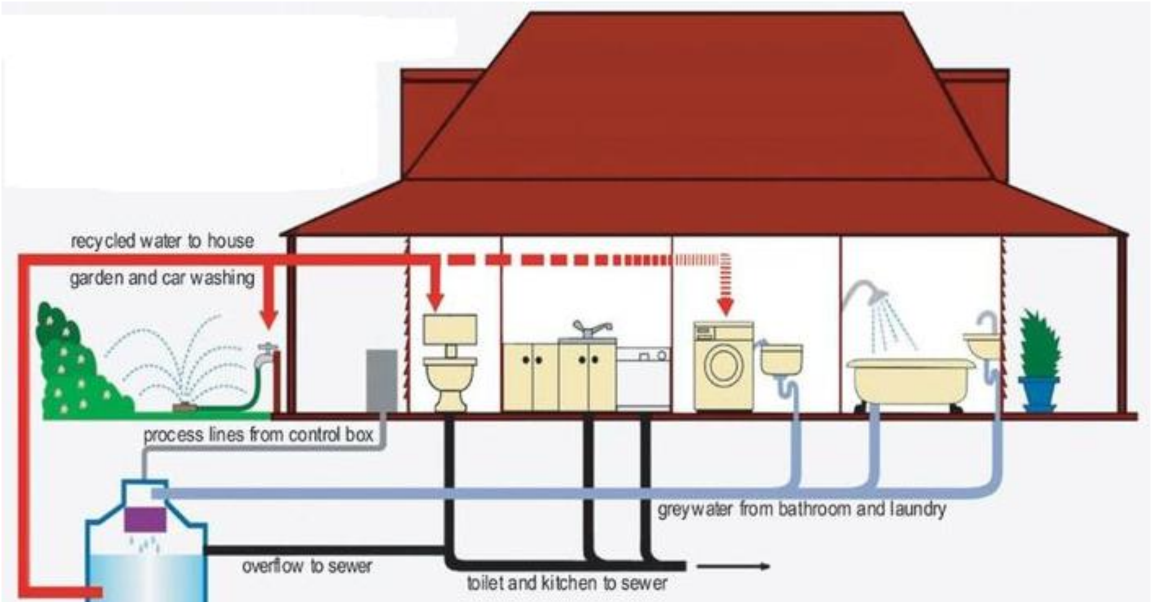
# Course outline

## What is greywater ?

Greywater is all wastewater generated in households or office buildings from streams **without fecal contamination**, i.e. all streams except for the wastewater from toilets.

Sources of greywater include :
Sinks,
Showers,
Baths,
Clothes washing machines,
Dish washers.

*Environment Canada*


*www.pinterest.com/lelemia808/greywater-treatment/*

Toilets or fecally contaminated wastewater of any kind, is designated sewage or blackwater to indicate it contains human waste.
However, under certain conditions traces of feces, and therefore pathogens, might enter the greywater stream via effluent from the shower or washing machine.

## Recommendations & Benefits

Greywater contains fewer pathogens than domestic wastewater:
⇒ Generally safer to handle and easier to treat and reuse onsite for:

toilet flushing,
landscape or crop irrigation,
other non-potable uses.

<u>However</u>, the use of non-toxic and low-sodium soap and personal care products is recommended to protect vegetation when reusing greywater for irrigation purposes

The application of greywater reuse in urban water systems provides <u>substantial benefits</u> for:

- the water supply subsystem by reducing the demand for fresh clean water
- the wastewater subsystems by reducing the amount of wastewater required to be conveyed and treated

## Greywater characteristics

Main vigilance parameters

BOD5 : Biochemical Oxygen Demande over 5 days. An excessive BOD5 can generate serious problems of color and smell;

COD : Chemical Oxygen Demand;

TSS : Total Suspension Solids. Organic pollutant and heavy metals can be absorbed by particles, being protected against desinfectants et creating smell problems;

Turbidity : an excessive turbidity (cloudy liquid) can generate smell and be detrimental to desinfection.

Threshold limits and greywater reuse posibilities are country policies dependent !

## Greywater characteristics

Greywater composition mainly depends on:
Geographic origin, building category, occupants activity

Significant variation in time and space, depending on water consumption and rejected substances quantities

In a same place:

> Normal variations: use evolution depending on the occupation (eg: high activity in the morning and in the night for personal hygiene, variations between weeks and week end or holiday periods)

> Accidental variations: ponctual, relative to an exceptional event (eg: hair dye presence, household maintenance or do-it-yourself chemical products, chlorine desinfectant excess)

