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The comparison of calculated and experimentally determined available water supply in the root zone of selected crops

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Abstract

Determination of the water supply available in soils for crops is important for a calculation of the water balance, and the prediction of water shortages. Available water content, at several Czech Republic localities at the start of growth, were calculated with simple pedotransfer functions from the texture of soil layers, and compared to water contents to a depth of 130 cm, determined experimentally. Available water content in the root zone of selected crops was calculated from data on root density distribution and from the estimation of water depletion distribution.

Keywords: water shortage, root system, depletion, texture

Introduction

Drought poses a serious problem for farmers in a large part of the world. Under the climatic conditions of the Czech Republic, fluctuations of precipitation often cause water shortages at critical stages of growth; especially, during yield formation, when the winter supply of water is exhausted and precipitation is not sufficient to cover the high evapotranspirative demands of a crop.

Farmers have demanded innovations and tools from agricultural researchers to apply measures for reducing the negative impacts of drought. Improvements of water use effectiveness is an urgent task for applied crop research. It is evident that the approach for an effective solution must be complex and needs to include several measures: new stress tolerant and plastic cultivars, innovative technologies of seeding, fertilizing or soil tillage, use of growth regulators and anti-stress compounds, as well as measures for sustaining and enhancing soil water capacity. Root system traits and effective utilization of the water supply from the root zone is recognized as some of key factors in the effort.

Calculation of the available soil water supply for a crop is a need for predictions of the onset of water shortage, and decisions for the support of relevant agronomic measures on both the short- and long-term scales. Considering the water supply of a given field, the site, year, and cultivar-specific crop management demands reliable data on the availability of water from a soil profile. The distribution of roots in a soil profile is the basis for calculations of water and nutrient uptake from the different soil zones. Any description of root development, related to water and nutrient uptakes, includes many physiological, developmental, and morphological traits of greater and lesser importance. When calculating the uptake, the demand for water and nutrients is distributed according to root distribution and the availability of the source (e.g., Kuhlmann et al. 1989). Primarily, it is the root length distribution (root density) used; however, Himmelbauer et al. (2008) did not find significant differences between the water extraction functions (sink term) based on the root dry mass, length, or surface area density distribution of three crops. The maximum root penetration and rooting depth is important for determinations of the potential utilization of water reserves in the deep subsoil layers (e.g., Kirkegaard et al. 2007). The root density of annual crops decreases with depth; in most cases exponentially or near linearly (Haberle & Svoboda 2014, Zuo et al. 2013). Annual crops reach their maximum root length and depth at about the time of flowering; during seed growth the root depth does not significantly increase. In cases of an exhaustion of available water and nutrients from the top soil zones, the deep subsoil layers may represent a significant reserve for overcoming periods of temporary shortage (Kong et al. 2013).

Under farm conditions, simplified approaches for estimations of the available water supply for a given crop must be used. As the first step, the amount of water in the soil at the start of growth must be determined or estimated. It is often assumed in model calculations that soils reach their maximum available water content after winter, at the start of the regeneration of winter crops or at the start of the growth of spring crops. Further, the water available for root uptake needs to be specified. The maximum possible physiological depletion of water from the root zone can only be observed when water in the top soil is exhausted and the demand has been shifted to deeper and less densely rooted soil layers.

The aim of the study was to compare the calculated and observed available water contents in the soil, and to estimate the maximum possible depletion of the supply in relationship to the root distributions of several crops.

Materials and methods

At the start of spring growth of six crops, the soil gravimetric water content to a depth of 130 cm was determined in nine sites with different soil-climate conditions: Praha-Ruzyně, Chrášťany (near Rakovník), Čáslav, Lukavec at Pacov, Valečov, Ivanovice na Hané, Dlouhá Třebová, Sudslava, and Horní Dobrouč (the last three are in the Ústí nad Orlicí region). Winter wheat, oilseed rape, spring barley, potatoes, sunflower, and maize were observed both in field experiments and farm fields. Water content in the soil layers (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-90 cm, 90-110 cm, and 110-130 cm) was calculated from the soil moisture and soil volume weight. The soil texture was determined in the laboratory of Research Institute for Soil and Water Conservation (VÚMOP, Ing. H. Macurová).The available water capacity (AWC) of the soil layers was calculated from the field capacity and wilting point (AWC=FC-WP), estimated with simple pedotransfer functions (Váša 1958, Váša 1960, Saxton et al. 1986, Novotný et al. 1990). Average values of FC and of WP calculated according to the authors were used for the following analysis. The values of AWC were reduced according to the content of soil particles greater than 2 mm in the respective soil layers.

