

Simulating Root Density Dynamics and Nitrogen Uptake – Can a Simple Approach be Sufficient?

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Objective for this work

Our use and purpose of a root sub-module in a soil plant model

- Model used as a management tool in field scale

What do we observe in our field trials?

- Highly difference in root development between species

Lack of flexibility in soil plant model

- Models we are using can not simulate all crop species as regards to root profilation and N uptake from deeper soil layers

Improvement of root model

- Contribution to root modeling for better simulation of N uptake in different soil layers in field scale

Next step

- ***Paramatisation and validation of model to field data - In progress now!***

- Our use of a plant soil model:
 - Simulate 1-5 years of a rotation
 - Predict N uptake and the amount of residual N in the rooting zone
 - In general as a management tool to avoid N losses
 - Rotation includes cereals, vegetables, catch crops

15 years of field trials at University of Aarhus, (Former DIAS), has given insight into root development and soil mineral N dynamic

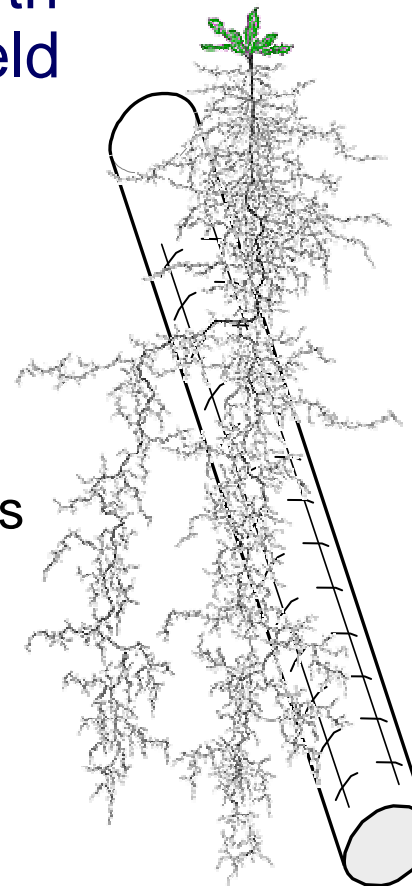
Field observations of root growth by using minirhizotrons in field plots:

Information:

- Rooting depth
- Rooting intensity
- Below and between crops rows

Further measurements:

- Biomass production
- Soil mineral N in rooting zone



Observations of root development in field trials

Arable crops

- Mono/dicot
 - » Eg. Spring cereals ~1m, Winter cereals ~1.5m, sugar beet, oil seed rape >2m

Vegetable crops

- Mono/dicot, short/long season, harvest over season
 - » Eg. Onion, leek ~0.35m, cauliflower ~1m, white cabbage >2m

Catch crops

- Mono/dicot, winter persistent
 - » Eg. Ryegrass ~1m, fodder radish >2m

Field Data:

- Some species had deep root growth and high root density in deeper soil layers
- Some species show affinity to N uptake from deeper soil layers

Our approach for the root model:

- Flexible with a simple root model setup to adapt root development, for covering the significant different root pattern we observed between mono/di-cot species
- Simple setup to manage root development and N-uptake
- The root model should improve N dynamic calculations influent by crop N uptake in **FIELD SCALE**

Root module contains:**Rooting depth**

Accumulated temperature with individual T_{\min} T_{\max} for crops and a crop specific root penetration rate

