ROOTING DEPTH AND THE DEPLETION OF WATER FROM DEEP SOIL LAYERS BY WINTER WHEAT*

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The changes of water content in a soil profile under winter wheat were studied in a field experiment. The study was carried on in Prague-Ruzyně on a degraded chernozemic soil in the years 1996–1999. Two treatments, unfertilized and fertilized with nitrogen, were observed. Rooting distribution and depth were determined by washing soil taken by soil auger and measuring root length. The apparent depletion of water from subsoil layers, as reflected in the decrease of water content during growth, varied among years. Wheat crop utilized water to at least 70 cm depth without restriction under given condition. The depletion of layer 70–90 cm and 90–120 cm varied in years depending on water supply in top soil by precipitation, crop growth and rooting depth. The water supply under 120 cm was partially available only in the year 1997 in that wheat had a high root density in deep subsoil layers. The amount of water depleted from layers 70–90 cm, 90–120 cm and 120–150 cm ranged in experimental years between 6–20 mm, 8–22 mm a and 2-13 mm, resp.

soil water; moisture; precipitation; water depletion; root depth; nitrogen; winter wheat

INTRODUCTION

Crops extract water from various depths of soil profile depending on plant lemand, root depth and distribution and water availability in a soil. Even in emperate climate zone the growth and yield of high-yielding crops are limted by water shortage during a part of the growing season in some years. The maximum utilization of water supply accumulated in soil is important or growth in such dry periods. The 10cm layer of soil represents from 12 l o 28 $l.m^{-2}$ of potentially available water that may play an important role in

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critical stages of crop development, for example, during grain filling (Barraclough et al., 1989; Zhang-JianHua et al., 1998).

The degree of depletion of subsoil layers depends chiefly on crop demand, available water distribution in a soil profile during growth and rooting pattern. There is a lack of data on root density and water or nutrient depletion from sparsely rooted deep soil layers. Further, the relation between root density and water uptake is not straightforward. The information on the depletion of deep subsoil is important for reliable estimation of available water supply in irrigated crops and for water stress modelling (Cabelguenne, Debaeke, 1998; Jamieson, Ewert, 1999). The possible agrotechnical measures for increasing water and nitrogen uptake from subsoil are of interest because of both, economical and environmental reasons (Kuhlman et al., 1989).

The objective of the study was to compare water depletion from subsoil layers and rooting depth of winter wheat.

MATERIAL AND METHODS

Winter wheat's (cv. Samanta) growth, rooting depth and water distribution in a soil profile were studied in a field experiment at Prague-Ruzyně; degraded chernozemic soil, altitude 340 m, long term average precipitation and temperature: 450 mm per year and 7.8 °C, resp. (Haberle et al., 1997). Daily precipitation was recorded in a near (150 m) meteorological station. Main characteristics of the soil are given in Table I (Matula, unpublished). Two treatments were observed; unfertilized with N and fertilized with 100 kg N.ha^{-1}. Only average values of soil moisture and root length are shown here as the differences between treatments were small. Soil was sampled in 10 to 30 cm layer increments to the depth of 150–170 cm for soil gravimetric water content. There were three replicates per treatment. Standard errors are not shown to improve legibility of data in Fig. 1. The coefficient of variation was mostly under 12%. The apparent depletion of water was derived as the decrease of water content in a soil layer during growth, calculated from soil moisture and soil density. Soil was sampled in 10 cm increments about anthesis, roots washed from soil, cleaned and their length and dry weight were determined (Haberle, Svoboda, 1996).

