Soilless cultivation systems

Definition:

Soilless culture is an artificial means of providing plants with support and a reservoir for nutrients and water in a system isolated from the soil.

Terminology:

Soilles culture; Hydroponics; Water culture

History of soilless cultivation

- Use of containers in ancient, renaissance, Baroque times
- Experiments in the 17th century (Malpigi, Boyle, Woodward)
- Plant nutrition studies in the 19th century, first nutrient solutions (Sachs, Knap, Liebig)
- Beginning of 20th century – use of aggregate medium in the USA - (Hall, Pember and Adams)
- Gericke 1929 – attempt for commercialisation; the technical background was not quite ready yet
- Hoagland and Arnon 1938 – complete nutrient solution; 1950 the first review
- 2nd World War – used in the Pacific islands and Japan

History of soilless cultivation

- 1950's and 60's – strategic importance during the Cold War ; slight but significant reasearch activity
- new systems are developed – Nutrient Film Technique 1966 (1950); rockwool culture 1969; aeroponics 1973; floating hydroponics 1976
- 1970's revival of the method (UK, Scandinavia, NL)
- Sonneveld – species specific nutrient solutions, claculation protocols
- 1980's – becomming widespread (e.g. NL 1976 – 5ha, 1984 – 1.500 ha, 1989 – 2.500 ha, 1996 – 4.100 ha)
- 1990's – considerations of environmental effects
- 2000's – sustainability; commercial use also in open field

Present situation of soilless cultivation

- **World area:** cc. 35.000 ha (?) in 2012
- Europe: The Netherlands, Spain, Poland, France, Belgium, UK, Germany
- Other continents: Japan, Israel, China, South-Korea, Canada, USA
- **crops:** tomato, green pepper, cucumber, eggplants, melon, salad crops, spice plants; cut flowers, pot plants; strawberry
- **substrates:** NW-Europe – rockwool, coco fibre, peat (synthetic materials); S-Europe – coco fibre, rockwool, mineral materials (perlite, pumice, tuff)
- Hungary – cc. 500 ha ≈ 20% (?); rockwool, coco fibre, peat mixtures

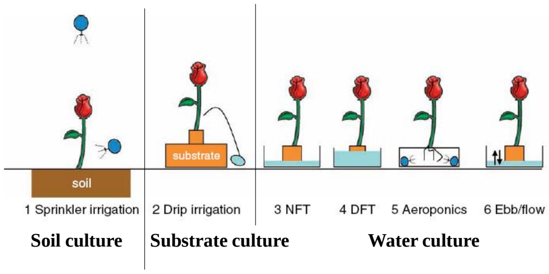
Advantages of soilless cultivation

- Independence from soil and soil related (biological, chemical, physical) problems → possibility of continual cultivation
- Precise nutrient and irrigation control → better plant growth → high yield, good (external) product quality
- Better water and nutrients use efficincies (especially in recirculating systems, in open sytems ?)
- Higher root zone temperature (Energy saving)

Disadvantages of soilless cultivation

- High installation and operation costs
- Small buffer capacity → little room of error → need for high level professional knowledge and technical background
- Good water quality is a basic requirement
- Reuse and recycling of substrates
- Risk of infection in recirculating systems
- Consumers' aversion

Types of soilless cultivation systems



van Os et al. 2008

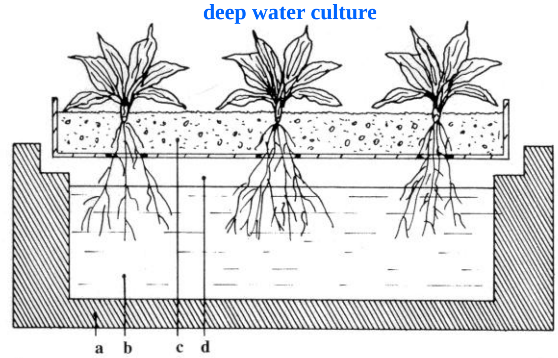
Types of soilless cultivation systems

- **Water cultures (hydroponics)** – systems without a solid medium
- Deep Flow Hydroponics/Technics (DFH/DFT)
  - deep water culture
  - floating hydroponics
- Nutrient Film Technique (NFT)
- (Plant Plain Hydroponics)
- Aeroponics
- Ebb and flow system

