STEM SAP FLOW, MEASURED USING PROTON NUCLEAR MAGNETIC RESONANCE, IN COMPARISON WITH TRANSPIRATION AND WATER UPTAKE OF CUCUMBER IN A GREENHOUSE CLIMATE

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Abstract

A portable NMR spectrometer, developed at the Dept. of Molecular Physics of the Wageningen Agricultural University, was used to study the diurnal course of stem sap flow rate of cucumber in a crop in a greenhouse environment and to consider its possible application in a climate control system. Stem sap flow rate was compared with plant transpiration and water uptake rate, using a lysimeter and potometer. Stem sap flow was measured at the base of the shoot. At night the stem sap flow rate was within 10 % of the water uptake rate, both being higher than transpiration rate, because of water uptake for growth. The short term fluctuation of stem sap flow rate at night resembled that of transpiration rate. Around midday it followed the fluctuation in global radiation instantaneously. It is concluded, that results so far look promising, but that additional validation of the accuracy of the measurement as a valuation of momentary stem sap flow is needed. The NMR spectrometer is useful for understanding and quantification of internal plant water relations.

1. Introduction

With the aid of quantitative knowledge of greenhouse climate and crop physiological processes it is now becoming feasible to optimize greenhouse climate control with respect to these processes. For this purpose the use of crop simulation models is promising (Challa, 1988; Gijzen & Goudriaan, 1989). Direct monitoring of plant physiological processes (the speaking plant approach, (Hashimoto, Morimoto & Fukuyama, 1985)) might also prove to be very useful, not only as input for control but also as tuning of, or feedback to a control system, containing a simulation model.

Although the prime interest has been focussed mainly on optimizing carbon assimilation by means of control of CO_2 (Challa & Schapendonk, 1986) nowadays the crop water relations are gaining more interest (Marcelis, 1989). Influencing plant water status through transpiration control and/or control of electrical conductivity in substrate or nutrient film is a way to manipulate crop growth, production and product quality (Bakker, Welles & van Uffelen, 1987; Sonneveld & Welles, 1988; Stanghellini & Van Meurs 1990). Moreover the transpiration of a crop in the greenhouse is a major energy consuming process and therefore important with respect to energy saving (Stanghellini, 1987).

At the Department of Molecular Physics of the Agricultural University of Wageningen the nuclear magnetic resonance (NMR) technique has been used to study water flow in and water content of plants (van As, this Acta). Measurements on cucumber in laboratories or in controlled climate conditions have been presented by van As & Schaafsma (1984), van As, Schaafsma & Blaakmeer (1985), Reinders, van As, Schaafsma, de Jager & Sheriff (1988a) and by Reinders, van As, Schaafsma & Sheriff (1988b) and show the usefulness of the method in non-destructive monitoring of plant water balance. To allow the NMR spectrometer to be used in a greenhouse a high degree of automation of data acquisition and control was achieved and the electromagnet, normally heavy, voluminous and not transportable, was replaced by a relatively small sized, (trans)portable magnet. A magnetic field lock system was included to correct for long term drift.

It was our aim to study the diurnal course of stem sap flow rate, measured with this sensor, adjusted for operation in a dynamic greenhouse climate. For this purpose a cucumber crop was grown in a greenhouse and an experiment was set up in which the NMR technique was used and compared with measurements of rate of plant transpiration and water uptake.

2. Material and methods

In a spring cucumber crop, grown in a greenhouse on water culture, one plant was chosen for NMR measurements and an adjacent plant for measurements of plant transpiration and water uptake rate. At the time of the measurements the crop had reached the supporting wires and individual plants carried a fruit load of about 1.3 kg. Minimum temperature was set to 20 °C and day-time temperature was allowed to rise to a maximum of about 28 °C, the actual temperature depending on the level of solar irradiation.

The NMR sensor was placed at the base of the shoot, measuring stem sap flow in a stem segment slightly above the cotyledons. The equipment used has been described by de Jager, Reinders, Polder & van As (1988). The NMR flow measurement produces a time-dependent signal from which parameters are derived. These parameters are linearly related to linear sap velocity and to flux. Calibration constants are obtained by measuring water flow in a glass capillary of dimensions comparable to those of a stem. Every 7 minutes 20 measurements were performed (taking a total of 3 minutes time) and averaged to obtain one stem sap flow rate measurement.

