Identification of deep-rooting crop species in arable subsoil by the minirhizotron technique

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Key words:deep roots, maximum rooting depth, root intensity, perennials, cropping system

Abstract

Our current understanding of the plant deep root system and its relevance for crop production is limited. A field trial was established in order to monitor the root growth of various deep-rooted crops down to 5 m of soil depth with the minirhizotron technique. Root intensity (RI: intersections m^{-1}) and maximum rooting depth (m) of seven different crop species indicate varying degree of root penetration capacity among the tested crops. Overall, within one season over 89 % of RI was concentrated at 0-1.0 m of soil depth. Sugar beet (1.4 m) as an annual crop showed the most rapid root growth rate (10.6 mm day^{-1}). On average the perennials resulted in 0.7 m of maximum rooting depth (5.6 mm day^{-1}), which indicates their potential to establish deep root systems in coming seasons.

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Introduction

Arable subsoil is a hidden but important part that comprises of potentially-reachable soil resources (Lynch and Wojciechowski 2015). Therefore, promotion of plant *deep roots* within a cropping system is essential to enhance crop productivity without further increasing the use of external inputs (Thorup-Kristensen et al. 2012); this is one of the aims of organic agriculture (Köpke et al. 2015). Despite the previously reported capacity of numerous crop and grass species for deep-rooting (see Canadell et al. 1996), investigation on the root system in arable fields is often limited to a relatively shallow range of soil depths (e.g. 0.3-1.0 m) unlike the majority in forestry or agroforestry (e.g. 3.0 m of soil depth; da Silva et al. 2011). Therefore, the objective of our study is to extend the range of agronomically relevant subsoil down to 5 m of depth by identifying deep-rooted crops and cropping systems.

Material and methods

A field trial was established at the experimental station of the University of Copenhagen in Taastrup, Denmark (55 °40’N; 12 °18’E). The soil was classified as an Agrudalf as sandy loam. Detailed description on the study site is available in Dresbøll et al. (2016). The experimental design was a strip-split design. Seven crop species were involved in the study (see Table 1). Prior to the crop season, 6 m long minirhizotron tubes were inserted in the plots at an angle of 30° from vertical covering approximately 0.0-5.2 m of soil depth. Multispectral images were taken along the minirhizotron tubes at each 0.05 m-length interval by a Videometer lab instrument (Videometer

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A/S, Hørsholm, Denmark). Image-taking took place from Aug 9 to Sep 6 in 2016 to 3.0 m of soil depth at maximum. Light illumination setup for UVA, violet, amber, red and NIR was adjusted to 365, 405, 590, 660 and 970 nm, respectively. The size of each of the images was 40 mm * 50 mm (width * height) consisting of 2048 x 2448 pixels. The images were analyzed with the VideometerPreview (Videometer A/S, Hørsholm, Denmark) software as Pseudo RGB.Root intensity (intersections m^{-1}) was calculated as the number of roots intersecting a grid overlaid the images divided by the total length of grid lines (0.89 m per image). Maximum rooting depth (m) was calculated as the soil depth where the roots were identified at the deepest depth within one minirhizotron tube. Sowing dates for the crops and root measurement dates are indicated in Table 1. Statistical analysis was done with the R version 3.3.0 (R Core Team 2016). A mixed-effects model (Pinheiro and Bates 2000) with log-transformed variables was used as univariate analysis, and if required, post hoc tests (Tukey's HSD, $P \leq 0.05$) were carried out.

Table 1: Crops, Latin names, sowing dates/density and measurement date

Crop	Latin name	Sowing date	Sowing density	Measurement date
Curly dock	*Rumex crispus* L.	29/05/2016	0.4 g m^{-2}	9/08/2016
Intermediate wheatgrass	*Thinopyrum intermedium*	7/04/2016	2.5 g m^{-2}	24/08/2016
Lupine	*Lupinus albus* L.	11/04/2016	0.5 g m^{-2}	24/08/2016
Mugworth	*Artemisia vulgaris* L.	28/05/2016	0.2 g m^{-2}	6/09/2016
Silphium	*Silphium perfoliatum* L.	30/05/2016	9 plants m^{-2}	1/09/2016
Sugar beet	*Beta vulgaris* L.	11/04/2016	9 plants m^{-2}	24/08/2016
Sweet clover	*Melilotus officinalis* L.	14/04/2016	0.6 g m^{-2}	8/09/2016

Results

Among the tested crops, sugar beet resulted in the highest maximum rooting depth (1.43 m) followed by lupine (0.93 m), intermediate wheatgrass (0.93 m), silphium (0.82 m), sweet clover (0.67 m), curly dock (0.42 m), and mugworth (0.27 m; Figure 1). In the same manner, the highest root growth rate was also observed with sugar beet (10.6 mm day^{-1}) and mugworth revealed the lowest root growth rate (2.7 mm day^{-1}). Below 0.5 m of soil depth sugar beet showed the highest RI (5.15 intersections m^{-1}; Table 2). Mugworth did not deploy any roots beyond the topsoil (i.e. >0.5 m) at the time of measurement. Proportional distribution of RI showed that lupine allocated 31.5 % of roots below topsoil followed by sugar beet (30.3 %), the intermediate wheatgrass (22.3 %), silphium (9.3 %), curly dock (1.8 %) and sweet clover (0.5 %).

