BIOLOGIA PLANTARUM (PRAHA)

1 (3) : 167—175, 1959

A Photoelectric Planimeter for Measuring Leaf Area

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Received October 1, 1958

Souhrn

V práci se popisuje nový typ fotoelektrického planimetru pro měření plochy listů. Planimetr je založen na absorpci nejzazšího červeného a blízkého infračerveného záření, proto jsou jeho údaje málo závislé na tloušťce a zabarvení listů. Konstrukce optické části přístroje je poměrně jednoduchá. Planimetr má dva optické kanály, jeden měřicí, do něhož se vkládají listy a druhý kontrolní, který vyrovnává výkyvy v toku záření od zdroje, způsobené kolísáním napětí v síti. Tok záření v obou kanálech se mění v elektrické signály argentsulfidovými hradlovými fotonkami. Diference fotoproudů měrné a kontrolní fotonky se zesiluje citlivým stejnosměrným diferenciálním zesilovačem v můstkovém zapojení. Pro dosažení stability nuly jsou všechny anodové obvody tohoto zesilovače a žhavení prvého stupně napájeny elektronkovým stabilisátorem. Stupeň zesílení lze regulovat a tak dosáhnout toho, aby dané ploše odpovídal zvolený počet dílků výstupního měřidla. Shodná konstrukce obou kanálů dovoluje provádět měření také tak, že se do kontrolního kanálu vkládají kusy papíru o známé ploše a měřidla na výstupu zesilovače se používá pouze jako indikátoru nuly. Planimetrem nelze měřit více objektů současně, neboť měřený objekt se musí vkládat do osy kanálu.

Summary

This paper gives a description of a two-channel photoelectric planimeter for measuring leaf areas. It is based on the absorption of rays within the range 0·6 to 1·4 μ. The flux of radiation is converted to electric signals by argentum sulphide photocells. The difference in the photoelectric currents from the measuring and control channels is amplified by a sensitive and highly stable d.-c. differential amplifier and is indicated by a meter which can be calibrated direct in area units.

Introduction

The measurement of leaf area plays a direct and important part of research in photosynthesis and related questions. Leaf area is also an important factor in the study of the water relations and nutrition of plants, in examining the influence of herbicides and stimulators and in investigating the mutual relations between plants. In such cases it is often necessary to measure large numbers of leaves and for this reason attempts are made to accelerate the operation as much as possible.

Very rapid and sufficiently accurate measurement of leaf area is possible by photometric methods in which the reduction in light flux caused by the object to be measured makes it possible to deduce its area. Besides visual photoplanimeters (e. g. Bolas and Melville 1933), a number of photoelectric planimeters have been suggested, based on various principles and having the most various constructions (e. g. Spoehr and McGee 1923, Gerdel and Salter 1928, Frear 1935, Petrov and Gavrilov 1939, Grigor'ev and Metreveli 1958). The great majority of these instruments suffer, however, from the drawback that the data they afford are not dependent only on the area of the objects measured, but also to a greater or lesser extent on their optical properties. In the case of leaves, their thickness and colour, and the proportion of light which they reflect are important. Such instruments have to be calibrated using samples of known area, taken from leaves of the same species as those to be measured. In the case of articulated leaves such calibration is difficult, if not impossible.

This drawback is removed in principle in the apparatus described by Miller, Shadbolt and Holm (1956). Its construction, however, requires good quality large Fresnel lenses, which are not always available. It is therefore necessary to seek another solution, which reduces the effect of the optical properties of the leaves, to a minimum.

In the apparatus described here data sufficiently independent of the quality of the leaves measured are obtained by following the absorption of rays within the wave lengths of 0·6 to 1·4 μ, that is within a range where the leaves absorb radiation to a great extent. In addition, such weak illumination is used that almost total absorption is achieved. Independence of the readings of this apparatus on fluctuations in the output of the source of radiation is obtained using a balanced circuit with two AgS-photovoltaic cells. For the detection of the differences in the very weak photoelectric currents from these photoelectric cells a very sensitive and highly stable amplifier is used.

Construction of the Instrument

Fig. 1 shows the block scheme of the instrument, divided into two identical channels. The flux of radiation from a plane source S passes the filters F′ and F″ in each channel and is further directed by the two light leading prisms C_1 and C_2 to the photocells P_1 and P_2. The object O whose area is to be measured is placed between the filters in one of the channels. The resultant difference in the photoelectric currents is amplified by means of a differential amplifier (A) and indicated by the galvanometer (M).