## Greywater characteristics

*Eriksson et al., 2002*

| | | Shower/bath | Bathroom | Shower/bath | Washbasin | Bath | Washbasin | Shower |
|---|---|---|---|---|---|---|---|---|
| | | Siegrist, Witt and Boyle (1976) | Christova-Boal *et al.* (1996) | Surendran and Wheatley (1998) | Surendran and Wheatley (1998) | Almeida, Butler and Friedler (1999) | Almeida, Butler and Friedler (1999) | Almeida, Butler and Friedler (1999) |
| Temperature | °C | 29 | | | | | | |
| Color | Pt/Co | | 60 - 100 | | | | | |
| Turbidity | NTU | | 60 - 240 | 92 | 102 | | | |
| Suspended matter | $mg.L^{-1}$ | 120 | 48 - 120 | 76 | 40 | 54 | 181 | 200 |
| pH | | | 6,4 - 8,1 | 7,6 | 8,1 | | | |
| BOD5 | $mgO_2.L^{-1}$ | 170 | 76 - 200 | | | | | |
| Total COD | $mgO_2.L^{-1}$ | | | | | 210 | 298 | 501 |
| Soluble COD | $mgO_2.L^{-1}$ | | | | | 184 | 221 | 221 |
| Total-N | $mgN.L^{-1}$ | 17 | | | | | | |
| NTK | $mg.L^{-1}$ | | 4,6 - 20 | | | | | |
| NH4-N | $mgN.L^{-1}$ | 2 | < 0,1 - 15 | 1,56 | 0,53 | 1,1 | 0,3 | 1,2 |
| NO3-N | $mgN.L^{-1}$ | 0,4 | | 0,9 | 0,34 | 4,2 | 6 | 6,3 |
| Total-P | $mgP.L^{-1}$ | 2 | 0,11 - 1,8 | | | | | |
| PO4-P | $mgP.L^{-1}$ | 1 | | 1,63 | 45,5 | 5,3 | 13,3 | 19,2 |
| Total | | | | | | | | |
| Total coliforms | $UFC.100mL^{-1}$ | 70 - 8200 | $500 - 2,4.10^7$ | $6.10^6$ | $5.10^4$ | | | |
| Faecal coliforms | $UFC.100mL^{-1}$ | 1 - 2500 | $170 - 3,3.10^3$ | 600 | 32 | | | |
| Faecal streptoccus | $UFC.100mL^{-1}$ | 1 - 70000 | $79 - 2,4.10^3$ | | | | | |

=> High content heterogeneity depending on the bibliographic source and the greywater source

## Treatment

Most greywater is easier to treat and recycle than blackwater (sewage), because of lower levels of contaminants.

If collected using a separate plumbing system from blackwater, domestic greywater can be recycled directly within the home, garden or company and used either immediately or processed and stored.

If stored, it must be used within a very short time or it will begin to putrefy due to the organic solids in the water.

Recycled greywater of this kind is never safe to drink, but a number of treatment steps can be used to provide water for washing or flushing toilets.

*Example of a source of greywater in the household: dirty water from cleaning the floor (Wikipedia)*

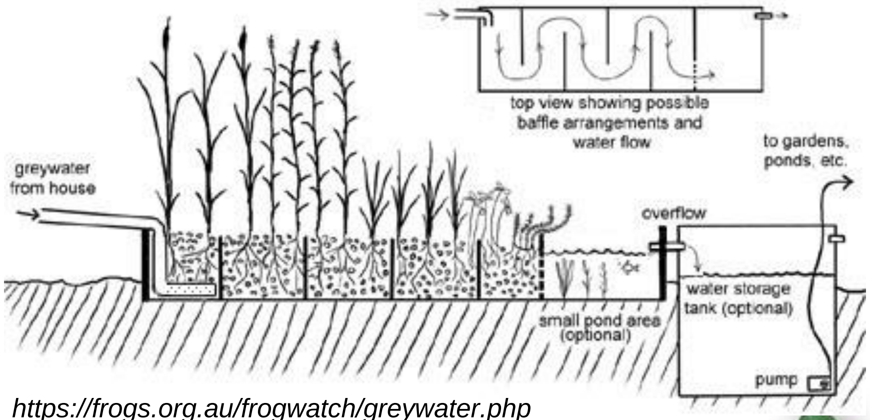
## Treatment

The treatment processes that can be used are in principle the same as those used for sewage treatment:

**Biological systems** are a variation of the activated sludge process and is also used to treat sewage:

=> constructed wetlands

*http://www.wecf.eu/english/water-sanitation/practice/wetlands-filters.php*




*https://frogs.org.au/frogwatch/greywater.php*

Plants use contaminants of greywater, such as food particles, as nutrients in their growth. However, salt and soap residues can be toxic to microbial and plant life alike but can be absorbed and degraded through constructed wetlands and aquatic plants such as sedges, rushes, and grasses

