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USE OF POROUS TUBES FOR MEASURING WATER EXTRACTION BY ROOTS AND SIMULTANEOUS MAINTAINING OF SOIL WATER POTENTIAL IN GROWTH CHAMBER EXPERIMENTS*

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A b s t r a c t. The efficiency of a system based on porous tubes in maintaining soil water potential during water extraction by plants in growth chamber experiment was evaluated. The effect of porous tubes area, soil type and density on water flow through porous tubes as induced by various water potentials was evaluated. The rate of change of soil water potential in response to pressure change depends strongly on the area of ceramic tubes per soil volume. If rapid changes or precise control of soil water potential are needed, the area of ceramic tubes per soil volume should be large. Experiments in which porous tubes are used for maintaining water potential should reach a compromise between plant water demands and permissible disturbance caused by the presence of porous tubes in the soil environment.

K e y w o r d s : porous tubes, soil water potential, root water extraction, watering

INTRODUCTION

Most of the laboratory experiments on the effect of soil condition on plant growth face the problem of proper supplying plants with water. Soil water potential that determines the accessibility of water for plants affects the rate of root growth, root-shoot mass partitioning, evapotranspiration and many more secondary processes between soil, plant and the atmosphere (Philip 1997). Although constant soil water potential during longer periods of plant growth does

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not appear or appears very rarely, there is a need to observe plant function in that kind of conditions when we can separately observe the effect of different factors on plant growth.

Plant watering in growth chamber experiments can be carried out daily or every few days, watering with doses of water and keeping the weight of the pot at a specified level using drip irrigation systems based on perforated pipes. Precise control of soil water potential in laboratory experiments can be met by the "negative pressure circulation system" (Lipiec *et al.* 1988, 1993) that supplies water using buried porous tubes with water under specified pressure. The method allows for simultaneous maintaining of the soil water potential and measuring of water volume extracted by roots (Whalley *et. al*. 2000). The system supplies water quantitatively, adjusting the volume of water absorbed by the soil to the constant value of soil matrix potential. Such good conditions are possible only when the volume of water used for evapotranspiration from soil is smaller than the capacity of ceramic tubes to supply water. This makes porous tubes an important element of the water supply system capable to supply water depending on their material, shape and dimensions. Constant water potential can be kept for a period of time depending on the plant water demands and soil properties. Increasing transpiration and leaf area with time during plant growth requires more water in the soil to keep the water potential at a specified level.

Porous tubes have been used at the interface between the water supply system and the soil in many growth chamber experiments (Lipiec *et al*. 1996, Veen *et al*. 1992, Nosalewicz and Lipiec, 2002). Application of water by a constant water potential system in combination with perlite or paraffine-wax layers that are impermeable to water (Nosalewicz and Lipiec, 2002, Araki and Iijima, 2005) allows to build an artificial soil profile in which the process of root water extraction can be analysed in detail at a specified depth.

Limited amount of water supplied to the soil by the system with porous tubes is crucial as it determines the ability of the system to maintain the soil water potential and the accuracy of root water extraction measurements. One of the ways to increase the efficiency of the system is to use longer tubes per soil volume, however some balance between the volume taken up by the soil and the porous tubes should be kept.

The aim of the study was to test porous tubes for their efficiency in supplying water to pots with soil and to measure the effect of various lengths of porous tubes per test pot on the rate of change of soil water potential in response to the change of water pressure inside the porous tube.

MATERIALS AND METHODS

Porous tubes built from two materials (T1 and T2) were tested for their potential permeability in water. More detailed measurements of the performance in soil were performed with one type of the porous tubes. Ceramic tubes used in the experiment were produced in the Institute of Power Engineering Ceramic Department CEREL, Poland.

Two soils were used for the experiment: sandy loam – Kiso river alluvial (1) and grey-brown developed from silt formation (2).

Table. 1. Textural characteristics of the soil

Soil	Soil texture, mm (%)		
	1-0.1	0.1-0.01	0.01-0.001
(1) Kiso River alluvial soil	72	21	7
(2) Grey-brown soil	31	44	25

The soils were compacted to get uniform density of 1.30; 1.48 and 1.58 Mg m^{-3} in PVC cylinders of 7.5 cm height and 7.5 cm in diameter.

The dimensions of the porous tubes used in the experiment were: 5cm in length, 9 mm in inner and 11mm in outer diameters, respectively. The tubes were glued to elastic pressure resistant tubes that were connected to a cylinder with a scale.

Coefficient E (cm^3 cm^{-2} h^{-1}), defined as the volume of water that flows through the area of one square centimetre of porous tube during one hour induced by water potential differences, was used to describe water flow through porous tube to water after submersing the tube in distilled water and changing the water potential in the system. Water potential in the system was regulated in the range from –65 up to –20 kPa using a vacuum pump, and the volume of water that flowed through the porous tubes was measured during 2 h.