The calculated AWC (to a depth of 100 cm or 130 cm), which represents the theoretical maximum water reserve for a crop, was compared with the experimentally determined available water content at the start of crop growth. For the latter, wilting points, calculated from soil texture were used (as also for the calculation of AWC), as no reliable data on the hydrolimit were available.

Further, precipitation and potential evapotranspiration sums calculated (according to Allen et al. (1998) from the 1st of October to the term of sampling are presented for the experimental sites.

Finally, the theoretical available water contents of the soil layers, determined from soil texture (AWC) and with observations in the fields, was corrected according to observed distributions of root density of the crop (Haberle, Svoboda 2012, 2014, Svoboda, Haberle 2006, and others). The roots were sampled after flowering, during seed filling, and tuber growth; at the stage of the maximum rooting depth. The cases with the lowest and highest root depth observed during several years in two or more sites (not only the experimental ones described here) were used to obtain more generally applicable outputs (Fig. 1). For a calculation of available water for the roots, a simplified empirical approach was used, based on previous studies (Haberle, Svoboda, 2012) and field observations of apparent depletion of soil water from the root zones of crops. The maximum utilization of water from the root zone is realized under conditions of well-developed root systems and crop canopy; with great evaporative demand, exhaustion of the available water from the top soil, and gradual depletion of water from the subsoil layers. We assume that 90% of potentially available water (AWC) from the arable layer is available for all crops, as the level of the wilting point is hardly attainable in field conditions, even under severe drought. In the subsoil layers, the potential maximum depletion decreases in direct relationship to the root density (RD). The maximum depletion (90%) of the amount of potentially available water (AWC) is used for RD greater than 0.9 cm.cm^{-3}. For the root density under 0.9 cm.cm^{-3}, the potential water depletion is proportionally related to root density (e.g., a RD of 0.15 cm.cm^{-3} enables a utilization of up to 15% of AWC).

From the data, root available water contents in a soil profile for the cases of maximum (AWC), as well as for the range (minimum and maximum), of the observed spring water contents for the lowest and the highest root densities were calculated and compared. The results represent ranges of water supply attainable for six crops at nine sites.