Deep water culture

- Gericke, 1929
- Originally 10 m long, 0.6 m wide, 15 cm deep toughs
- Netting supporeted „seed beds"
- Roots are immersed in the nutrient solution
- Poor aeration of the solution (originally)
- Improvment with conitnuous solution circulation

deep water culture

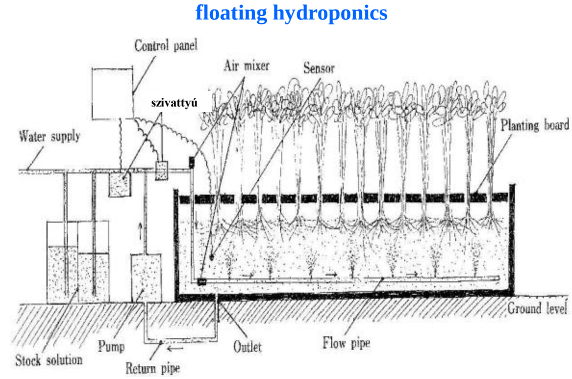


Maloupa, 2002

Floating hydroponics

- Jensen and Massantini, 1976
- Pool sized tanks (originally 70 m long, 4 m wide, 30 cm deep)
- Plants are supported above the surface of the solution on „rafts" of lightweight plastic materials
- Roots are immersed in the nutrient solution
- Nutrient solution is monitored, replenished, recirculated and aerated
- Easy to plant and harvest; good light absorption by the plants
- Big solution volume → better buffer capacity

floating hydroponics

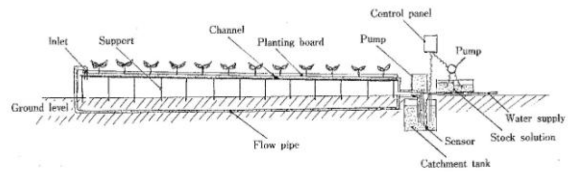


Jensen and Collins, 1985

Nutrient Film Technique

- (Steiner, 1950) Cooper, 1966
- A very shallow stream of solution (continuously) flows down throghs (gullies) having 1.5-2% slope by gravity
- A capillary material is placed at the bottom for more uniform nutrient solution distribution
- The plants stands in the gullies/troughs
- In the base of the throughs roots form a two-dimensional mat → better aeration
- Smaller amount of solution – easier to heat up or cool down
- Mainly used for leafy vegetables and herb plants
- Much more simple, flexible layout - the most popular water culture system

Nutrient Film Technique

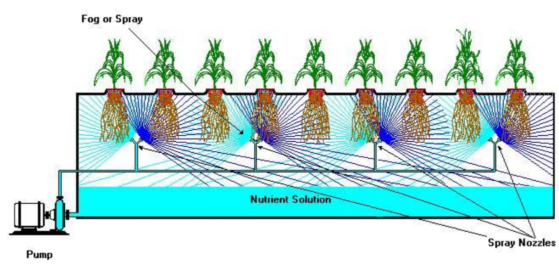


Jensen and Collins, 1985

Aeroponics

- Massantini, 1970
- Roots are suspended in a closed, sealed box, saturated with fine mist of nutrient solution
- The nutrient solution is sprayed for only a few seconds every 2 to 3 minutes
- Aeration of the roots is very good
- Higher plant density in A-frame system
- Very expensive method
- Mainly used for raising propagation material of ornamental crops, for rooting of foliage cuttings

Aeroponics



Evaluation of water culture systems

- Lack of substrates → possibility of more precise control, more uniform nutrient distribution
- Lack of substrates → smaller buffer capacity
- Big solution volume is used → usually recirculating systems → very good water quality is required
- High plant density is easier to achieve