Control

Rooting depth

Row crops: Horizontal / Vertical growth

Root profilation

Exponential decrease of root density in soil profile

One form parameter adjust root density

Control

Root density at different depth

Row crops: Root density below or between rows

N-uptake

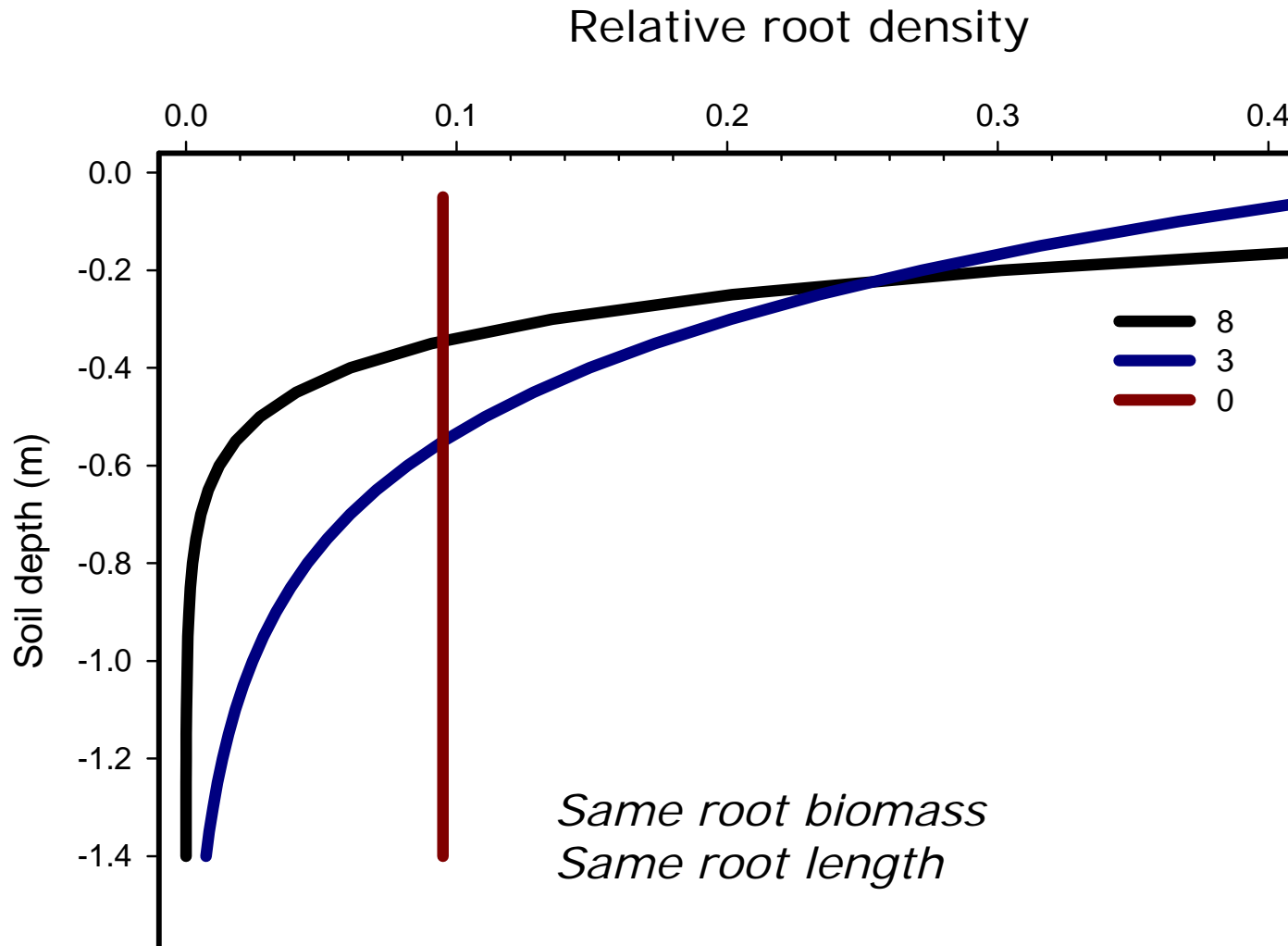
N-uptake is calculated by each unit of root length

Other relation for the root module to soil module and crop calculation above ground:

