Fine root demography in alfalfa (*Medicago sativa* L.)

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Abstract

In perennial forages like alfalfa (*Medicago sativa* L.), repeated herbage removal may alter root production and mortality which, in turn, could affect deposition of fixed N in soil. Our objective was to determine the extent and patterns of fine-diameter root production and loss during the year of alfalfa stand establishment. The experiment was conducted on a loamy sand soil (Udorthentic Haploboroll) in Minnesota, USA, using horizontally installed minirhizotrons placed directly under the seeded rows at 10, 20, and 40 cm depths in four replicate blocks. We seeded four alfalfa germplasms that differed in N\(_2\) fixation capacity and root system architecture: Agate alfalfa, a winter hardy commercially-available cultivar; Ineffective Agate, which is a non-N\(_2\)-fixing near isoline of Agate; a new germplasm that has few fibrous roots and strong tap-rooted traits; and a new germplasm that has many fibrous roots and a strongly branched root system architecture. Video images collected biweekly throughout the initial growing season were processed using C-MAP-ROOTS software.

More than one-half of all fine roots in the upper 20 cm were produced during the first 7 weeks of growth. Root production was similar among germplasms, except that the highly fibrous, branch-rooted germplasm produced 29% more fine roots at 20 cm than other germplasms. In all germplasms, about 7% of the fine roots at each depth developed into secondarily thickened roots. By the end of the first growing season, greatest fine root mortality had occurred in the uppermost depth (43%), and least occurred at 40 cm (36%). Survival of contemporaneous root cohorts was not related to soil depth in a simple fashion, although all survivorship curves could be described using only five rates of exponential decline. There was a significant reduction in fine root mortality before the first herbage harvest, followed by a pronounced loss (average 22%) of fine roots at the 10- and 20-cm depths in the 2-week period following herbage removal. Median life spans of these early-season cohorts ranged from 58 to 131 days, based on fitted exponential equations. At all depths, fine roots produced in the 4 weeks before harvest (early- to mid-August) tended to have shorter median life spans than early-season cohorts. Similar patterns of fine root mortality did not occur at the second harvest. Germplasms differed in the pattern, but not the ultimate extent, of fine root mortality. Fine root turnover during the first year of alfalfa establishment in this experiment released an estimated 830 kg C ha\(^{-1}\) and 60 kg N ha\(^{-1}\), with no differences due to N\(_2\) fixation capacity or root system architecture.

Introduction

Alfalfa (*Medicago sativa* L.) roots are essential to productivity and persistence of the crop, but also promote accumulation of soil organic matter and organic N (Andrén et al., 1990). Annual inputs of C and N from decomposition of roots under continuous alfalfa have been estimated to be 1520 kg C ha\(^{-1}\) and 32 kg N ha\(^{-1}\) in Sweden (Andrén et al., 1991). During the establishment year on a silt loam soil in Minnesota, about 21 kg N ha\(^{-1}\) was released from decomposition of roots and nodules (Dubach and Russelle, 1994).

Growth and decomposition of fine roots occur simultaneously in a root system. Life spans of fine roots are highly variable and range from a few weeks to several years for trees and certain grass species (Vogt and Bloomfield, 1991). It is unknown whether fine...
roots have indeterminate life spans that are regulated by source-sink C partitioning or if fine roots have determinate life spans and die when they have fully metabolized a given supply of starch (Marshall and Waring, 1985; Vogt and Bloomfield, 1991). In either case, actual rates of fine root turnover (production, death, and decomposition) in the field are influenced by soil nutrient availability, cultural practices, species composition of the ecosystem, pathogen infestation, and soil faunal predation (Aber et al., 1985; Cheng et al., 1990; Joslin and Henderson, 1987; Nadelhoffer et al., 1985).