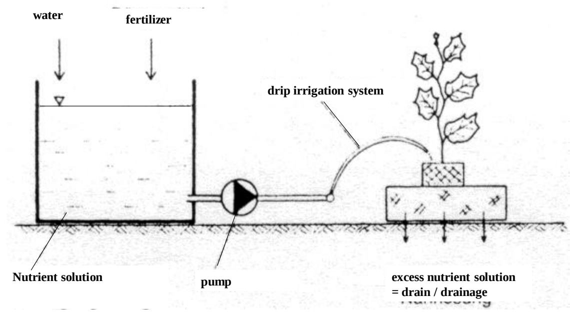
Types of soilless cultivation systems

- Aggregate cultures (substrate cultures) – systems incorporating a solid medium
- Based on the handling of drain water
  - open system (the drain is let out from the system)
  - recirculating (closed) system (drain is recirculated)
- Based on the placement method of the substrate
  - in beds, trenches
  - in containers, pots, boxes
  - in slabs (plastic bags)
- Based on the substrate employed

Aggregate cultures

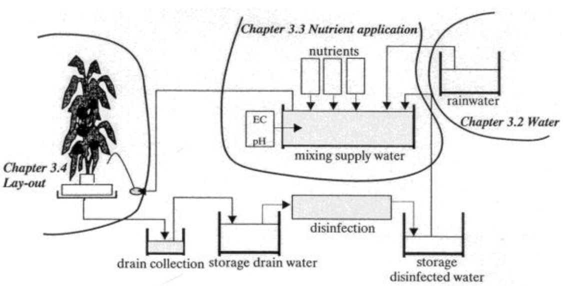
- **A solid medium provides support to the plants.**
- **The nutrient solution is delivered into the medium and the plants take up nutrients and water from this medium.**
- **Usually drip irrigation systems are used for providing the nutrient solution**
- **Better suited for cultures with small plant density**
- **Buffer capacity of the system depends on the type of the medium and on the volume of the medium**

Design of open systems



Göhler and Molitor, 2002

Design of recirculating systems



van Os, 2002

Comparision of a recirculating and an open system in Italy

In the recirculating system:

– less water (-21%), N (-35 %), P (-20%) and K (-17%) were used

– there was no increased infection level because of the recirculation

– yield and quality were unchanged

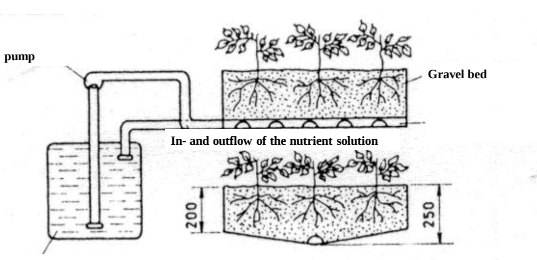
– average berry weight was smaller by 5 g

Rate of return: 2.6 year

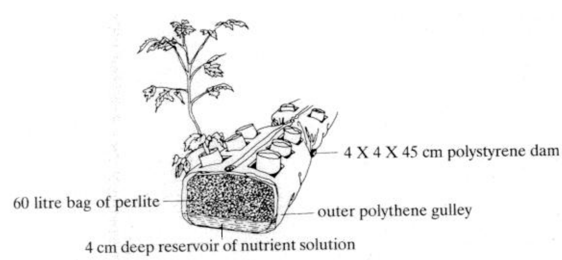
Oppinion of the grower:

– very happy about the less water and fertilizer use, but still very affraid of the infection → will not use the recirculating system until it is not compulsory /Pardossi et al., 2012/

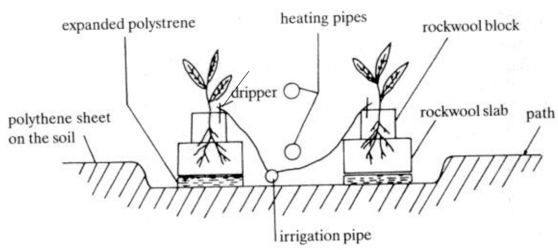
Design of a bed system



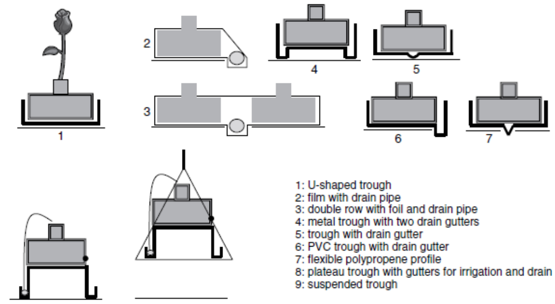
Göhler and Molitor, 2002



Maloupa, 2002; 163. o.