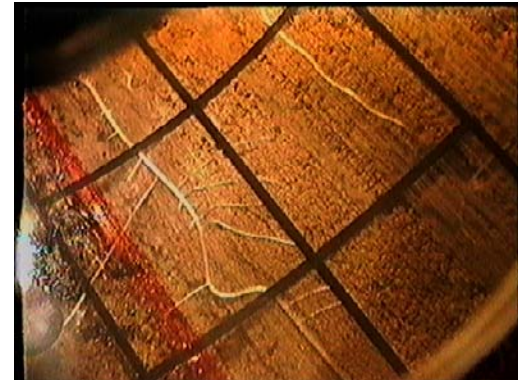
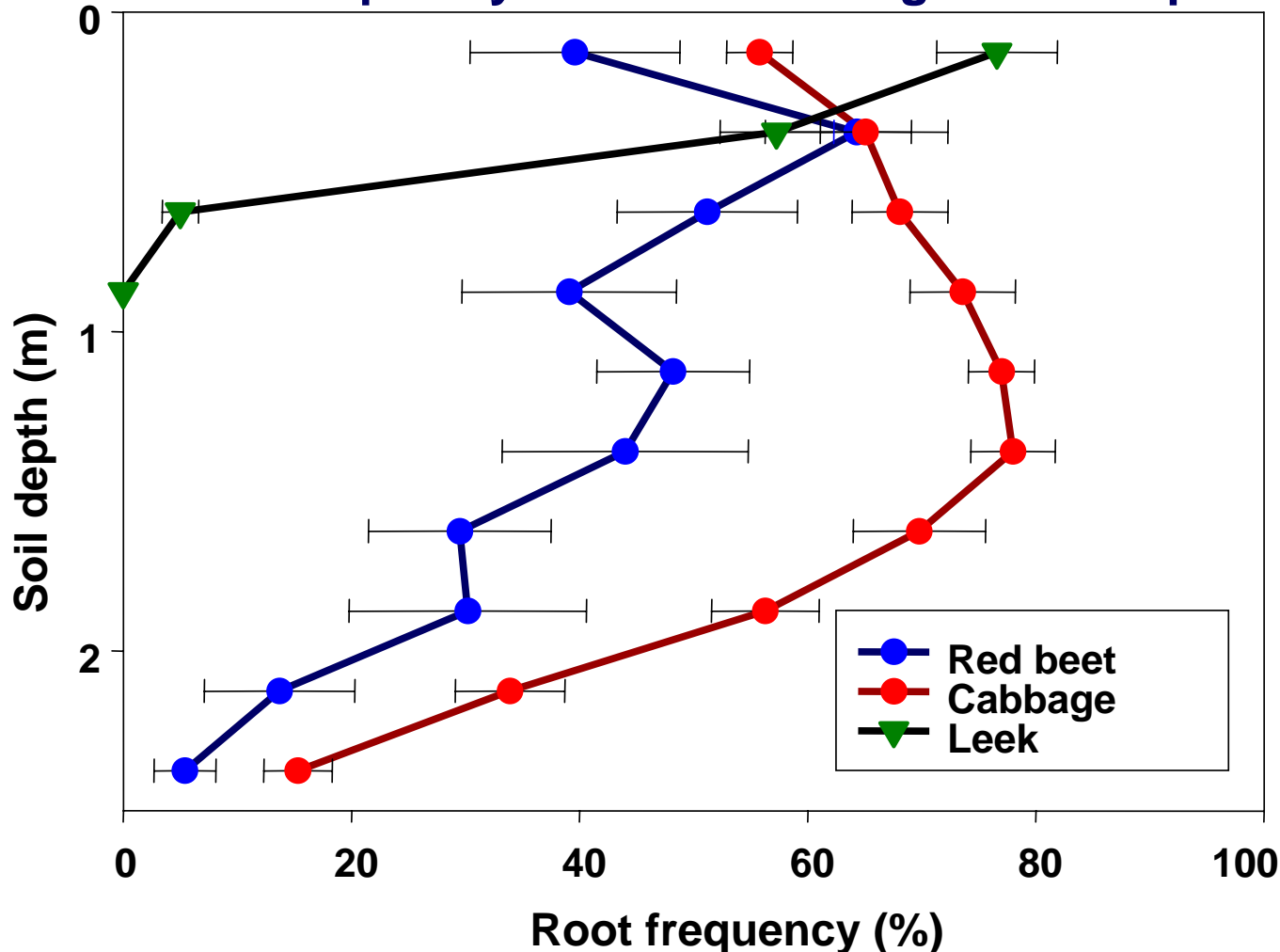
Shoot/root ratio, daily water and N-demand, min. and max.

temperature for growth, water