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An easily operated apparatus to register the amount of the aqueous solution absorbed by a plant root system

JERZY CZERSKI

Institute of Botany, the University of Warsaw, Poland
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ABSTRACT

An easily operated apparatus was constructed (figs. 1,2) allowing to register the amount of the aqueous solution absorbed by a plant root system. The device allows for simultaneous registering of the solution absorption by two plants. The recording of a definite volume of the absorbed solution can be controlled within wide limits. Experiments (figs. 3,4) confirmed the efficiency of the apparatus.

INTRODUCTION

Quantitative measurements of water absorption by higher plants was effected first by Vesque in 1876. Nonetheless, in spite of numerous studies in existence (Grafe 1914; Rosene 1937; Gregory and Woodford 1939; Hayward Blair and Skaling 1942; Kramer 1946; Brouwer 1953; Wiebe and Kramer 1954; Tarłowski 1955, 1956; Ivanov 1962, 1963; Lebedyew, Chuchkin, Sabinina and Bryukwin 1964; Kuperman, Bochkov and Labzun 1968; Larkum 1969), investigations aiming at new experimental solutions are still going on. The variety of methods in use in measurements of water absorption by plant root systems seems to result not only from the specific character of the investigation in water regime and from the diversity of used plant material, but equally from the limited utility of elaborated methods.

While working at building the apparatus we aimed to obtain a construction which would fulfill the following requirements:

1. usability for measurements of water absorption by plants of various sizes
2. high sensibility of the system, expressed by the capability of registering possibly small portions of absorbed water
3. possibility of running the automatic recording of the measurements
4. simplicity of construction and easy operation.

I. CONSTRUCTION OF THE APPARATUS

When constructing the apparatus mentioned, use was made of the phenomenon of small gas bubbles, formed at the mouth of a tube submerged in the liquid when the external atmospheric pressure, in a closed system, is higher than the gas pressure above the liquid. The factor causing the fall of pressure within the system is the loss of a certain volume of the water solution absorbed by the plant root system. The recording of the gas bubbles enables to determine quantitatively the process of the solution absorption by the plant root system.

The apparatus for continual measurement of water absorption by the plant root system (Fig. 1), functioning on the principle mentioned, is composed of elements constructed as follows:

1. The container of nutrient solution, a large bottle *s* of 2 l capacity, where the root system of the tested plant is placed. The correct functioning of the apparatus depends on the tightness of fixing the plant. In order to avoid the cutting of the stopper and also to avoid damaging the root system, the new plant is placed in the stopper aperture drilled in advance. When the plant attains adequate size, the space between the inner wall of the stopper aperture and stem of the plant is simply filled up by a soft plasticine; thus necessary tightness of plant fixing is obtained.

2. The calibration capillary *k* is connected by its lower part with the vessel *w* and the bottle *s* by means of T-form glass tube. The upper part of the capillary, during the calibration of the apparatus is connected with the vessel *z* by a three-way cock *f* and by a rubber tube. The capacity of the lower can enlargement on the measurement capillary is determined with accuracy; in our case it amounts to approximately 0.505 ml. The part of the capillary between the upper and the lower enlargement and that below the lower one is provided with scalling marks every 20 µl.

3. The compensating vessel *w*, of approximately 100 ml volume is connected, through its lower contracted part with the bottle s and with

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Fig. 1

A — Scheme of the apparatus for measurement of nutrient solution absorption by the plant root system.

s — Container of nutrient solution; *k* — Calibration capillary; *w* — Compensating vessel; *f* — Three-way cock; *z* — Vessel containg the saturated potassium chloride in ethanol; *r* — Glass capillary; *m* — Glas tube; *e* — Ground joint; p_1 *p* Platinum electrodes; *h* — Recording sets (telephone counters); *g* — Programing clock; *d* — Electrode head; *l* — Water bath; *u* — Monitoring system; *j* — Handwheel; n_1 *n* — Rubber tubes; *o* — Ultrathermostat.