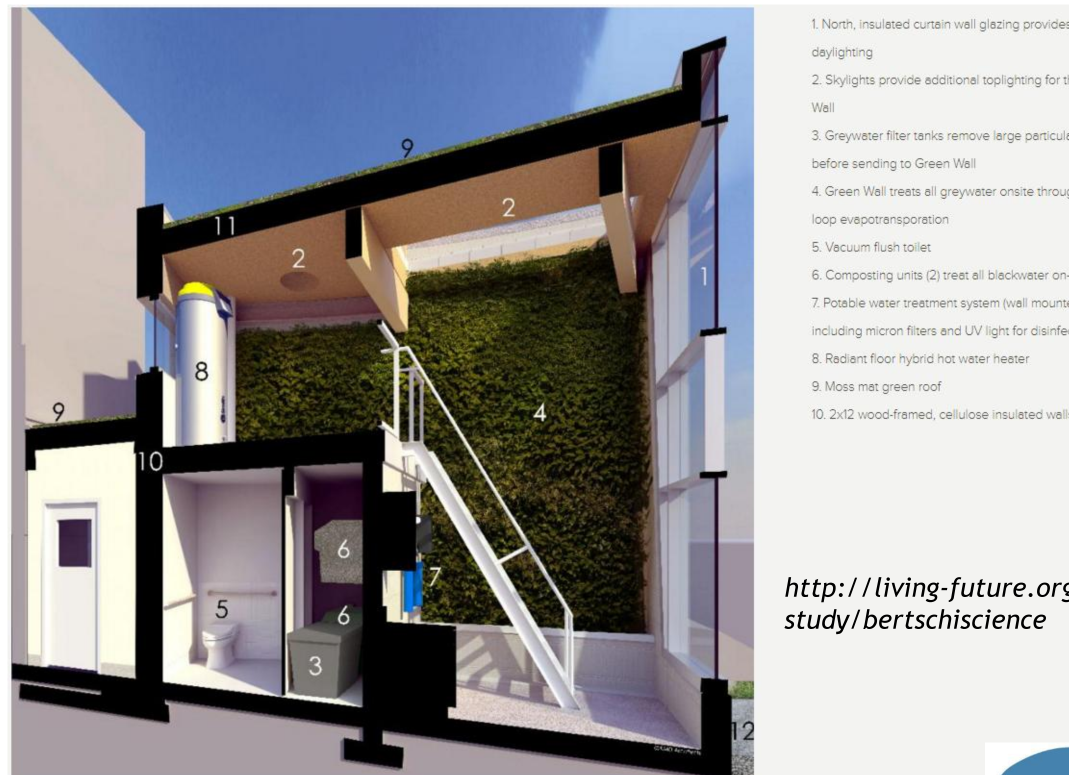
## Treatment

The treatment processes that can be used are in principle the same as those used for sewage treatment:

**Biological systems** are a variation of the activated sludge process and is also used to treat sewage:

=> living walls

*http://www.privateislandsblog.com/*
*ey-water-treatment/*



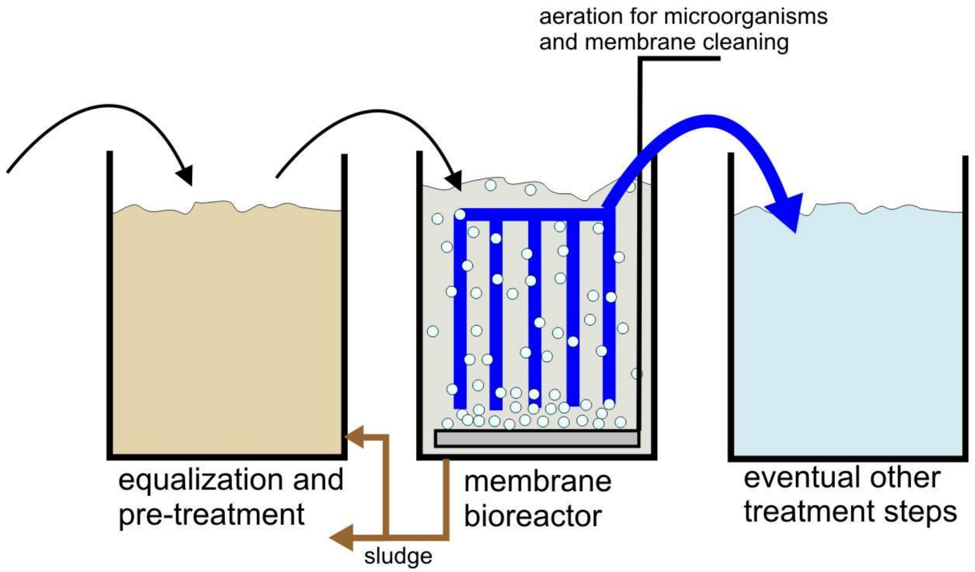

*http://living-future.org/case-study/bertschiscience*

## Treatment

The treatment processes that can be used are in principle the same as those used for sewage treatment:

**Biological systems** are a variation of the activated sludge process and is also used to treat sewage:

=> bioreactors or more compact systems such as membrane bioreactors



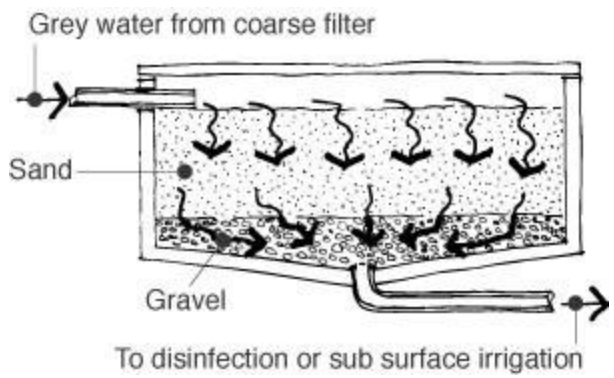

*http://www.colloid.ch/index.php?name=membranes*

## Treatment

The treatment processes that can be used are in principle the same as those used for sewage treatment:

**Mechanical systems :**

=> sand filtration / lava filter systems




*http://www.reuk.co.uk/Sand-Filters-for-Greywater.htm*

For greywater to be stored for more than a day it must be disinfected – typically with chlorine or iodine to kill any pathogens which remain in it

## Regulations about treated greywater reuse

World Health Organisation: main recommendations made in 1989, revised in 2006. Recommendations related to treated greywater reuse for agriculture, based on health risks

USA and Australia published in 2004 and 2006 (resp.) national recommendations.