uptake, soil water content, soil bulk density

Root density – One form-parameter



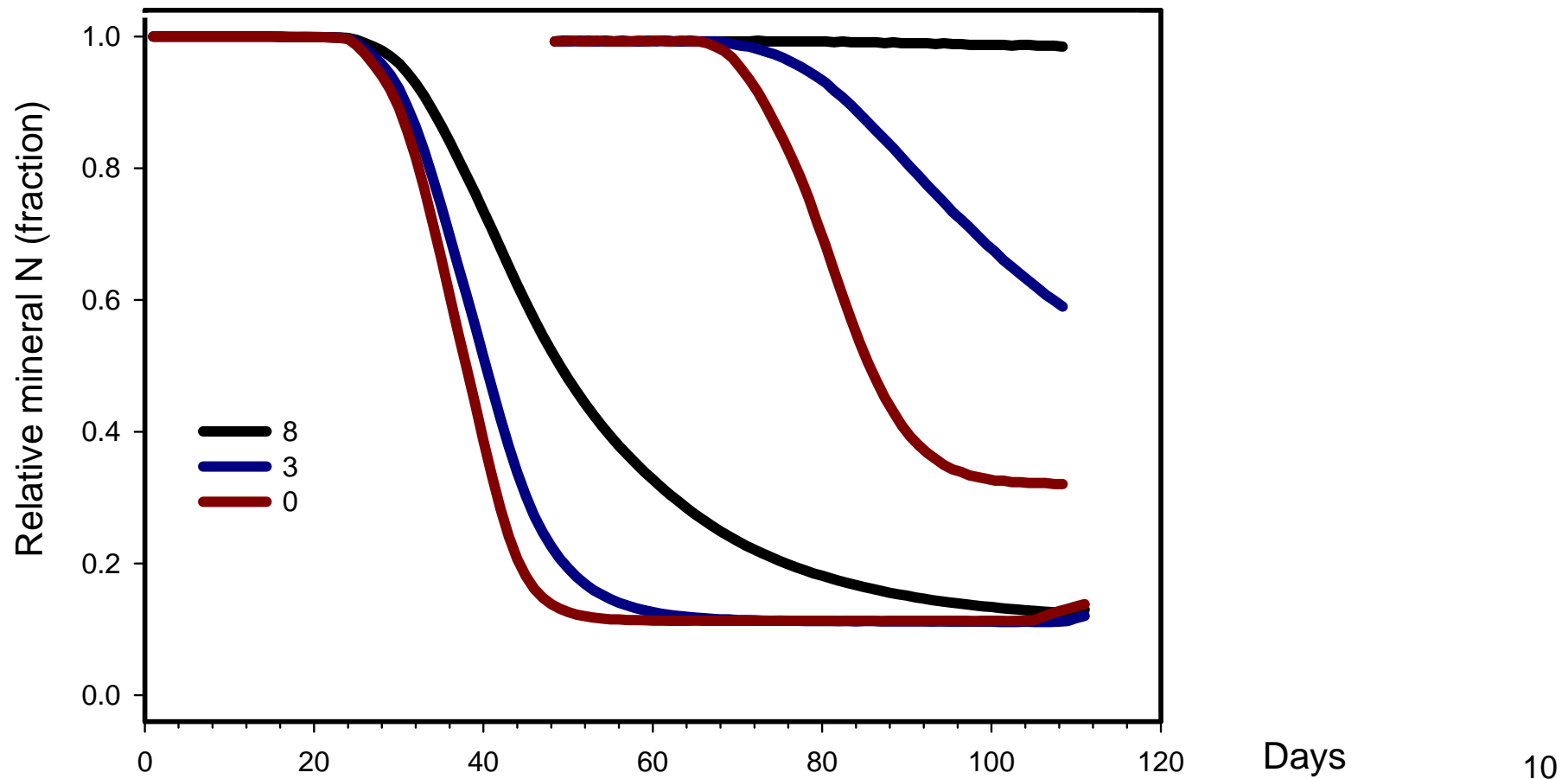
Root frequency at harvest of vegetable crops



