OWC 2020 Paper Submission - Science Forum

Topic 4 - Innovation in Organic farming: "thinking out of the Box"

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STRIP INTERCROPPING PROMOTES NUTRIENT-SNATCHING BY DEEP ROOTS

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Abstract: The potential of intercropping systems for acquisition of deep-placed nutrients is still not well-known. We examined root growth and nutrient uptake potential of a strip intercropping system with a deep-rooted perennial and a shallow-rooted annual crop species. We compared root growth of sole-cropped winter rye (Rye), rye "intercropped" with an adjacent lucerne strip (Rye|Luc), and sole-cropped lucerne (Luc). Tracer uptake of the crops were measured, including tracer uptake of lucerne grown adjacent to winter rye (Luc-Rye) was determined to reveal the possibility of nutrient-snatching. Our results showed that roots recovered from below the rye in the Rye|Luc intercropping contained roots from both crop species and did not reduce overall root growth. Nutrient uptake potential by Rye|Luc was equivalent to rye as a sole crop, meaning that no competition were observed. Lucerne grown adjacent to labelled rye (Luc-Rye) was able to reach the nutrient source under winter rye by its deep roots. We conclude that strip intercropping shall consider the contrasting root systems of cropping components in order to maximize the resource use efficiency from deep-soil layers.

Introduction: Low input systems such as *organic agriculture* require efficient use of resources, and an effective protection of the crop plants to maintain the crop yield. Strip intercropping, the simultaneous cultivation of two or more species in a distinct row arrangement, has advantages over monocropping such as increased crop yield by creating more "edge" rows (e.g. Maize-soybean strip intercropping; Du et al. 2018) and suppressing pest outbreaks by inducing biological control (e.g. Wheat aphid control under wheat-lucerne strip intercropping; Ma et al. 2007). Creating a complementary relationship between the simultaneously growing crops is key to achieve the benefits, in which, belowground root-to-root interactions play an important role (Hutchings and John 2003; von Felten and Schmid 2008). It is acknowledged that the share of plant nutrients derived from the subsoil by deep roots can be substantial (Kautz et al. 2013). Establishment of deep roots depends on crop species, e.g. a rooting depth of ≤1 m for spring wheat while it can be >3 m for lucerne, on management strategies such as early sowing leading to deeper rooting depth and on their interactions. As far as strip intercropping is concerned, only little is known of (1) how two contrasting root systems interact in the subsoil, (2) how the differences in root occupancy promotes or reduces root competition for crop nutrients, and (3) how deep the effects persist. Therefore, the aims were (1) to measure the effects of strip intercropping of perennials and annuals on root growth in the subsoil; (2) to compare the effects of strip intercropping on the nutrient uptake potential of sole-cropped and inter-cropped annual crops; and (3) to determine whether deep-rooted perennial crops can access a nutrient source placed under the shallow-rooted annual crop. We put forward the hypotheses that i) strip intercropping promotes root growth in the subsoil; ii) perennial deep roots are able to access nutrients located under the annual crop (called *nutrient-snatching*).

Material and methods: A field trial was established at the experimental station of the University of Copenhagen in Taastrup, Denmark (55 º 40' N; 12 º 18' E). The soil was classified as an Agrudalf soil. Lucerne (*Medicago sativa* L.) was sown on Sep 9, 2015 with the seeding density of 2.5 g m^{-2} in plots with 1.5 m x 10 m dimension. Winter rye (*Secale cereale* L.) plots (3 m x 10 m) were created adjacent to the plots of lucerne by sowing 15 g m^{-2} of seed on Sep 12, 2016. The distance between the edges of lucerne and winter rye plots was made approximately 0.5 m. The set up created three treatments for determining root growth; winter rye sole crop (Rye), winter rye with nearby lucerne strip (Rye|Luc), and lucerne sole crop (Luc). For tracer uptake, four treatments were created - the former three (Rye, Rye|Luc, Luc) plus lucerne grown adjacent to the labelled winter rye (Luc-Rye). All treatments were tested with 6 replicates.

^{15}N and Cs were used as nutrient tracers in the forms of $^{15}NH_4Cl$ and $CsCO_3$ with the amount of 275.24 mg and 728.26 mg per ingrowth-core, respectively. and $CsCO_3$, respectively. Cs was used as an analogue to K. The tracers were prepared in solution form and mixed with a subsoil medium (sandy loam). The labelled medium was packed into stainless steel ingrowth-cores (Length: 0.55 m; Diameter: 100 mm; total volume: 4320 cm^3) to the bulk density of 1.78 g cm^{-3}. The ingrowth-cores were inserted (May 4, 2017) into stainless steel access-tubes installed in the field plots at 30º from vertical to the depth-levels of 1.0 m (0.74-1.21 m) and 2.5 m (2.25-2.73 m). The ingrowth-cores were placed at plot-heads of each treatments, except Luc-Rye which did not have an in-growth core.

