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ROOT STUDIES IN CROP SUCCESSIONS
A MODEL EXPERIMENT WITH SPRING WHEAT AND CATCH CROPS

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Abstract

Due to environmental and health reasons nitrogen (N) inputs to croplands should be reduced without decreasing grain yields. Wheat is the most widely grown crop in the world and its importance is even larger if protein supply is considered rather than dry matter production. N fertilization in wheat is necessary to produce high yields and to optimize protein content. However, increasing N inputs to achieve high yields with high quality entails the risk of N pollution. The use of crop genotypes that efficiently use N sources and catch crops, for the in situ recycling of N, are among the most promising and currently available strategies to reduce N inputs without reducing yield and quality in wheat. Although, important progress has been made to understand the crop physiological and soil processes governing N nutrition in wheat and in several catch crops, little is known about the root system in the context of these agricultural management strategies. It has been suggested that increasing our knowledge of root systems could be fundamental to link our physiological understanding of crops with the processes occurring in the soil and, thus, develop breeding and management strategies that enhance crop productivity.

The objectives of the present study were to: i) describe the temporal and spatial development of the root system of spring wheat at high and low N supply during four growing seasons; ii) identify differences in the root development of three spring wheat genotypes and four catch crops at low and high N supply and availability, respectively; and iii) evaluate at two levels of N supply, nitrogen uptake of spring wheat, the spatial and temporal characteristics of their root development and how these characteristics are affected by the presence of a catch crop in a two-year crop succession.

Three spring wheat genotypes were grown in 1999 and 2000 and from 2000 to 2002 the cultivation of a spring wheat genotype was followed by catch crops (phacelia, sunflower, white mustard and winter rape) or by a bare soil fallow treatment in an intra-annual succession. The number (no.) of roots cm⁻² was obtained from regular minirhizotron observations at different soil depths for the spring wheat genotypes and the catch crops. In spite of differences among treatments, the cumulative no. of roots cm⁻² (CNR) in time followed the same general pattern in all the cases: i) an initial lag period was followed by a period of rapid increase, as CNR increased exponentially with time; ii) this period was followed by a phase of continued increase, in which
CNR incremented linearly; iii) finally, the rate at which new roots were observed, slowed down but seldom declined to zero before the physiological maturity of the spring wheat or the harvest of the catch crops. Therefore CNR as a function of time was fitted to a logistic equation to study the course of root development. Root development of the spring wheat genotype Toronit was additionally studied using a non-parametric regression approach (splines) to study the vertical patterns of root distribution at selected developmental stages. The parameters of the logistic and non-parametric regression models were influenced by all studied factors, indicating also different responses at low and high N supplies and a high plasticity of the root system of Toronit to varying soil conditions. The percentage of roots developed after anthesis ranged from 2 to 22 % of the total roots developed to physiological maturity, demonstrating that root development of spring wheat can still be very important after anthesis. The differences observed in the subsoil at both N supply levels in the time course of root development as indicated by the length of the period of linear increase in the number of roots, suggests that the development of roots in later growth stages could be modified by seasonal effects. The spatial distribution of CNR was characterized by an exponential decrease with depth at beginning of tillering for all the years and N supplies. An equally clear pattern was not found at later developmental stages.

Three spring wheat genotypes (cv. Alcis and Toronit and the experimental line L94491), identified to vary in nitrogen use efficiency characteristics, were studied in 1999 and 2000. Shoot N off take was different among the genotypes only at high N supply, where it was lower in Alcis than in Toronit and L94491. The lower shoot N off take of Alcis was mainly associated to lower grain yields. Among the parameters of the logistic equation, a main genotype effect was observed in the magnitude of root development in the topsoil (0.10 and 0.25 m); more roots were developed in Toronit than in Alcis and especially L94491.

When grown after spring wheat white mustard, winter rape, phacelia and sunflower differed in their capacity to take up N and in the way their root systems explore the soil profile. Although, the N supplied to the preceding spring wheat had greater effects on shoot biomass and N off take and rather heterogeneous and low effects on root development. Shoot N off take was higher in phacelia than in the brassica species and in phacelia than in sunflower in two (2000 and 2001) and one (2001) of the experimental years, respectively. Most of the differences in the patterns of root
development among the catch crops were found below 0.60 m where N is more prone to be lost by leaching. Phacelia at 0.80 m and phacelia and the brassica species at 1.00 m had more roots than sunflower, indicating variation in the distribution of roots in the soil profile. This variation was confirmed by differences in calculated mean root depth starting at 680 °C days ($T_b=0°C$) of the catch crop growth season. The catch crops also differed in the time course of root development. Brassica species had an earlier development of the root system in all the subsoil (below 0.45 m) but the differences were particularly important at 0.80 and 1.00 m. At these soil depths the period when most of the roots were developed was 7 to 15 % shorter as compared to sunflower and phacelia.

