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Root growth dynamics of Aleppo pine (*Pinus halepensis* Mill.) seedlings in relation to shoot elongation, plant size and tissue nitrogen concentration

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Abstract Large and high nitrogen (N) concentration seedlings frequently have higher survival and growth in Mediterranean forest plantations than seedlings with the opposite traits, which has been linked to the production of deeper and larger root systems in the former type of seedlings. This study assessed the influence of seedling size and N concentration on root growth dynamics and its relation to shoot elongation in Aleppo pine (*Pinus halepensis* Mill.) seedlings. We cultivated seedlings that differed in size and tissue N concentration that were subsequently transplanted into transparent methacrylate tubes in the field. The number of roots, root depth, and the root and shoot elongation rate (length increase per unit time) were periodically measured for 10 weeks. At the end of the study, we also measured the twig water potential (ψ) and the mass of plant organs. New root mass at the end of the study increased with seedling size, which was linked to the production of a greater number of new roots of lower specific length rather than to higher elongation rate of individual roots. Neither plant size nor N concentration affected root depth. New root mass per leaf mass unit, shoot elongation rate, and pre-dawn ψ were reduced with reduction in seedling size, while mid-day ψ and the root relative growth rate were not affected by seedling size. N concentration had an additive effect on plant size on root growth but its overall effect was less important than seedling size. Shoot and roots had an antagonistic

elongation pattern through time in small seedlings, indicating that the growth of both organs depressed each other and that they competed for the same resources. Antagonism between shoot and root elongation decreased with plant size, disappearing in large and medium seedlings, and it was independent of seedling N concentration. We conclude that root and shoot growth but not rooting depth increased with plant size and tissue N concentration in Aleppo pine seedlings. Since production of new roots is critical for the establishment of planted seedlings, higher absolute root growth in large seedlings may increase their transplanting performance relative to small seedlings. The lack of antagonism between root and shoot growth in large seedlings suggests that these plants can provide resources to sustain simultaneous growth of both organs.

Keywords Nitrogen content · Rhizotron · Root elongation · Shoot growth · Sink-source relations · Water potential

Introduction

Abiotic and biotic factors have a profound influence on root growth and structure (Alvarez-Uria and Kerner 2007; Andersen et al. 1986; Lopushinsky and Max 1990; Lyr 1996; Munro et al. 1999). Root growth and structure also vary across plant species and are linked to species functional and ecological characteristics (Comas and Eissenstat 2004; Schenk and Jackson 2002). By contrast, fewer studies have analysed how plant functional characteristics affect root growth and structure within a given species. Nursery cultivation conditions may determine future root growth and architecture. For instance, root restriction by containers in nursery-cultivated plants can affect root

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