N uptake (Low N conditions)

Soil layer 0.25-0.50 m

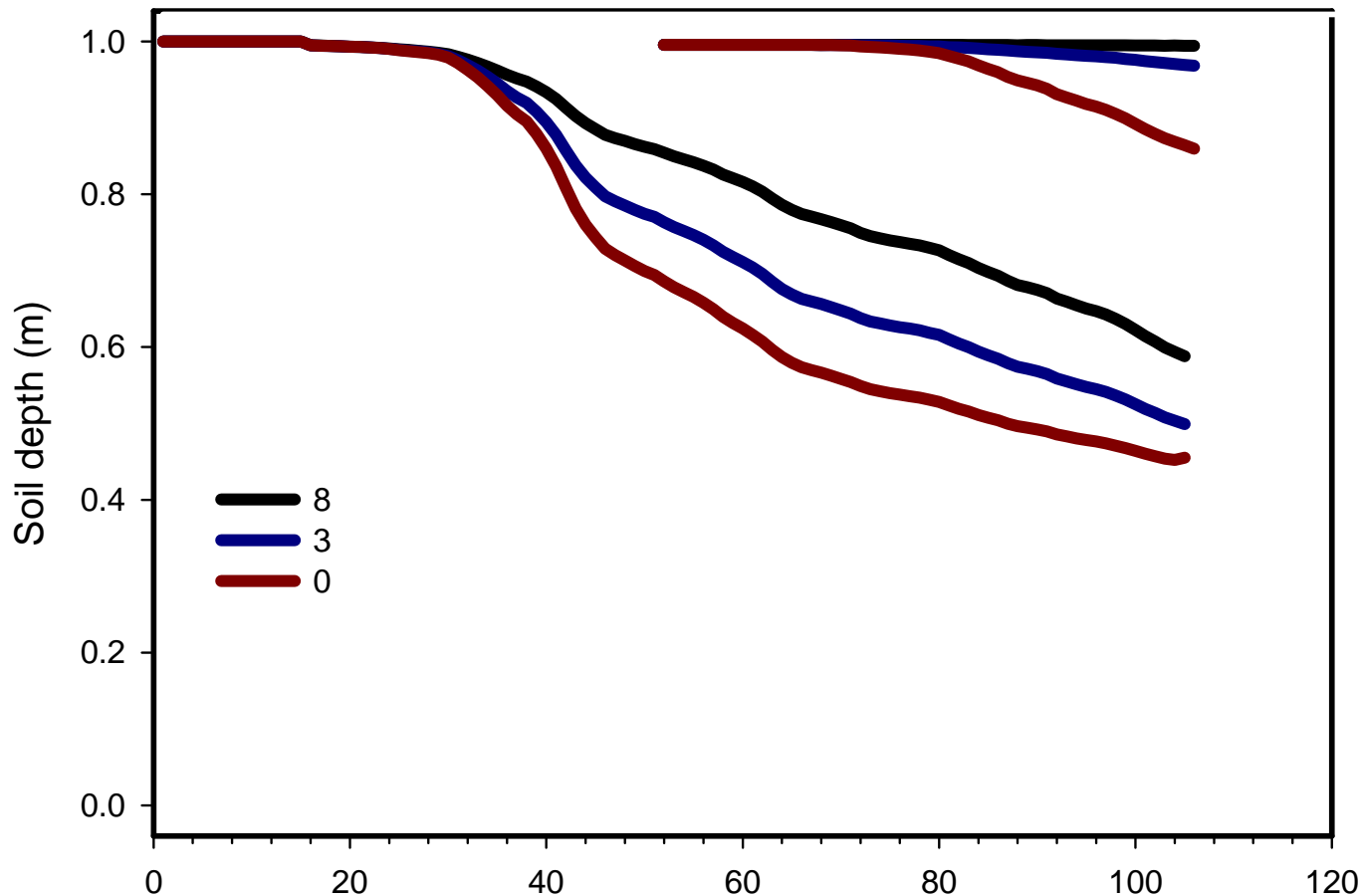
Soil layer 1.00-1.25 m



N uptake (High N conditions)

