Quantifying seasonal transpiration of winter wheat with different root length distributions

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Abstract. In this study the effect of root growth and root length distribution on seasonal transpiration of winter wheat grown in a medium European soil under a temperate maritime climate was numerically investigated using an agro-hydrological model. Rooting depth of the crop was assumed to be proportional to the above-ground dry weight, and root length distribution was exponential from the soil surface with a shape parameter controlling root distribution. Results show that in dry growing years only about half potential transpiration was met, and more than 90% potential transpiration was supplied in wet growing years in both scenarios with a different shape parameter value. The seasonable transpiration with the shape parameter equal to 1 increased by 0.7% to 12.8% with the overall value of 5.6% over the simulation period of 21 years, compared with those from the shape parameter value of 3.

1. Introduction

Agricultural water use is increasingly becoming a pressing issue due to water shortage worldwide and extreme water scarce caused by global warming. A great deal of efforts has been directed towards devising effective irrigation techniques and developing numerical models to save water use in crop production[1-3].

Nowadays, numerical models are well accepted as a powerful tool for precise water and nutrient use in agriculture[2,4]. Greenwood et al. have reviewed the application of such models for the irrigation purpose[5]. A key process in such models is the quantification of root dynamics since both root length density and distribution are closely related to water uptake from soil[6]. On one hand, the effect of root length distribution on water uptake requires further investigation despite great advances in the area over the last few decades. On the other hand, with the development of molecular biology in plant science, scientists are now even able to manipulate root systems to enhance use efficiency of water and nutrient resources. However, the consequences of the root manipulation on water acquisition need to be quantified in order to develop effective root systems under different circumstances. It is, therefore, important to understand the relationship between the root length distribution and water uptake.

The main purpose of this study was first to investigate the effect of root length distribution on seasonal transpiration of winter wheat over a number of years using a validated agro-hydrological model.
model, and then to quantify the differences in meeting potential transpiration between dry and wet years.

2. Materials and methods

The model used in this study was proposed by Yang et al.[6]. The capability of the model in simulating root water uptake was validated fairly extensively over a number of crops and soils. The detailed description of the model can be seen elsewhere[6]. In order to run the model, three types of input data are required.

2.1. Model parameters used in the simulations

The model parameter values used in the simulations are as follows.

**Soil data:** The soil hydraulic functions used in simulations are given by van Genuchten (V-G)[7]. A medium European soil with the topsoil of 30 cm was selected. The soil hydraulic property values for topsoil and subsoil were from Wösten et al.[8] where a comprehensive soil database was constructed based on an extensive survey on soils across the entire Europe.

|          | θs (cm³/cm³) | θr (cm³/cm³) | α (1/cm) | n (-) | Ks (cm/h) |
|----------|--------------|--------------|----------|-------|-----------|
| Topsoil  | 0.439        | 0.01         | 0.0314   | 1.1804| 12.1      |
| Subsoil  | 0.392        | 0.01         | 0.0249   | 1.1689| 10.8      |

Crop data: Winter wheat was selected in this study. The crop was planted in October previous year, and harvested in late August. Durations of various growth stages and their corresponding crop coefficient for potential transpiration were according to the FAO56[9]. Rooting depth was assumed to be proportional to the above-ground dry weight in a way proposed by Greenwood[10]. Root length distribution was exponential from the soil surface, similar with that by Pedersen et al.[11], i.e.

\[ L(z_R) = e^{-\alpha z_R} \left[ \alpha z_R / (1 - e^{-\alpha z_R}) \right] \] (1)

where \( L \) is the normalised root length density at \( z_R \) (0–1), and \( \alpha \) is the shape parameter for root length distribution (see Figure 1).

![Figure 1. Normalised root distributions used in the simulations](image)

Weather data: Actual measured weather data, including daily air temperature, relative humidity, rainfall, solar radiation and wind speed, at the Wellesbourne weather station UK from 1989-2009 was...
used. The weather data was mainly used for calculating daily evapotranspiration based on the FAO56 approach[9]. The cumulative rainfall for the simulation period in each year is shown in Figure 2.

Figure 2. Cumulative rainfall for each simulation period during 1989-2009

2.2. Simulation period and initial conditions
For each growing season, the simulation was carried out from DOY1 (Day Of Year) to DOY210 (assuming senescence starts 30 days before harvest), and the soil water content in the profile on DOY1 was at field capacity. The maximum rooting depth was 150 cm. Two scenarios with the value of the shape parameter $\alpha_z$ for root length distribution of 3 and 1 were simulated.

3. Results and analysis

3.1. Comparison of cumulative rainfall and transpiration
Over the growing season the cumulative rainfall varied from 223.1 to 558.4 mm, and the cumulative potential transpiration ranged from 326.8 to 461.6 mm, indicating that in dry growing seasons the potential transpiration greatly exceeded the cumulative rainfall. It can be seen that Figure 2 and Figure 3 generally have the same pattern, i.e greater cumulative rainfall led to greater satisfaction to meet the potential transpiration. Results showed that in dry growing seasons only about half potential transpiration was met, while more than 90% potential transpiration was supplied in wet growing seasons in both scenarios. Figure 3 also revealed that in each year the root system with the shape parameter $\alpha_z$ of 1 extracted more water from soil profile. Furthermore, it is worth pointing out that in dry growing seasons the amount of water stored in the soil from the previous winter could make a significant contribution to satisfy crop transpiration.

Figure 3. Effect of different root shape parameter on seasonal transpiration (cumu Tact: simulated seasonal transpiration, cumu Tpot: potential seasonal transpiration)
3.2. Benefit of increase in transpiration
The seasonable transpiration with $\alpha_z$ being 1 increased by 0.7% to 12.8% with the overall value of 5.6% over the simulation period of 21 years, compared with those from $\alpha_z$ of 3 (see Figure 4). This implied that more roots distributed in the subsoil could increase water uptake by root systems under temperate maritime climates. It has been well documented that wheat grain yield is positively correlated with seasonal transpiration\cite{12-14}. The results in this study indicate that the increase in winter wheat yield could be achieved by developing a species which has a more evenly distributed root system in the soil profile.

![Figure 4. Overall effect of altering root shape parameter on transpiration](image)

4. Conclusions
The following conclusions could be drawn from this study: (1) agro-hydrological models are powerful tools to study the soil-crop water relations and the relationship between crop yield and transpiration, and (2) distributing more roots in the deep soil is beneficial in enhancing the capacity of water acquisition by root systems under temperate maritime climates.

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