The effect of growing catch crops (white mustard, phacelia or sunflower) or keeping the soil bare (Fallow) as the control treatment on the succeeding spring wheat was studied in 2001 and 2002. Depending on catch crops and N supply the wheat grain yield was either increased or decreased. Grain yield and N off take of spring wheat after catch crops outperformed those of spring wheat after bare soil only when the supply of N was high. Growing catch crops changed the root development and rooting depth of the succeeding spring wheat crop in both years. Spring wheat after white mustard produced more roots at 0.10 m than after the other soil cover treatments and sunflower had a later development of the root system at 0.10 m and 0.45 m at low N supply in 2002. In contrast to the other catch crops, CNR of spring wheat after sunflower was significantly correlated with the CNR of sunflower.
Zusammenfassung


Die Wurzelentwicklung der Sommerweizensorte Toronit wurde zusätzlich untersucht, indem ein nicht-parametrischer Regressionsansatz (Splines) angewandt wurde, um die vertikalen Muster der Wurzelverteilung in ausgewählten Entwicklungsstadien zu studieren. Die Parameter der logistischen und nicht-parametrischen Regressionsmodelle wurden durch alle Untersuchungsfaktoren beeinflusst, was auch auf unterschiedliche Reaktionen bei niedriger und hoher N-Versorgung sowie eine große Plastizität des Wurzelsystems von Toronit bei unterschiedlichen Bodenbedingungen schließen lässt. Der Prozentsatz der Wurzeln, die sich nach der Anthese entwickelten, reichte von 2 bis 22 % des Gesamtwurzelwerks bis zur physiologischen Reife, was belegt, dass die Wurzelentwicklung des Sommerweizens auch nach der Anthese noch sehr bedeutend sein kann. Die Unterschiede, die im Unterboden bei beiden N-Versorgungsniveaus im Zeitverlauf der Wurzelentwicklung anhand der Dauer des Zeitraums der linearen Zunahme der Zahl der Wurzeln beobachtet wurden, deuten darauf hin, dass die Entwicklung der Wurzeln in späteren Wachstumsstadien durch die jährlichen Unterschiede in den Vegetationsperioden bedingt sein könnte. Die räumliche Verteilung der Wurzelanzahl war durch eine exponentielle Abnahme mit der Bodentiefe zu Beginn der Bestockung in allen Jahren
und bei allen N-Versorgungsniveaus gekennzeichnet. Ein ähnlich deutliches Muster ließ sich in späteren Entwicklungsstadien hingegen nicht feststellen.


Die in Bezug auf die N-Aufnahme der Pflanzen im Jugendstadium und die Wurzelentwicklung beobachteten Unterschiede zwischen Weißem Senf, Winterraps, Phacelia und Sonnenblumen beim Anbau nach Sommerweizen lassen darauf schließen, dass deren Fähigkeit zur N-Aufnahme und die Art und Weise, in welcher ihre Wurzelsysteme das Bodenprofil durchdringen, unterschiedlich sind. Allerdings hatte die N-Versorgung des zuvor angebauten Sommerweizens größere Auswirkungen auf die Biomasse der Pflanzen im Jugendstadium und deren N-Aufnahme, eher heterogene und geringe Auswirkungen hingegen auf die Wurzelentwicklung. Die N-Aufnahme der Pflanzen im Jugendstadium war während der drei Versuchsjahre in zwei Jahren (2000 und 2001) höher bei Phacelia als bei den Brassica-Arten und in einem Jahr (2001) höher bei Phacelia als bei Sonnenblumen. Die Unterschiede bei den Mustern der Wurzelentwicklung der Zwischenfrüchte wurden überwiegend in einer Tiefe unterhalb von 0,60 m festgestellt, einer Tiefe also, in welcher der Stickstoff stärker auswaschungsgefährdet ist. Phacelia hatte bei 0,80 m Tiefe mehr Wurzeln als die Sonnenblumen, Phacelia und die Brassica-Arten hingegen bei 1,00 m Tiefe, was auf eine unterschiedliche Wurzelverteilung im Bodenprofil schließen lässt. Diese Abweichung wurde durch ein errechnetes Mittel der Wurzeltiefe nach einer Temperatursumme von 680°C bis zur Ernte der Zwischenfrüchte bestätigt, die unterschiedlich ausfiel. Die Zwischenfrüchte wiesen im Zeitverlauf ebenfalls eine unterschiedliche Wurzelentwicklung auf. Die Wurzelsysteme der Brassica-Arten entwickelten sich in allen Unterböden früher, jedoch waren die Unterschiede insbesondere bei Tiefen von 0,80 und 1,00 m signifikant; in diesen Bodenschichten war der Zeitraum, in dem sich die meisten
Wurzeln entwickelten, bei Brassica-Arten um 7 bis 15 % kürzer als bei Sonnenblume und Phacelia.