Maloupa, 2002



van Os et al., 2008

Functions of the substrate

- supplying the plant with water and nutrients
- providing oxygen for the roots
- supporting the plants

- Physical properties (bulk density, particle size distribution, total porosity, air filled porosity, water holding capacity, eesistance to compaction) ↔ water and air supply
- Chemical properties (cation exchange capacity ↔ buffer capacity, pH, salt content, C/N ratio) ↔ nutrient supply
- Other properties (price, availability, duration of use, sterility, possibility of sterilization, uniformity, posibility of recycling) ↔ economical and environmental considerations

Substrate characteristics compared to those of the soil

- Superior physical and chemical properties
- Low infestation rate
- Ease of disinfestation
- Limited volume → lower buffer capacity, limited nutrient reserves

Physical characteristics of substrates

- Bulk density (BD) ↔ container (in)stability, air filled porosity, mixing and transportation
- Particle size distribution ↔ aeration, hydraulic properties
- Total porosity (TP) (the aqueous and the gaseous phases) – usually 60-90%, optimum 80-90%
- Air filled porosity (AFP) ↔ root respiration; - usually 10-30%, opt. 20-30%
- Water holding capacity (WHC), hydraulic conductivity (easily available water (EAW) optimum 20-30%) – determines irrigation management
- Resistance to compaction, steady structure; stability of organic matters – speed of decomposition

Bulk density (kg/m^3) of some substrates

Coco fibres, coir	40-80
Rockwool	50-100
PU-foam	78
Vermidculite	80-100
Perlite	65-130
Peat	80-180
Bark	100-300
Compost	100-400
Expanded clay granule	280-630
Pumice	400-800
Zeolite	600-700
Tuff, scoria	800-1500
Gravel	1500
Sand	1500-1800

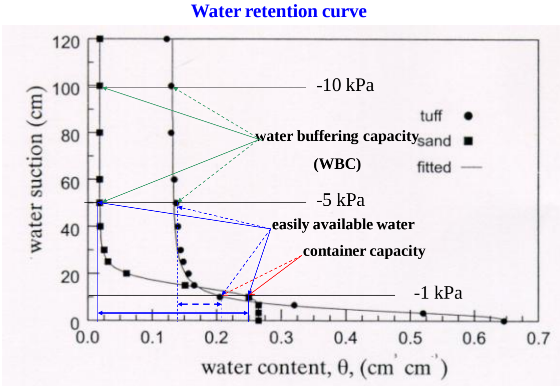
Total porosity (TP) (%)

Rockwool	92-97
PU foam (Agrofoam)	93-95
Perlite	91-97
Coco fibre, coir	86 ; 94-98
Compost	73-94
Bark	80-82
Expanded clay granule	80
Pumice	70-85
Peat	50-95
Tuff, scoria	60-80
Rice hull	72
Gravel	41
Zeolite	35-50
Sand	30-45

Air filled porosity (AFP) (%)

Rockwool	82
Peat	30-70
Compost	15-60
Expanded clay granule	50
Coco fibre, coir	10-15 ; 70
Bark	40-65
Pumice	25-40
Perlite	35-70
Sand	32
Rice hull	25
Zeolite	10-30
Gravel	6

Water retention curve



Raviv et al. 2002

Easily available water (EAW) (%)

Perlite	-37
Coco fibre, coir	-35
Zeolite	-34
Compost	10-25
Bark	1-22
Expanded clay granule	4

Chemical characteristics of substrates

- Cation exchange capacity (CEC) ↔ chemical reactions in the rhizosphere; inert and not inert substrates
- Phosphorous retention
- Buffer capacity ↔ CEC, volume
- pH – opt. 5.5-6; dosage of acids doesn't modifies much the root zone pH; changing NH_4/NO_3 ratio
- Salt content – opt. <1 mS/cm
- C/N ratio – opt. 30:1 - 20:1
- Level of harmful chemicals, materials