For measurements of transpiration and water uptake rate a plant was grown in a vessel containing a nutrient solution. This solution was aerated for 15 minutes every two hours. Evaporation of water directly from the solution or during aeration was limited to a minimum and considered to be negligible. The vessel was connected with a flexible tube to a second small adjacent nutrient solution containing vessel, the level of nutrient solution in both vessels thus being equalized. As a result water loss from the second vessel was due to and proportional to the water taken up by the plant in the first vessel. Water loss from the second vessel (the potometer) was recorded by weighing using an electronic balance. The proportionality factor was obtained by calibration through addition of known amounts of water. Short and long term changes in root volume in the first vessel were not taken into account. The system as a whole was put on a second electronic weighing

Challa, H., Schapendonk, A.H.C.M., 1986. Dynamic optimalization of CO2 concentration in relation to climate control in greenhouses. In: H.Z. Enoch and B.A. Kimball (Editors), Carbon dioxide enrichment of greenhouse crops. Volume I: Status and CO2 sources. CRC Press Inc., Boca Raton, Florida, pp. 147-159.

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physiological characteristics, like the ratio of flowing to stationary water, will have their effect on the NMR output, because these characteristics influence the calibration constants. This might have caused the NMR to behave differently during the day and during the night. An other source of error probably is the non-linear relation between flux and NMR output, as was found at high flow rates (Reinders, 1987). This causes the NMR measurement to overestimate flux at high rates.

Water uptake and transpiration rate, although measured on the same plant, were different. This difference is due to water uptake for growth and to changes in plant water content. On the 1st of April at night, when plant water content was assumed to be constant, the average difference, and thus total shoot fresh weight increase was 2.9 $g.h^{-1}$.

Although in general the monitoring of a single plant or some plants in a crop has disadvantages with respect to the usefulness as an input signal for greenhouse climate control the portable NMR-technique nevertheless is a powerful tool in measuring in situ and non-destructive the stem sap flow on a diurnal or hourly basis. However, to justify the relatively high investment needed its applicability as an accurate momentaneous recording of stem sap flow in a fluctuating environment, like a greenhouse, need to be validated further. Relatively low-cost heat balance stem flow gauges (Baker & van Bavel, 1987; Ham & Heilman, 1990) have comparable accuracy over prolonged periods of time, but their dynamic response in a greenhouse might not be adequate. The agreement between the dynamics of the NMR measurements and global radiation indicates, that the (trans)portable sensor is in fact measuring actual sap flow momentarily and accurately. Apart from application in greenhouse climate control, in which control of plant water status over longer integration time might be sufficient or even more desirable, the NMR spectrometer is a useful technique in the research of internal plant water relations. The possibility to scan stem sap flow along the height of a stem and the combination of these measurements with measurements of plant water potential (for instance, leaf (Oosterhuis & Wullschleger, 1989) and stem psychrometry (McBurney & Costigan, 1982)) might contribute to further understanding and quantification of internal water relations with respect to resistances and capacitance (see, for instance, Jarvis, Edwards & Talbot, 1981)

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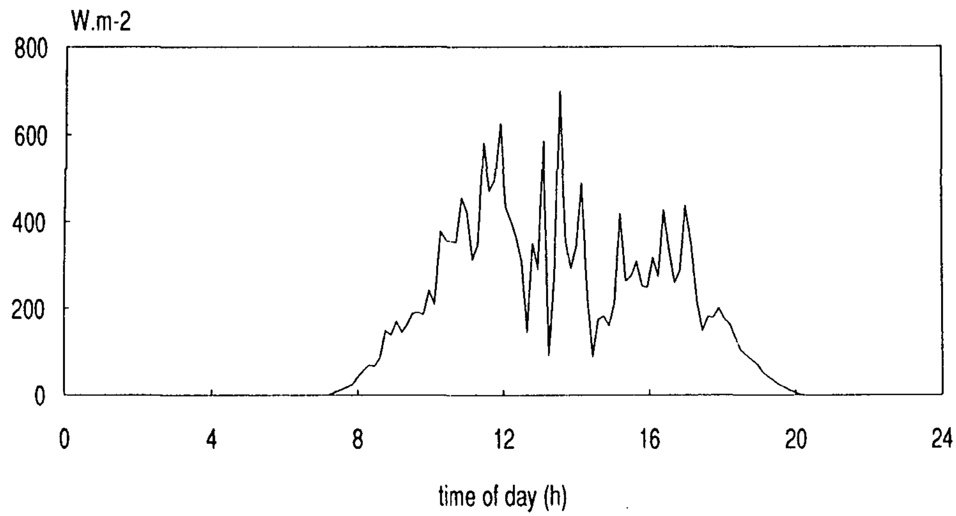

