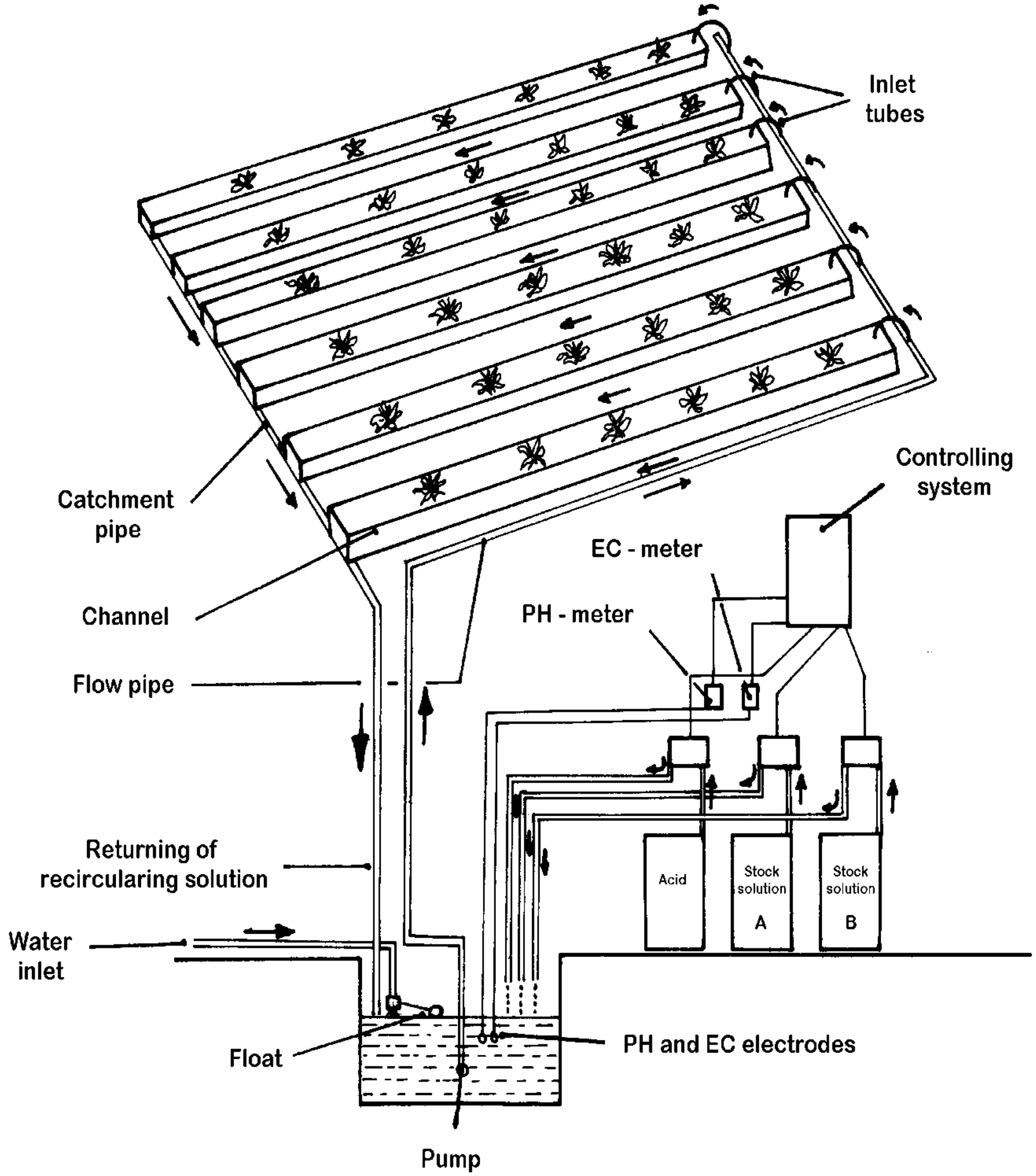
Recycling of nutrient solution in closed soilless culture systems

