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Simulation of Water and Air Distribution in Growing Media

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Background

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- Oxygen supply is one of the biggest problems for optimizing plant growth in growing media
- Usual parameter: Air capacity
  (air content at container capacity CC;
  CC: water content at h = -10 hPa)
- Horticultural practice shows that this parameter is not sufficient to describe oxygen supply in growing media
- Air capacity: static conditions; Growing media: dynamic system
- Dynamic systems can be described with simulation models

Objectives of the Investigations

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- To describe physical parameters related to water and gas transport of different growing media
- To test HYDRUS-1D to describe water uptake and redistribution in growing media
- To use HYDRUS-1D to simulate oxygen movement and supply in growing media
- Final goal: to develop a (simple) system to describe water and oxygen supply in growing media, based on a simulation model, usable under practical growers conditions

Ebb-and-Flow Irrigation

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Growing Media

White Peat

Seedling Substrate

Chemical Properties

Some properties of the studied materials

	pH	EC (mS/m)	DB (g/cm³)	DP (g/cm³)	OM (g/g)
Seedling Substrate	**5.5**	**25**	**0.139**	**1.63**	**0.886**
White Peat	**3.9**	**10**	**0.130**	**1.57**	**0.969**

DB: Bulk Density; DP: Particle Density; OM: Organic Material

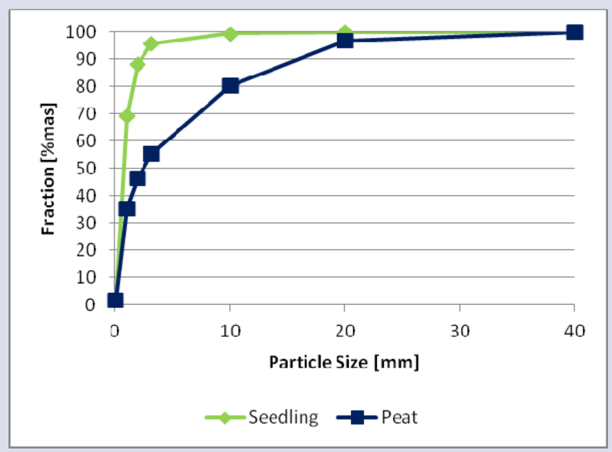
Physical properties

Physical properties of the two materials

Material	Total porosity (TP) cm³ cm⁻³	Container Capacity (CC) [at -10 hPa] cm³ cm⁻³	Air Capa-city (AC) [at -10 hPa] cm³ cm⁻³	Easily Avail. Water (EAW) [-10 to -50 hPa] cm³ cm⁻³	Sat. Hydr. Conductivity (Ks) cm s-1	Mean weight diameter mm
Seedling Substrate	**0.91**	**0.88**	**0.03**	**0.44**	**0.097**	**1.15**
White Peat	**0.92**	**0.71**	**0.21**	**0.26**	**0.121**	**5.65**

MWD: mean weight diameter

Physical properties



Mean weight diameter:

- Seedling Substrate: 1.15 mm
- White Peat: 5.65 mm

van-Genuchten Parameters

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Parameter	White Peat	Seedling Substrate
θ_s [cm³ cm⁻³]	**0.920**	**0.910**
θ_r [cm³ cm⁻³]	**0.187**	**0.373**
α_d	**0.232**	**0.055**
n	**1.411**	**3.022**
Air entry value [hPa]	**-1**	**-8**
Largest Pore [mm]	**3.0**	**0.4**

Initial Conditions

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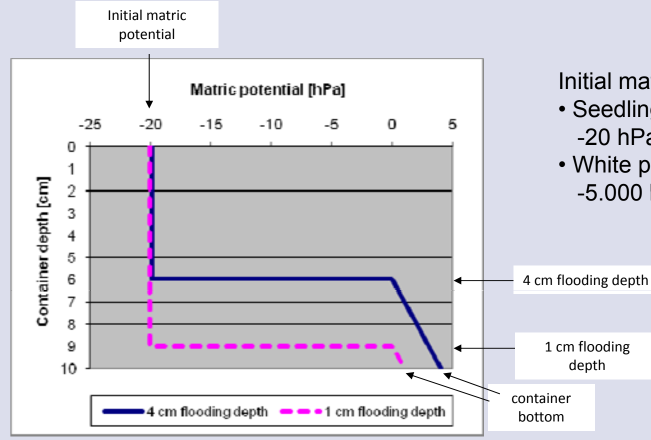
Initial conditions for the simulation (example for the seedling substrate)