In Europe, there are no regulations.
=> Directive 91/271/EC – art.12: «  greywater are reused when it is suitable »
=> Some european countries defined their own regulations, more or less restrictives

## Regulations: case of France

The National Health Agency (ANSES) estimates that greywater reuse is possible for strictly limited uses exclusively in areas submited to repeated water shortage.

If greywater treatment is operated and is appropriate, its reuse is posible for:
- toilet flush supply
- green spaces irrigation
- outside surfaces cleaning without aerosol generation (no spray use)

## Regulations: case of France for cropping systems

4 quality levels of greywater
(A, B, C and D)

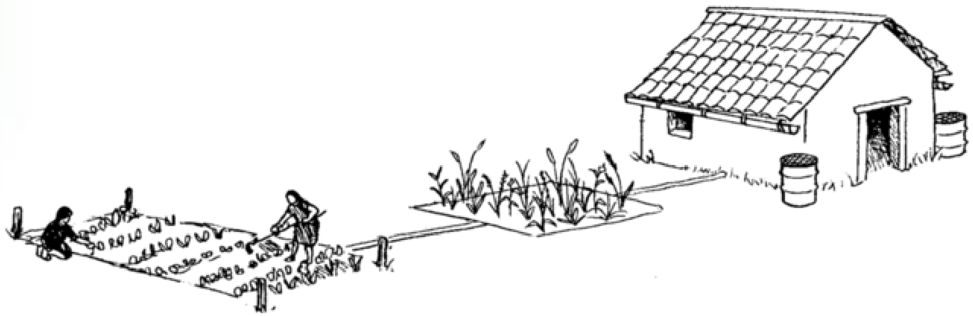
| PARAMETER | SANITARY QUALITY LEVEL OF TREATED GREYWATER | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Suspended matter (mg/L) | < 15 | Consistent with treated blackwater rejection | | |
| Chemical Oxygen Demand (mg/L) | < 60 | | | |
| Escherichia coli (UFC/100 mL) | ≤ 250 | ≤ 10 000 | ≤ 100 000 | - |
| Fecal enterococcus (log unit) | ≥ 4 | ≥ 3 | ≥ 2 | ≥ 2 |
| F-ARN specific phages (log unit) | ≥ 4 | ≥ 3 | ≥ 2 | ≥ 2 |
| Sulfate reduction anaerobic bacteria spores (log unit) | ≥ 4 | ≥ 3 | ≥ 2 | ≥ 2 |

*2010, August 2nd Decree for treated graywater reuse for crop and urban green space area irrigation*

| USE | SANITARY QUALITY LEVEL OF TREATED GREYWATER | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Gardening, fruit and vegetable crops not transformed by an adequate industrial thermic treatment | + | - | - | - |
| Gardening, fruit and vegetable crops transformed by an adequate industrial thermic treatment | + | + | - | - |
| Pasture | + | + (3) | - | - |
| Public urban green spaces | + (5) | - | - | - |
| Sold cutted flowers | + | + (6) | - | - |
| Nursery and bushes and other flower crops | + | + | + (6) | - |
| Fresh fodder | + | + (3) | - | - |
| Other cereal and feed crops | + | + | + (6) | - |
| Fruit arboriculture | + | + (7) | + (8) | - |
| Short thicket rotation with controled public access | + | + | + (6) | + (6) |
| Wood, short thicket rotation excluded, with controled public access | - | - | - | - |

+ : permited, - : prohibited

## Advantages / inconvenients of greywater reuse for irrigation



*http://en.hesperian.org/hhg/A_Community_Guide_to_Environmental_Health:Waste water:_A_Problem_or_a_Resource%3F*

Main advantages
- Preservation of the water ressource
- Supply in nutrients:
  organic matter, phosphorus, nitrogen, major ions…