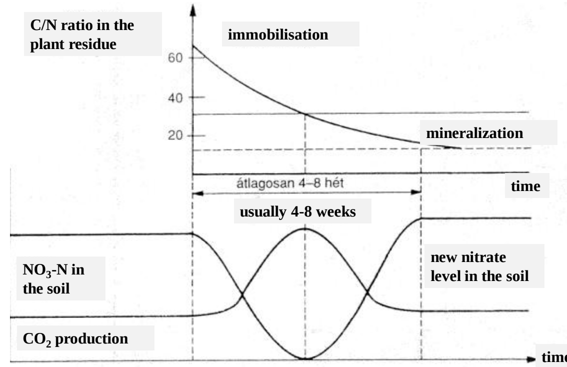
Cation exchange capacity (CEC) (meq/l)

Sand	0
Expanded clay granules	0
Pumice	0
Rockwool	0-2
Perlite	0-6
Vermiculite	15-20
Rice hull	30
Coc fibre, coir	15-110
Bark (fresh)	15-210
Peat	70-400
Compost	80-160
Tuff (scoria)	100-600
Zeolite	800-3000

pH

Peat	3,0 – 7,5
Bark, etc.	4,5 - 7,5
Coco fibre, coir	5,2 – 7,0
Synthetic materials	5,5 – 6,5
Vermiculite	6,0 – 7,0 (- 8,7)
Sand	6,0 – 8,0
Compost	6,5 – 7,5
Pumice	6,3 - 7,0
Expanded clay granule	7,0 - 8,0
Perlite	6,3 – 7,5
Rice hull	7,7
Rockwoll	6,2 - 8,0 (- 9,5)
Tuff (scoria)	7,9 – 9,3

Nitrogen immobilisation (Nitrogen lock-up)



Füleky, 2004

Other characteristics

- Price
- Availability
- How long it can be used
- Sterility
- Possibility of sterilization, disinfection
- Uniformity
- Possibilities of recycling, disposal after the cultivation

Substrate prices in Germany (Euro/m^3)

Sand	4-6 (/ton)
Polistirole	8-10
Peat	10-15
Bark	15-23
Wood chips	21-31
Rockwool	26-31
Coco fibre, coir	28-33
Rice hull	31-36
Compost	31-130
Vermiculite	41-51
Perlite	44-51
Expanded clay granules	46-130 (/tonna)
Synthetic (HFS)	61-74

Göhler and Molitor, 2002

Requirements towards a substrate in a sustainable soilless production system

- Usable for 3-4 years
- Steady physical properties during this period
- Its desinfestation by steam is possible
- Doesn't emit any harmful materials
- Its recycling is possible

(van Os, 2001)

Types of substrates

- Inorganic (mineral derived) materials
- inert materials - CEC ≈ 0
- Rockwool – P(rocessed)
- Perlite - P
- Expanded clay granules - P
- Sand, gravel – N(atural)
- Pumice - N
- not inert materials – CEC ≠ 0
- Tuff (scoria) - N
- Vermiculite, zeolite - P

Types of substrates

- Synthetic organic materials
- Polyurethane, polystyrol, phenol raisin, carbamide-formaldehyde, polyester
  - Foams, slabs and granules derived from mineral oil
  - Very light materials, very high TP, high AFP porosity, low EAW content
  - Inert, slightly acidic, nowadays don’t contain harmful organic materials
  - Can be used for at least 10 years, sterile, can be steamed; disposal or recycling can be a problem

Types of substrates

- Organic materials
- Peat
- Coco fibre, coir
- Tree waste products (bark, fibre, chips, sawdust)
- Composts
- Rice hulls

Rockwool

- First used in Denmark in 1969, the most important substrate since 1985
- 60% basalt, 20% limestone and 20% coke heated to 1600°C, and spun into thin (50 µm) fibres, then pressed
- Low BD, high TP, low WBC capacity, uneven water and air distribution (more dense top layer or mixing in clay particles could be a solution)
- Usually used in slabs (40-200 x 10-30 x 7,5-10 cm) and blocks (for propagation), rarely in granulated form
- High pH, inert, no buffer capacity → „unforgiving”
- Sterile, can be steamed, consistent performance, recycling was a problem earlier