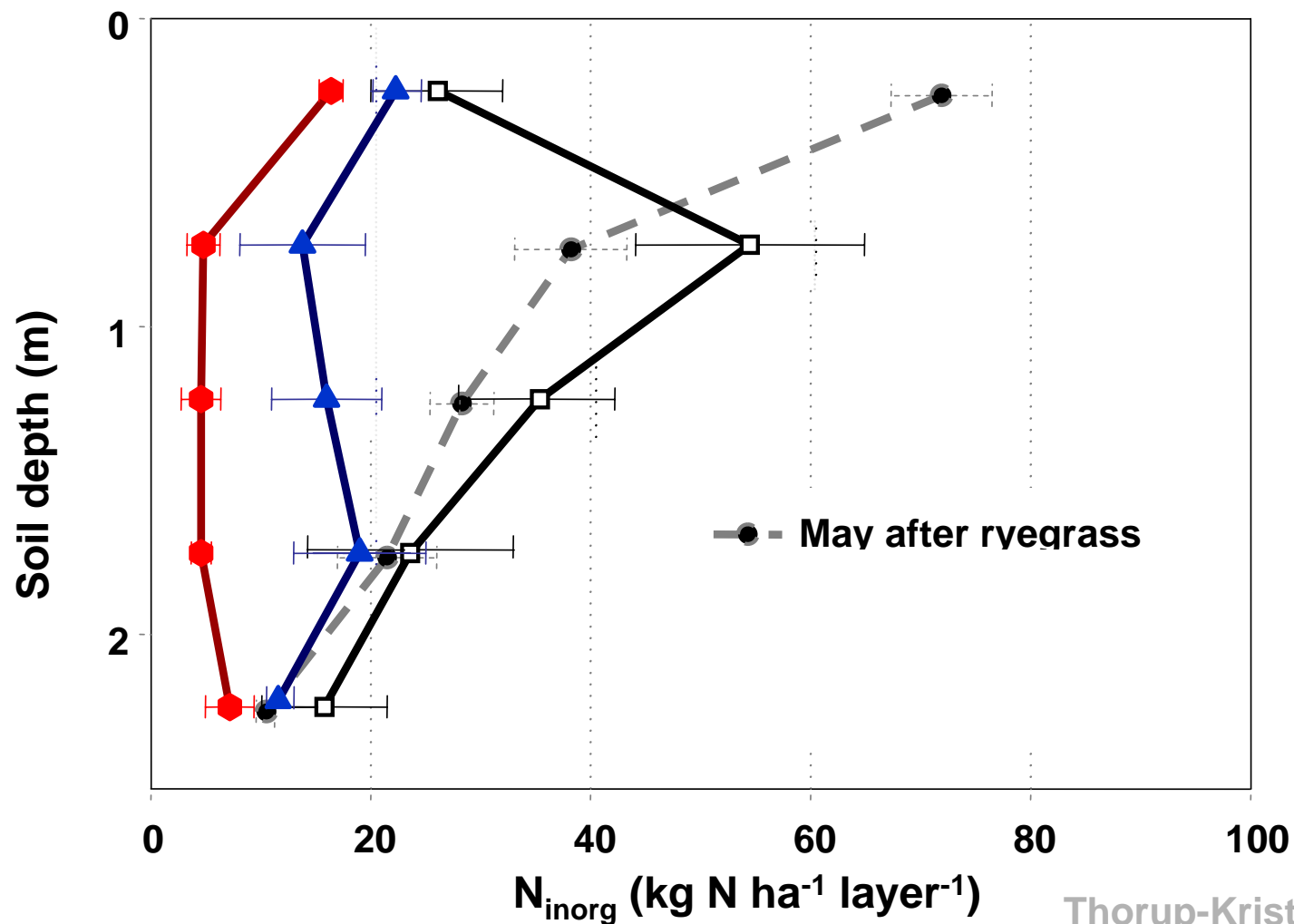
Soil layer 0.25-0.50 m

Soil layer 1.00-1.25 m



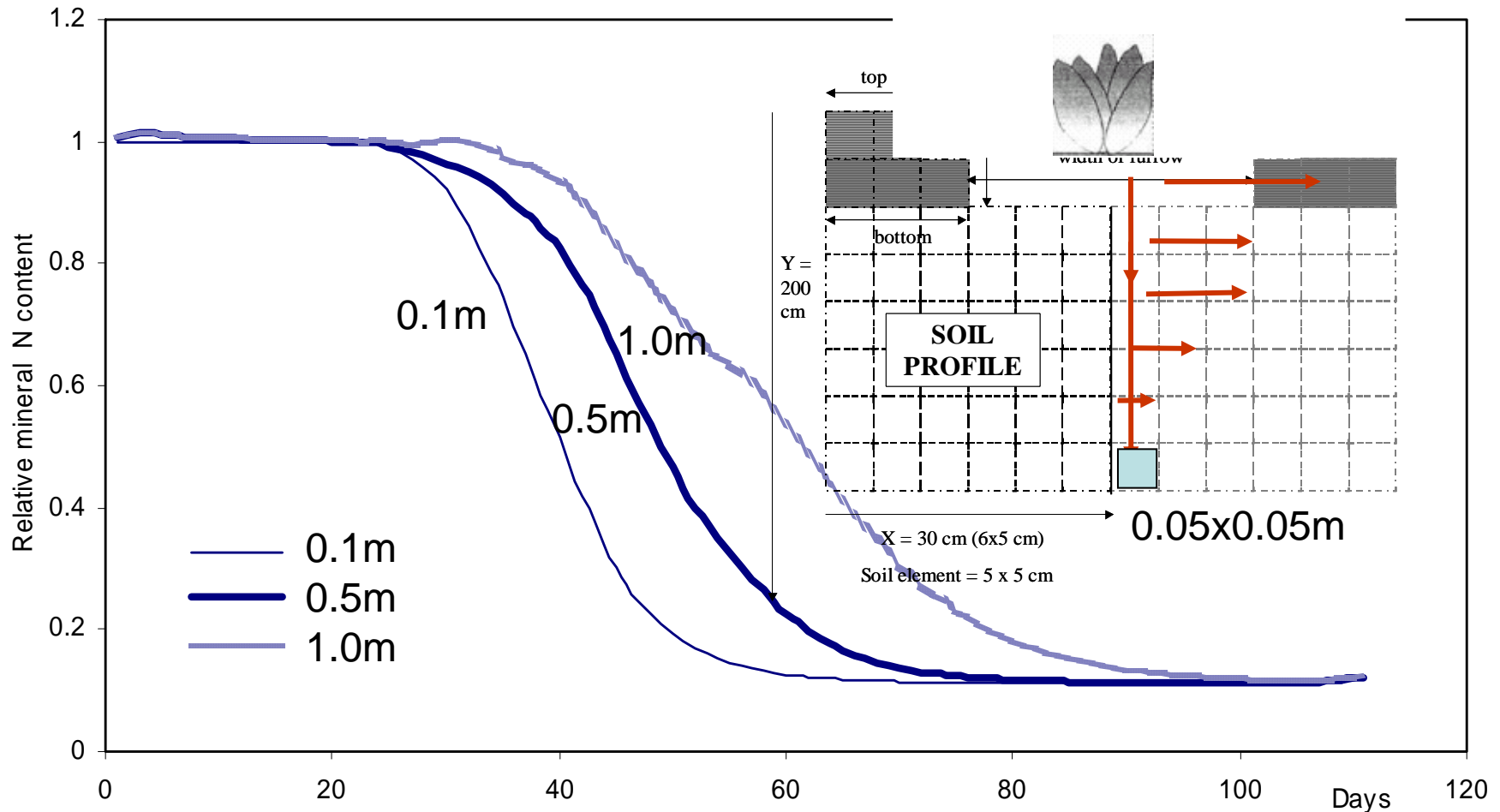
N uptake in the soil profile

Vegetable effect on N profile at harvest
- after ryegrass catch crop



Row crops, Increasing row width and N uptake

Soil layer 0.25-0.50 m




Conclusions

- Simple approach
 - To simple application for:
 - Calculating root length in the surface layer
 - Identical root density calculation as measured in field trials
 - Possible to model:
 - Rooting depth
 - Manage high or low root density in deeper soil layers
 - Simulate N uptake from deeper soil layers
 - Simulate different crop species in relation to N-uptake

Future work –paramatisation and validation of model to field data!

