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

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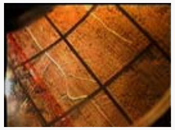
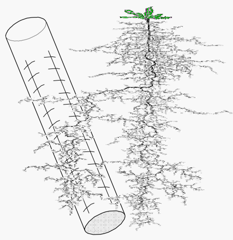
Plant soil and atmosphere models are commonly used to predict crop yield and associated environmental consequences. Such models often include complex modelling of water movement, soil organic matter turnover and above ground plant growth. However, the root modelling in these models is often very simple, 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 row crops and its significance for 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 actually 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 cross 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.

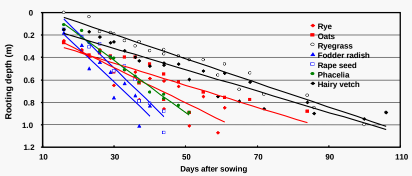
Field Trials





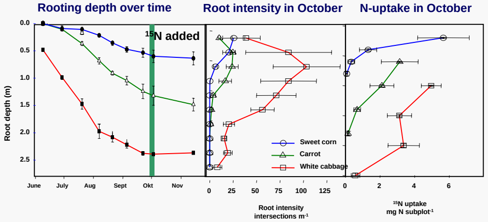
Minirhizotron studies

Minirhizotrons were used to provide a non-destructive, in situ method for directly viewing and studying roots in the soil profile with an angel of 35 ° from vertical in 0.0 to 2.5m depth. They can be placed in or between the plant rows for analysing horizontal and vertical growth. (Photo: DJF Aarslev, Denmark)



Rooting depth

Rooting depth for cereals, oil seed and catch crop species under Danish conditions were measured using a minirhizotron. Dicotyledonous species such as fodder radish, rape seed and phacelia have a high penetration rate and can obtain a rooting depth of more than 2.5 m in 3 months. Monocotyledonous species such as ryegrass and cereals shows a slower root penetration rate, often only half the rate of the fastest dicotyledonous species. Penetration rate follows a linear increase with accumulated air temperature.



Field study to support model evaluation

Sweet corn, carrot and white cabbage were grown in a Danish sandy loam soil (Kristensen and Thorup-Kristensen, 2004).Rooting depth and root intensity were measured using minirhizotrons. In October ^{15}N was added in different soil layer 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-module in a plant and soil model, receiving and sending information between the others modules on a daily basis. The root module receives information about: ***Temperature, Root biomass, Water, Ammonia and Nitrate*** content in each soil grid (0.05 x 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, and to a maximum width of half the crop row distance. The soil units used in this array are 0.05 by 0.05 m. Rooting depth is calculated using accumulated temperature from the day the crop was planted. After a lag period the rooting depth increases linearly with accumulated temperature. Here crop specific parameters are T_{min} and T_{max} for minimum and maximum temperature for growth. T_{air} is air temperature. Root depth. R_z is calculated as:

$$R_z = \begin{cases} 0 & ; \quad \sum T_{air} \le T_{lag} \\ \sum T_{air} - T_{lag} * k_{rz} + z_{min} & ; \quad \sum T_{air} > T_{lag} \\ z_{max} & ; \quad \sum T_{air} - T_{lag} * k_{rz} + z_{min} > z_{max} \end{cases}$$

K_{rz} crop specific root penetration rate. T_{lag} lag phase in degree days. Z_{min} sowing or planting depth.

Same equation for horizontal development, where a crop specific rate k_{rx} is used.

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

The root distribution horizontal and vertically

$$L_z = \begin{cases} L_0 e^{(-a_z * z)} \quad z < R_z & ; z < R_z \\ L_0 e^{(-a_z * z)} \left(1 - \frac{z - R_z}{q * R_z}\right) & ; 1.3R_z > z > R_z \\ 0 \quad z > q*R_z & ; z > R_z \end{cases}$$

L_z root length at soil depth z, L_0 root length at soil surface, R_z rooting depth. q linear increase of root density below the exponentially increasing part. This is a modification of the distribution of root length in Gerwith and Page (1974) and Hansen et al. (1990). Root length is distributed in soil layer (0.05 m layer), and if distance to the middle of the row is above 0.05 m, root length in each layer will be distributed horizontally to the root width 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 then 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 simulated nitrogen uptake will be below either value, but at very high or low nitrogen supply relative to demand, the uptake will be fully controlled by crop nitrogen demand and potential root nitrogen supply, respectively.

