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The Role of Organic Soil Profiles on Water Availability in Forests: Sensitivity Analyses

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Abstract

This research concerns the soil organic matter linked availability of water in forests on dry, sandy soils. Results show that changes in soil organic matter (SOM) storage influences soil water retention, especially at low SOM contents. Further the organic forest floor allows a significant evaporation flux from the forest floor (yearly max. 30% of the evapotranspiration). Sensitivity analyses show that forest transpiration is only indirectly affected by SOM. A change in water retention does hardly change the transpiration but can alter the strategies of water uptake by roots. Global changes can thus indirectly affect the vitality of forests although the effects may vary with soil type.

1. Introduction

Forest growth and development is related to soil organic matter (SOM) dynamics and water supply. In order to estimate the sensitivity of forest development to climatic change, it is necessary to have the relations in figure 1 quantified. As a part of this research effort, we study organic matter linked water availability in forests on sandy soils. We presume that these forests are sensitive to climate change because 1) changing meteorological conditions may alter the supply of water and the transpiration demand, and 2) altered primary production and decomposition may change the accumulation of soil organic matter in the mineral soil and organic debris on the forest floor, both changing the water availability in the soil profile.

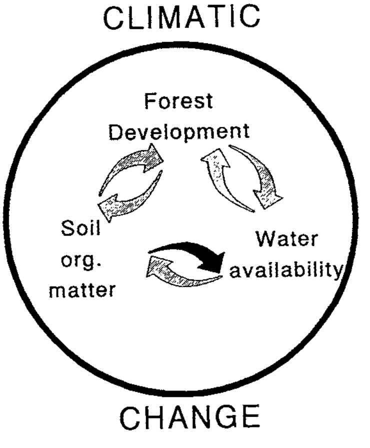

Figure 1. The relations between forest development, soil organic matter and water availability. Our project is represented by a black arrow.

In this project we focused only on the effects of different SOM levels on soil water availability. A high water availability leads to optimal transpiration and carbon assimilation. Soil organic matter influences forest hydrology in three ways:

A. Changes in hydraulic functions of the mineral soil
B. Changes in the amount of dead organic debris on the forest floor
C. Adaption of the root system

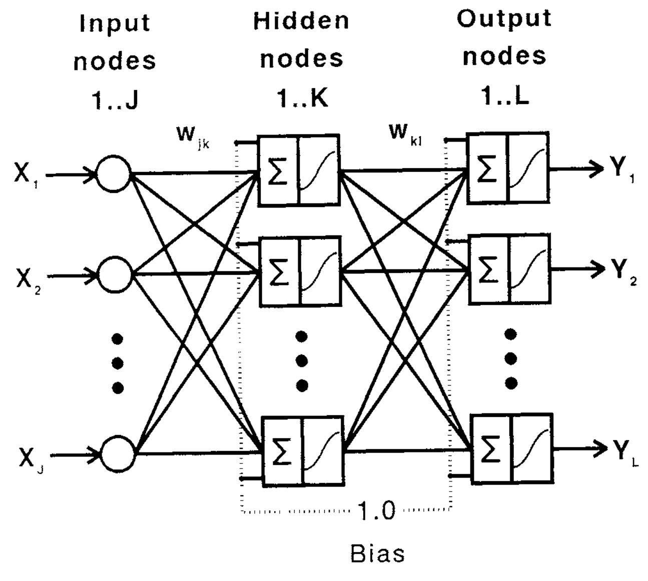

Figure 2. General structure of the neural network as used in this project. Model input is represented with X, model output with Y. Using selected examples an optimizing algorithm takes care that the neural network 'learns' to predict Y from X without the need for an a-priory model.