Perlite

- Natural volcanic material grounded, sieved and heated to 1000-1200 °C, expands to 4 to 20 times its original volume
- Grades ↔ physical characteristics, usually <3.0 mm
- Low BD, high TP and AFP, frequent irrigations with small amounts are needed, placement of the drain holes (slits) is important
- Inert, neutral, sterile, can be steamed, sensitive to mechanical compression

Expanded clay granules

- Used in horticulture since 1936
- Dry, heavy clay heated to 1100°C
- Light; amount of EAW is small; the usual grade is 3-10 mm diameter
- Stable, consistent material, can be used even for 10 years
- Neutral, sterile, can be sterilized, very stable

Sand

- Coarse sand (0,2-2 mm) is preferred
- Physical characteristics are inferior: heavy, low TP, can have aeration problems
- High pH types should be avoided
- Inert, stable, cheap, as a natural deposit often not constant, can be steamed

Pumice

- **Product of volcanic activity**
- **Mined, ground, sieved**
- **Light, TP is 70-85%, mainly large pores, low water holding capacity (WHC)**
- **Inert, high amount of Na is leached out at the beginning of use**
- **Sterile and stable, can be used for a long time; not available everywhere**

Vermiculite

- **Produced from natural clay mineral on a similar way, like perlite**
- **Produced in 0-2, 2-4, 4-8 mm grades**
- **Light, very porous, has strong capillary action**
- **Neutral ; has high CEC and buffering capacity for pH; adsorbs phosphate**
- **Not used as a stand-alone medium**
- **Sterile; can not be steamed; sensitive to mechanical compression**
- **Zeolite – has extremely high CEC; stable**

Tuff (scoria)

- **Volcanic material**
- **Properties are determined by primary mineral composition and weathering stage (+ grinding and sieving)**
- **Higher BD, medium TP (60-80%)**
- **Has buffering capacity, adsorb or release nutrients (mainly P)**
- **Sterile, stable, can be steamed, not available everywhere**

Peat

- **Used for horticulture since the 18th century**
- **Result of anaerobic decomposition of plants**
- **Properties depends on many factors (plant species, climate, water quality, harvesting [block cut or mined], processing) → quite changeable**
- **Sphagnum peat moss – from cool regions, possibly the best peat for growth media**
- **Low BD, very high WHC**
- **High CEC, low EC, Sphagnum peat is acidic – lime is used for increasing its pH**
- **Not sterile, sterilization can be a problem, easy to dispose**

Composts

- **Organic matter which undergone a long, thermophilic, aerobic decomposition**
- **Properties vary according to the raw material and to the process used; properties are not constant in the long term**
- **Can contain significant amount of nutrients**
- **Not sterile, salinity and content of phytotoxic materials can be high**

Coco fibre, coir

- **Derived from the mesocarp tissue coco palm's fruit**
- **Used for horticulture since the 1980's; the best peat substitute**
- **Several materials are separated: long fibre, coarse fibre, fine fibre, chips, dust → large variability of end products → predetermined AFP and EAW can be obtained; light, high TP, resistance to compression**
- **Composting, washing, (buffering with Ca and Mg), dehydration, compressing**
- **Aerobic decomposition during storage – CEC, TP, EAW, WBC increase; C/N, AFP decrease**
- **Raw coir is rich in Na and Cl, P and K, high CEC, C/N**
- **Possible to sterilize, easily disposable**

Tree waste products

- **By-products of the wood and paper industries**
- **Rarely used as stand-alone medium**
- **Both physical and chemical properties are not favourable in raw stage; not sterile**
- **Easily disposable**
- **Bark is very resistant, hydrophobic, fresh bark can be phytotoxic (phenols, terpenes); improves AFP in mixtures**
- **Light, high AFP, low EAW; high CEC, N immobilisation can occur; sterilization is not recommended**
- **Chips, fibres, sawdust – cheap, readily available**
- **Very high C/N ratio, N immobilisation**

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