Initial matric potential
- Seedling Substrate:
  -20 hPa → 32.0 %vol
- White peat:
  -5.000 hPa → 18.7 %vol;

Boundary Conditions

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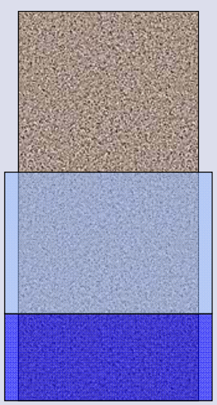
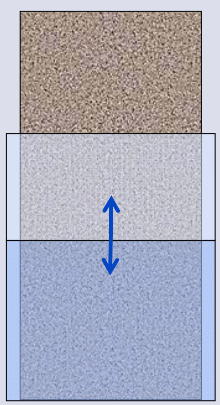


Upper BC:
Constant Flux
q=0

Simulatipon of Capillary Rise in Growing Media

Lower BC:
Constant Head
h=0

Flooding Phase (5 to 15 mins)



Upper BC:
Constant Flux
q=0

Simulatipon of Capillary Rise and Drainage from Growing Media

Lower BC:
Seepage Face
q=0 if h<0
h=0 if $\theta \geq \theta_s$

Drainage Phase (30 to 90 mins)

Experimental container

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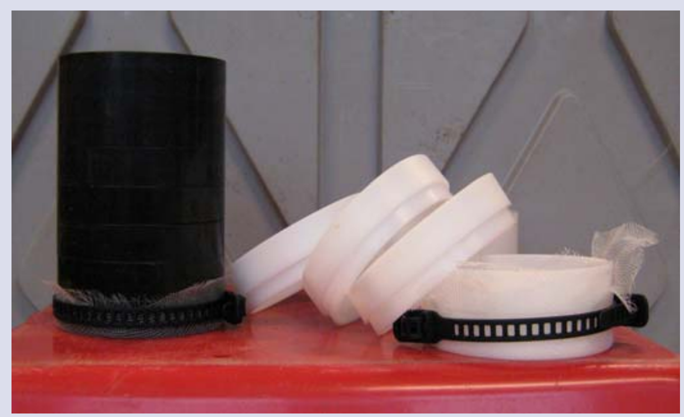
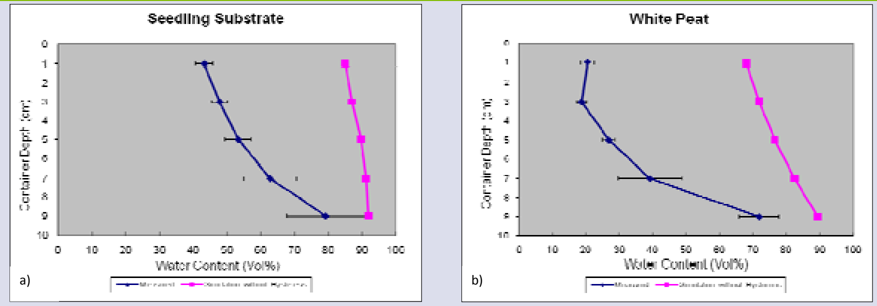
Experimental container with 10 cm inner diameter and 15 cm height



Flooding tub with experimental containers

Flooding tub with experimental containers

Results: Simulation without Hysteresis of the WRC



Water content (%vol) after 15 min of flooding, flooding depth 1 cm and after subsequent 90 min of drainage simulated without hysteresis for the seedling substrate (a) and the white peat (b)

Results:

- **Model highly overestimates water uptaky by capillary rise**
- **Very poor simulation quality**
- **Possible reason: Hysteresis of the WRC**