• More information at my poster


37th Biological Systems Simulation Conference Beltsville, Maryland



Simulating Root Density Dynamics and Nitrogen Uptake -Field Trials and Root Model Approach in Denmark

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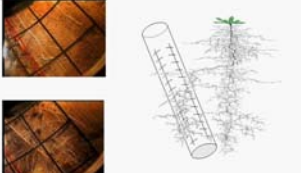


Field trial and atmosphere models are commonly used to predict crop yield and associated environmental consequences. Such models often include complex modeling of water movement, soil organic matter turnover and above ground plant growth. However, the root modeling in these models is often very simple, partly due to a limited access to experimental data. Here we propose a root model developed to describe root growth, root density and nitrogen uptake. The model focuses on annual crops, and attempts to model root growth of different crop species and root growth of nitrogen uptake from different parts of the soil volume.

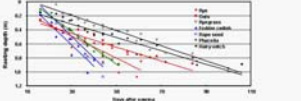
The approach was not to simulate a specific root architecture in soil profile—the intentions was to approximate actual N uptake in the whole rooting zone. And make a simulation tool to avoid nitrate leaching in short cereal and vegetable rotations!

Generally depth distribution of root density have been simulated by logarithmic functions. This seem to simulate the root systems of grasses and cereals reasonably well. However, many dicotyledonous crops show very different root distribution patterns, with higher root density at deeper soil layers than can be simulated by logarithmic equations. The depth distribution of these root systems appears to vary strongly enough to render crop species functions for simulating root distribution inaccurate. However, we have adjusted the logarithmic function to allow for a larger fraction of roots in deeper soil layers. The modelled distribution will not fully correspond to field observations, but algorithms for nitrogen uptake can be adjusted in order to better fit plant nitrogen uptake.

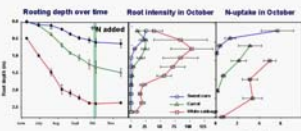
Field Trials



Microphotos studies
Microphotos were used to quantify root distribution, in this method for identifying and analyzing roots in the soil profile with an angle of 30° from vertical (0 to 20 cm depth). They can be placed in soil between the plant roots for analyzing horizontal and vertical growth. (Photo: G.P. Aarssen, Cleburne)



Rooting depth for cereals, oil seed and catch crop species under Danish conditions were measured using a microphotos. Cereals and oil seed species such as winter wheat, rye and barley have a high penetration rate and can obtain a rooting depth of more than 2.0 m in 3 months. Microphotos studies on catch crops such as lupine and cereals showed a lower root growth rate, after half the year of the fastest root growth of cereals. Penetration rate follows a linear increase with accumulated air temperature.



Field study to support model evaluation
Sweet corn, carrot and winter cabbage were grown in a Danish sandy rain soil (Kristensen and Thorup-Kristensen, 2004). Rooting depth and root intensity were measured using microphotos, in October. The results are shown in different soil layers to investigate from which layers the different crops are able to take up N.

Model Approach

Root model
The root model operates as a sub-model in a plant and soil model, receiving and sending information between the others modules on a daily basis. The root model receives information: Temperature, Water, Ammonia and Nitrate contents in each soil grid (0.05 m) and can be controlled with different crop specific parameter values.

The extension of the root system horizontal and vertically
Root distribution is calculated to a maximum depth of 2 m, which is a maximum width of half the crop height. The soil cells used in this way are 0.05 by 0.05 m. Rooting depth is calculated using accumulated temperature from the day the crop was planted. After a big period the rooting depth increases linearly with accumulated temperature. Three crop specific parameters are: α_{root} , β_{root} to maximum and maximum temperature for growth T_{max} is temperature. Root depth R_d is calculated as:

$$R_d = \begin{cases} 0 & \sum_{i=1}^n T_{max} - T_{i-1} < T_{max} \\ \sum_{i=1}^n T_{max} - T_{i-1} & \sum_{i=1}^n T_{max} - T_{i-1} > T_{max} \\ T_{max} & \sum_{i=1}^n T_{max} - T_{i-1} > T_{max} \end{cases}$$

α_{root} crop specific root penetration rate, T_{max} is the air in degree days, T_{i-1} cooling in planting depth. Same equation for horizontal development, where a crop specific rate β_{root} is used.

The total root length of the crop is calculated daily by a summation of calculated above ground biomass. Root length was obtained by using a specific root weight.