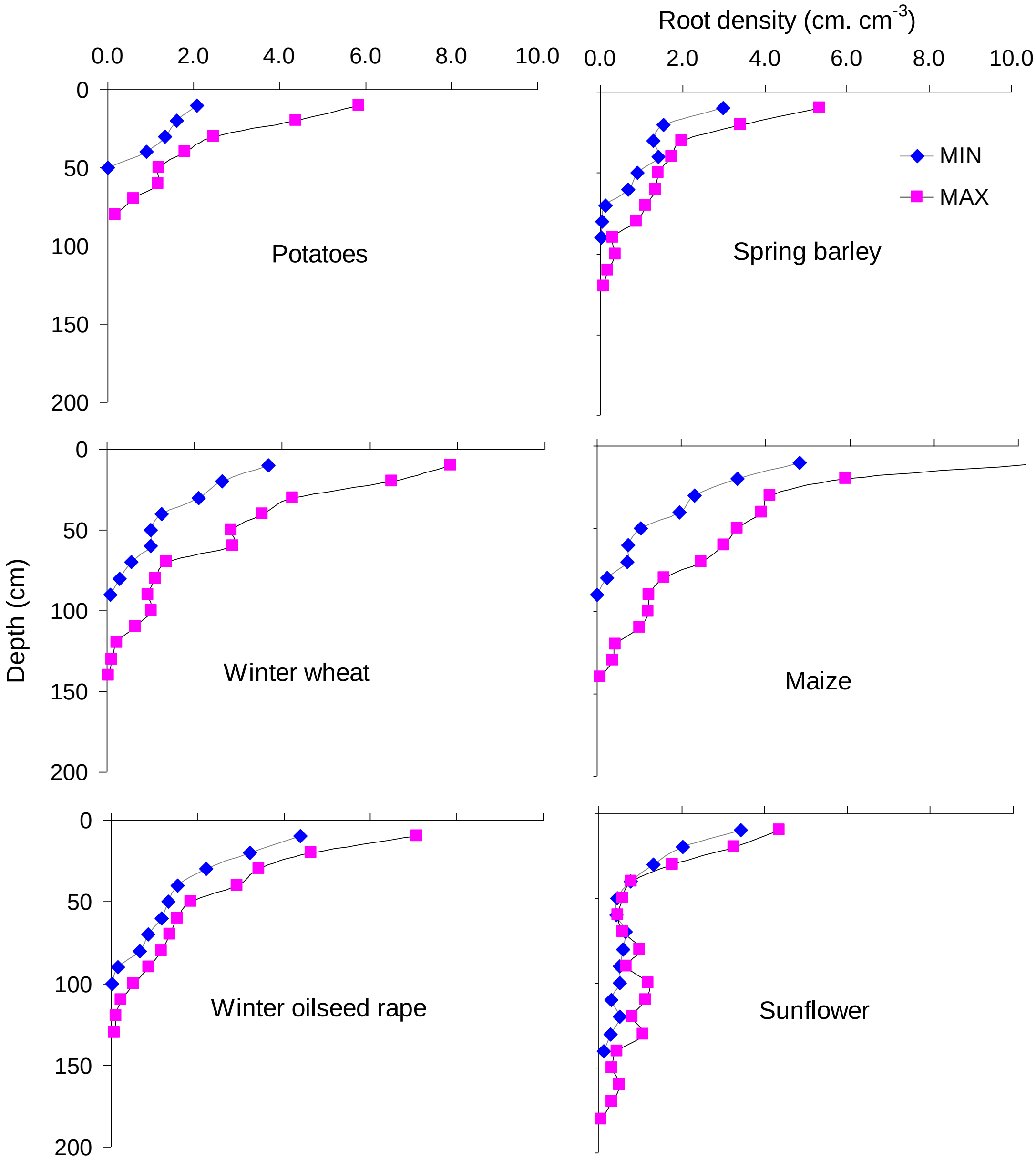

Fig.1: The lowest (MIN) and the highest (MAX) root densities observed in selected crops.

Results and discussion

The lowest and the highest observed root depth and density in the field are shown in Fig. 1. The differences are more pronounced in maize and winter wheat than in the other crops; however, the data can not cover the diversity of soil conditions in agricultural regions of the country. Also, the numbers of our experimental data are not balanced; we have gained in past years more results for cereals (especially winter wheat) than for sunflower or maize. Using the crop model CERES-Wheat, we showed that relatively small differences in root distribution had some impacts on simulated yield and water use but the effect seems small in comparison with other sources of uncertainty (Haberle, Svoboda 2014). Generally, the root depth of the crops corresponded to the published data and expected ranking of the crops: from shallow rooted potatoes, with less depth in spring cereals compared with winter one and maize, and a deep root system in the sunflower.

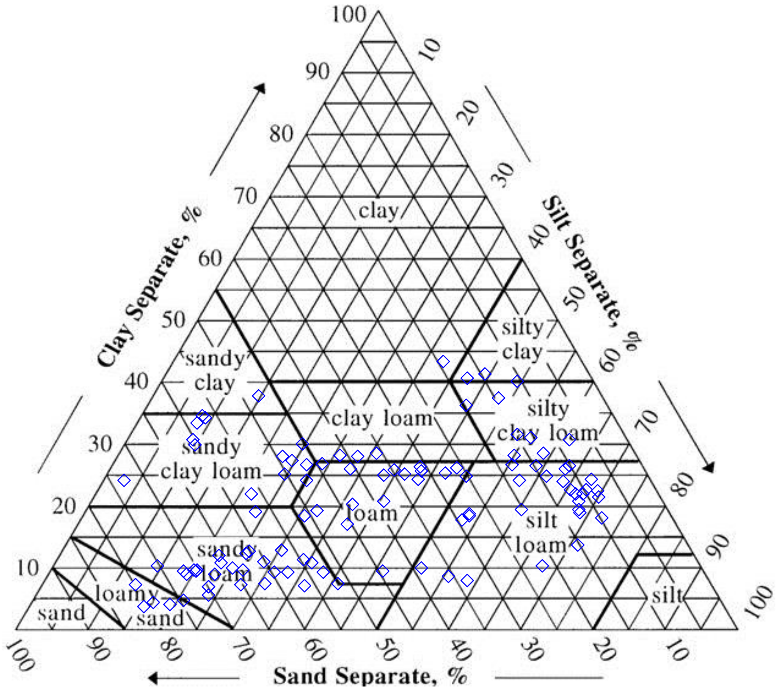

Fig. 2: The texture of soil layers at experimental sites drawn upon a background of a soil texture triangle.