The system maintaining soil water potential and allowing for measuring the water flow was built according to Whalley *et al*. (2000). The system consisted of a vacuum chamber, a regulated vacuum pump, a water reservoir with the volume of 250 ml with a scale, ceramic tubes, three way valves used to remove air from the system, pressure resistant PCV tubes to connect all the elements of the system together.

Depending on the treatment, there were one, two or four porous tubes placed inside a single PVC cylinder filled with soil, giving total length of porous cylinders equal to 5, 10 and 20 cm, respectively. Porous tubes were placed perpendicularly to the axis of PVC cylinders within holes of 11 mm diameter drilled in soil. One 5cm long porous tube was placed in the centre of a PVC cylinder, two porous tubes were placed parallel in the middle of the height of the PVC cylinder, with 3cm distance between them, four porous tubes were placed similarly as the two porous tubes but 2.5 and 5 cm from the top surface of the PVC cylinder. To assure good contact between the porous tubes and the soil the tubes were additionally covered with a liquid mixture of soil and water before insertion in the soil.

Series of tests were performed to measure the rate of water flow as induced by soil water potential difference. Two available kinds of porous tubes of the same size were initially tested – T1 and T2. The potential water flow through porous tubes was measured after immersing the tubes in distilled water. The potential of water inside the porous tubes, regulated by the vacuum pump, allowed for measuring coefficient E determining water flow through porous tube to water induced by water potential P for two porous materials T1 and T2.

The rate of flow of water through the ceramic tubes to or from the soil was measured in the next step. Different area (length) of porous tubes, particle size distribution and soil density, plant water uptake were the analysed factors.

During the experiments care was taken for the vertical distance between the water level in a cylinder with a scale and the porous tube not to exceed 5cm, the value corresponding to 0.49 kPa. Porous tubes were tested for different water potential differences, limited by water entry pressure at about –80kPa. Tensiometers (TENSIMETER, USA) placed in the centre of the soil pots were used to control the soil water potential.

The means of four measurements and standard errors were used to describe the results.

RESULTS

Comparison of two porous materials of different porosity (obtained by different sintering temperature values) used for porous tubes (Fig. 1) showed a difference in their potential ability to supply soil with water indicated by coefficient E. The porous tube T1 is more permeable to water than T2, i.e. the corresponding value of E at 600 kPa water potential difference is 1.5 $cm^3\ cm^{-2}\ h^{-1}$ greater for tube T1 than for tube T2, as calculated from fitted curves.

Soil (1) in the pots was initially moistened to the soil water potential equal to -10 kPa corresponding to water content of 23.5% w/w. Then, the value of –55 kPa was set to test the effect of different lengths (area) of porous tubes buried in the soil (Fig. 2) on water flow. This comparison shows the combined effect of both the area of porous tubes and the soil hydraulic properties on the work of the system. Apart from observed differences in volumes of water at a time for different tube lengths, for 20 cm long tubes almost no flow was observed after 10th hour indicating steady soil water potential in the soil pot.

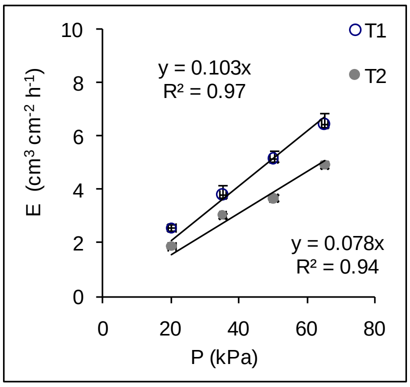

Fig. 1. Coefficient E determining water flow through different porous tubes T1 and T2 as a function of soil water potential

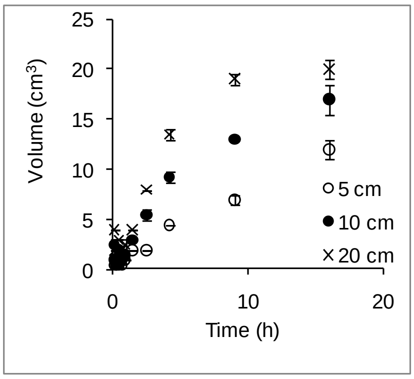

Fig. 2. Cumulative water flow through porous tubes of lengths from 5 up to 20 cm to a cylinder with soil (1) induced by change of water potential from –10 down to –55 kPa at t = 0h

A similar experiment was conducted using grey brown soil (Tab. 1) of various density and 20 cm long porous tubes. Water flow induced by a 20 kPa difference in water potentials is presented in Figure 3A. The difference between treatments results from differences in soil hydraulic conductivity. Recalculated values presented in Figure 3 B. show the highest flow per unit of porous tube area and per one hour during the first hour of water potential change equal to 0.28 $cm^3\ cm^{-2}\ d^{-1}$ for 1.30 Mg m^{-3} soil density being more than three times higher than for soil compacted to 1.58 Mg m^{-3}.