Hysteresis of the WRC

Ψ=-8 hPa = pF 0.90

Ψ=-6 hPa = pF 0.78

Ψ=-4 hPa = pF 0.60

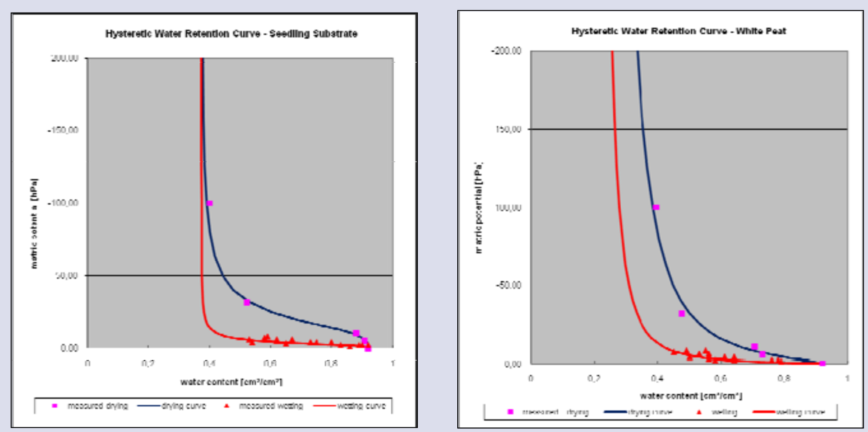
Ψ=-2 hPa = pF 0.30

flooding depth 1 cm

Measuring Hysteresis:

- **Simple and quick method**
- **Growing media with initial water content and bulk density**
- **Measuring water content in the rings at equilibrium**
- **Determination of the drying WRC by adjusting only van-Genuchten parameter α**

Hysteresis of the WRC



Water retention curves (drying and wetting curves) for the seedling substrate and the white peat

van-Genuchten Parameters

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Hysteretic van-Genuchten parameters for the water retention drying and wetting curves for the peat and the seedling substrate

Parameter	White Peat	Seedling Substrate
α_d	**0.232**	**0.055**
α_w	**1.600**	**0.320**
α_w/α_d	**6.90**	**5.82**

Simulation with Hysteresis

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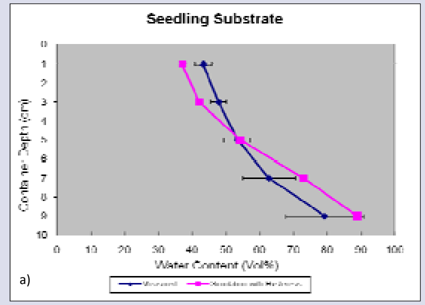

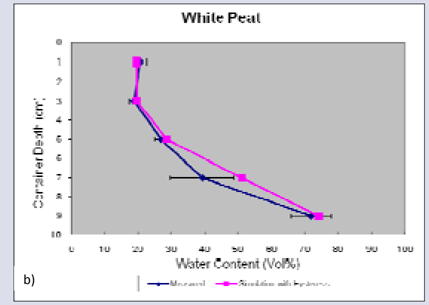

Water content (%vol) after 15 min of flooding, flooding depth 1 cm and after subsequent 90 min of drainage simulated with hysteresis for the seedling substrate (a) and the white peat (b)

Results:

- **Water uptake is much smaller due to hysteresis**
- **Good simulation quality with minor deviations**

Simulation Quality: Water Content

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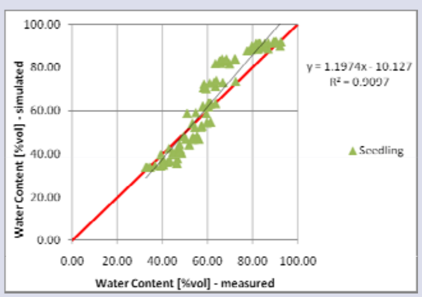

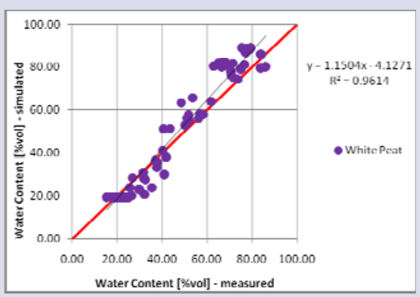

Measured against simulated water content (%vol) for the seedling substrate (left) and the white peat (right)

Results:

