Application of Magnetic Resonance Imaging (MRI) in Plant-Water Relationship

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Abstract – The aim of our research is to expand the adaptability of MRI measurements used in human diagnostics for examination of water barriers in living plants. Cucumber (Cucumis sativus) and Phyllirea angustifolia were chosen as test plants. The measurements were carried out at Kaposvár University Institute of Diagnostic Imaging and Radiation Oncology by Siemens Avanto type MRI equipment. Two different relaxation times were applied: T_1 that is capable of histological mapping, and T_2 which is used for examining water content. MRI measurements were made using 3-3 sample plants in the same position. In the analysis, proof was found that certain histological formation and branching cause modification in the intensity detected in T_2 relaxation time and these positions can be detected in T_1 measurements. Linear correlation can be experienced between T_1 and T_2 measurements. Linear correlation coefficient was 0.8223 in case of cucumber and 0.8874 for Phyllirea angustifolia, respectively. During the statistical examination of the signal intensities of xylem it can be concluded that they are not independent in statistical sense. The course of the intensity in xylem elements depends on the anatomic structure. Intensity profile is modified by nodes, by leaves and branches.

Keywords: MRI / xylem / nodes / water content

1. INTRODUCTION

Water plays an essential role in plant development (VAN AS et al. 2009). According to the last IPCC Report (2007) and regional climate modeling results, possible change is expected for the Carpathian-basin in the quantity and distribution of the precipitation (BARTHOLY et al. 2009). Several abiotic stress factors have negative effects on plant-water relationship (DAUDET et al. 2002; VERSLUES et al. 2006), therefore in purpose of suitable development of the plants it has high importance to investigate this relationship in wide details. Repeating elements can be found on the plant stem in certain order, which is nodes, internodes, leaf fundaments and axillary buds (MOHR - SCHOPFER 1995). Internodes has key role in plant growth (HARASZTY et al. 1978). Above these several other factors influencing plant development cannot be forgotten, e.g. mineral supplies, in which the zinc content of the plant plays key role (SOMMER - LIPMAN 1926; FARAGO 1980; CAKMAK et al. 1989; RENGEL - GRAHAM 1995) that has importance in processing auxin hormone (COSGROVE 2005). Light exposition of the plants can be mentioned too (LARCHER 2003). Presence of water has great importance in the extension of plant cells. There are several methods for measuring the water content of the plants, but most of them are unreliable and destructive. In consequence of the destructive methods, it seems to be impossible to repeat the measurements on the same plant part. The application of MRI equipment that is a novel procedure in detecting plant-water relationship can provide solution for this problem. The method used in human diagnostics is non-destructive for plants; therefore measurements can be repeated several times on the same sample plant. The other big problem of the classical plant physiological measurements is

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accuracy (PEARCY et al. 1991). It is hard to detect the changes because of the effects of the environment by classical methods. The application of MRI measurements in plant physiological researches can be a solution for this problem. This method makes measurements on the basis of spins' system in living plants that does not interfere rudely in the measured system. The spins have just a weak interaction with the macroscopic parameters of the examined biological system that influence its biological and chemical behavior. Magnetic characteristics have negligible role in biochemical processes at cell level (BERÉNYI et al. 1997). At the same time biochemical parameters influence the spin-system well detectably, therefore measurements made on the spin-system gives conclusions for the behavior of the examined biological system (BERÉNYI et al. 1997, FÖLDES et al. 2003, BUXTON 2009).

The basis of the MRI measurements is the interactions between the external magnetic field, the electromagnetic waves and the hydrogen atoms of the material. The MRI measures the quantity and distribution of the protons. The relative biggest content of protons is presented in the water; therefore MRI is suitable for detection of plant-water relationship. MRI does not detect the particular anatomic structure, but the quantity and distribution of water that on the other hand determines the given anatomic structure (WESTBROOK et al. 2005, JAKUSCH et al. 2010).

MRI that is non-invasive and non-destructive gives information of high resolution about the quantity of hydrogen in the tissues. It is a spectacular adoption in physiological researches that were carried out on fruits (RAFFO et al. 2005; MUSSE et al. 2009), trees (VAN AS 2007) and vegetables (MOREDA et al. 2009; ANDAUR et al. 2004).

2. MATERIAL AND METHODS

Measurements were carried out at Kaposvár University Institute of Diagnostic Imaging and Radiation Oncology by Siemens Avanto type MRI equipment that is capable to produce a magnetic field of 1.5 T.

The settings used in the measurements are presented in Table 1. The applied sequence is a mixture of the sequences used in human diagnostics of cranium, ankle and knee (JAKUSCH et al. 2010). The plant samples are of small mass compared to human body and has much less total water content, therefore cranial coil were applied that could localize the sample and could make small slice thickness (*Table 1*).

