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Modeling root length density of field grown potatoes under different irrigation strategies and soil textures using artificial neural networks

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ABSTRACT

Root length density (RLD) is a highly wanted parameter for use in crop growth modeling but difficult to measure under field conditions. Therefore, artificial neural networks (ANNs) were implemented to predict the RLD of field grown potatoes that were subject to three irrigation strategies and three soil textures with different soil water status and soil densities. The objectives of the study were to test whether soil textural information, soil water status, and soil density might be used by ANN to simulate RLD at harvest. In the study 63 data pairs were divided into data sets of training (80% of the data) and testing (20% of the data). A feed forward three-layer perceptron network and the sigmoid, hyperbolic tangent, and linear transfer functions were used for the ANN modeling. The RLDs (target variable) in different soil layers were predicted by nine ANNs representing combinations (models) of the eight input variables: soil layer intervals (D), percentages of sand (Sa), silt (Si), and clay (Cl), bulk density of soil layers (Bd), weighted soil moisture deficit during the irrigation strategies period (SMD), geometric mean particle size diameter (d_g), and geometric standard deviation (σ_g). The results of the study showed that all the nine ANN models predicted the target RLD values satisfactorily with a correlation coefficient $R^2 > 0.98$. The simplest and most complex ANN architectures were 3:2:1 and 5:5:1 consisting of D, SMD, d_g, and D, Bd, SMD, σ_g, d_g as the input variables, respectively. Low values of normalized root mean square error (NRMSE) (min = 0.101, max = 0.227) and mean absolute error (MAE) (min = 0.345 cm cm^{-3}, max = 0.79 cm cm^{-3}) proved the high capability of the ANN to predict RLD. The RLD prediction was more accurate in the top soil layers than in the deeper layers; this discrepancy could be possibly attributed to the non-homogenous root distribution in the three soil textures, soil pore structure, and nutrient availability. Results also implied that ANN is a strong modeling tool for simulating the RLD in small data sets. Conclusively, ANN is a powerful tool to predict RLD under a range of soil physical conditions with a high degree of accuracy and may be used in crop growth modeling.

1. Introduction

Roots are the sole part of the crops that take up water and nutrients from the soil profile. In agricultural and ecological studies root distribution is a very important plant trait that plays a major role in the soil–plant–atmosphere continuum. Root growth and distribution is highly dependent on the conditions and environment where the crop is growing (Stalham and Allen, 2001; Benjamin and Nielsen, 2006; Ahmadi et al., 2011). Therefore, the understanding of how root grows and develops under diverse environmental conditions is very important in terrestrial ecological systems (Qiao et al., 2010).

Besides invasive and non-invasive field and greenhouse methods have been developed to monitor and measure root distribution pattern and production (Parker et al., 1991; Smit et al., 2000), there are several practical concerns about soil sampling for root study purposes (Smit et al., 2000). The crop growth models generally need the root length density (RLD, length of root in a unit volume of soil) as input for the root water uptake module and it is assumed that water uptake is proportional to RLD (Abrahamsen and Hansen, 2000; Heidmann et al., 2008). (Zuo et al., 2004) reported that although root distribution can be described with a single function during the growing season, it still needs extensive or at least one

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