I. Basic characteristics of soil (Prague-Ruzyně)

Depth (cm)	Clay content < 0.01 mm (%)	Coarse fraction 0.1–2 mm (%)	Soil density (g.cm^{-3})	Field capacity (vol. %)
0–30	52.6	8.3	1.30	35.3
30–50	56.0	5.4	1.43	36.0
50–70	52.1	9.2	1.55	35.1
70–90	50.7	13.4	1.55	36.9
90–120	55.9	13.2	1.65	37.2
120–150	53.8	18.7	1.60	nm
150–190	51.9	13.9	1.60	nm

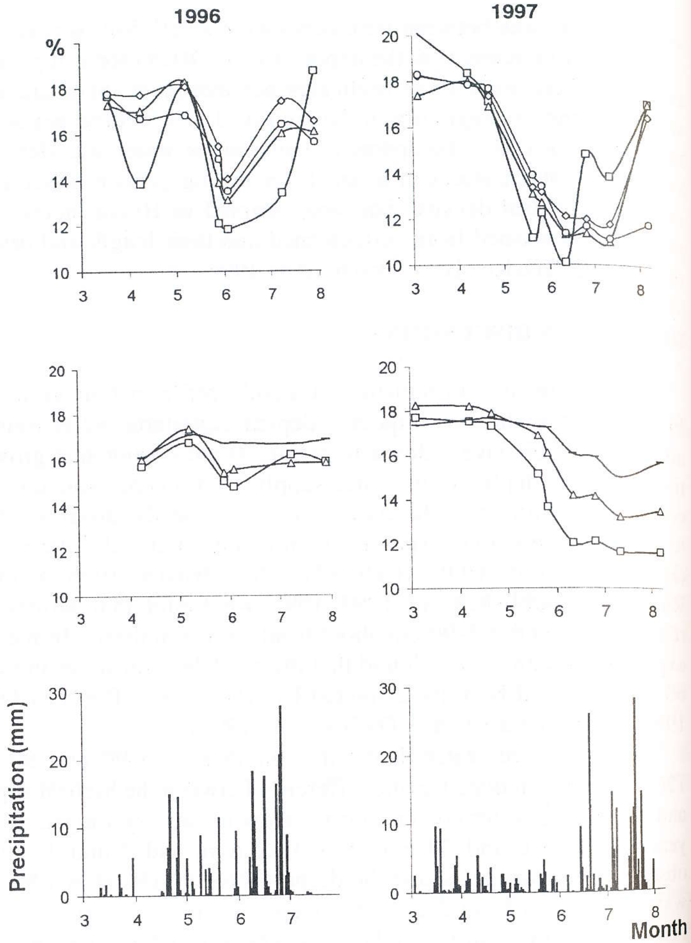
nm – not measured

RESULTS AN DISCUSSION

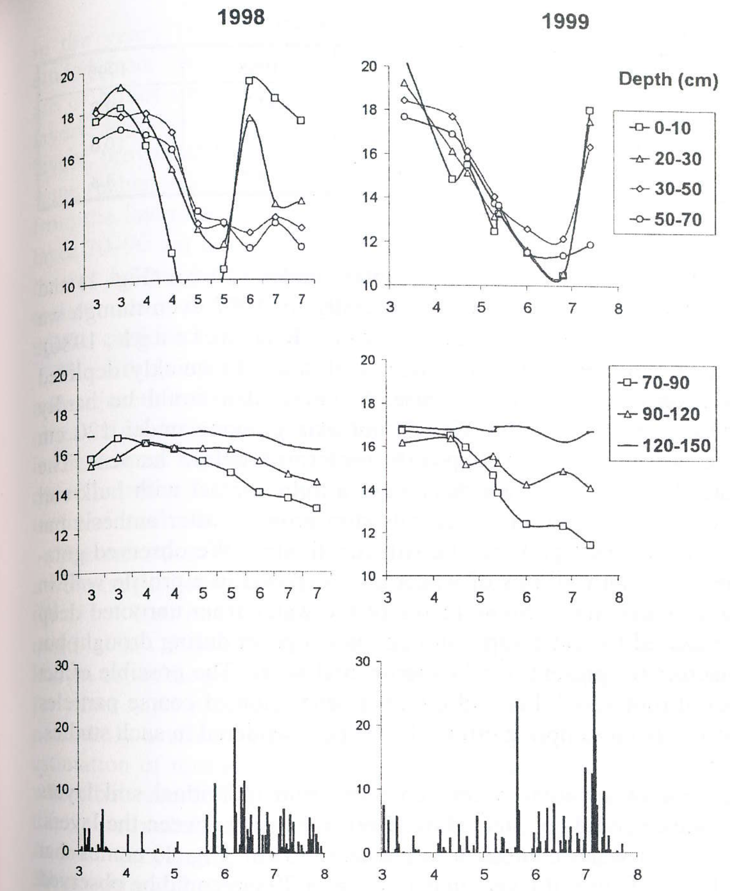
The changes of soil moisture in a soil profile in four years are shown in Fig. 1. Winter wheat crop quickly depleted available water from top soil and adjacent subsoil layers down to 50 or 70 cm during fast growth from full tillering. The depletion of water supply from deeper soil layers delayed in comparison with above layers as expected from the progress of root growth to subsoil. In previous experiments in loamy-sand soil at Pernolec at Tachov (Haberle et al., 1996; Haberle, Svoboda, 1996) and brown soil in Ruzyně (unpublished) in 1993–1995 we found that winter wheat roots reached the depth 60–90 cm about heading and anthesis. In the most of field experiments authors also found that the available soil water in the zone above 60–80 cm could be fully extracted by wheat crop (Barraclough et al., 1989; Cabelguenne, Debaeke, 1998).

The amount of water depleted from layers 70–90 cm, 90–120 cm and 120–150 cm, calculated as the difference between the highest supply at spring and the lowest water content during growing season, ranged in experimental years between 6 and 20 mm, 8 and 22 mm, and 2 and 13 mm, resp. We observed the most dense and the deepest roots in subsoil in 1997 (Fig. 2). The water extraction from deep subsoil was the most intensive in 1997, as well (Table II). In the year the highest dry weight of wheat crop in the experiment was reached suggesting a high demand for water. A high content of mineral N in deep subsoil layers in 1997 (Haberle et al., 