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# Evidence of improved water uptake from subsoil by spring wheat following lucerne in a temperate humid climate

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ABSTRACT

Dry spells during the summer period affecting water uptake and plant growth in central Europe may occur more frequently in the future due to climate change. Improving the ability of crops to take up water from deeper soil layers is a potential strategy to secure water supply. The objective of this paper is to report on the effect of different preceding fodder crops on root growth and water uptake of spring wheat from the subsoil. Water extraction and root length density during grain filling of spring wheat were observed between anthesis and maturity in six different soil depths (0–15, 15–45, 45–60, 60–75, 75–90 and 90–105 cm) and with four different preceding crops: 1 year of fescue (Fes1Y), 2 years of chicory (Chi2Y), 2 years of lucerne (Luc2Y) and 3 years of chicory (Chi3Y). While there was no difference in total water extraction by wheat in the four crop sequences, water extraction from the deepest layer (90–105 cm) was significantly higher after 2 years of lucerne (Luc2Y). This was consistent with the root length densities measured in the 90–105 layer, which were 82, 89 and 112% higher in Luc2Y as compared to Fes1Y, Chi2Y and Chi3Y, respectively. Results suggest that lucerne as preceding crop supports deeper rooting and higher rooting density of following spring wheat enhancing access to water in deeper soil layers in response to prolonged dry spells. Effects facilitating root penetration like improved soil structure and higher nitrogen availability after lucerne are discussed. We conclude that suitable crop rotations with lucerne might be a cost-effective adaptation measure to overcome drought stress.

## 1. Introduction

Climate change will most likely lead to an increase in the frequency of dry spells during the summer period in southern and central Europe (Calanca, 2007; IPCC, 2007; Jacobs et al., 2008). Water is the most limiting factor for crop productivity in Europe's intensive cropping systems. Securing water supply will therefore be essential to maintain crop yields (Brisson et al., 2010). Water supply can be improved by irrigation, but this is an option only in few regions in Europe. Another strategy to maintain crop yields under water scarcity is to increase drought tolerance through breeding e.g. the development of crop cultivars with a deeper and more efficient rooting system (Challinor et al., 2010; Debaeke and Aboudrare, 2004). Kirkegaard et al. (2007) showed in a field experiment that the water use efficiency of subsoil water at post-anthesis is 2 times higher than the total post-anthesis water use. However, the expansion of the rooting system into deeper soil layers depends not only on the genotypic ability of the crop but also on the change of soil properties from the topsoil to the subsoil. Although soil properties and in particular subsoil properties are difficult to modify, some crops with deep taproot systems are potentially able to penetrate even compacted layers and to create biopores in the subsoil which may support root growth and water uptake from subsoil layers of the following crop. One of these crops is lucerne (*Medicago sativa L.*) (Abdul-Jabbar et al., 1982; Carof et al., 2007; Li and Huang, 2008).

Hence, the objective of this study was to investigate under a temperate humid climate the effects of two deep-rooting fooder crops (lucerne and chicory [*Cichorium intybus* L.]) in comparison with one shallow-rooting crop (tall fescue [*Festuca arundinacea* Schreb.]) on soil water content, root growth and water uptake from the subsoil of the following spring wheat in a field experiment.

## 2. Materials and methods

### 2.1. Design of field experiment

The investigations are based on a field experiment which was established at the Klein Altendorf experimental station (6°59′29″N,

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**Table 1**
Average physical and chemical properties of the soil in the four treatments.

| Treatment | Depth (cm) | Silt (%) | Sand (%) | Clay (%) | Texture | pH | Bulk density (g cm−1) | Initial soil moisture (m$^3$ m$^{-3}$)[a] | WP (m$^3$ m$^{-3}$)[b] | Corg |
|---|---|---|---|---|---|---|---|---|---|---|
| Fes 1Y | 15 | 77 | 8.8 | 15 | SiL | 5.0 | 1.31 | 25.4 | 8.9 | 0.77 |
| | 45 | 75 | 5.9 | 19 | SiL | 6.3 | 1.51 | 27.9 | 13.2 | 0.35 |
| | 60 | 63 | 7 | 30 | SiCL | 5.0 | 1.56 | 30.2 | 14.0 | 0.49 |
| | 75 | 68 | 4.1 | 28 | SiCL | 5.4 | 1.56 | 30.3 | 16.8 | 0.40 |
| | 90 | 69 | 3.6 | 27 | SiCL | 7.4 | 1.56 | 35.0 | 18.7 | 0.76 |
| Chi 3Y | 15 | 78 | 4.5 | 18 | SiL | 6.8 | 1.46 | 30.9 | 12.2 | 1.06 |
| | 45 | 71 | 4.7 | 25 | SiL | 5.5 | 1.59 | 28.8 | 13.0 | 0.56 |
| | 60 | 63 | 4.2 | 33 | SiCL | 5.0 | 1.55 | 32.2 | 17.5 | 0.49 |
| | 75 | 62 | 6 | 32 | SiCL | 5.0 | 1.62 | 33.9 | 18.7 | 0.41 |
| | 90 | 63 | 4.9 | 32 | SiCL | 5.0 | 1.60 | 34.1 | 20.2 | 0.44 |
| Chi 2Y | 15 | 75 | 7.7 | 18 | SiL | 6.2 | 1.46 | 29.2 | 11.9 | 1.00 |
| | 45 | 68 | 3.8 | 28 | SiCL | 6.4 | 1.60 | 30.0 | 15.7 | 0.51 |
| | 60 | 68 | 3.2 | 29 | SiCL | 6.1 | 1.58 | 32.6 | 18.1 | 0.47 |
| | 75 | 64 | 3.2 | 33 | SiCL | 6.8 | 1.62 | 33.0 | 19.8 | 0.45 |
| | 90 | 67 | 3 | 30 | SiCL | 7.4 | 1.61 | 33.6 | 18.9 | 0.36 |
| Luc 2Y | 15 | 73 | 7.9 | 20 | SiL | 5.7 | 1.44 | 29.1 | 13.6 | 0.83 |
| | 45 | 67 | 5.9 | 28 | SiCL | 5.9 | 1.56 | 29.5 | 16.1 | 0.50 |
| | 60 | 63 | 3.1 | 34 | SiCL | 6.4 | 1.52 | 32.6 | 18.7 | 0.77 |
| | 75 | 61 | 4.8 | 34 | SiCL | 6.3 | 1.55 | 29.6 | 19.0 | 0.47 |
| | 90 | 66 | 4.1 | 30 | SiCL | 5.6 | 1.56 | 31.6 | 17.0 | 0.37 |