B — Positions of the three-way cock f

C — Scheme of fixing the electrode in to capillary and the structure of the electrode head (comments in the text)

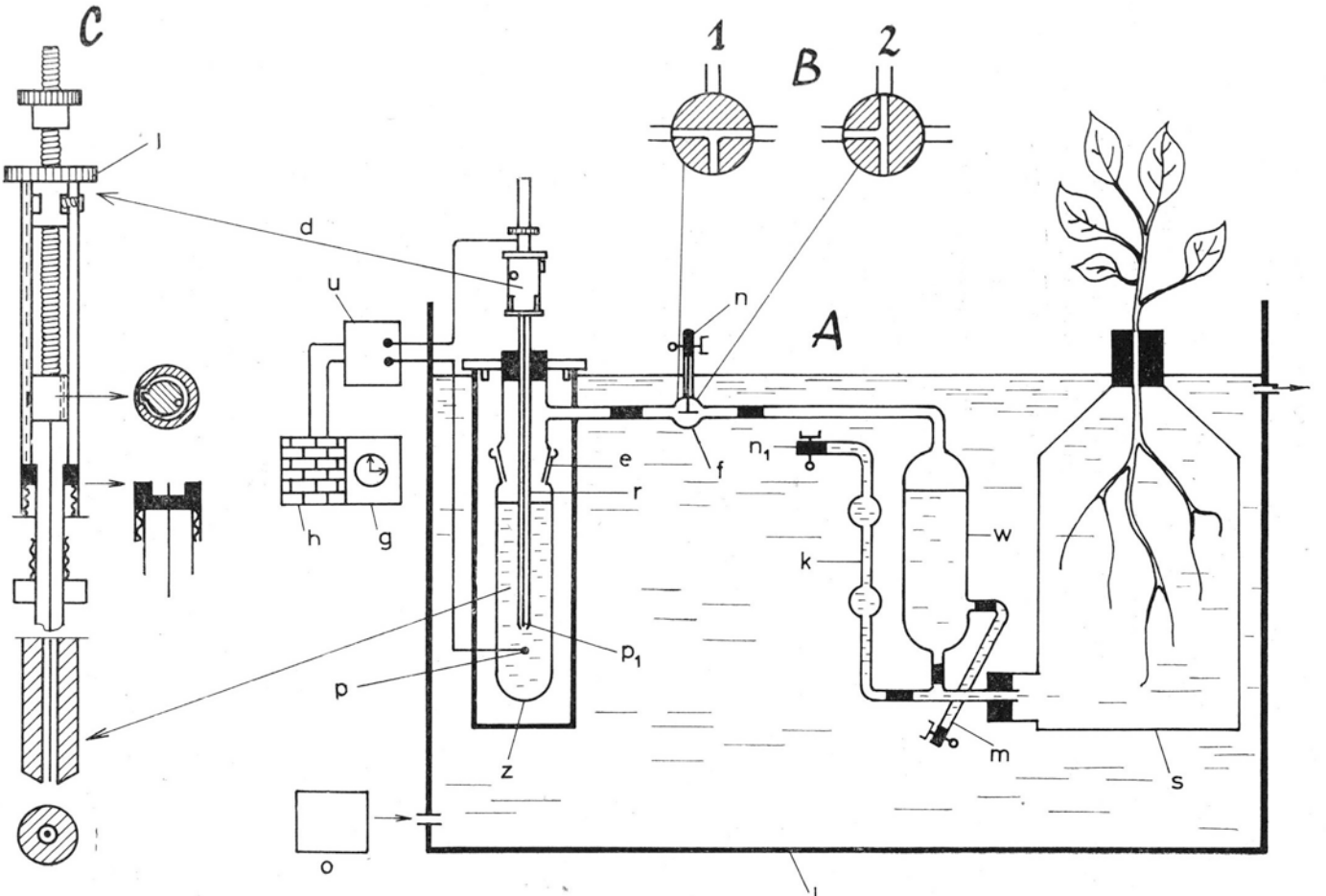

Fig. 1

the measurement capillary k. The upper part of the vessel w allows, by use of the three-way cock f, to realize the connection as presented in the scheme in Fig. 1 B. The side tube m serves to replenish the nutrient solution absorbed by the plant.

4. The vessel z contains 80 ml of the saturated potassium chloride in ethanol. In the upper part of the ground joint e a rubber plug is fixed; the glass capillary r runs accross it; the capillary contains a movable platinum electrode p_1. The construction of the glass capillary head d is shown in Fig. 1 C. A second platinum electrode p immersed in a potassium chloride solution in ethanol is fused to the container's z wall. The container z is screened by an air jacket in plexiglass.