The range of textures of the soil layers in the sites is shown on the basis of a soil triangle classification (Fig. 2). The textures ranged from sandy to clay soils; often but not always, the proportion of sand and gravel increased with depth. The calculated AWC in the 1 m soil layer ranged from 144 mm (178 mm in the 130 cm layer) in Chrášťany to 188 mm (241 mm) in Ivanovice (Fig. 3). When individual PTF were used, the range of AWC was wider - from 126 to 227 mm (150 - 270 mm) (not shown), which shows onother source of uncertainty of the analysis. Comparison with data in the literature is difficult, as the approaches and calculations differ greatly. Often, the classes of soil with ranges of AWC from less than 79 mm to greater than 200 mm, in one meter of soil, are used for Czech soils (e.g., http://sucho.vumop.cz/mapserv/sucho/uvodni.php) or in the AVISO agroclimatic model (Richterová, Kohut, 2013). In the cases gravel and stone content was probably not considered. AWCs used in the current CGMS for the region of the Czech Republic are mostly in the range of 75-175 mm (http://eusoils.jrc.ec.europa.eu/projects/sinfo/5_3_en.htm).

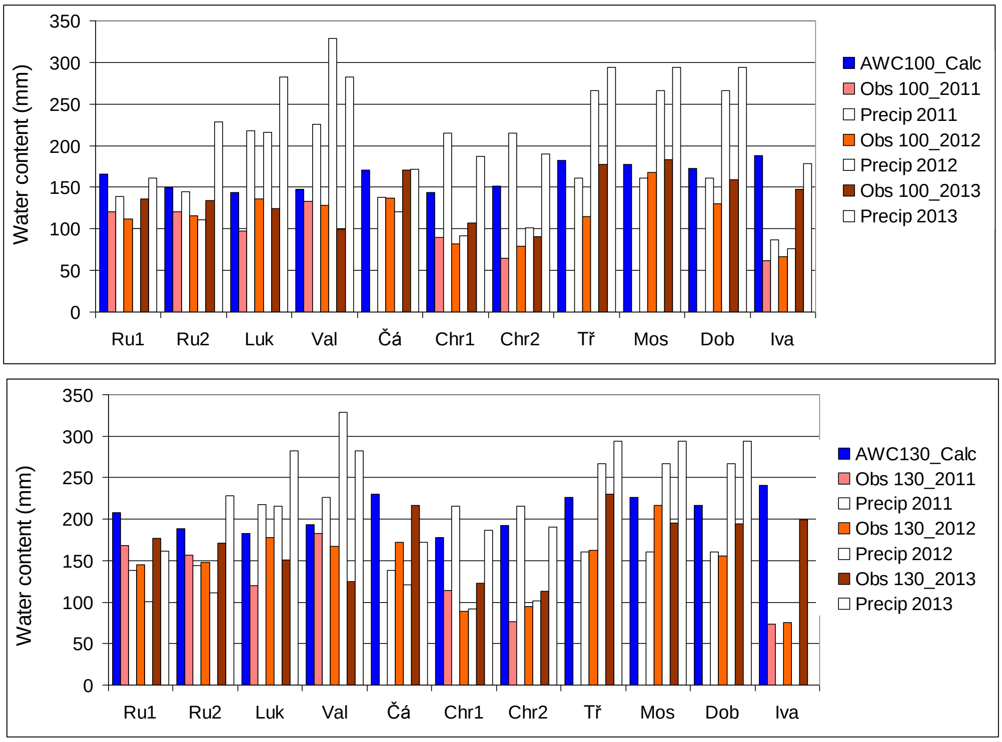

Fig. 3: Comparison of the calculated available water capacity (AWC), in the 100 cm (top) and 130 cm soil layers (bottom), with the observed available water content (Obs) in spring 2011-2013 at several sites. The sum of precipitation from 1st of October of the previous year to sampling term is indicated by white columns.