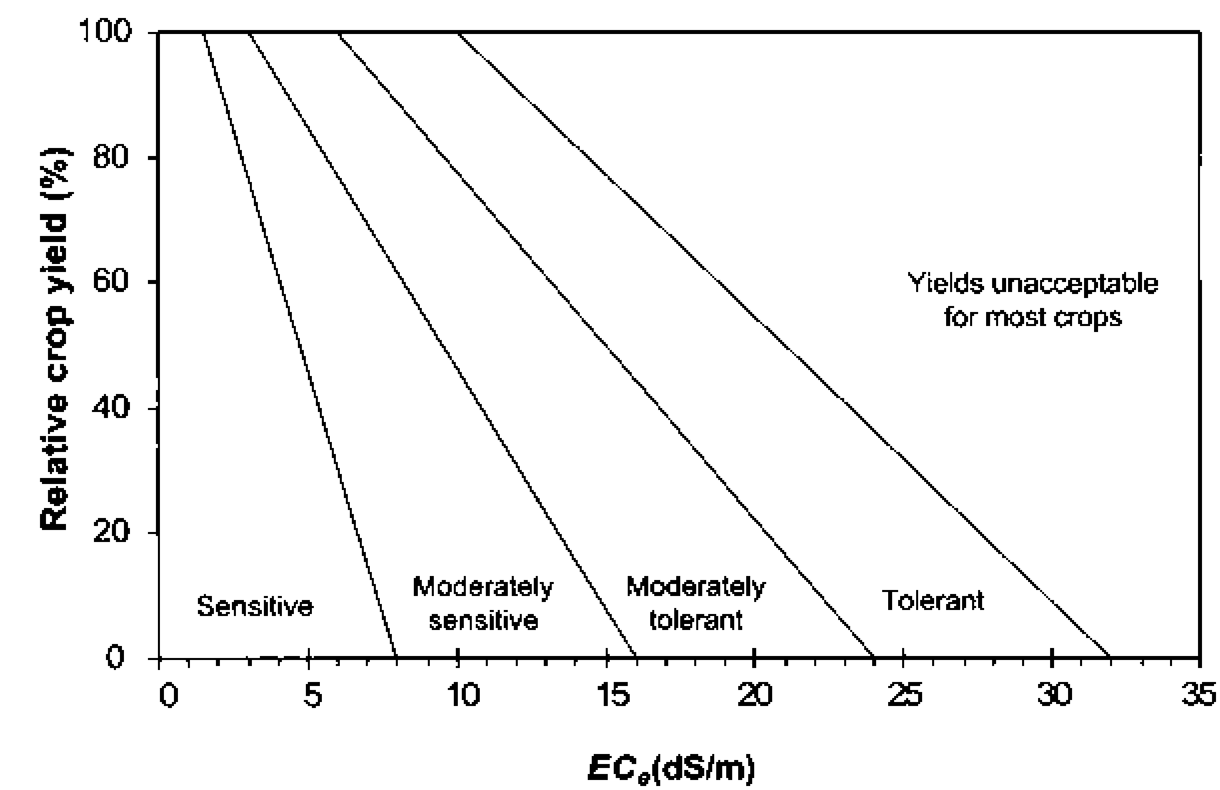
Main inconvenients
- High salts content : soil salinization risk and plant tolerance
- Accumulation of metals
- Presence of pathogens and antibiotics…

100 mm of greywater spread over 1 ha can provide :

· 16 to 62 kg nitrogen,
· 2 to 69 kg potassium,
· 4 to 24 kg phosphorus,
· 18 to 208 kg calcium,
· 9 to 100 kg magnésium,
· 27 to 182 kg sodium.
*(Faby et Brissaud,1997)*

## Plant tolerance to salinity

EC = electric conductivity (ie salinity)




*http://www.fao.org/docrep/005/y4263e/y4263e0e.htm*

## Salt tolerance of crops

**Woody crops** (EC = electric conductivity (ie salinity), Rating: S = sensitive, MS = moderately sensitive, MT = moderately tolerant, T = tolerant)

| Crop | | | Salt Tolerance Parameters | | | |
|---|---|---|---|---|---|---|
| Common name | Botanical name‡ | Tolerance based on | Threshold§ ($EC_e$) dS/m | Slope % per dS/m | Rating¶ | References |
| Almond | *Prunus duclis* (Mill.) D.A. Webb | Shoot growth | 1.5 | 19 | S | Bernstein *et al*., 1956; Brown *et al*., 1953 |
| Apple | *Malus sylvestris* Mill. | | - | - | S | Ivanov, 1970 |
| Apricot | *Prunus armeniaca* L. | Shoot growth | 1.6 | 24 | S | Bernstein *et al*., 1956 |
| Avocado | *Persea americana* Mill. | Shoot growth | - | - | S | Ayars, 1950a; Haas, 1950 |
| Banana | *Musa acuminata* Colla | Fruit yield | - | - | S | Israeli *et al*., 1986 |
| Blackberry | *Rubus macropetalus* Doug. ex Hook | Fruit yield | 1.5 | 22 | S | Ehlig, 1964 |
| Boysenberry | *Rubus ursinus* Cham. and Schlechtend | Fruit yield | 1.5 | 22 | S | Ehlig, 1964 |
| Castor seed | *Ricinus communis* L. | | - | - | MS* | USSL Staff, 1954 |
| Cherimoya | *Annona cherimola* Mill. | Foliar injury | - | - | S | Cooper, Cowley & Shull, 1952 |
| Cherry, sweet | *Prunus avium* L. | Foliar injury | - | - | S* | Beeftink, 1955 |
| Cherry, sand | *Prunus besseyi* L., H. Baley | Foliar injury, stem growth | - | - | S* | Zhemchuzhnikov, 1946 |
| Coconut | *Cocos nucifera* L. | | - | - | MT* | Kulkarni *et al*., 1973 |