The ingrowth-cores were retracted, the soil was removed, and visible roots were separated by washing. The clean root samples were scanned on a flatbed scanner (Epson Perfection V700). The root images (600 dots per inch; DPI) were analyzed with the 'WinRHIZO Pro' (Version 2016c, 32 Bit) software from which root-length density (RLD; cm cm^{-3}) was determined. Specific root-length density (SRL; m g^{-1}) was calculated based on root dry matter (oven-dried over 48 hours at 85ºC). The collected shoot samples were oven-dried at 85º for 48 hours, and ground for further analysis of δ^{15}N, and Cs. Excess tracer concentration (dTC) was calculated by subtracting tracer concentrations of un-labelled samples taken at least 5 m away from the labelled samples concentrations of the labelled samples. R version 3.5.3 (R Core Team 2019) was used for statistical analysis. The package lme4 was used for linear mixed-effects model analysis.

Results: RLD was not significantly affected by crop species and only moderately affected by the soil depth ($P=0.07$; Figure 1a). SRL was significantly affected by crop species (Figure 1b). Rye|Luc intercropping did not differ significantly from neither of the sole crops, and the SRL was not affected by soil depth. The excess tracer concentrations of δ^{15}N and Cs were affected by crop species and intercropping, however, the effects were associated with significant interactions. Multiple comparisons revealed that Rye|Luc showed the highest δ^{15}N concentration when labelled at 1 m soil depth, which was significantly different to all other treatments except for Rye at 1 m (Figure 2a). Luc-Rye treatments at both depth-levels exhibited no significant difference to the other treatments except the Rye|Luc treatments at 1.0 m. The highest Cs concentration was shown by Luc-Rye at 2.5 m, which was significantly different to rye sole crop at both depth-levels and Rye|Luc intercropping at 2.5 m soil depth (Figure 2b).

Discussion: Our results indicate significant differences in SRL between the two sole-cropped species (Rye vs. Luc), while intermediate results were obtained from the intercropped Rye|Luc. It can be only speculated that the roots from Rye|Luc component are a mixture of rye and lucerne roots despite being sampled below the rye. Therefore, we can confirm the morphological difference between two crop species, winter rye and lucerne, and simultaneous root growth into the ingrowth-core in case of Rye|Luc treatments. However, our hypothesis (i) on promoted root growth by intercropping was not confirmed by the measured RLD. We also expected that the deeper roots of lucerne would have access to the nutrient source located directly under Rye|Luc (Hypothesis ii), which was not shown by ^{15}N uptake but only by the Cs uptake. The nutrient-snatching by deep roots of lucerne was more vividly shown at 2.5 m. Considering that there was not much Cs uptake by the sole-cropped rye (Rye) at 2.5 m, we can conclude that the intercropping can lead to a complimentary relationship, when one component has a deeper root system and thereby access to nutrients in deep soil layers as shown previously (von Felten and Schmid 2008).

The disagreement between RLD and dTC has been exhibited in our study. Nutrient uptake is determined by several factors, not only by root density but also rhizosphere activity (McGahan et al. 2014) and types of nutrients as our own results demonstrate – ^{15}N vs. Cs. In addition, as we do not have a separate result on rooting density of lucerne alone when grown under Luc-Rye treatments, quantitative relationship between root density and tracer concentration cannot be confirmed in this case. However, evidences are present that perennially grown lucerne can reach 4 m of soil depth (Weaver 1926; Fan et al. 2016), whereas winter cereals can barely reach the rooting depth of 2 m (Rasmussen et al. 2015).

Our results partially suggest that a complimentary relationship can be promoted by strip intercropping that combines deep-rooted perennials with shallow-rooted annuals. Contrasting to previous studies that focused on topsoil layers, our data derived from the subsoil exhibited no sign of competition between the intercropped components. This is a plausible indication for organic management without intensive nutrient management, which can benefit, firstly, from the subsoil resource acquisition, and, second, from the reduced competition between the crop components. We conclude that intercropping when implemented with considering deep root occupancy can minimize the competition for resources.