2. Results

We used a neural network to link soil water characteristics to organic matter contents, the density and textural properties of the soil. The new technique of neural networks allowed us to establish a more reliable model for the retention characteristic than with other methods. Retention characteristics were predicted for two soils of existing Douglas fir sites in the central part of the Netherlands. Both soils mainly differ in soil texture, resulting in a lower water retention in site 1 than in site 2 (figure 3). The organic matter contents were changed from 0 to 200 % of the present level. Water availability appears to increase with SOM, especially at low content. Figure 3 shows that the

difference between field capacity (θ_{FC}) or the point of water uptake reduction (θ_{RED}) and the wilting point (θ_W) is higher on site 2.
The forest floor (FF) can be significant in water supply to trees because it can store large amounts of water (up to 20 mm) which can either be discharged to the root system or evaporated. With a two year monitoring program of FF water contents and evaporation we estimated a FF evaporation of 85 mm per year in a dense Douglas fir forest (site 2). Higher amounts are expected for forests with a lower canopy density.
Root development is linked to soil organic matter because of the supply of water and nutrients and because of the mechanical limitations for root penetration at low porosities which only occur at very low SOM.

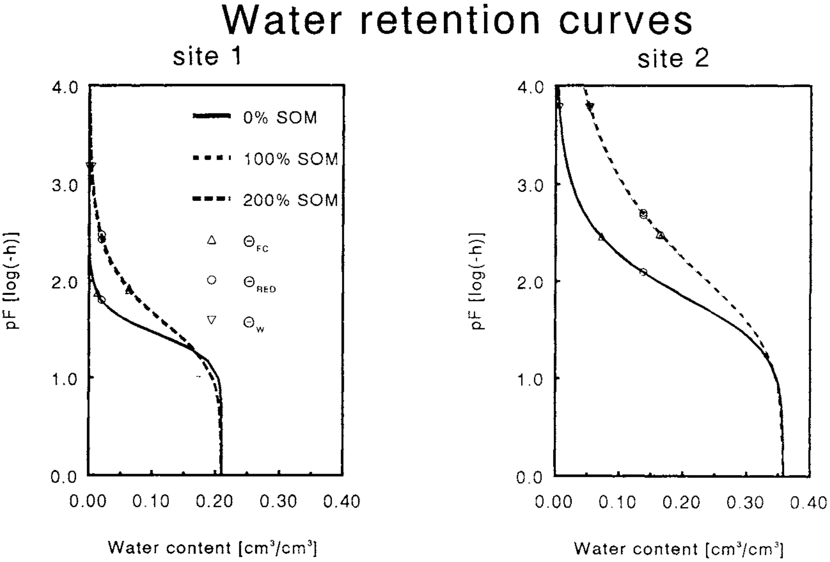

Figure 3A and B. Modeled water retention characteristics for site 1 and 2 as well as hydrologically relevant water contents. θ_{FC}: field capacity water content after free drainage in winter, θ_{RED} point of reduced water uptake, θ_W: wilting point.

3. Sensitivity analyses

It is difficult to predict a-priory what the integrated effects SOM on the water availability will be because root water uptake is a process with many feedbacks. Answers can only be obtained with dynamic models calculating forest transpiration from altered soil properties and meteorological variables. We used the FORest HYDrological package (FORHYD) to perform sensitivity analyses of the transpiration of two Douglas fir forests

while varying the amount of soil organic matter, using the meteorological conditions of the past 30 years.
Water availability was evaluated as the transpiration reduction (RED), calculated from the potential Makkink-transpiration (PT) and the actual transpiration (AT):