5. The monitoring system u (Fig. 2) is composed of 2 independent channels, each one containing a lamp cathode follower built on one lamp triode ECC 81, and a stage controlling the counter built on a transistor of the BF 506 type. The feeding of both channels is common. The platinum electrodes (p_1, p) are connected with a pair of clamps, marked as input. During the electrode gaps a current of circa 1 mA is flowing through the lamp, and this causes a voltage drop at the cathode resistance of circa 4 V. At that time the transistor shows no conduction — consequently no current is flowing through the counter. At the very moment when shorting occurs through the liquid between the platinum electrodes, the current flowing through the lamp rises suddenly, this resulting in a positive voltage rush on the cathode. This rush is applied, through high capacitance (100μ F) to the transistor basis, bringing about the flow of the current through the counter which records instantly the impulse produced. The average value of the current flowing through the transistor depends on the constant of the condensator charging time The resistor 7.5 KΩ placed between the input clamp and the triode grid cause the reduced sensitivity of the system to electric interferences of any kind. The current maximum flowing through the triode in case of short-circuit of input clamps is controlled by the position of the potentiometer slide. This current cannot exceed 8—10 mA.

6. The described system of monitoring, with its 2 output channels is connected to 2 recording sets h (Fig. 1), each covering 24 telephone counters. This enables the simultaneous measurements of the water absorption of two plants.

7. The functioning of telephone counters is controlled by a programming clock g which switches every hour the control systems on the successive counter. Thus we obtain the number of impulses corresponding to the volume of solution absorbed by the plant during each of consecutive hours.

8. The described set of the apparatus (the electric system except) is placed in the bath l of circa 130 l of water. An ultrathermostat o maint-