### Herbaceous crops

| Crop | | | Salt Tolerance Parameters | | | |
|---|---|---|---|---|---|---|
| Common name | Botanical name‡ | Tolerance based on | Threshold§ ($EC_e$) dS/m | Slope % per dS/m | Rating¶ | References |
| **Fibre, grain and special crops** | | | | | | |
| Artichoke, Jerusalem | *Helianthus tuberosus* L. | Tuber yield | 0.4 | 9.6 | MS | Newton *et al*., 1991 |
| Barley# | *Hordeum vulgare* L. | Grain yield | 8.0 | 5.0 | T | Ayars *et al*., 1952; Hassan *et al*., 1970a |
| Canola or rapeseed | *Brassica campestris* L. [syn. *B. rapa* L.] | Seed yield | 9.7 | 14 | T | Francois, 1994a |
| Canola or rapeseed | *B. napus* L. | Seed yield | 11.0 | 13 | T | Francois, 1994a |
| Chickpea | *Cicer arietinum* L. | Seed yield | - | - | MS | Manchanda & Sharma, 1989; Ram *et al*., 1989 |
| Corn‡‡ | *Zea mays* L. | Ear FW | 1.7 | 12 | MS | Bernstein & Ayars, 1949b; Kaddah & Ghowail, 1964 |
| Cotton | *Gossypium hirsutum* L. | Seed cotton yield | 7.7 | 5.2 | T | Bernstein, 1955, 1956; Bernstein & Ford, 1959a |

### Vegetable and fruit crops

| | | | | | | |
|---|---|---|---|---|---|---|
| Artichoke | *Cynara scolymus* L. | Bud yield | 6.1 | 11.5 | MT | Francois, 1995 |
| Asparagus | *Asparagus officinalis* L. | Spear yield | 4.1 | 2.0 | T | Francois, 1987 |
| Bean, common | *Phaseolus vulgaris* L. | Seed yield | 1.0 | 19 | S | Bernstein & Ayars, 1951; Hoffman & Rawlins, 1970; Magistad *et al*., 1943; Nieman & Bernstein, 1959; Osawa, 1965 |
| Bean, lima | *P. lunatus* L. | Seed yield | - | - | MT* | Mahmoud *et al*., 1988 |
| Bean, mung | *Vigna radiata* (L.) R. Wilcz. | Seed yield | 1.8 | 20.7 | S | Minhas *et al*., 1990 |
| Cassava | *Manihot esculenta* Crantz | Tuber yield | - | - | MS | Anonymous, 1976; Hawker & Smith, 1982 |
| Beet, red## | *Beta vulgaris* L. | Storage root | 4.0 | 9.0 | MT | Bernstein *et al*., 1974; Hoffman & Rawlins, 1971; Magistad *et al*., 1943 |
| Broccoli | *Brassica oleracea* L. (Botrytis Group) | Shoot FW | 2.8 | 9.2 | MS | Bernstein & Ayars, 1949a; Bernstein *et al*., 1974 |
| Brussels sprouts | *B. oleracea* L. (Gemmifera | | - | - | MS* | |

http://www.fao.org/docrep/005/y4263e/y4263e0e.htm

## Soil salinization risk

Water irrigation can contain high salt contents, leading to soil and soil water salinity.

<u>Consequences</u>:

For plants:

Osmotic effects: turgescence modification, osmolyte biosinthesis
Ion effects: toxicity, mineral and water uptake perturbations
Plant physiology: leaf necrosis, chlorophyll production inhibited

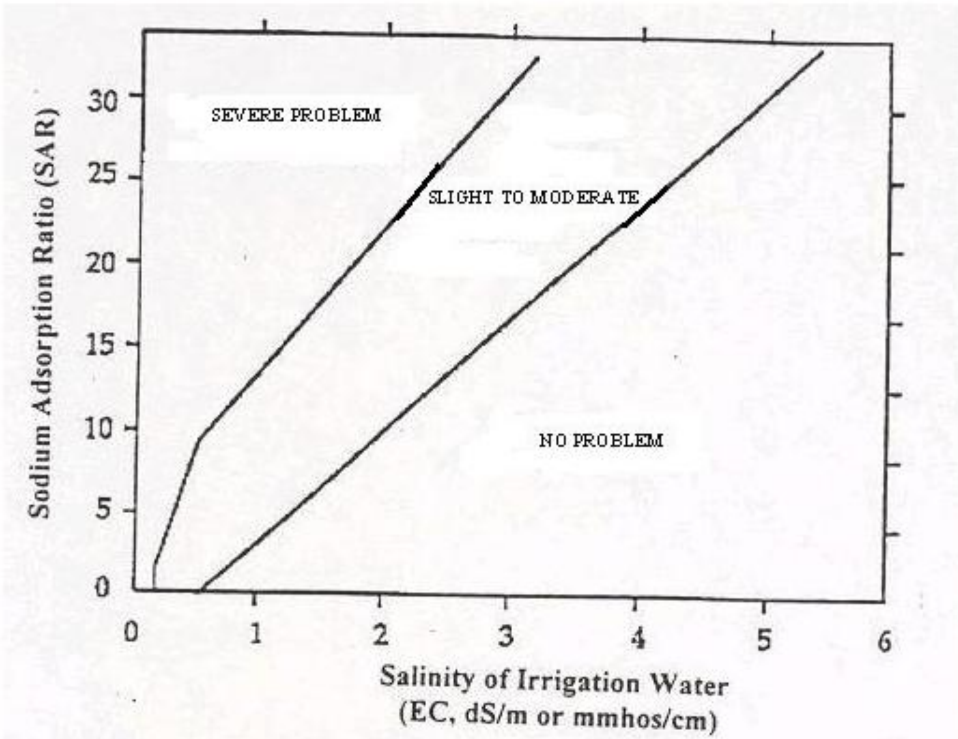
$\Rightarrow$ Sodium Adsorption Ratio (SAR)