- **high correlation coefficient (0.96 and 0.91)**
- **EF (Nash-Sutcliffe): 0.97 – 0.84 (Seedling Substrate); 0.83 – 0.70 (White Peat)**
- **Slope 1.15 and 1.20 indicate slight overestimation of high values and underestimation of low values**

Simulation Quality: Water Content

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measure	Seedling substrate			White peat		
	1 cm flooding depth	4 cm flooding depth	All	1 cm flooding depth	4 cm flooding depth	All
bias (%vol)	**-0.32**	**-4.30**	**-2.31**	**-0.36**	**-4.44**	**-2.40**
MAE (%vol)	**2.66**	**7.15**	**4.90**	**5.72**	**6.63**	**6.18**
RRMSE (%)	**10.01**	**17.91**	**13.63**	**11.66**	**11.99**	**10.84**
EF	**0.973**	**0.844**	**0.905**	**0.827**	**0.698**	**0.766**

MAE: mean absolute error; RRMSE: relative root mean squared error;
EF: modeling efficiency (Nash-Sutcliffe)

Simulation Quality: Water Uptake

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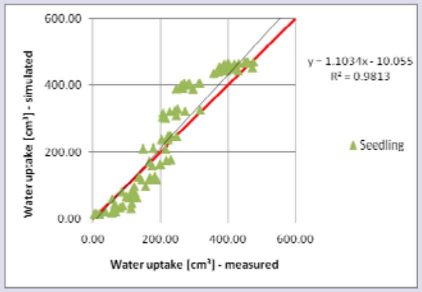

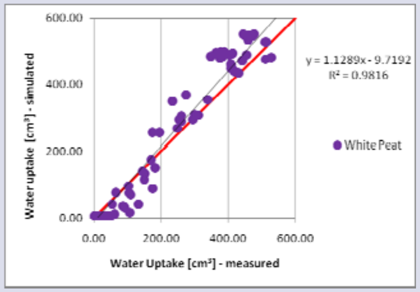

Measured against simulated water uptake (cm³) for the seedling substrate (left) and the white peat (right)

Results:

- **high correlation coefficient (0.98 both)**
- **EF (Nash-Sutcliffe): 0.99 – 0.95 (Seedling Substrate); 0.99 – 0.97 (White Peat)**
- **Slope 1.13 and 1.11 indicate slight overestimation of high values and underestimation of low values**

Simulation Quality: Water Uptake

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measure	Seedling substrate			White peat		
	1 cm flooding depth	4 cm flooding depth	all	1 cm flooding depth	4 cm flooding depth	All
bias (cm³)	**-12.65**	**-168.67**	**-90.66**	**-13.96**	**-174.24**	**-94.10**
MAE (cm³)	**25.27**	**168.67**	**96.97**	**38.96**	**174.24**	**106.60**
RRMSE (%)	**16.24**	**45.79**	**32.97**	**16.26**	**36.98**	**27.25**
EF	**0.994**	**0.948**	**0.958**	**0.994**	**0.966**	**0.975**

MAE: mean absolute error; RRMSE: relative root mean squared error;
EF: modeling efficiency (Nash-Sutcliffe)

Summary and Conclusions

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- Growing media show strong hysteresis of the water retention curve; hysteresis must be measured and taken into account for the simulation
- HYDRUS-1D is able to describe water uptake and redistribution in growing media under ebb-and-flow irrigation sufficiently well
- Possible reasons for differences could be the simplification of describing hysteresis only be changing the van-Genuchten parameter α
- HYDRUS-1D is a promising tool to overcome pure static descriptions of physical properties of growing media, such as air capacity, towards a dynamic description of water movement.

Outlook and Future Work

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- We measured and modeled the dependency of the <u>oxygen diffusion coefficient</u> on air content for different growing media with different bulk densities (diffusion chambers)
- We measured <u>oxygen consumption</u> for different growing media, bulk densities and water contents (Isermeyer method)
- We measured <u>oxygen concentration profiles</u> under different irrigation situations (optical O_2 sensors)
- Next step: O_2 simulation with slightly modified HYDRUS source code

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I am very much interested in contacts with colleagues working on the simulation of water and gas transport in growing media!!

Thank you for listening!