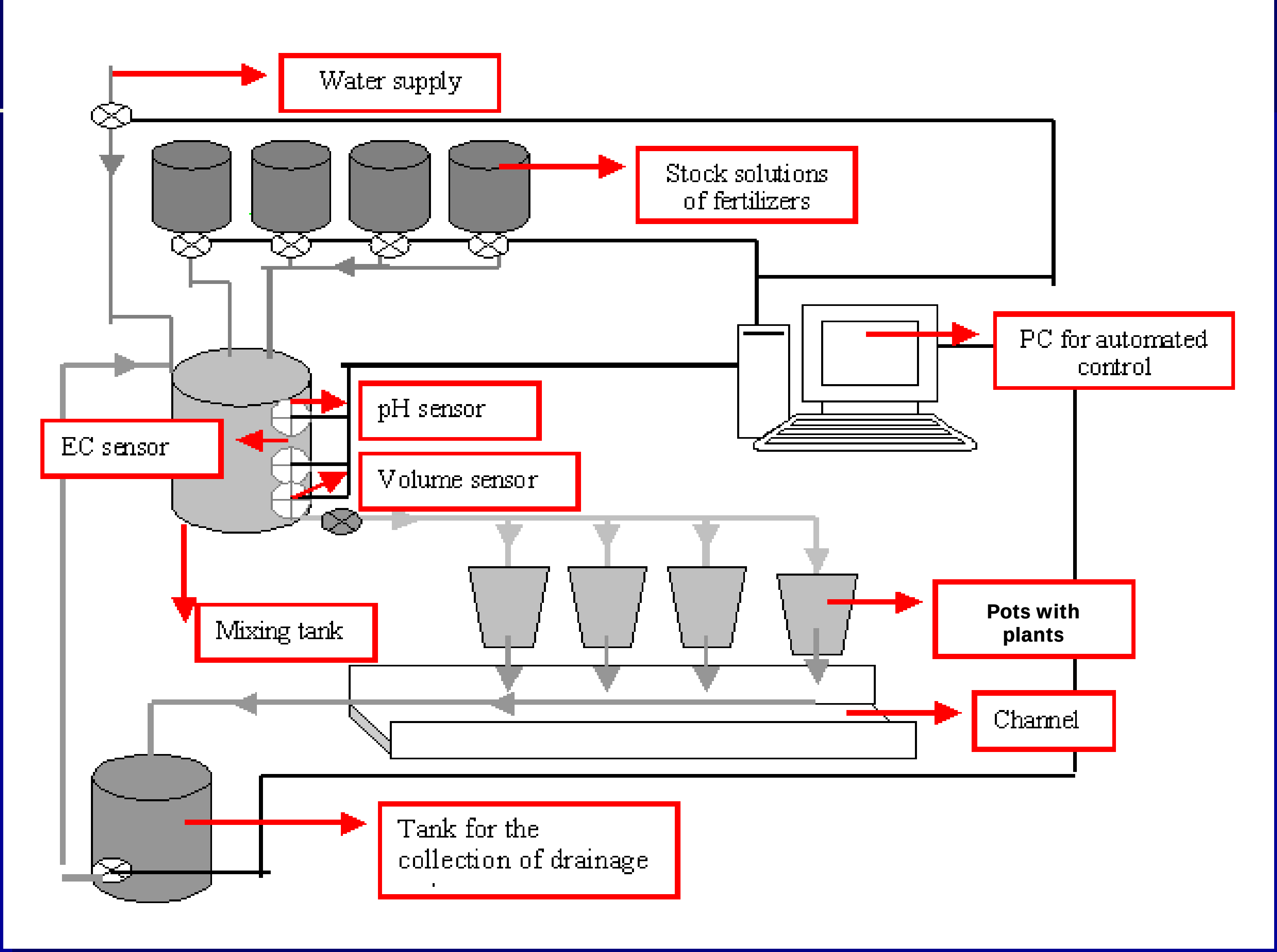
Recycling concepts

- Continuous recirculation
- Capture and recycling of fertigation effluents (drainage solution)

Schematic representation of a hydroponic system involving <u>continuous recirculation</u>



Schematic representation of a closed hydroponic system with intermittent nutrient solution supply



Difficulties related to nutrient solution recycling

- Recycling of the nutrient solution may result in recycling of pathogens

- The composition of the nutrient solution changes as it passes through the root environment and thus the nutrient concentrations in the drainage solution are not similar with those in the solution supplied to the crop.

Some pathogens that may infect plants via the recycled nutrient solution (1)

No	Pathogen	Literature source
1.	Pythium sp.	Jenkins and Averre, 1983, *Plant Desease* 67: 968-970
2.	Phytophthora sp.	Runia et al., 1996, *9th Int. Cong. ISOSC, Proc*., 395-407
3.	Fusarium sp.	
4.	Verticillium sp.	Wohanka, 1992, *8th Int. Cong. ISOSC, Proc*., 497-511
5.	Thielaviopsis basicola	
6.	Cylindrocladium scoparium	
7.	Xanthomonas campestris	
8.	Pelargonium Flower Break virus (PFBV)	Berkelmann and Wohanka, 1995, *Acta Hort*., 382: 256-262

Some pathogens that may infect plants via the recycled nutrient solution (2)

9.	Cucumber green mottle mosaic virus (CGMMV)	Paludan, 1985, cited by Runia, 1995, *Acta Hort.*, 382: 221-229
10.	Tomato mosaic virus (ToMV)	
11.	Tobacco mosaic virus (TMV)	
12.	Lettuce big vein agent (LBVA)	
13.	Cucumber mosaic virus (CMV)	Büttner et al., 1995, *Acta Hort.*, 396: 265-272
14.	Tomato spotted wilt virus (TSWV)	
15.	Tobacco necrosis virus (TNV)	
16.	Platylenchus vulnus	Runia and Amsing, 1996, *9th Int. Cong. ISOSC, Proc.*, 381-395
17.	Meloidogyne incognita	
18.	Radopholus similis	

A synopsis of methods used to disinfect the drainage solution prior to recycling in closed hydroponic systems