Table 1. Settings used in the MRI measurements

	MRI Setting	**Cucumber**	**Phyllirea angustifolia**
	Repetition time (sec)	1160	1160
	Echo time (sec)	4.24	3.94
T_1	Pixel spacing	0.36	0.97
	Slice thickness (mm)	0.69	0.89
	Resolution	0.089	0.837
	Repetition time (sec)	11.7	5.27
	Echo time (sec)	5.7	2.38
T_2	Pixel spacing	0.35	0.976
	Slice thickness (mm)	1	0.7
	Resolution	0.122	0.666

Test plants were grown in different conditions. Cucumber was grown in modified Hoagland nutrition solution (KOVÁCS et al. 2010; JAKUSCH et al. 2011) and Phyllirea

angustifolia were grown in container. Cucumber plants were 15-20 cm high and Phyllirea angustifolia was 30-35 cm high.

Intensity of the signal detected in xylem elements were presented as a function of distance from the root. The interactions of the xylem elements inside the plant were tested by linear correlation. Water barriers caused by nodes and differences in the intensities caused by anatomic structure were detected by T_1 measurements and correlated to T_2 measurements. The effect of nodes on the water content of the branch was examined by the analysis of the slope of the linear trend fitted on the intensities' graph.

3. RESULTS AND CONCLUSIONS

3.1. Examination of the xylem of cucumber

Xylem in the hypocotyls of cucumber was examined by MRI measurements one by one. In this part of the branch the vascular tissues can be well separated. Independency of the xylem was tested by χ^2 test, because the distribution of the data was not normal distribution. The calculated value of χ^2 test in T_1 measurements was 43.32, and the critical value was 18.3 (degree of freedom: 10). For T_2 measurements the calculated value of χ^2 test was 31.07 and the critical value was 18.3 (degree of freedom: 10). According to the statistics the xylems in the hypocotyls are not independent. A significant relationship can be observed between the T_1 and T_2 measurements where the correlation coefficient was 0.8223 (Figure 1).

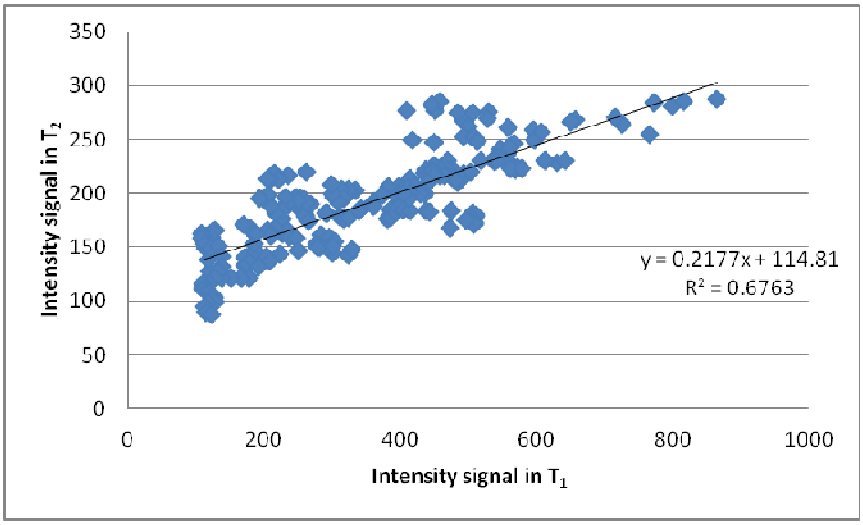

Figure 1. Linear relationship between T_1 and T_2 measurements of cucumber

3.2. Examination of the xylem of Phyllirea angustifolia

Segmentation was made on the branch part of Phyllirea angustifolia too. The plant has main stem and lateral stems. Two sides can be differentiated on the pictures of MRI where the curve of the intensity signals is partly diverse towards the apex. Examinations were carried out on the main branch. The intensity signals of the two sides of the branch are not independent. The calculated value of χ^2 test is 26694.43, critical value is 27.58, respectively (degree of freedom: 17), independency is proved by the statistical test. The relationship between T_1 and T_2 measurements is very strong, the linear correlation coefficient is 0.8874 (Figure 2).