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Figure list

Figure 1: Root growth as affected strip-intercropping

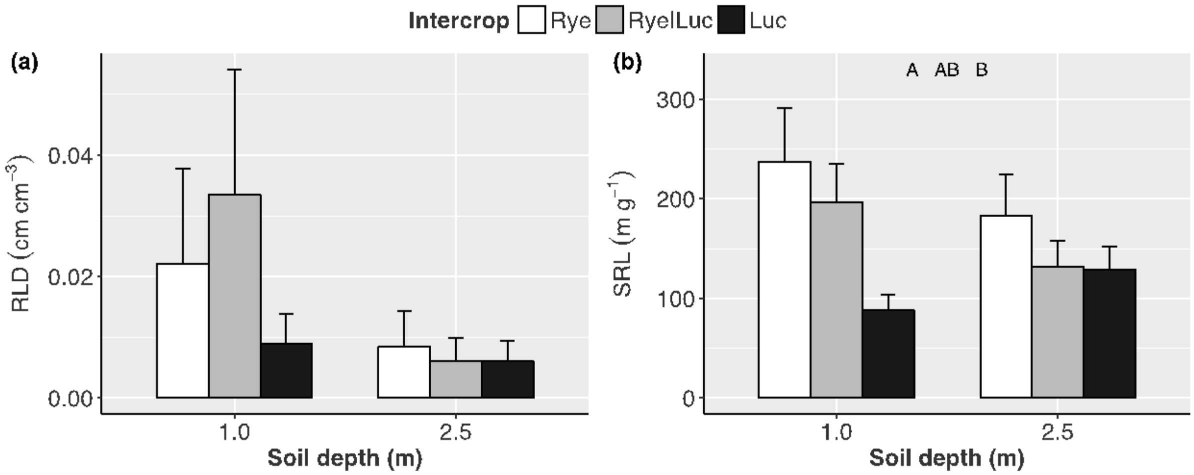

Figure 1. Root-length density (RLD; cm cm^{-3}, a) and specific root-length (SRL; m g^{-1}, b) as affected by intercropping i.e., sole-cropped winter rye (Rye), intercropped winter rye with lucerne (Rye|Luc), sole-cropped lucerne (Luc) and soil depth (1.0 and 2.5 m). Estimates (bar) and SE (error bar) back-scaled from the log-transformation are presented. Capital letters indicate significant differences between cropping components regardless of the soil depth (Tukey HSD; $P \leq 0.05$).

Figure 2. Excess tracer concentration as affected by strip intercropping

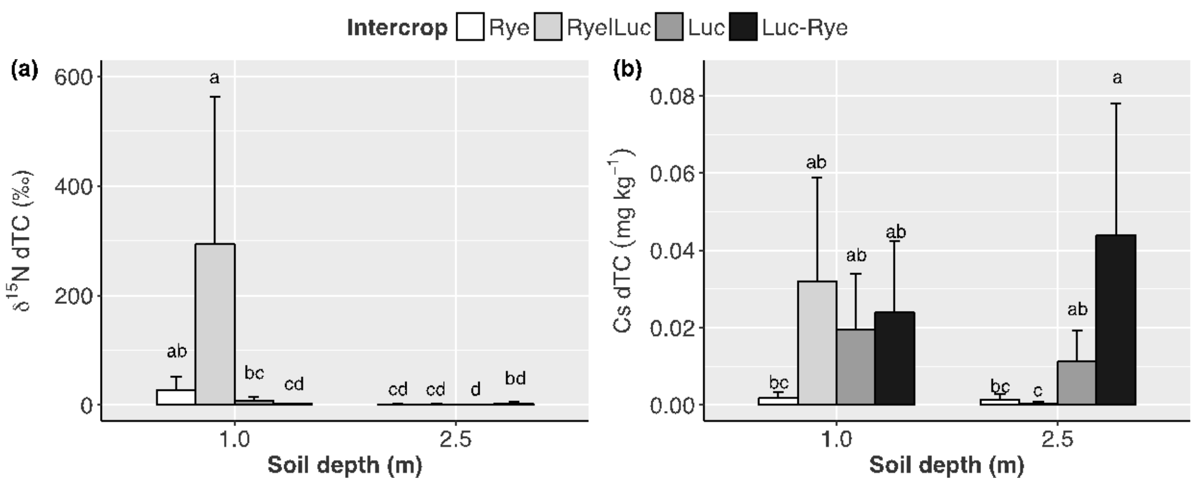

Figure 2. Excess tracer concentration (dTC) of $\delta^{15}N$ (‰; a) and Cs (mg kg^{-1}; b) affected by intercropping i.e., sole-cropped winter rye (Rye), intercropped winter rye with lucerne (Rye|Luc), sole-cropped lucerne (Luc) and lucerne adjacent to winter rye (Luc-Rye*) and soil depth (1.0 and 2.5 m). Estimates (bar) and SE (error bar) back-scaled from the log-transformation are presented. Small letters indicate significant differences between all 8 treatments.
*Luc-Rye: Tracers were not placed directly under lucerne plants but under winter rye plants grown nearby lucerne plants (~0.5 m of horizontal distance).

Disclosure of Interest: None Declared

Keywords: deep roots, intercropping, subsoil