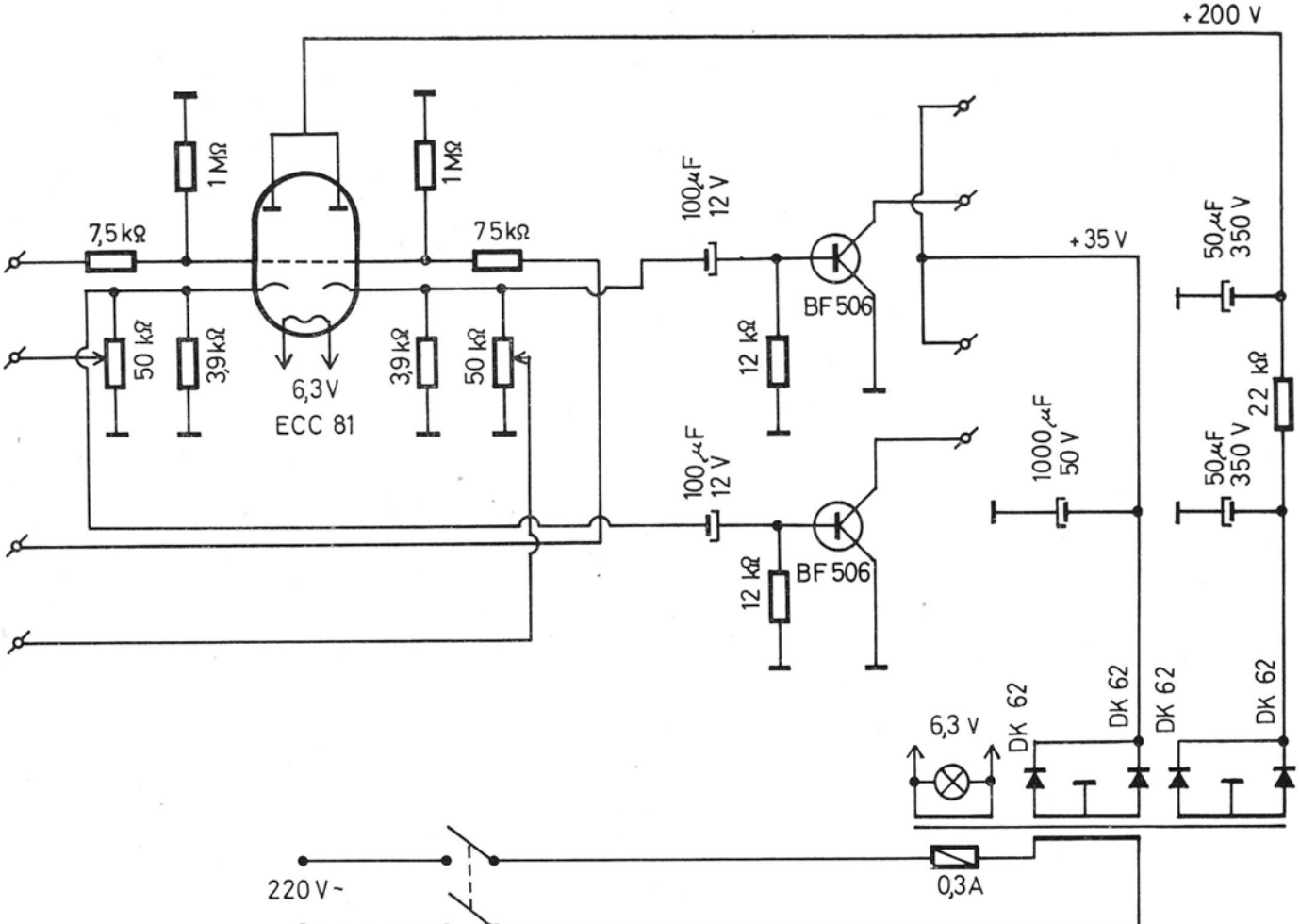

Fig. 2. Scheme of the monitoring system (comments in the text)

ains the temperature of the bath with exactness to ± 0.01 C (this brings about a volumetric error for 2 l of the bottle *s* with medium equal to $\pm 18 \cdot 10^{-5} \cdot 10^{6} \cdot 0.01\ \mu l = 3{,}6\ \mu l$ of solution).

II. FUNCTIONING OF THE APPARATUS

The bottle *s* is filled thouroughly with the nutrient solution, while the measuring capillary *k* and the compensating vessel *w* are filled only to a determined level, marked on Fig. 1. Then the root system of the plant is fixed tightly in the bottle. The three-way cock *f* is placed in position 1 (Fig. 1 B), connecting the vessel *z* with the bottle *s* through the vessel *w*. Through the rubber tube, connected to the side lower tube *m* of the compensating vessel *w*, the nutrient is fed in such amount as to make the level of the ethanolic potassium chloride in the capillary reach its mouth. When the plant is absorbing the solution, at the mouth of the capillary *r*, which through the head *d* is in contact with the atmosphere, the gas bubble appears, of a volume corresponding to that of the solution absorbed. As the plant absorbs the solution, the gas bubble grows and after having attained certain size, it comes off the tapered capillary *r*, and is replaced by the ethanolic potassium chloride, penetrating into the capillary. Using the handwheel *j* of the head *d* (Fig. 1 C), we position the platinum needle of the electrode so as to ensure the connection of the solution with the platinum electrode after the comming off of the gas bubble and the repeated penetration in the capillary of the ethanolic potassium chloride. Since the electrodes are connected with the monitoring system, the solution penetrating into the capillary causes the closure of the electric circuit and generates a short impulse, registered by the counter operating actually.

III. THE CALIBRATION OF THE APPARATUS

The calibration capillary *k* is connected to the vessel *z* and bottle *s* through the rubber tube n_1 and the tube *n* by positioning the three-way cock *f* in position 2 (Fig. 1 B). Therefore the plant root system in the bottle *s* is brought in contact with the atmosphere through the calibration capillary *k* and with the vessel *z* while the vessel *w* is left out. The nutrient solution, being initially in the upper, enlargement of the calibration capillary *k*, descends, as it is absorbed by the plant, reaching down the scaled part of the capillary. In the moment of the gas bubble coming off the mouth of the capillary *r* and of the penetration in its place of the ethanolic potassium chloride, note is taken of the liquid meniscus in capillary *k* and of the record of the counter. The repeated read-out of the volume of absorbed solution is performed at the lower scale, and

the reading of the corresponding value of registered impulses. At the Table 1 examples of a calibration performance are referred to.