1997) might stimulated root proliferation (Haberle et al., 1998) but there was a high content of mineral N in 1996, as well, and the root depth was less than in 1997. In a dry year 1999 the total root length in a whole profile was less than in 1997 but the root length in deep soubsoil layers was similar (Fig. 2). It corresponds well with apparent depletion of water from the layers (Fig. 1, Table II).

The comparison of the years 1996 and 1998 shows the modifying effect of water supply (precipitation) during growth on the depletion of a deep subsoil water supply. The root length under 80 cm was greater in 1996 than



in 1998 yet the depletion from under 90 cm was higher in 1998 than 1996 (Fig. 1, Table II). We suppose that it was caused by a stable precipitation during May and June 1996 and less demand of wheat crop for water due to a reduced growth (infestation by *Tilletia caries*). In spite of the less demand for water in 1996 the supply of mineral nitrogen under 90 cm was depleted by wheat roots in the year (Haberle et al., 1997), while in the other experimental years the maximum depth of N and water depletion coincidented. The same effect, i.e. uptake of nitrogen from rooted subsoil layers



1. Soil water content in a soil profile under winter wheat crop (in %, g.g^{-1}). Average of nitrogen fertilization treatments. Daily precipitation in experimental years in Prague-Ruzyně (in mm)

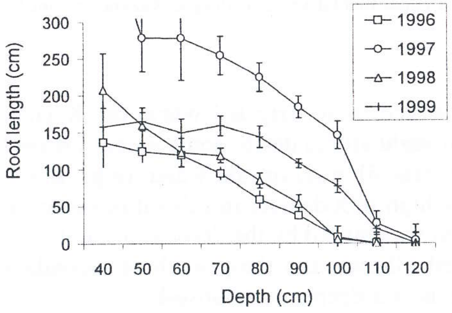
without depletion of water, was observed in an irrigated wheat by Kuhlman et al. (1989). Generally, the drought stimulates to some extent the root growth to depth and depletion of subsoil reserves of water (e.g. Barraclough et al., 1989). Relatively high root density in subsoil in comparison with top soil, in 1998 (not shown) was caused by the dryness of top layers in spring 1998 (Fig. 1) that inhibited tillering and the growth of secondary roots and stimulated root proliferation in a deep moist subsoil.