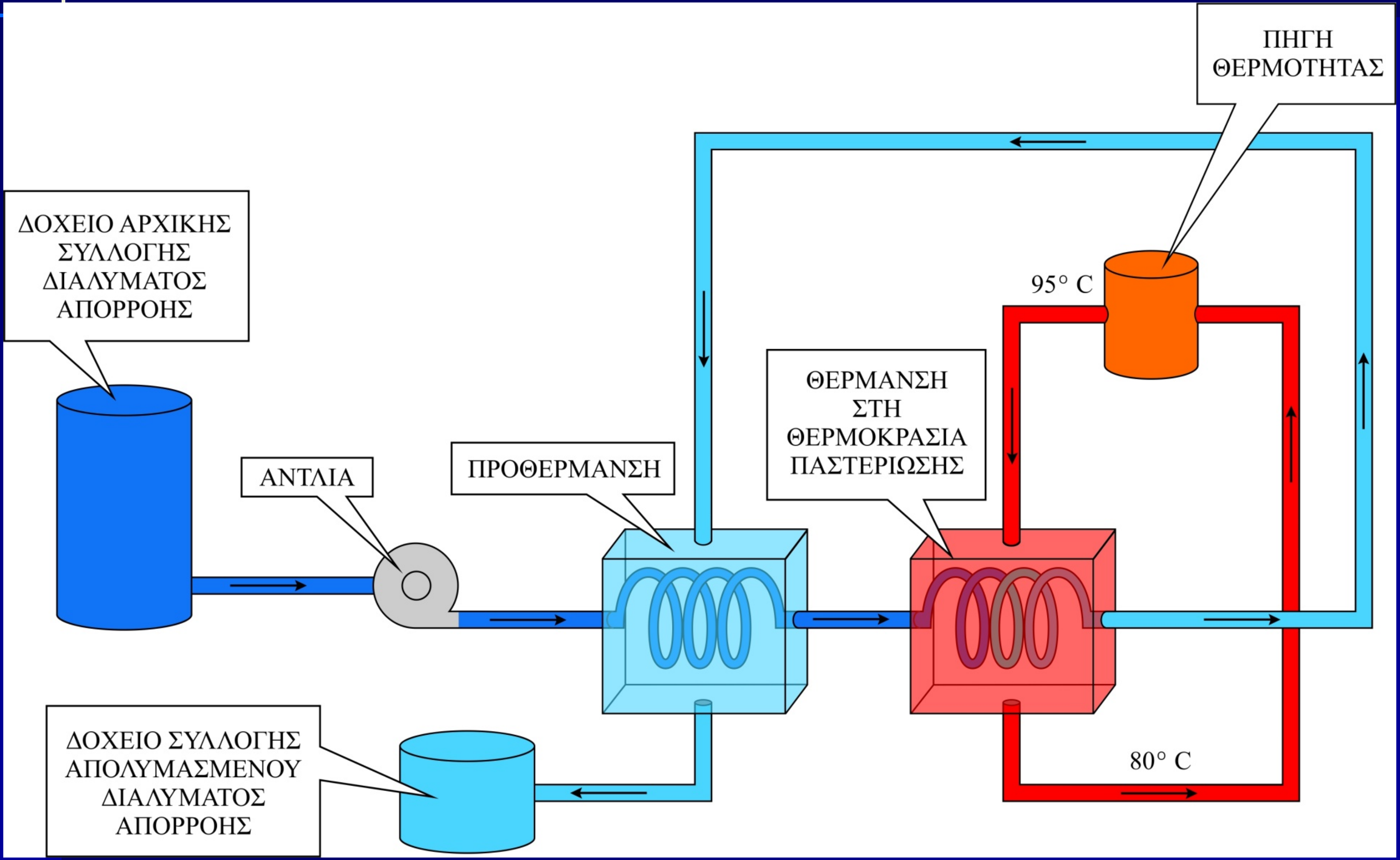
No	Disinfection method	Application details
1	Pasteurization	95 °C for 15´´ 85 °C for 3 min (*Fusarium*, ToMV)
2	UV radiation	200-280 nm, 250 mJ/cm^2
3	Slow sand filtration	Filtration rate: 0.1-0.3 m/h. Size of sand particles: 0.2-0.6 mm
4	Micro-membrane filtration	Removal of *Fusarium oxysporum*: Pore size 0.05 µm.
5	Ozonation (O_3)	10 ppm for 1 h (Redox potential 754 mV)
6	Active hydrogen peroxide	Killing of *Fusarium oxysporum*: 50-100 ppm for 5 min. Killing of viruses: (TMV: 400 ppm)
7	Iodine application	Killing of *Fusarium oxysporum*: 0.7 ppm

Methods of drainage solution disinfection

Pasteurization using heating

Advantages	Disadvantages
• Full efficacy for all relevant pathogens (fungi, bacteria, viruses). • Relatively simple technology. • No phytotoxicity problems. • During the winter, it can be supported by the central heating system of the greenhouse.	High cost is required to achieve the proper temperature level for disinfection.

Schematic representation of a pasteurization device



Disinfection by means of ultraviolet (UV) irradiation

- UVc (200 – 280 nm) is required. Microbicidal activity is restricted at 200 – 315 nm, with an optimum at about 260 nm.
- UVc-irradiation inactivates pathogens by a photochemical reaction that mainly affects nucleic acids, which absorb strongly at or close to 260 nm.

UV-disinfection equipment

Disinfection using UV irradiation

- A coarse sand (0.4-0.8 mm) filter is required before the UV radiation filter to retain organic compounds and other suspending material.
- The lethal doses for fungi, including *Fusarium oxysporum*, and for viruses are 100 and 250 mJ/m^{-2}, respectively.
- Mercury vapour (MV) lamps are efficient sources of UVc radiation for NS disinfection.
- Low pressure (MV) lamps are preferable due to their higher energy utilization efficiency (0.4) compared to high pressure MV lamps (0.1).