The decrement of determined volume of medium in vessel *w* accompanied by cyclic closing and opening of electric circuit, depends on the form of capillary *r* and on physical properties of the solution in container *z*. The volume of the registered portion of absorbed nutrient solution may be controlled within wide limits through a change of the angle of the capillary level and by matching solutions of various surface tensions.

Table 1

Calibration of apparatus

Volume of solution absorbed in µl	Number of impulses	Volume of the solution corresponding to 1 impulse in µl
1900	50	38.00
1950	51	38.23
1860	49	37.95
1940	51	38.03
1980	53	37.35
1940	52	37.30
1920	51	37.64
1940	51	38.04
1940	51	38.04
1920	51	37.64
		average 37.82

The correctness of measurement is influenced by the stability of temperature and of the atmospheric pressure. It is relativelly easy to secure a stable temperature by help of an ultrathermostat, and it may be kept at a constant level with high accuracy (up to 0,01°C). The effects of fluctuations of atmospheric pressure may be limited by keeping low the gas phase volume in vessel *z* and container *w*.

The calibration of the apparatus operated by various speed of solution absorption (1 impulse per 20″ — 1 impulse per 130″) yielded compatible results and stayed within limits as shown on Table 1.

IV. EXPERIMENT AND DISCUSSION

Using the described apparatus measurements were made to check its usability in quantitative determination of the dynamics of medium absorption by the plant root system.

The experiments were performed on seedlings of apple-tree *Malus*

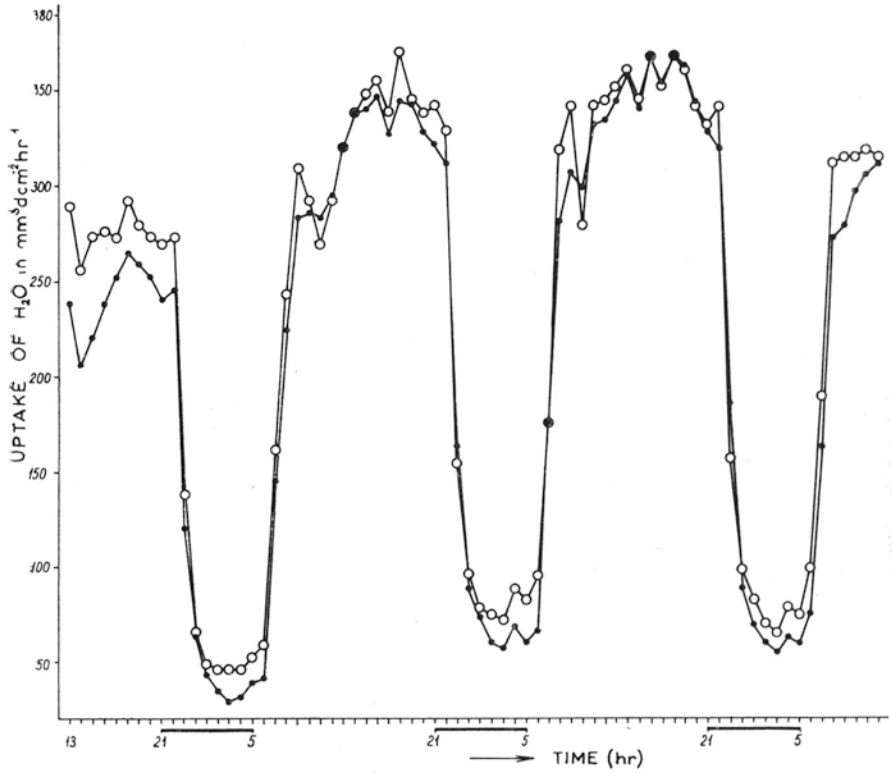

Fig. 3. The course of the absorption of nutrient solution by two apple-tree seedlings

domestica Borkh. c.v. 'Antonówka' of 9—15 weeks old. The experimental plants were bred in a hydroponic vessel, with use of nutrient solution no 11 according to B e n t l e y (1959) at 25°C in the day time and at 18°C at night. The day time length was 16 hrs, using fluorescent lamps RF-40 W as lighting, which gave at the plant level a luminous intensity of $1.8 \cdot 10^4$ erg cm^{-2} sec^{-1}.