The shoot supplies carbohydrate to roots for growth, respiratory maintenance, and nutrient uptake (Lambers et al., 1983). Cultural practices that reduce the amount of C fixed by vegetative tissue, or that divert C from roots, can increase root senescence (Vogt and Bloomfield, 1991). In perennial forage species like alfalfa, vegetative regrowth following harvest appears to be dependent upon assimilates stored in the roots and crown (Hendershot and Volenec, 1993). After defoliation, new alfalfa shoots and crown buds are strong sinks for carbohydrates stored in the crown and taproot, which would slow root growth (Butler et al., 1959). The shoot becomes less dependent upon previously stored root reserves as photosynthetic capacity increases (Smith and Marten, 1970) and eventually root growth resumes, which suggests that there may be a cyclic pattern between root and shoot growth dependent upon the internal photosynthetic status of the plant (Butler et al., 1959). For recently developed non-N2-fixing alfalfas (Barnes et al., 1990), one might expect altered root growth and turnover because limited N supply would decrease shoot regrowth.

Root senescence in red clover (Trifolium pratense L.), white clover (Trifolium repens L.), and big trefoil (Lotus uliginosus Schk.) increases as a result of herbage removal by cutting (Butler et al., 1959; Wilson, 1942). Jones (1943) noted that net fine root growth of alfalfa was slow during summer and after harvest, but his observations were qualitative. Alfalfa root elongation rates become slower one day after harvest, and this effect lasted for 2 weeks, causing decreased rooting depth (Hodgkinson and Baas Becking, 1977). We found only limited evidence in the literature that total fibrous root mass in alfalfa declines after herbage cutting (Meyerhoff, 1981). Ta and Faris (1987) concluded that root turnover after harvest may help explain increased rates of N transfer from alfalfa to timothy (Phleum pratense L.), but did not measure root length changes.

Most work on fine root demography has concentrated on comparing plant species (Butler et al., 1959; Dubach and Russell, 1994; McMichael et al., 1992; Meyer and Barrs, 1991) or environments (Andrén et al., 1993; Hansson et al., 1992; Hendrick and Pregitzer, 1993; Meyer and Barrs, 1991; Pregitzer et al., 1993), rather than on differences among plant genotypes or rootstocks (Kosola and Eissenstat, 1994). These latter researchers did not detect differences in fine root survival in dry topsoil of four citrus genotypes selected for different specific root length (cm g⁻¹ root, Kosola and Eissenstat, 1994).

Root system architecture in most plants is thought to influence nutrient uptake and water-use efficiency (Fitter, 1991; Shein and Pachepsky, 1995), affects C partitioning between shoot and root (Nielsen et al., 1994), and may influence the extent of symbiotic N₂ fixation and winter hardiness in alfalfa (Johnson, 1992). Genetically-mediated expression of root system architecture can be influenced by soil type and condition, weather, cultural treatment, and mechanical and biotic plant injury (Carlson, 1925; McIntosh and Miller, 1981; Weaver, 1926).

Selection for alfalfa root traits such as lateral root number and fibrous root mass has been successful (Johnson, 1992). Recently, alfalfa germplasms (unique selections used in plant breeding programs) with different root system architectures have been produced via divergent phenotypic selection (Lamb et al., 1995a). The structural relationship between fine and secondarily thickened roots in these alfalfa germplasms ranges from highly branched and fibrous to strongly taprooted with few fibrous roots. Germplasms with contrasting root system architectures are being developed to serve different agronomic and environmental goals, such as rapid root elongation into the subsoil to help remediate nitrate-contaminated soil (Meyers et al., 1996), or high root length densities in the topsoil to absorb nutrients applied in agricultural and food processing wastes. Knowledge of root demography characteristics associated with these germplasms is important, because rapid root turnover could help alleviate N deficiencies in eroded soils or in neighboring plants, but also might exacerbate a nitrate contamination problem in soils subject to nitrate leaching.

Our objective in this experiment was to determine the extent and patterns of fine-diameter root production and loss of four contrasting alfalfas during the stand establishment year. Two germplasms are essentially isolines that differ in N₂ fixation and two are selections that differ in root system morphology.