Disinfection by means of ultraviolet radiation

Advantages	Disadvantages
If the radiation dose is sufficient, the UV-filters kill all pathogens	• Fe chelates may be oxidized and can, thus not be recycled. • Precipitation of minerals on the surface of the quartz glass tube may reduce their transmission ability. • The functional cost of UV filters is considerable. • The UV lamps have a relatively limited lifetime.

Slow sand filtration

Sand filter

Upper surface of a sand filter

Side overview of a sand filter

Technical specifications of sand filters

- **A sand filter consists of 2-3 lower layers for drainage and a main sand layer.**
- **Height of sand layer: > 80 cm**
- **Height of drainage layers: 35-40 cm**
- **Particle size of sand:: 0,2-0,6 mm**
- **Particle size of drainage aggregates:**

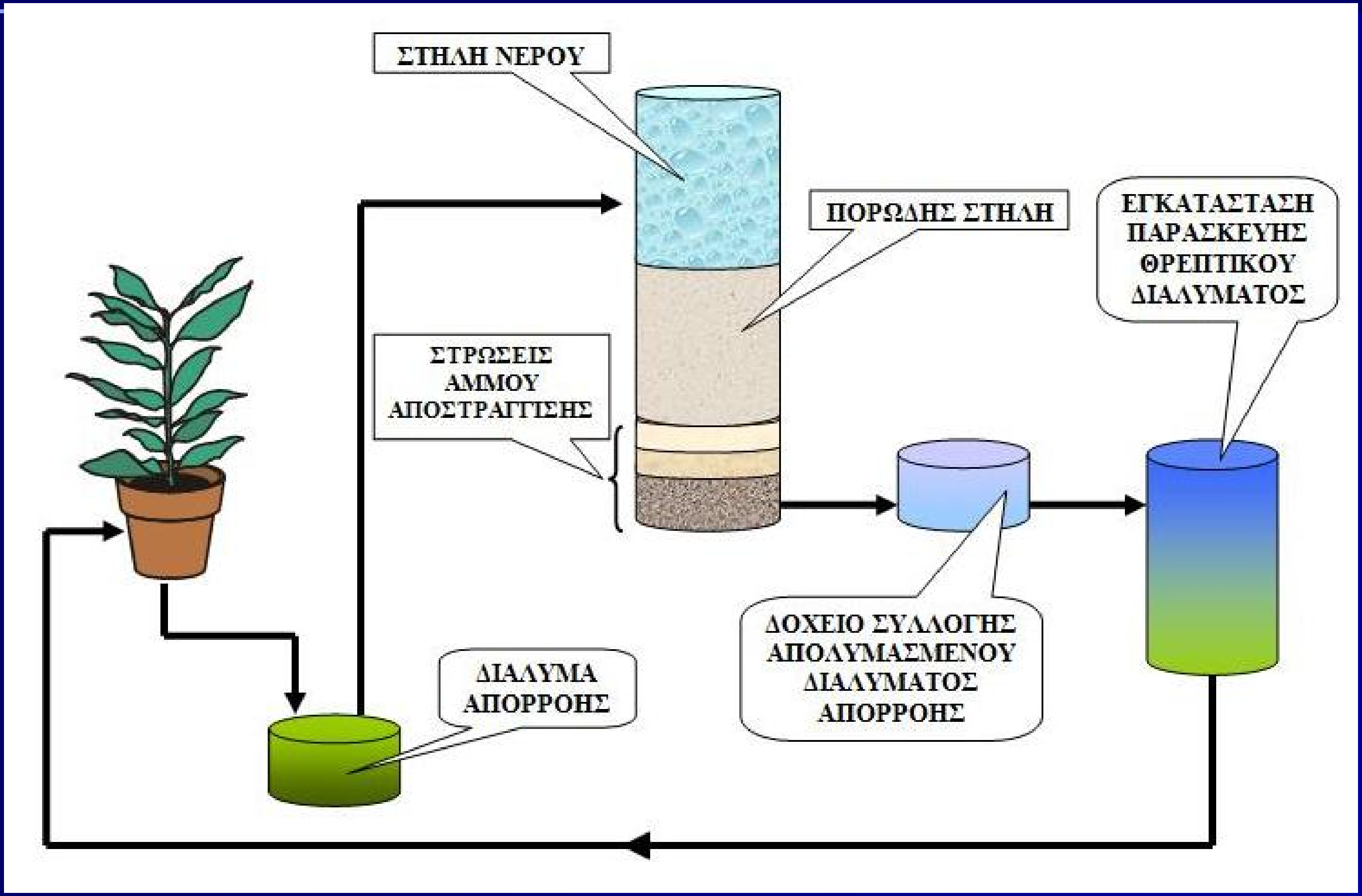
a) Higher: 2-7 mm
b) Intermediate: 7-17 mm
c) Lower: 16-32 mm

Technical specifications of sand filters:

Characteristics of particle size distribution

- **Effective size (ES ή D_{10}): 0.15-0.40 mm**
- **Uniformity coefficient (UC: D_{60}/D_{10}):
  >3 (acceptable), >2 (desired).**
- **Level of water above the surface of the filter:
  20 - 50 cm.**
- **Desired flow rate through the filter:
  0.1-0.3 m/h.**

Schematic representation of a sand filter



Slow sand filtration

Advantages	Disadvantages
• It is a relatively simple technology. • The problems that may arise during use of a sand filter are simple and occur not frequently • Low maintenance cost. • It is mainly based on the microflora established in it and is, therefore, the most environment friendly method of removing possible pathogens from the drainage solution to be recycled. • The filtered drainage solution becomes clear and free from suspended material.	• Its efficacy against *Fusarium* and some other phytopathogenic Fungi is not always guarantied. • ΔIt is not possible to use any type of sand. • A sand filter requires a relatively large area to be established.