Discussion

It is plausible to observe that establishment of deep roots beyond 1 m of soil depth was already possible in one season of cultivation. For the perennials (e.g. silphium and curly dock), a substantial increase in rooting depth in coming season is expected as duration of growth influences the root growth in deeper soil horizons (Thorup-Kristensen et al. 2009). Ability of plants to establish deep roots mainly depend on their root diameter (Materechera et al. 1992); this corresponds with the higher root growth of the taprooted crops such as sugar beet (e.g. Thorup-Kristensen et al. 2012) and lupine (e.g. Pennisi 2008). Also our observation might be the first report showing the root growth of the intermediate wheatgrassunder European soil conditions, which showed a strong tendency to intensify its root system in the subsoil as did in its origin in the U.S. (Cox et al. 2006).

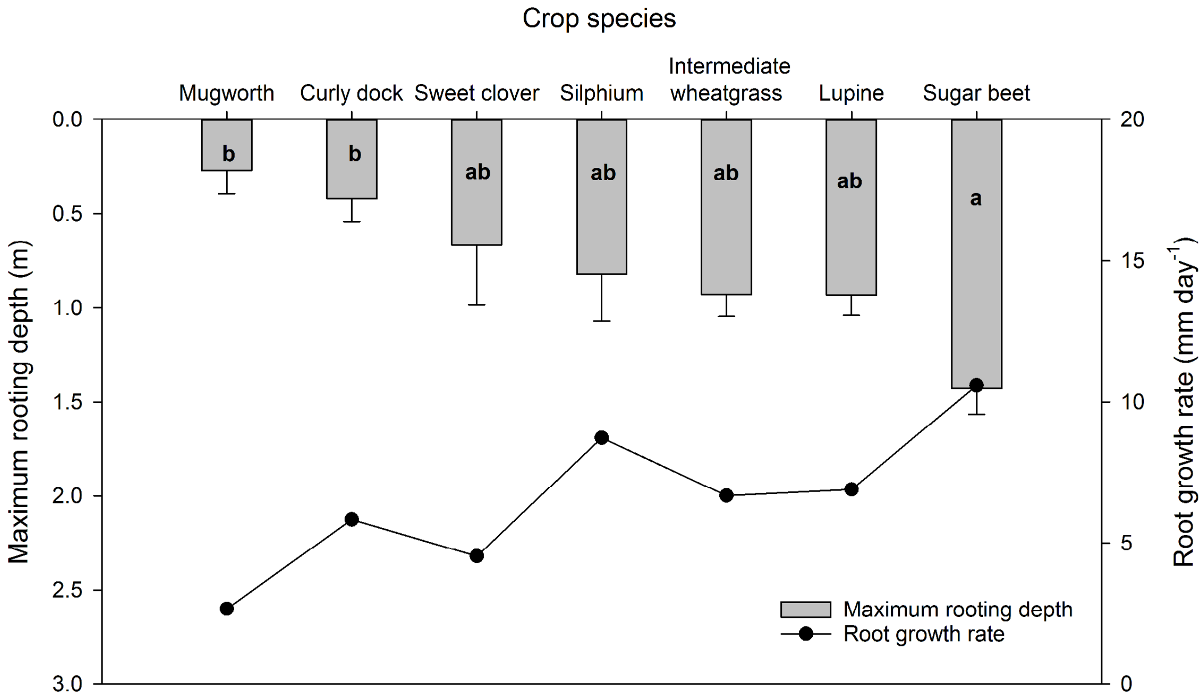

Figure 1. Maximum rooting depth (m) and root growth rate (mm day^{-1}) of the seven crop species. Different small letters indicate significant differences between the crop species (Tukey’s HSD; *P*≤0.05). Analysis was done with log-transformed variables but mean (one±SE) values are shown here (root growth rate was not analyzed).

Development of deep roots can be beneficial for the standing plants as they gain more access to the limiting nutrients and water. Deep-rooted crops also positively influence the following crops as they function as N catch crops. In addition, they provide preferential pathways for roots of the following crops by the increased biopore density.

Table2: Rootintensity (RI; intersectionm^{-1}) measuredat 0.0-0.5 m, 0.5-1.0 m, 1.0-1.5 m, 1.5-2.0.mand 2.0-2.5 mofsoildepth

Soil depth (m)	Sweet clover	Curly dock	Intermediate wheatgrass	Lupine	Mugworth	Silphium	Sugar beet
0.0-0.5	11.06 bc	42.56 a	22.48 bc	11.33 bc	12.30 bc	8.56 c	25.17 ab
0.5-1.0	0.06 b	0.78 b	6.70 bc	5.24 b	0	0.92 b	13.69 a
1.0-1.5	1.18 b	0	0.95 b	0.05 b	0	0.42 b	6.38 a
1.5-2.0	0	0	0	0	0	0	0.02
2.0-2.5	0	0	0	0	0	0	0.50

Different small letters indicated significant differences between the crop species within the soil depth (Tukey’s HSD; *P*≤0.05).

Our study indicates that crop plants have potential to establish deep root systems in arable subsoil. Organic management should consider the deep soil as an alternative nutrient reservoir and formulate crop sequence/rotation to better exploit the deep soil nutrients. Future study should focus on activity of deep roots under field conditions by developing methods applying nutrient tracers in deep soil horizons.

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