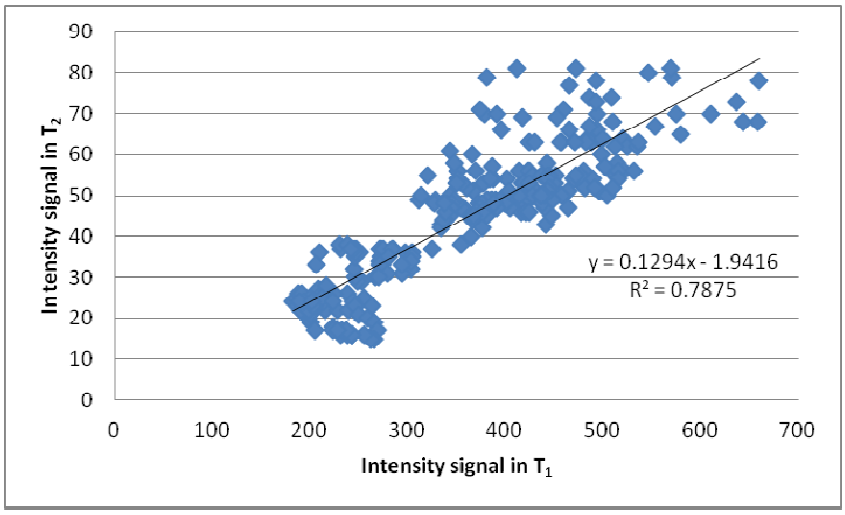

Figure 2. Linear relationship between T_1 and T_2 measurements of Phyllirea angustifolia

3.3. Detection of anatomic structure and interpretation

Anatomical differences that caused local maximum and minimum points in intensity signals of T_2 measurements could be detected by T_1 measurements. By using the two types of measurement technique the place of the nodes on the branch that caused local maximums could be determined. Local maximum points are at 26.22 mm, 71.76 mm, 91.08 mm, 109.02 mm, and 130.41 mm height, respectively (Figure 3.) in cucumber.

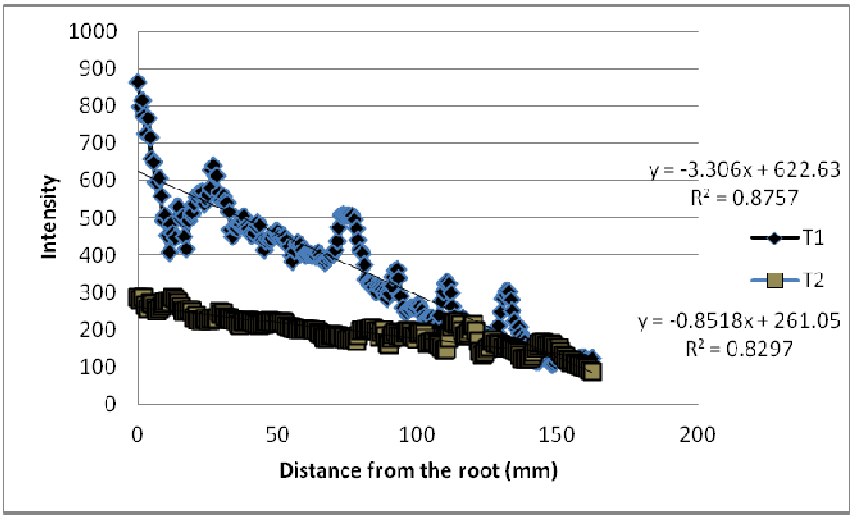

Figure 3. The intensity signal of T_1 and T_2 measurements as a function of the distance from the root for cucumber

Nodes can be determined also for Phyllirea angustifolia several times on the stem. The local maximums and minimums in the signal intensity were detected by applying the pictures of T_1 measurements. Nodes can be found at 10.5 mm, 25.2 mm, 39.9 mm, 60.2 mm, 72.8 mm, 86.1 mm, 102.2 mm, 118.3 mm, 128.1 mm, 154.7 mm and 186.2 mm height, respectively.

During the examination of the two plant species, it can be considered to be proved that in plants without fruit the intensity signal of MRI (that is in linear correlation with the water content) is decreasing from the root towards the branch apex. In general the water content of the plant is not independent from the plant height. Several water barriers deriving from the anatomy of the plants can be found that is caused by the special structure of nodes. These anatomic elements and their effects can be detected and determined by MRI measurements.

Intensity signal data deriving from the T_1 and T_2 measurements has very good correlations for both plant species used in the research.

4. DISCUSSION

MRI measurements used in human diagnostics gives a novel tool to the researchers of plant physiology to examine the plant-water relationship. MRI makes the examinations on the spin-system; therefore it can realize very accurate measurements. This non-destructive method allows to measure one plant several times shifted in time. During the interpretation of the measurements the exact anatomic element can be detected by accuracy of μm.

Measurements can be made by T_1 and T_2 relaxation time technique that complement each other. For the interpretation of the maximum and minimum values of T_2 data, T_1 measurements are necessary. The curve of the intensity signal of xylem elements depends on the proper anatomic structure. Intensity profile is modified by the nodes, leaves and the branches.

Measurements of very high resolution can be made by MRI equipment. This tool can claim high importance in the future during tracing processes of the plants.

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