$$RED = 100 \, \frac{PT - AT}{PT}$$

Figures 4A and B show the transpiration reduction as influenced by hydraulic properties which change with organic matter content. To produce these figures, only one property was varied at the time while the others were kept constant. It appears that the point of root water uptake reduction is the dominating factor. Further, the transpiration reduction increases with lower SOM. An increase of SOM above the present level hardly affects the reduction. The impact of SOM is greatest in site 2 which has a higher water availability. This is confirmed in the three dimensional diagrams which show the transpiration reduction when SOM is varied simultaneously with forest floor thickness or with root depth. A decrease in SOM increases the reduction more in site 2. This can be explained by the difference in effective storage: in figure 3A and B the mineral soil water content difference between field capacity and the wilting point is far greater in site 2 than in site 1. Therefore, the thickness of the forest floor is more important in site 1 than site 2 (fig. 5A and 5B) because this layer can supply a part of the desired water uptake. For the same reason the transpiration reduction decreases much more in site 1 than in site 2 if the rooting depth is varied (fig. 5C and 5D). A deeper extending root system allows more water uptake from the mineral soil. Due to the better water retention, site 2 has already sufficient water storage with a limited rooting depth, an increase of roots beyond 50 cm decreases the reduction less than site 1. Whether trees can extend roots to deeper soil layers depends mainly on penetration resistance or soil chemical limitations. The penetration resistance is determined by bulk density and organic matter content and to a lesser extent the soil texture. In fact, the rooting depth in site 1 was only 30 cm due to mechanical resistance and 200 cm in site 2, which leads to large differences in present transpiration reduction between the sites.

4. Conclusions

Our research lead to quantification of the relation ships between soil water retention characteristics, soil organic matter content and soil texture. Soil texture was the main determining factor in the water retention characteristic, while SOM increases effective water storage, especially at low SOM contents (fig. 3A and B). However, sensitivity analyses show that forest transpiration is linked to SOM due to alteration of root water uptake effectiveness rather than altered soil water retention.

Measurements showed that forest floor evaporation is higher than previously estimated. Yearly amounts may be as high as 30% of the evapotranspiration or 80-150 mm per year. Forest floor transpiration can thus cause a significant decrease in water availability, especially in more open types of forest where wind speeds and radiation levels at the forest floor are high.

Concluding it is expected that forests on uniformly textured poor (drift sand) soils are sensitive to forest floor thickness and root depth. Forests or broadly textured (river or glacial) soils are more dependent on the amount of SOM in the mineral soil but have a high water holding capacity. Possible future changes in meteorological circumstances (rainfall and evaporation patterns) would therefore have a larger impact in the water availability of forests on uniformly textured soils. Changes in accumulation and decomposition of SOM would have a larger effect of forests with soils having broader textures. The research results still need to be integrated with predictions of SOM accumulation or decomposition dynamics and altered meteorological conditions due to climatic change.

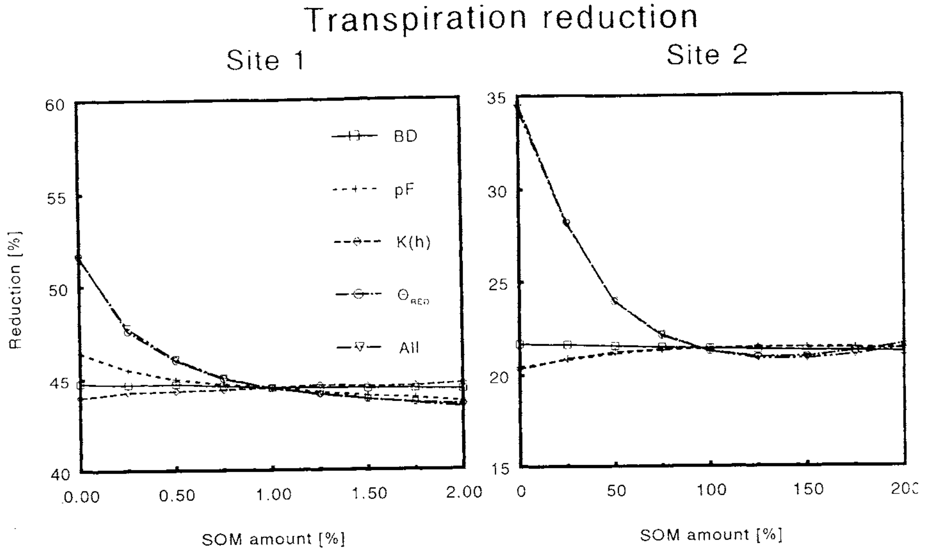

Figure 4A,B. Transpiration reduction as affected by soil hydraulic properties varying with soil organic matter content. One property is varied at the time while the rest is kept constant. pF: water retention characteristic, K(h) hydraulic conductivity, BD: soil bulk density, θ_{RED} point of water uptake reduction, All: all properties varied.