Methods of replenishing the drainage solution with nutrients and water prior to recycling

- Replenishment according to the estimated uptake concentrations or uptake ratios (estimated nutrient/water uptake ratios)

- Replenishment according to a target composition of the nutrient solution supplied to the crop

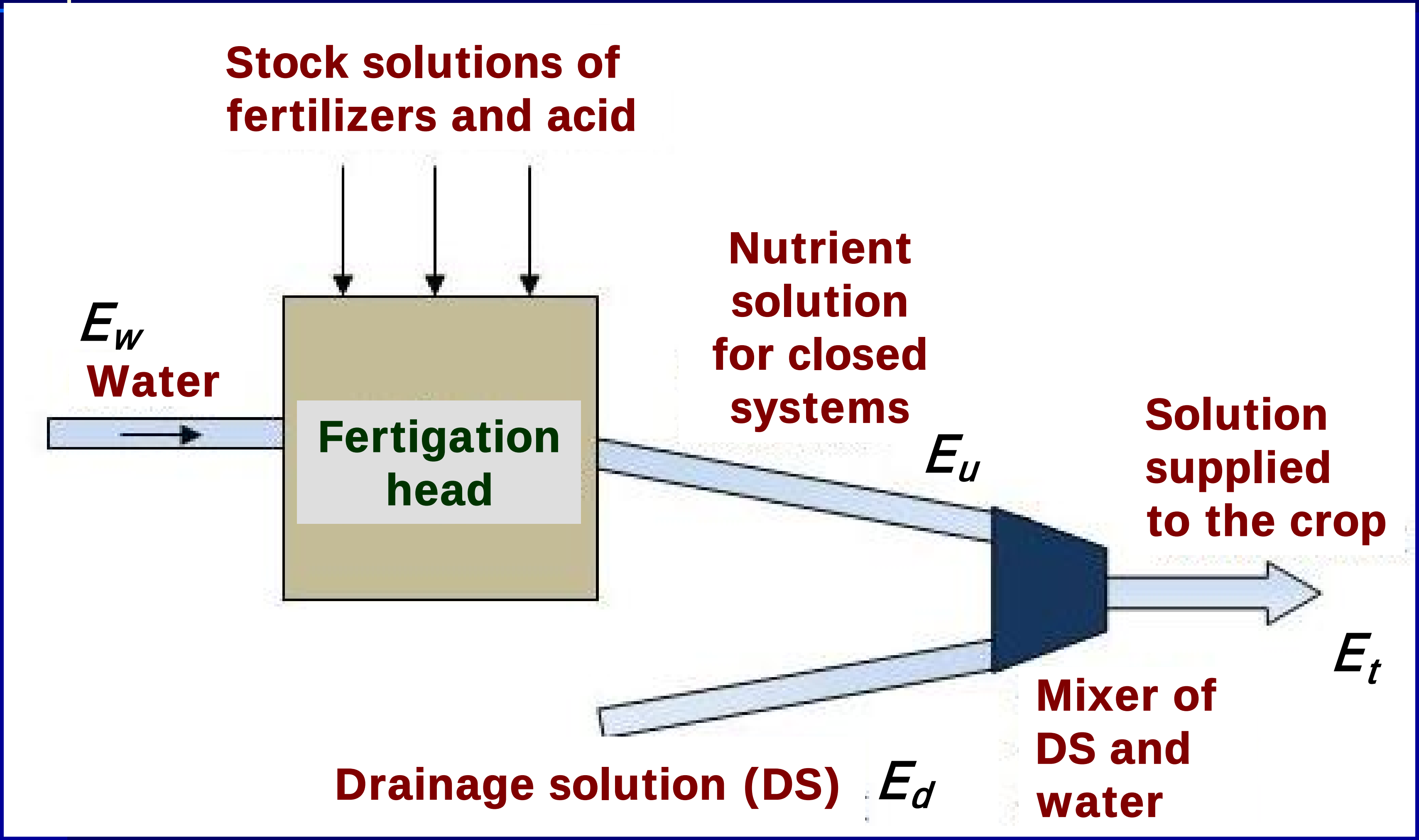
Recommended EC (dS m^{-1}), pH and nutrient concentrations (mmol L^{-1}) in nutrient solutions (NS) for soilless tomato crops grown under Mediterranean climatic conditions.

