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A non-invasive optical system for the measurement of phloem and xylem sap flow in woody plants

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Over the past 70 years, heat has been widely used as a tracer for estimating the flow of water in woody and herbaceous plants. Most commercially available techniques for the monitoring of water-use by a whole plant are however invasive and the measurements are potentially flawed due to wounding to the *xylem* tissue. The study of photosynthates transport in the *phloem* is still in its infancy, and very little information regarding transport rates is readily available due to the fragility of the vascular tissue.

The aim of the present work is to develop a compact, stand-alone, non-invasive system allowing for direct detection of phloem and xylem sap movement.

The proposed method uses heat as a tracer for sap flow. Heating is applied to the surface of the stem using a near-infrared laser source, and heat propagation is monitored externally by means of thermocouples and an infra-red camera. Heat pulse velocities are determined from the thermometric data and related to a more useful quantity, mass flow rate.

Simulation experiments on the xylem tissue of severed silver birch branches were carried out in order to assess the feasibility of the proposed approach, highlight issues inherent to the technique and outline calibration strategies. Good agreement between imposed and measured flow rates was achieved leading to experimentation with live silver birch (*Betula pendula Roth*.) and oak (*Quercus robur L*.) saplings. It was demonstrated that water flow through xylem vessels can be monitored non-invasively

on an intact stem with satisfactory accuracy despite simultaneous sugar transport in the phloem. In addition, it was demonstrated that the technique allows for unequivocal monitoring of flow velocities through the phloem tissue.