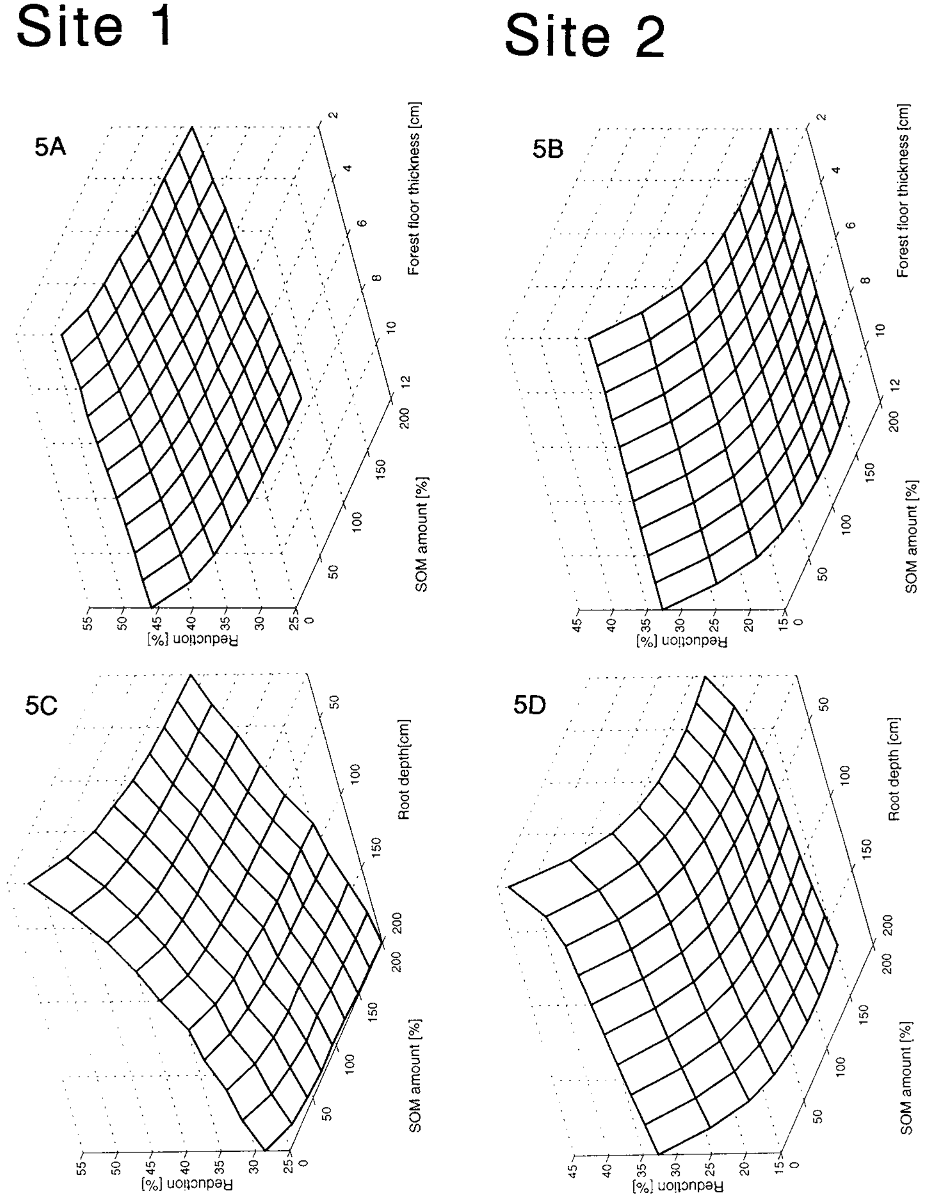

Figure 5A-D. Transpiration reduction dependent on the simultaneous variation of mineral soil SOM and forest floor thickness (5A and B) and mineral soil SOM and root depth (5C and D).