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{1}{2}\left([Ca^{2+}]+[Mg^{2+}]\right)}}$$

concentrations in cmol+/l

Recommendation of SAR < 20 for water irrigation, without salinity risk

## Soil salinization risk: relations between SAR and EC

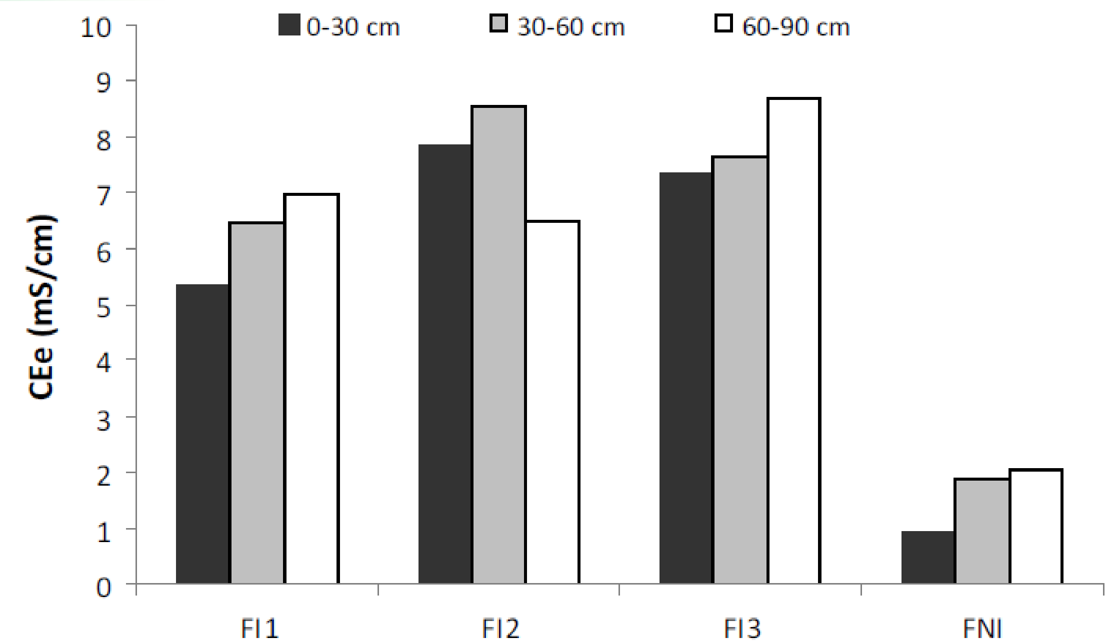



Potential for reduction in infiltration rates resulting from various combinations of EC and SAR of applied water
(After Hanson et al., 1999)

| | EC dS/m | EC dS/m | EC dS/m |
|---|---|---|---|
| SAR | No Problem | Slight to Moderate | Severe Problem |
| 0 to 3 | > 0.9 | 0.9 to 0.2 | < 0.2 |
| 3 to 6 | > 1.3 | 1.3 to 0.25 | < 0.25 |
| 6 to 12 | > 2.0 | 2.0 to 0.35 | < 0.35 |
| 12 to 20 | > 3.1 | 3.1 to 0.9 | < 0.9 |
| 20+ | > 5.6 | 5.6 to 1.8 | < 1.8 |

Guidelines for saline-sodic water quality suitable for irrigation (After Ayers and Tanji, 1981)

## Impact of greywater reuse on soil properties




*Belaid, 2010*

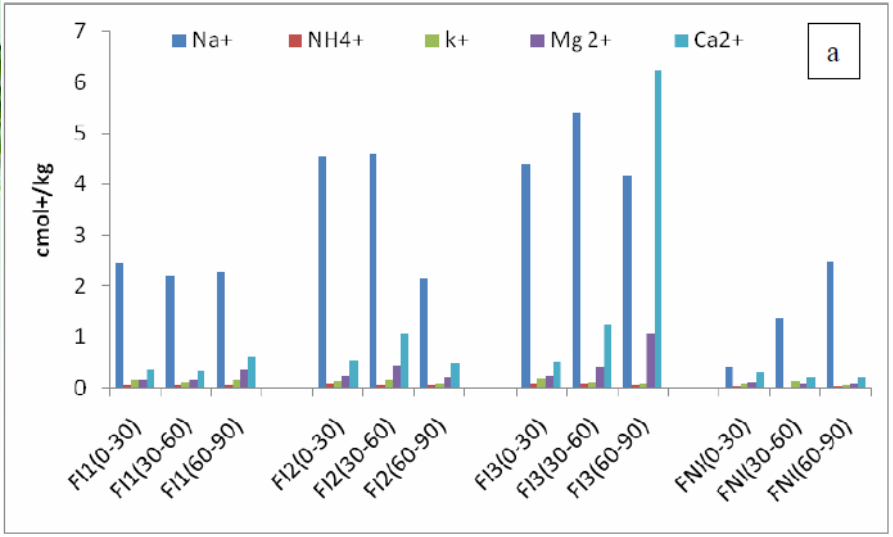
**Impact of 4 years of greywater supply on soil salinity from 0 to 90 cm depth**