Desired characteristics	Initially applied NS	Vegetative stage			Reproductive stage		
		SSOS[1]	SSCS[2]	RE[3]	SSOS	SSCS	RE
EC	2.80	2.50	2.00	3.20	2.40	1.85	3.40
pH	5.60	5.60	-	5.8 – 6.7	5.60	-	5.8 - 6.7
[K^+]	6.80	7.00	6.40	7.50	8.00	7.50	8.20
[Ca^{2+}]	6.40	5.10	3.10	7.80	4.50	2.30	8.00
[Mg^{2+}]	3.00	2.40	1.50	3.40	2.10	1.10	3.40
[NH_4^+]	0.80	1.50	1.60	<0.60	1.20	1.40	<0.40
[SO_4^{2-}]	4.50	3.60	1.50	5.00	4.00	1.50	6.00
[NO_3^-]	15.50	14.30	12.40	18.00	12.40	11.00	17.20
[$H_2PO_4^-$]	1.40	1.50	1.30	1.00	1.50	1.20	1.00
[Fe]	20.0	15.00	15.00	25.00	15.00	15.00	25.00
[Mn]	12.00	10.00	10.00	8.00	10.00	10.00	8.00
[Zn]	6.00	5.00	4.00	7.00	5.00	4.00	7.00
[Cu]	0.80	0.80	0.80	0.80	0.70	0.70	0.80
[B]	40.00	35.00	20.00	50.00	30.00	20.00	50.00
[Mo]	0.50	0.50	0.50	-	0.50	0.50	-

[1]<u>SSOS:</u> solution supplied to open systems; [2]<u>SSCS:</u> solution supplied to closed systems; [3]<u>RE:</u> target concentrations in the root environment.

Replenishing the drainage solution with nutrients and water in closed soilless culture systems according to the concept of the uptake concentrations

Schematic representation of the equipment used to prepare NS in a closed soilless culture system according to the concept of uptake concentrations

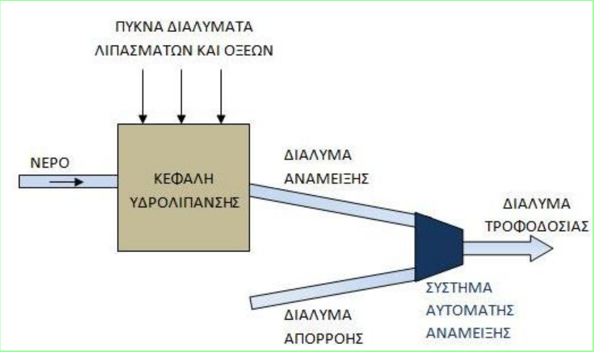


Adjustment of the supplied nutrient solution in a closed hydroponic system after chemical analysis of drainage solution and drip solution samples

$$C_{it} = C_{iu} + a(C_{id} - C_{iu}) \iff C_{iu} = \frac{C_{it} - aC_{id}}{1-a}$$

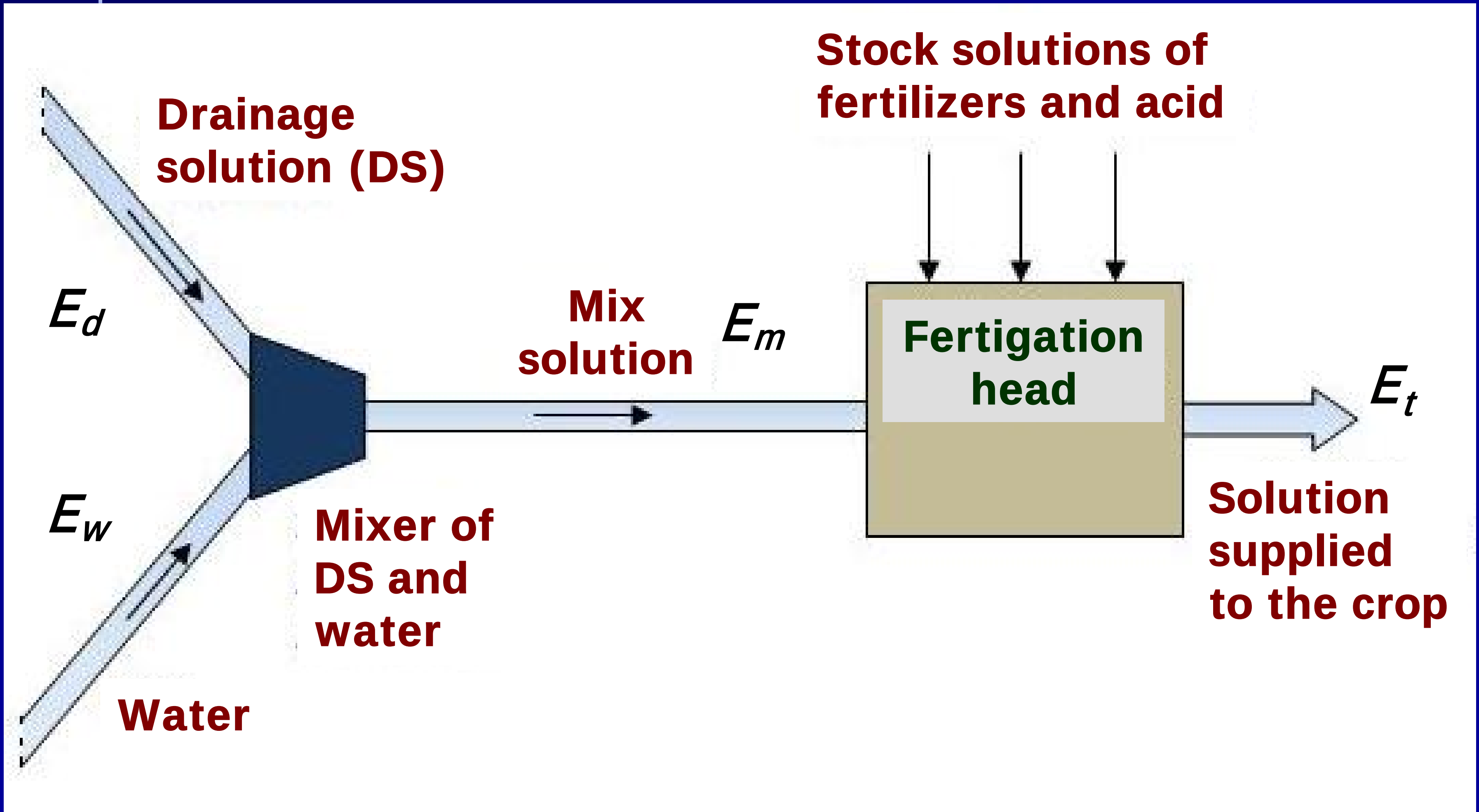
$$C_{tu} = \sum C_{i^{+}u} \implies E_u = \frac{C_{tu} + 1.462}{9.819}$$