Fig. 2 gives a photograph of all operational parts of the instrument.

O p t i c a l p a r t s. The source of radiation consists of four regularly spaced glow lamps 127 V/26 W, two above each channel. In view of the spectral properties of the filters and photoelements used, it is preferable to operate them at a lower than nominal voltage, e. g. at cca 70 to 80 volts. The differential method of measurement makes the stabilization of the feeding voltage superfluous. A sheet of milky lucite 6 mm. thick placed beneath the bulbs scatters the light and makes the iradiation of the working area of both channels reasonably even.

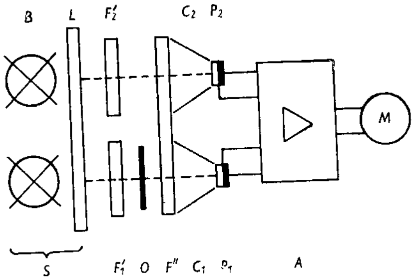


Fig. 1. Block scheme of optical planimeter. For explanation see text.

The leavers are placed on a 2 mm. sheet of getinax in the measuring channel and are covered by a sheet of red-coloured lucite 4 mm. in thickness. Getinax

Fig. 2. General view of the planimeter

is a plastic produced by the impregnation of paper pulp by bakelite. Therefore it is not transparent, it scatters light and absorbs a great deal of the radiation falling on it; only radiation of $\lambda > 0{\cdot}6\ \mu$ is transmitted (v. Fig.3). The spectrum of the radiation reaching the channels is further modified by the coloured lucite mentioned above, which was obtained by staining clear lucite with fuchsin ("Magenta-Rot" Merck preparation). Transmission spectrum of the filter formed by this combination of getinax and red lucite shown in Fig. 3, which also includes a diagram of the spectral characteristics of the photovoltaic cells used.

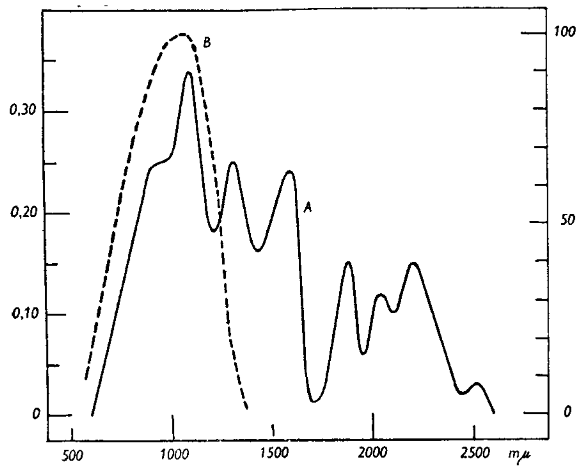


Fig. 3. Transmission spectrum of combined filters F′ and F″ (curve A) and spectral characteristics of the argentum sulphide photocell (curve B). Abscissa: Wave length in mμ. Ordinate (left): transmission in % (curve A), ordinate (right): selective spectral sensitivity in % (curve B).

The working area in each channel is 34 × 28 cm². The flux of radiation from this area enters the optical channels, which are pyramidal in shape. The photocells are mounted in the apexes of these inverted pyramids at a distance of 25 cm. from the sheet of getinax. The channels are made of sheet brass

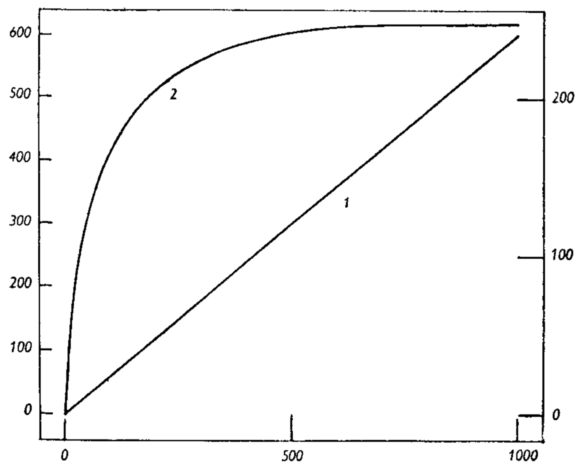


Fig. 4. Photoelectric characteristics of the argentum sulphide photocell. Abscissa: Illumination in lux. Ordinate (left): Short-circuit current in μA (curve 1), ordinate (right): opencircuit voltage in mV (curve 2).

and are lined by a layer of white material which scatters light. This is prepared by painting the insides of the channel walls with lacquer, which is covered by a layer of fine MgO or $BaSO_4$ powder before it has dried. The surplus powder is blown off after the lacquer has dried. Optical channels constructed in this way do not completely eliminate the influence of the position of the object in the measuring field. The objects are, therefore, always placed as far as possible in the centre of this field, which is marked by a cross.