[a] Soil moisture at 12 days after sowing (7th April).
[b] WP Permanent wilting point (1500 kPa).

50°37′21″E) of the University of Bonn in 2007. The climate is characterized by temperate humid conditions with maritime influence. Mean annual temperature is 9.6 °C with average rainfall of 625 mm, relatively evenly distributed over the year. Winter rainfall usually exceeds largely evapotranspiration which leads to a regular replenishing of the water storage in the subsoil. Frequently, dry spells occur in summer during the growing period. In 2010, the decadal climatic water balance (calculated as the difference between rainfall and potential evapotranspiration) was zero or negative from April to mid of August except for the first decade in May (Fig. 1). A pronounced dry spell occurred from June 7th to July 25th, where accumulated precipitation amounted to 58 mm against 212 mm of potential evapotranspiration (Penman–Monteith) (Fig. 1). The occurrence of dry spells is mainly due to the proximity of the Eifel mountains which at times prevent clouds from reaching the plain of Klein–Altendorf. The soil at the field experiment has been classified as Haplic Luvisol (FAO, 1998), which is characterized by a silty clay loam texture with clay accumulation in the subsoil (between 45 cm and 95 cm soil depth) and a calcium carbonate rich horizon below 95 cm (Table 1). Estimated available water capacity approximated 207 mm down to a soil depth of 100 cm. As rainfall in the winter term 2009/10 (October to March) was 300 mm against a total potential evapotranspiration of 94 mm, rainfall had been sufficient to replenish the water storage in the subsoil (Table 1).

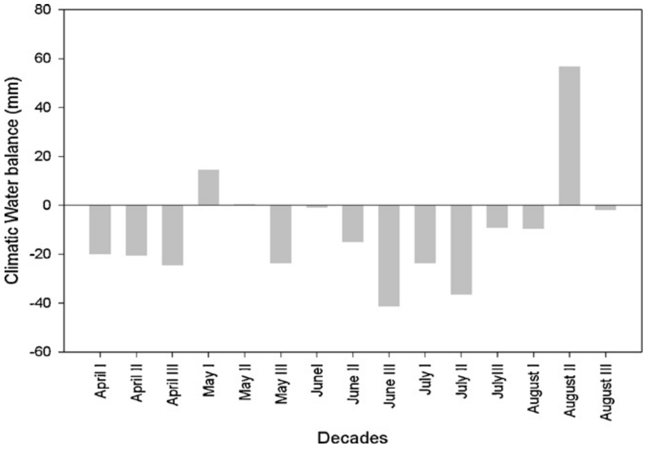

**Fig. 1.** Climatic water balance in 10 days periods at the experimental station Klein–Altendorf from planting to harvest of spring wheat in 2010.

Effects of four treatments, representing different cropping sequences with fodder crops on water uptake and root growth of spring wheat, were investigated in a randomised complete block design (Table 2). In order to simultaneously investigate the effects of fodder crops after one, two or 3 years of cultivation, the fodder crops were sown successively in the spring of 2007, 2008 and 2009, respectively. Seeding densities were 25 kg ha$^{-1}$ (lucerne), 5 kg ha$^{-1}$ (chicory) and 30 kg ha$^{-1}$ (tall fescue). Treatments designated for 2 years and 1 year of fodder cropping were previously sown with spring rye (in 2007) and oats (in 2008). The size of each plot was 60 m$^2$.

During the pre-cropping phase the fodder crops were regularly cut and chopped (three to four times a year) with a mulcher. The shoot biomass remained on the soil surface. Depending on the fodder crop, manual weeding was necessary several times in the first year to establish pure stands of the fodder crops. In order to avoid nitrogen limitations, which had been observed in the fescue stands sown in previous years, 50 kg ha$^{-1}$ N (as calcium ammonium-nitrate, CAN) were applied to 1 year fescue (Fes1Y). Apart from that, no other fertilizer was added to the fodder crops. Before tilling, the shoot mass was mowed and the residues incorporated twice with a chisel plough. The soil was tilled with a mouldboard plough to a depth of 30 cm before spring wheat was sown with a density of 450 seeds m$^{-2}$ on April 7th, 2010. In order to realize the same level of plant available nitrogen in all plots, CAN was applied with amounts of 15 kg ha$^{-1}$ N (Luc 2Y) and 77 kg ha$^{-1}$ N (Chi2Y, Chi3Y, Fes1Y) according to the amount of available soil nitrogen content in 0–90 cm soil depth in the four treatments. Fourteen

**Table 2**
Crop sequences under study.

| Year | Luc2Y | Chi2Y | Chi3Y | Fes1Y |
|---|---|---|---|---|
| 2007 | Rye | Rye | Chicory | Rye |
| 2008 | Lucerne | Chicory | Chicory | Oats |
| 2009 | Lucerne | Chicory | Chicory | Fescue |
| 2010 | Spring wheat | Spring wheat | Spring wheat | Spring wheat |