$$E_t = aE_d + (1-a)E_u$$



Replenishing the drainage solution with nutrients and water in closed soilless culture systems according to a target composition of the supplied nutrient solution

Schematic representation of the equipment used to prepare NS in a closed soilless culture system according to a target composition of the nutrient solution supplied to the crop



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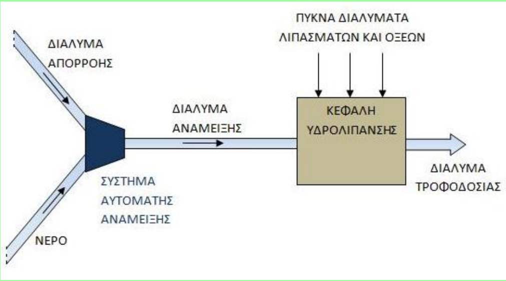
$$C_{tu} = \sum C_{i^+u} \implies E_u = \frac{C_{tu} + 1.462}{9.819}$$

$$E_t = aE_d + (1-a)E_u$$

$$E_m = E_t + (1 - a)(E_w - E_u)$$



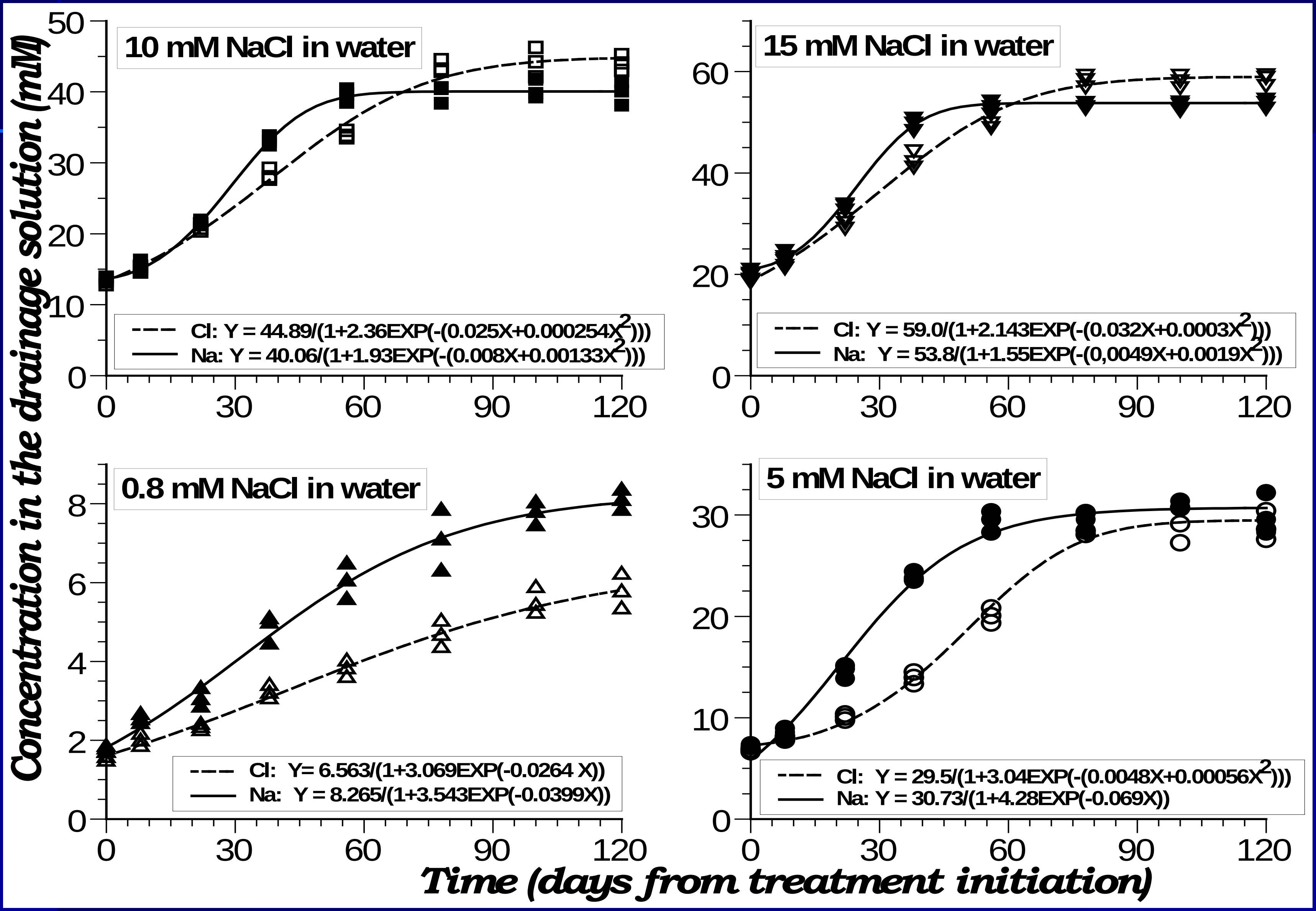
Na and Cl accumulation in closed soilless culture systems