Figure 1 - Diurnal course of global radiation (W/m2) outside the greenhouse on 1 April 1988

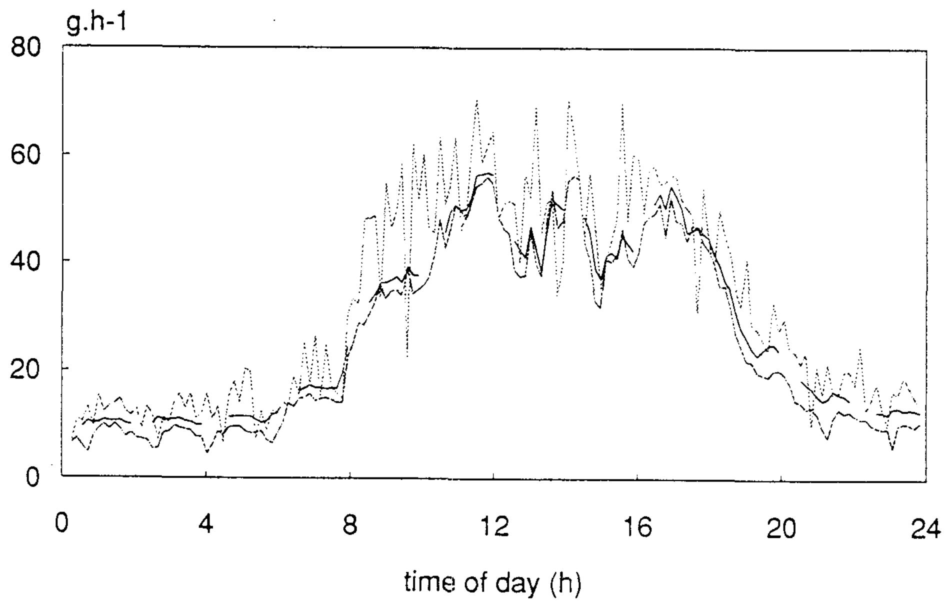

Figure 2 - Diurnal course (g.h-1.plant-1) of stem sap flow rate, as measured by NMR (···), transpiration (---) and water uptake (---) on 1 April 1988. The interruptions in the water uptake curve are due to periodic aeration.

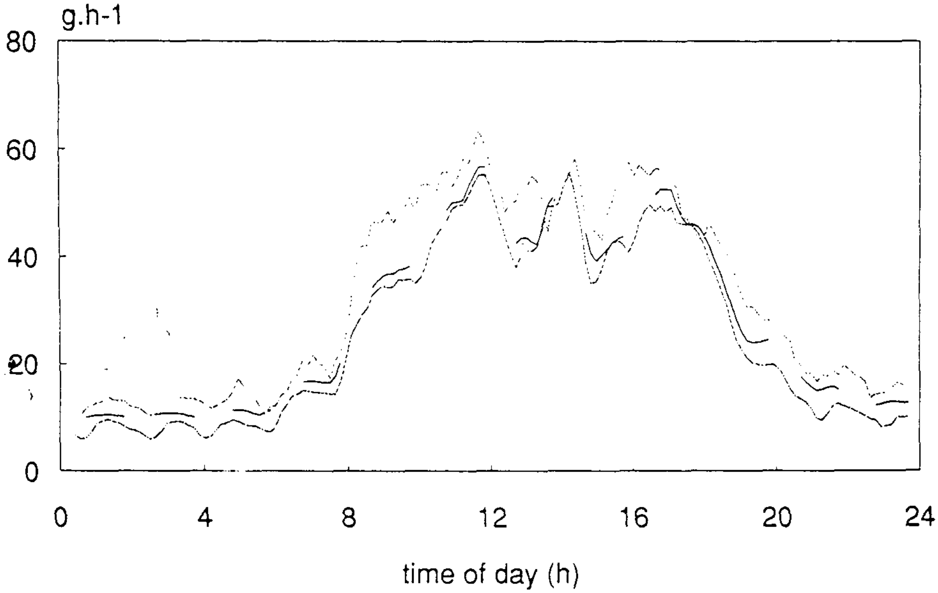

Figure 3 - As figure 2. Data are subjected to a half hour moving average filter.