The observed available water content in the 1 m layer at the experimental sites at the start of growth ranged from 62 to 188 mm (73 mm to 241 mm in 0 - 130 cm) in the experimental years (Fig. 4). Both minimum and maximum values were observed at Ivanovice. Maximum spring water content at 0 - 130 cm, observed during two or three years, was by 0% to 17% lower than the content calculated with PTF functions. This confirms the reasonable prediction of AWC, considering the short experimental period and water losses by evapotranspiration from the soil. Only in two fields in Chrášťany was the observed AWC (by 37% and 41%) lower than the AWC calculated with PTF. These soils have a high content of gravel and stones, possibly enhancing water percolation and evaporation. Comparison of the observed AWC with the precipitation sums (from October 1st of previous years) (Fig. 4) suggests that the soil traits strongly determine the filling of the soil water capacity. The relatively high precipitation in some sites (Valečov, and Lukavec) was not reflected in a significantly higher filing of soil water capacity. Calculated evapotranspiration from autumn to the sampling term is interesting for the comparison of sites with both a high water capacity and high evapotranspiration.

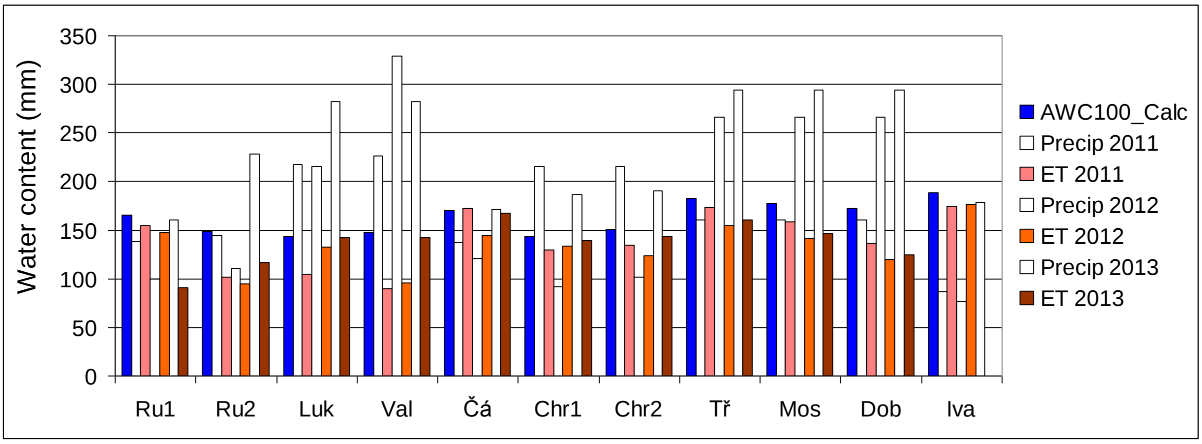

Fig. 4: Comparison of calculated soil AWC in the 100 cm layer, precipitation, and potential evapotranspiration from (1st of October of the previous year to sampling term) in years 2011-2013 at the experimental sites.

