Root descriptions of crop simulation models -do they serve studies of climate-smart agriculture?

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Introduction

Climate-Smart Agriculture (CSA) is increasingly framing the studies that apply crop simulation models (CSMs). This approach that combines sustainable intensification of production, climate change adaptation and mitigation places new demands on the use of models and the processes and variables they describe. CSA-related model applications require both reliable estimates of crop responses to changing growing conditions and accurate estimates of rising number of variables and processes with variable management options. For example, soil carbon balances are increasingly important to be able to assess the CO_2 sequestration potential of agricultural soils. CSMs should thus cover carbon, water and nutrient cycles and their interconnections with sufficient accuracy.

Plant root growth and other root-related processes are in many ways central elements in CSMs. Roots take care of crop water and nutrient uptake and rhizodeposition is considered the main source of stabilised carbon input to soil. Due to the obvious challenges in observing roots and related below-ground processes, our knowledge on how they respond to environment and management is still very limited compared to what is known about the responses of above-ground biomass. It is important to identify and acknowledge the key limitations in the root descriptions, how they affect the reliability of CSM results in CSA studies and what are the most efficient ways to improve them.

Material and Methods

We reviewed altogether more than 30 CSMs and model versions for the approaches they apply for describing the root systems of crops and factors affecting them. Models ranged from detailed, site-specific agroecosystem models to large area vegetation models. The scientific papers describing the models, user manuals and other technical model documents were used as a primary source of information. Models were reviewed for the variables and factors affecting root growth, root mortality, rooting depth, assumptions on root density distributions, possible root exudates and root quality parameters.

Results and Discussion

Our results showed a wide range of approaches for root descriptions which varied from very simple assumptions to detailed descriptions of root 3d-architectures.

Root biomass is calculated as an explicit model variable in most of the CSMs. Root biomass growth is linked to the development of the above-ground biomass with crop or cultivar specific allocation factors that depend on the crop phenological state. In few models only the biomass allocation to roots responses to changes in temperature, soil water content or nutrient status. Root mortality descriptions were overall very rough and were mainly linked to crop phenology. Direct impacts of crop or soil management on root biomass were implemented only in a couple of models. Root exudates as a flow of carbon from plants to soil were explicitly considered in only one of the models.

Rooting depth is an important determinant of plant's access to water and nutrient reservoirs available in the soil profile. The maximum depth reached by root system was the most common factor used to describe roots in the models. It is in nearly all cases linked to accumulated temperature sums. In some models, low soil temperature hinders the root depth progression. Root depth development was also impacted by drought stress or excess of water in some models, but the responses were sometimes contradictory. Soil nutrient status affected the root depth progression directly only in couple of the models. Soil physical limitations for root penetrations is considered in nearly all of the models either with a soil-specific maximum rooting depth or with layer-specific factors describing physical conditions for root growth. Root distribution over the soil profile in the models was in most cases assumed exponential, linear or sigmoidal. There was in some models link from root biomass to root length, but in many models these two aspects were not explicitly linked.

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Increasing demands for accurate root descriptions are coming particularly from the need to find effective means for climate change mitigation and biodiversity conservation. For example, more diverse cropping systems including grasslands with high plant diversity and intercropping with species that have different rooting patterns will bring new demands to cover essential root processes effectively. In addition, covering the impacts of extreme weather events, such as droughts and heavy rains, on crop production will require more detailed descriptions of the responses of root growth processes to them.

Enhanced knowledge on roots and processes affecting their development is necessary for effectively and robustly supporting the development of solutions for CSA. New development in methods for studying roots, such as root-image analyses and DNA-based root quantification methods from small soil samples, may provide useful data also for model development in near future.

Keywords: root responses, process descriptions, model improvements, rhizodeposition, below-ground biomass.