Na and Cl accumulation is a problem if the concentrations of these ions in the irrigation water is not very low

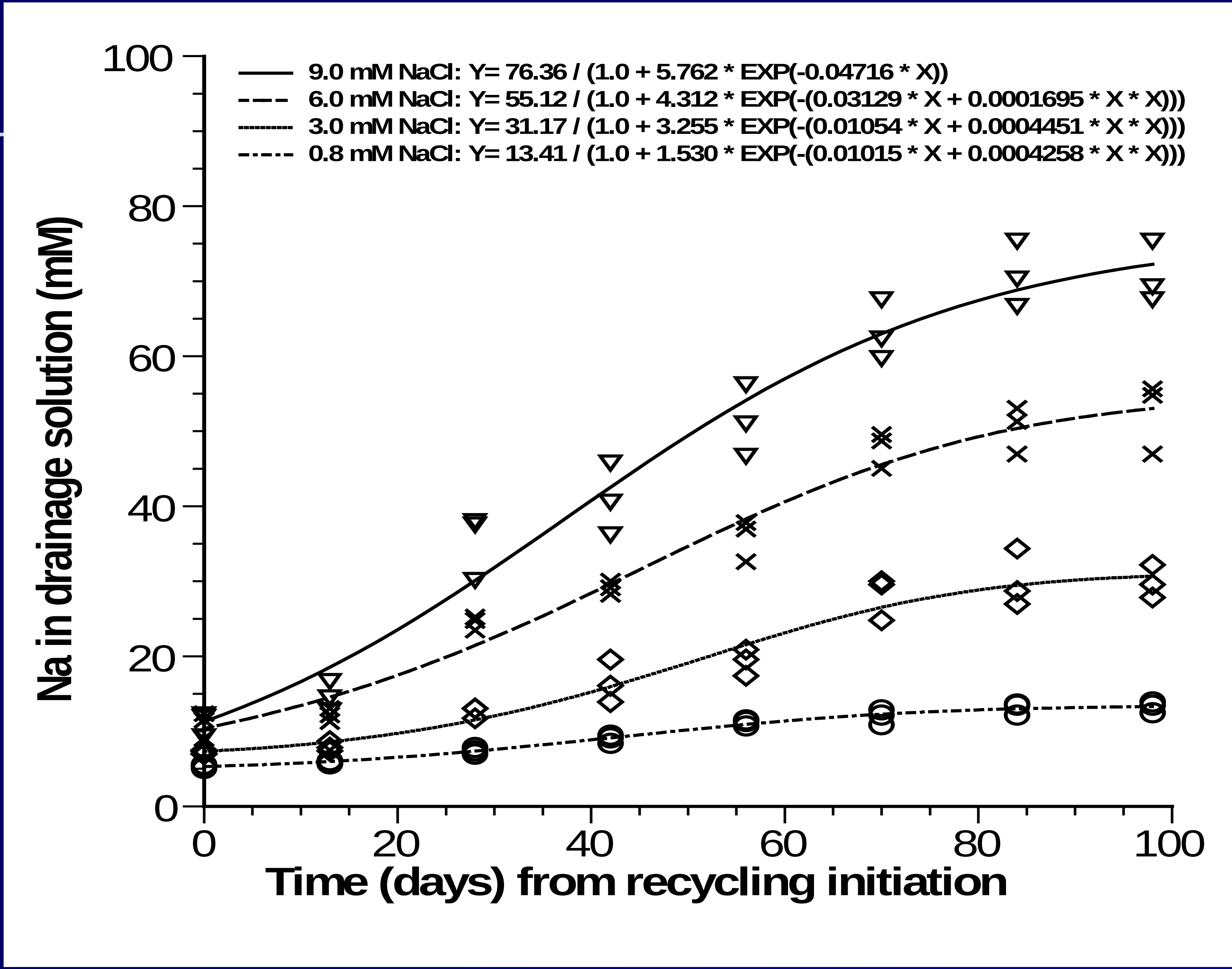
Reverse osmosis system for irrigation water desalination

NaCl accumulation in a cucumber crop grown in a closed system

(Savvas et al., Europ. J. Hort Sci. 2005, 70: 217-223).



Na accumulation in a bean crop grown in a closed hydroponic system (Savvas et al., 2005, unpublished data)



Na accumulation in a bean crop grown in a closed hydroponic system (Savvas et al., 2005, unpublished data)