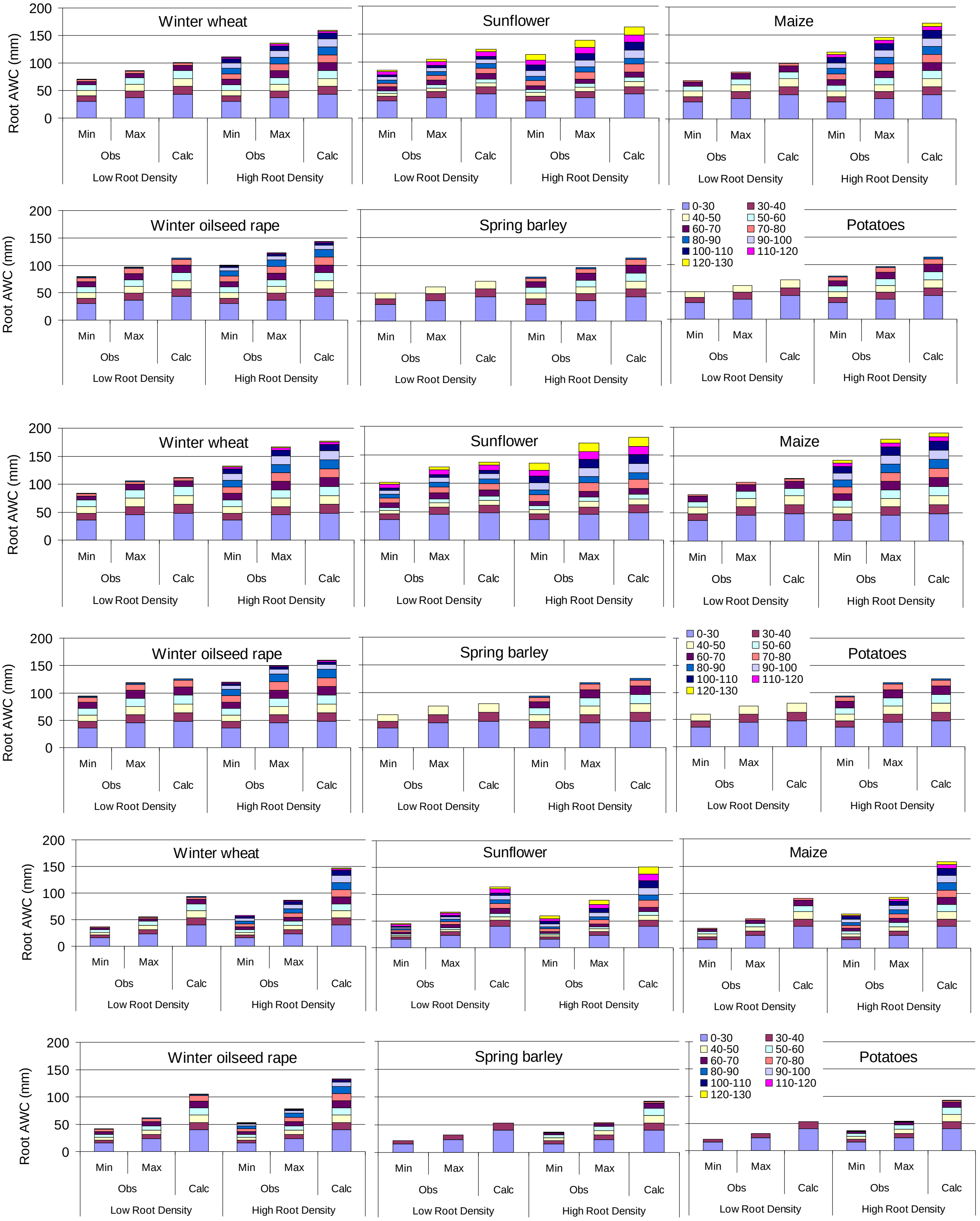

Fig. 5: Potential maximum depletion of water under combinations of root distributions, and water contents, at selected sites and crops. From top to bottom: Ruzyně, Čáslav, Chrášťany

Introduction of an estimation of water depletion distribution, according to root density distribution, significantly modified the amount of available water for the evaluated crops. The combination of the observed low and high root densities, with the calculated and spring water contents, produced a wide range of potentially available amounts of water at the experimental sites.

Conclusion

The calculations presented have a model characteristic, but they represent a range of possible water supply situations, considering distribution of the roots in sites with different soil conditions. The results contribute to a more realistic and reliable estimation of water available to crops, which is especially important under conditions of water shortage.

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Summary

Určení zásoby vody v půdě dostupné pro plodiny je základem pro bilancování spotřeby vody a predikci nástupu nedostatku vody. Na několika lokalitách v České republice byla porovnána maximální dostupná zásoba vody v půdě vypočtená pomocí jednoduchých pedotransferových funkcí ze zrnitostního složení vrstev půdy a obsah vody do hloubky 130 cm určený experimentálně. Na základě údajů o hloubce kořenů plodin a odhadu distribuce příjmu vody bylo vypočteno množství dostupné vody v kořenové zóně plodin. Výsledky jsou příspěvkem pro spolehlivější odhad nástupu vodního stresu na základě bilance vody.

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