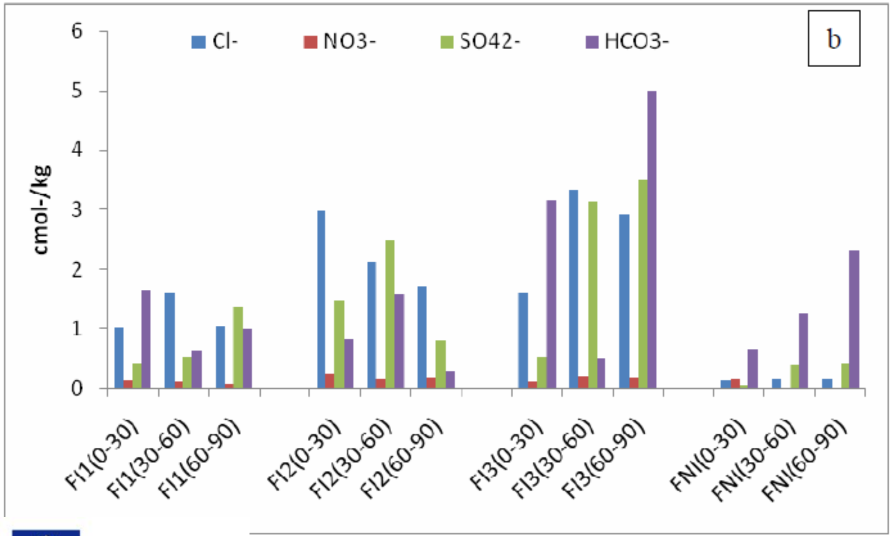
Soil salinity is evaluated by the soil electric conductivity (CE)

FI1, FI2, FI3 are 3 repetitions in a same field receiving greywater

FNI did not received greywater (=control)

## Impact of greywater reuse on soil properties




**Impact of 4 years of greywater supply on soil nutrient content from 0 to 90 cm depth**

FI1, FI2, FI3 are 3 repetitions in a same field receiving greywater

FNI did not received greywater (=control)

*Belaid, 2010*

## Negative impacts of greywater reuse on soil physical properties

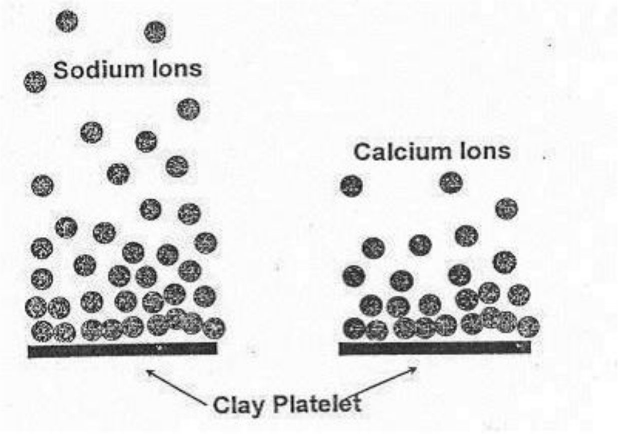
### >> Sodium and sodicity

Sodium has the opposite effect of salinity on soils.

The primary physical processes associated with high sodium concentrations are **soil dispersion** and clay platelet and **aggregate swelling**.

The forces that bind clay particles together are disrupted when too many large sodium ions come between them.

=> When this separation occurs, the clay particles expand, causing swelling and soil dispersion.




Behavior of sodium and calcium attached to clay particles (After Hanson et al., 1999)

Salts that contribute to salinity, such as calcium and magnesium, do not have this effect because they are smaller and tend to cluster closer to clay particles (Figure).
**Increased amounts of calcium and magnesium can reduce the amount of sodium-induced dispersion.**

## Negative impacts of greywater reuse on soil physical properties

**Infiltration**

Soil dispersion hardens soil and blocks water infiltration, making it difficult for plants to establish and grow.

⇨ **reduced plant available water and increased runoff and soil erosion.**

**Hydraulic Conductivity**

Soil dispersion not only reduces the amount of water entering the soil, but also affects hydraulic conductivity of soil.

When sodium-induced soil dispersion causes loss of soil structure, the **hydraulic conductivity is also reduced.**

⇨ The upper layer can become swollen and water logged.
⇨ This results in **anaerobic soils** which can reduce or prevent plant growth and **decrease organic matter decomposition rates.**
⇨ The decrease in decomposition causes soils to become **infertile, black alkali soil**

## Negative impacts of greywater reuse on soil physical properties

### Surface Crusting

**>>** Surface crusting is a characteristic of sodium affected soils. The primary causes of surface crusting are :

1) **physical dispersion** caused by impact of raindrops or irrigation water
2) **chemical dispersion**, which depends on the ratio of salinity and sodicity of the applied water.

>> Surface crusting due to rainfall is greatly enhanced by sodium induced clay dispersion.

>> When clay particles disperse within soil water, they **plug macropores** in surface soil by two means:

1) they block avenues for water and roots to move through the soil.
2) they form a cement like surface layer when the soil dries. The hardened upper layer, or surface crust, restricts water infiltration and plant emergence.

Thank you for your attention !