The experiments were operated with the same nutrient solution and in analogous conditions to those of the plant growing. The light source were mercury vapour tubes LRF-250 W, yielding a luminous intensity of 1.8×10^4 erg cm^{-2} sec^{-1}.

The bath temperature was kept at the level of 16.7°C ± 0,01.

On Fig. 3 is shown the intensity of absorption of solution by two apple-tree seedlings. According to expectations (Fig. 3) maxima were observed regularly in the process of water absorption occurring in day time. The absorption of medium by two experimental plants (Fig. 3) shows a similar course, testifying to correct functioning of both device sets. Measurements of water absorption by two apple-tree seedlings were made in a three-hour cycle of dark and light periods (Fig. 4), which confirmed the correct operation of the described aparatus.

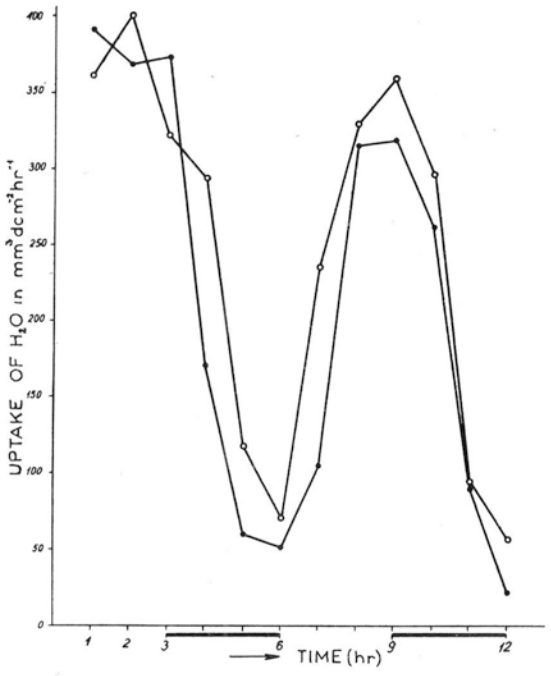

Fig. 4. Absorption of nutrient solution by two apple-tree seedlings during 3 hour cycles of light and darkness

The measurements of water absorption by the plant root system (Figs. 3 and 4) aimed solely at checking the efficiency and operating of the apparatus described. As was demonstrated, by help of the system discused consecutive portions (37.82 µl) of absorbed solution may be registered in a continuous manner. Registering of various volumes of absorbed solution may be ensured through filling the container *z* (Fig. 1) with a liquid of different surface tension or through the use of capillary *r* of different diameter. The simplicity of construction, the possibility of a simultaneous measurement of solution absorbed by several plants and the ease of operating the system seem to indicate that the described apparatus may find a wide use in investigations of the plant water regime.

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Aparat do pomiaru absorpcji roztworu wodnego pożywki przez system korzeniowy rośliny

Streszczenie

Skonstruowano łatwy w użyciu aparat (fig. 1 i 2) umożliwiający rejestrację pobieranego przez system korzeniowy rośliny roztworu wodnego pożywki.

Doświadczenia przeprowadzono na siewkach jabłoni *Malus domestica* Borkh. ('Antonówka') i na pomidorach, na tej samej pożywce i w tych samych warunkach, w jakich rośliny hodowano. Źródłem światła były lampy rtęciowe LRF—250 W dające natężenie światła $1{,}8 \cdot 10^4$ erg cm^{-2} $sek.^{-1}$. Temperaturę łaźni utrzymywano na poziomie 16,7°C±0,01.

Przeprowadzone pomiary absorpcji pożywki przez system korzeniowy rośliny (wykresy — fig. 3 i 4) miały na celu sprawdzenie działania aparatu. Jak wykazano, za pomocą opisanego układu mogą być rejestrowane w sposób ciągły kolejne porcje pobranej przez roślinę pożywki.

Wypełnienie zbiornika z cieczą o różnym napięciu powierzchniowym (fig. 1) lub zastosowanie kapilary *r* o zmiennej średnicy stwarza możliwość rejestracji różnej objętości pobieranej pożywki. Prosta budowa, jednoczesny pomiar absorbowanej pożywki przez kilka roślin oraz łatwy w użytkowaniu układ zdają się wskazywać, że opisany aparat może mieć szerokie zastosowanie w badaniach nad gospodarką wodną roślin.