Protoplasma (1999) 209: 126–131

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PROTOPLASMA

Dynamic studies of phloem and xylem flow in fully differentiated plants by fast nuclear-magnetic-resonance microimaging

Rapid communication

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Received February 9, 1999
Accepted May 5, 1999

Summary. A fast nuclear-magnetic-resonance imaging method was developed in order to measure simultaneously and quantitatively the water flow velocities in the xylem and the phloem of intact and transpiring plants. Due to technical improvements a temporal resolution of 7 min could be reached and flow measurements could be performed over a time course of 12–30 h. The novel method was applied to the hypocotyl of 35- to 40-day-old, leafy plants of *Ricinus communis* which were subjected to different light-dark regimes. The results showed that the xylem flow velocities and the xylem volume flow responded immediately to light on–off changes. Upon illumination the flow velocity and the volume flow increased as expected in respect to literature. In contrast, the phloem flow velocity did not change in response to the light-dark regimes. Interestingly, though, the volume flow in the phloem increased during darkness. These findings can be explained by assuming that the conducting area of the phloem becomes enlarged during the dark period due to opening of sieve pores.

Keywords: Phloem flow; Xylem flow; Water transport; Nuclear-magnetic-resonance imaging; *Ricinus communis* L.

Introduction

Nuclear magnetic resonance (NMR) imaging is a noninvasive and nondestructive technique and provides a great variety of contrast mechanisms such as chemical shift, relaxation times, diffusion or flow velocities. Recently, flow-weighted NMR imaging was used to obtain quantitative patterns of the flow velocity in the xylem of (intact) plants (Xia et al. 1993, Kuchenbrod et al. 1996). Due to the small diameter of the vessels (up to 50 μm) and flow velocities of less than 1 mm/s sophisticated equipment and pulse sequences are required to achieve a reasonable signal-to-noise ratio in the NMR images. Phloem flow is even more difficult to monitor because the diameter of the sieve tubes is significantly smaller than that of the xylem vessels and, thus, the total volume flow in the phloem is much less than that in the xylem.

Despite these difficulties, Köckenberger et al. (1997) recently reported measurements of the phloem flow in *Ricinus communis* seedlings by NMR flow-imaging techniques. However, due to the dimensions of the magnet bore, only 6-day-old (nontranspiring) seedlings could be investigated. Moreover, the total time for measuring a single flow data set was 4.5 h which made it impossible to detect dynamic flow changes in response to a light-dark regime.

In this communication, we will present measurements of phloem flow together with xylem flow in leafy, transpiring *R. communis* plants. Due to technical improvements the temporal resolution was only 7 min which was sufficient for dynamic (functional) studies. This could be shown by measurements of the response of the xylem and phloem flow upon light-dark regimes.

Material and methods

The experiments were performed with 35- to 40-day-old *R. communis* L. plants. The cultivation of the plants was similar to the

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