II. The apparent depletion of water from subsoil (in mm of water)

Soil layer (cm)	1996	1997	1998	1999
70–90	6.4	18.7	11.7	19.8
90–120	8.4	22.3	9.5	10.6
120–150	1.7	12.6	4.3	3.8

We observed some decrease of water content under 120 cm (Fig. 1) and also in layer 150–170 cm (not shown), especially, in 1997 even though we did not find roots in that depth (similarly Weir, Barraclough, 1986). We suppose that capillary rise and diffusion of water to quickly depleted above layers contributed to that decrease, however, that could be hardly quantified. Also, we observed individual root axis growing under 120 cm depth via macro(bio)pores in wall profile performed before harvest. The uptake of water by these roots which had not a tight contact with bulk soil is uncertain. Generally, the roots of cereals stop growing after anthesis but their youngest, i.e. deepest part may be still functioning. We observed gutation of the deepest vital root tips of wheat crop exposed in a profile wall in a wheat crop at dough stage. Some losses of the water from unrooted deep layers may be caused by water vapor through macropores during drought but there were macropores present in all experimental years. The possible effect of greater spatial root variability and a higher proportion of coarse particles in the deepest layers on sampling errors should be considered in such studies, as well.

The calculation of apparent water depletion from individual soil layers from simple balance could be affected by water transport between the layers. From the changes of water content during wheat growth (Fig. 1) comes that almost no recharge of subsoil layers under 50 cm or 70 cm could be observed in the years 1997–1999. Cabelguenne and Debaeke (1998) concluded from twenty years results with several crops that water movements are of minor importance below 60 cm during the growth. Dry depleted top layers, together with a high water consumption from these densely rooted layers, prevented leaching to a deeper subsoil in our experiment. If there was some recharge of deep layers for example by by-flow the actual water uptake from the layers would be higher than apparent one. There was a recharge of layer 70–90 cm in 1996 with a high precipitation and less demand for water but not below the depth. However, a possible short-term fluctuation of soil moisture as a result of a pulse of water from by-flow and following fast uptake could not be recorded without daily monitoring of soil moisture.



2. Root length distribution of winter wheat crop in subsoil (in cm per sample). Average of nitrogen fertilization treatments and standard errors

The nitrogen fertilization increased a little the water depletion in top soil and adjacent subsoil layers (not published). The opposite effect could be observed in deep layers, probably, in relation to a slightly higher root density in the deepest layers at unfertilized crop in some years. However, the differences between N fertilization treatments were negligible, especially in the terms of total water consumption.

The maximum rooting depth of winter wheat given in literature moves in a wide range, between 60 cm in a coarse sand soils to a common 100–160 cm (Weir, Barraclough, 1986; Barraclough et al., 1989; Kuhlman et al., 1989) to maximum observed 300 cm. However, very little is known about the year-to-year variation in rooting depth and the consequences for water and nitrogen uptake distribution. Hence, the reliable calculation of potentially available water supply in a soil profile is not possible without an estimation of rooting depth. We observed maximum rooting depth of winter wheat between 100–120 cm about anthesis in the presented experiment but there was probably some root growth to depth during grain filling, as well. A small (apparent) depletion of water could be detected from another 20–30 cm bellow the deepest roots.

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Hloubka prokořenění a odběr vody z hlubokých vrstev půdy u ozimé pšenice.