Often the calculated actual nitrogen uptake will be lower than the potential root nitrogen supply. When this is the case, the actual depletion of soil nitrogen will be reduced proportionally from the potential value in 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 Gerwitz and Page (1974) and Hansen et al. (1990) equation for root length density, in their approach root density at the bottom of the root zone was set to a fixed value whereas the root form parameter changes during the growth season. We set a fixed value for the root form parameter for root density distribution and let the root density at rooting depth be variable.

In Figures 1 the root model flexibility is illustrated. The figures show a situation where all parameters are equal except the form factor value (a_z) and the second figure where three different root penetration rates (krz) were tested. By changing the form factor from 0 to 3 or 8 it is possible to simulate a wide range of root density profiles (Figure 1, left). This results in significantly different patterns in soil nitrogen uptake from different layers in the soil profile (Figure 1, left). A slower root penetration rate determine the rooting depth (Figure 1, right) and reduce the ability to emptive deeper soil layers. By combining root form parameter, root penetration rate, root/shoot ratio and root N uptake rate, it will be possible to adapt this simple root model to simulate nitrogen uptake dynamics in a realistic way in soil-plant simulations models.

References

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Model Application

Distribution of root density and N uptake

Root pentration rate and N uptake

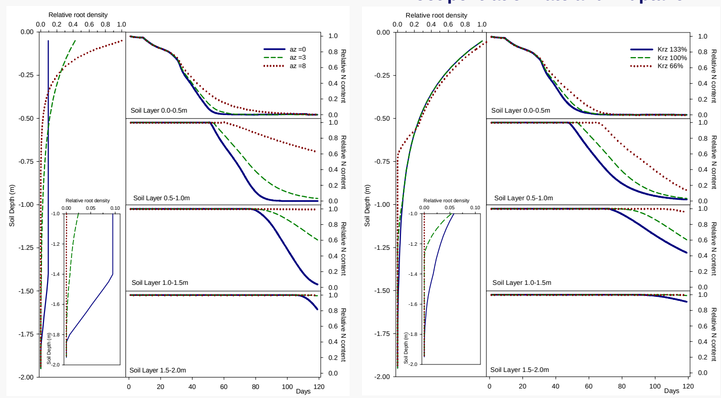

Figure 1. Simulation results from present root model where mineral content in soil was below potential nitrogen demand for the crop. **Left part:** Relative root ensity distribution in soil profile and N uptake with three **different form parameters for a_z**. Relative N uptake in four soil layers for three different form parameters. egend, Form parameters: Solid line (dark blue) a_z =0; Short dash line (dark green) a_z =3; Dotted (Dark red) a_z =8. **Right part: Different root penetration rates for Krz and N uptake**. Legend (dark blue) krz=133%; Short dash line (dark green) krz=100%; Dotted (Dark red) krz=66%.

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

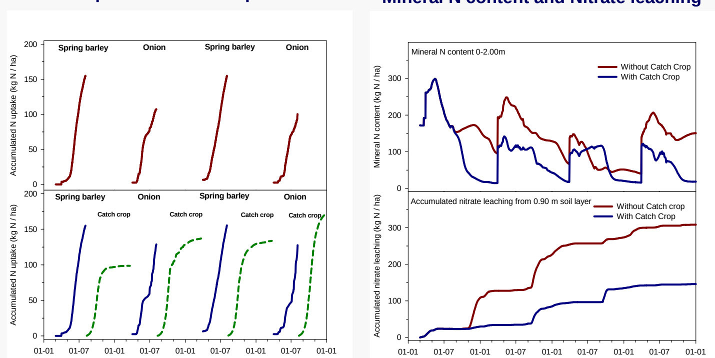

Figure 2. Root module used in a plant crop model to simulate N uptake in a crop rotation with and without use of catch crop. The root model will be used in crop models to identify crop management strategies for optimal N application and reduction in nitrate leaching. The model will contribute to develop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

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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