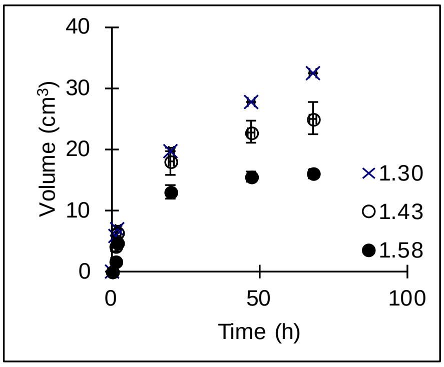

Fig. 3A. Cumulative water flow through porous tubes of a length of 20 cm from the soil (2) having different soil bulk density induced by decrease of water potential from –20 down to –40 kPa at t = 0 h. Bulk density in Mg m^{-3} is inside the Figure

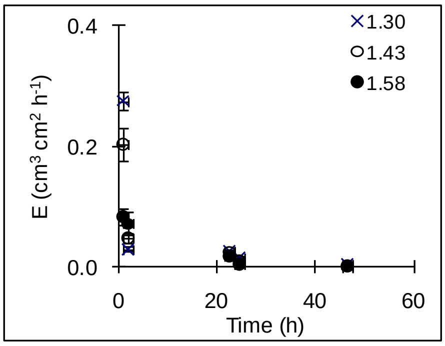

Fig. 3B. Coefficient E determining water flow through porous tube to soil having different bulk density – soil (2). Bulk density in Mg m^{-3} is inside the Figure

The system was tested in the experiment with two spring wheat plants growing in 40 cm high soil columns with moderately compacted grey brown soil (1.43 Mg m^{-3}) divided into 10 cm hydraulically isolated layers. Soil water potential values initially set up to –35 kPa were monitored using tensimeters placed in between porous tubes. As can be seen from Figure 4, the average plant water use at the 20th day of plant growth, equal to 7 $cm^3\ d^{-1}$ and 3 $cm^3\ d^{-1}$ from the 10-20 cm layer and 20-30 cm layer, respectively, did not change the soil water potential visibly. Soil water potential in the pot with buried water source and roots may be, however, described as a steady one only in proper time and spatial scales, when the properties of the water source, soil and a root system do not change too rapidly (Philip 1997).

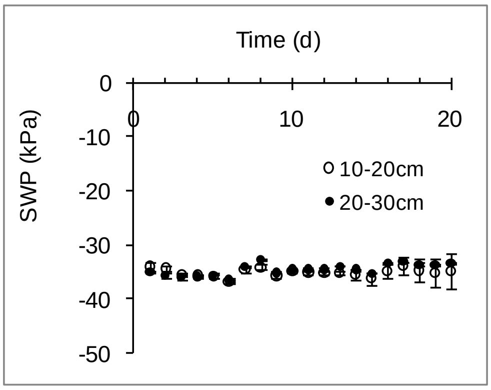

Fig. 4. Soil water potential (SWP) dynamics at 10-20 and 20-30 cm depth during wheat growth

Presented results are only examples of test measurements showing important factors that should be taken into account in experiments with a constant soil water potential during plant growth.

CONCLUSION

1. The method with porous tubes as an interface of water flow between soil and water reservoir is a useful tool for studying root water extraction in controlled soil water conditions. Care should be taken in long-lasting experiments or when high evapotranspiration is expected so that the area of porous tubes is sufficiency large to meet the water demands and to maintain soil water potential at desired level.
2. In experiments where high time resolution is required longer tubes per soil volume are strongly advised. If the plant transpiration measurements are the highest priority, reducing evaporation from soil surface (for example by covering it) may be a good way to increase the useful range of porous tubes application for more water demanding purposes.

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UŻYCIE POROWATYCH RUREK DO POMIARÓW POBORU WODY I JEDNOCZESNEGO UTRZYMYWANIA POTENCJAŁU WODY GLEBOWEJ W DOŚWIADCZENIACH FITOTRONOWYCH

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S t r e s z c z e n i e. W badaniach określono efektywność systemu opartego na porowatych rurkach do utrzymania stałego potencjału wody w trakcie poboru wody przez roślin w doświadczeniach fitotronowych. Analizie poddano wpływ powierzchni rurek i gęstości gleby na przepływ wody przez rurki wywołany różnicą potencjałów wody. Szybkość zmian potencjału wody w glebie w reakcji na różnicę ciśnień jest mocno uzależniony od powierzchni rurek, przez którą odbywa się przepływ wody do objętości gleby. Zaleca się użycie rurek o powierzchni możliwie dużej w doświadczeniach, w których wymagane jest precyzyjne utrzymanie lub planowane są szybkie zmiany potencjału wody glebowej. Doświadczenia fitotronowe z użyciem systemu opartego na porowatych rurkach wiążą się z kompromisem pomiędzy zapotrzebowaniem na wodę roślin i dopuszczalnym zaburzeniem struktury gleby wywołanym obecnością rurek porowatych w ośrodku glebowym.

S ł o w a k l u c z o w e: rurki porowate, potencjał wody glebowej, pobór wody przez korzenie, nawadnianie