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Zemědělské plodiny odčerpávají svými kořeny vodu z různé hloubky půdního profilu v závislosti na potřebě vody porostem, množství a distribuci fyziologicky přístupné vody v půdě a rozložení kořenů. Informace o míře využitelnosti zásoby vody v hlubokých, slabě prokořeněných vrstvách podorničí je důležitá pro určení optimální dávky vody v závlahách a pro modelování vlivu vodního stresu na růst a výnos plodin. Cílem pokusu bylo porovnat odběr vody z vrstev podorničí s hloubkou kořenů ozimé pšenice.

Růst, změny obsahu vody v profilu a distribuce kořenů ozimé pšenice cv. Samanta byly sledovány ve čtyřletém polním pokusu. Sledování probíhala v Praze-Ruzyni, na degradované černozemi, u varianty nehnojené dusíkem a porostu hnojeném dusíkem v dávce 100 kg.ha^{-1} v LAV. Základní hydropedologické údaje o stanovišti jsou uvedeny v tab. I, denní chod srážek byl měřen v blízké meteorologické stanici (obr. 1). Rozdělení kořenů v profilu bylo určeno vyplavením kořenů ze vzorků půdy odebraných ve fázi konce kvetení až do hloubky, kde již kořeny nebyly přítomny (obr. 2). Odběr vody z dané půdní vrstvy byl vypočten ze změn (úbytku) vlhkosti v průběhu růstu (tab. II).

Porost ozimé pšenice odčerpával od fáze plného odnožování až do začátku sloupkování rychle zásobu vody z vrstev ornice a podorničí do hloubky 70 cm (obr. 1). Odběr vody z hlubších vrstev půdního profilu nastupoval později s postupným pronikáním kořenů do hloubky. Největší odčerpání vody z hlubokých vrstev podorničí pod 70 cm jsme zaznamenali v roce 1997 a v roce 1999 (tab. II, obr. 1). Tomu odpovídalo i největší prokořenění podorničí v těchto letech (obr. 2). V roce 1997 jsme pozorovali úbytek vody i v neprokořeněné vrstvě 120–150 cm, pravděpodobně jako důsledek pokračujícího růstu kořenů biopóry do hloubky v době zrání a redistribuce vody difuzí. V obou letech bylo množství srážek v dubnu, květnu a částečně i v červnu relativně nízké, jak je patrné z průběhu změn vlhkosti půdy (obr. 1). Nejmenší odběr vody z podorničí jsme zaznamenali v roce 1996, kdy byla půda nasycena vodou ještě v dubnu a intenzivní odběr vody spojený s poklesem vlhkosti půdy trval jen kratší období, po kterém se již v červnu díky intenzivním srážkám obnovila vysoká zásoba vody v ornici. V roce 1998, s menším prokořením než v roce 1996, červnové srážky neobnovily zásobu vody pod 30 cm a odběr z vrstev podorničí pod 70 cm byl vyšší než v roce 1996. V práci jsou diskutovány další faktory, které mohly ovlivnit růst kořenů v podorničí a spotřebu vody v jednotlivých letech pokusu, jako je obsah nitrátového dusíku, potřeba porostu na vodu a další faktory, které mohou zkreslovat bilančně vypočtený odběr vody z vrstvy (průsak vody ze srážek, difuze a vzlínání z vlhčích vrstev). Výsledky sledování změn vlhkosti půdy v slabě prokořeněných vrstvách podorničí v průběhu růstu ozimé pšenice ukázaly ročníkové rozdíly ve využití těchto vrstev kořenovým systémem. Množství vody odčerpané z vrstvy 70–90 cm se v letech pokusu pohybovalo mezi 6 až 20 mm, ve vrstvě 90–120 cm bylo 8 až 22 mm a ve 120–150 cm mezi 2 až 13 mm.

vlhkost půdy; odběr vody; kořeny; hloubka kořenů; srážky; ozimá pšenice

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