The root distribution horizontal and vertically

$$L_{i,j} = \begin{cases} L_{i,j} e^{-\alpha_{root} z} & z < R_d \\ 0 & z > R_d \\ L_{i,j} e^{-\alpha_{root} z} \left(\frac{z - R_d}{q \cdot R_d} \right) + 1.3 R_d & z > q \cdot R_d \\ 0 & z > q \cdot R_d, z > R_d \end{cases}$$

$L_{i,j}$ root length of soil depth z , $L_{i,j}$ root length of soil surface R_d rooting depth, a linear increase of root density below the exponentially decreasing part. This is a function of soil depth and soil surface. q is the ratio of the root length of the root in the soil. Root length is distributed in root layer (0.05 to 0.05 m) and q is distance in the middle of the root in above 0.05 m, root length in each layer will be distributed equally by the root weight in each single soil layer.

The N uptake of the roots
Nitrogen uptake is calculated as a function of crop nitrogen demand and potential root nitrogen uptake on a specific day. The simulated crop nitrogen demand is received from the crop growth part of the model. The potential supply from the soil is calculated as a function of the root length in each soil unit, which controls root nitrogen uptake efficiency. A function is used to balance actual nitrogen uptake according to crop nitrogen demand and potential root nitrogen uptake. When crop nitrogen demand and potential root nitrogen uptake are close to each other, the potential nitrogen uptake will be below the root weight, but at any height or low nitrogen supply relative to demand, the uptake will be fully controlled by crop nitrogen demand and potential root nitrogen uptake respectively. Once the calculated actual nitrogen uptake will be lower than the potential root nitrogen supply, when this is the case, the actual absorption of soil nitrogen will be reduced proportionally from the potential value of all soil units.

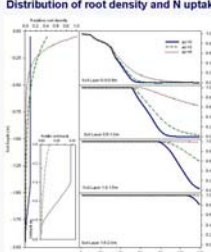
Conclusion
Although the presented model was built on a simple approach, it has the capacity to simulate different root distribution patterns by changing only one parameter, namely a root form factor which controls the root density in different soil layers. Root density is calculated by a modification of the Gentry and Page (1974) and Hansen et al. (1995) equation for root length density, in their approach root density at the bottom of the root zone was set to a fixed value when the root form parameter changes during the growth season. We set a fixed value for the root form parameter for root density distribution and set the root density at rooting depth to be variable.

In Figure 1 the root model flexibility is illustrated. The figures show a situation where all parameters are equal except the form factor value (i.e., and the second figure shows three different root penetration rates and were tested). By changing the form factor from 0 to 2 or 8 it is possible to simulate a wide range of root density profiles (Figure 1, left). This results in significantly different patterns in root nitrogen uptake from different layers in the soil profile (Figure 1, left). A slower root penetration rate determines the rooting depth (Figure 1, right) and reduce the ability to explore deeper soil layers. By controlling root form parameter, root penetration rate, root/soil ratio and root N uptake rate, it will be possible to adjust the simple root model to simulate nitrogen uptake dynamics in a realistic way in soil-plant simulations models.

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Model Application

Distribution of root density and N uptake



Root penetration rate and N uptake

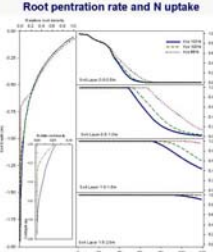
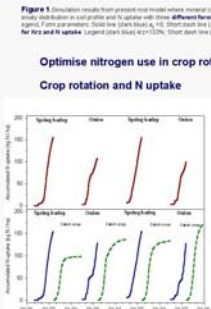


Figure 1. Simulation results from general root model where root form factor is set to 1.0. Left panel: Root density profile distribution in soil profile and N uptake with three different form parameters for α_{root} . Relative N uptake in four soil layers for three different form parameters. Same parameters: Solid line (dark blue) is 1.0, Dotted line (dark blue) is 0.5, Dashed line (dark blue) is 2.0. Right panel: Different root penetration rates for N and N uptake. Legend (dark blue) is 100%, Short dash line (dark green) is 100%, Dotted (dark blue) is 100%.

Optimise nitrogen use in crop rotations by use of a soil and plant model

Crop rotation and N uptake



Mineral N content and Nitrate leaching

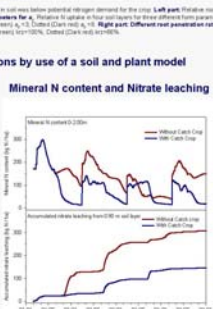


Figure 2. Root model used in a plant crop model to simulate N uptake in a crop rotation with and without use of catch crop. The root model will be used in crop models to study crop management strategies for optimal N application and reduction in nitrate leaching. The model will contribute to develop Codes of Good Agricultural Practice and in complying with the EU law Directive to reduce nitrate water quality.

• Thank you for your attention

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<http://www.darcof.dk/research/darcofii/i10.html>*
- **EU-Rotate_N** *European Community network to develop a model based decision support system to optimise nitrogen use in horticultural crop rotations across Europe*
- *<http://www.hri.ac.uk/eurotate/index.htm>*

- **Simulating Root Density Dynamics and Nitrogen Uptake – Can a Simple Approach be Sufficient?**
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