Barrier-layer photovoltaic cells, with argentum sulphide as semiconductor, are used for the detection of radiation. These were constructed at the Institute

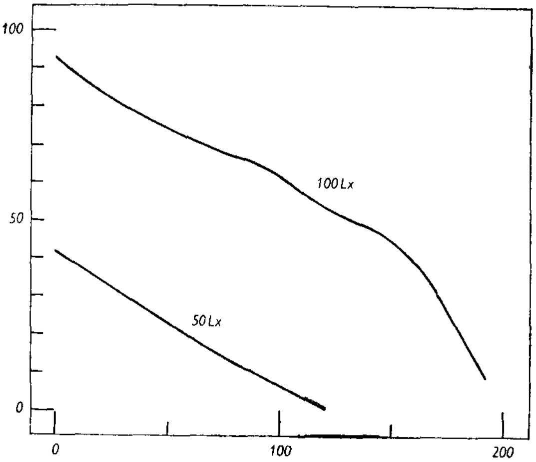


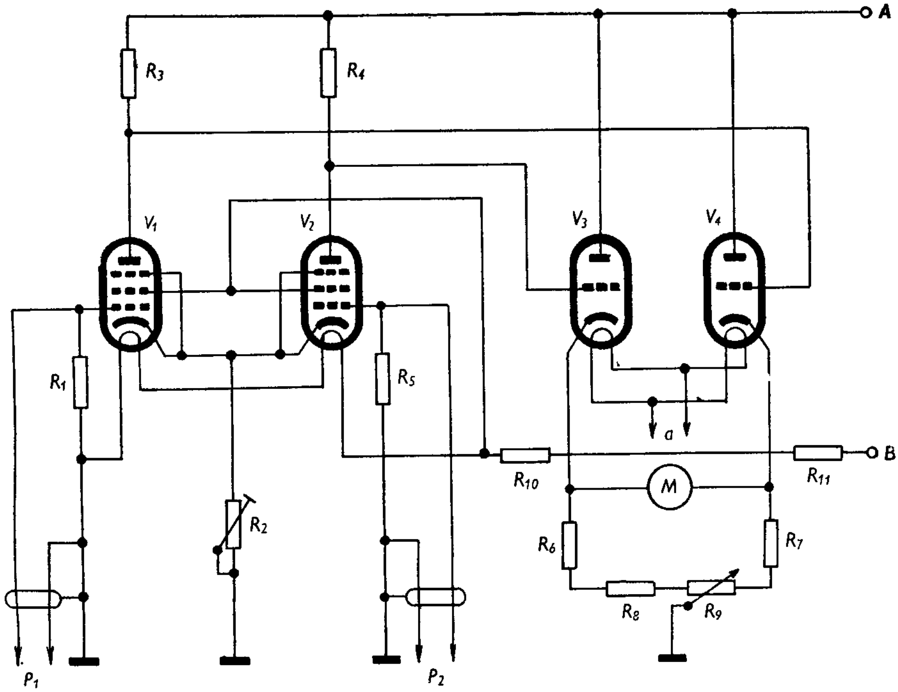
Fig. 5. Voltampere characteristics of the AgS photocell. Abscissa: Output voltage in mV. Ordinate: photoelectric current in μA.

of Physics of the Ukrainian Academy of Sciences. As is shown in Fig. 3, the transmission spectrum of the filters corresponds very well with the spectral sensitivity curve of the photovoltaic cells. The photoelectric characteristics of the photocells used, with a cross section of 2 cm^2, are given in Fig. 4. The voltampere characteristics of the cells are shown in Fig. 5. As can be seen from this figure, with 50 lx the relationship is still linear, but with higher irradiation intensities it deviates from linearity. It is therefore advantageous that in the instrument described only very weak radiation falls on the photovoltaic cells. Temperature dependence of short-circuit current and open-circuit voltage is presented in Fig. 5. Internal resistance of the photocells varies between 1,000 and 6,000 ohms. The photocurrent at a given intensity of radiation changes with time during the first two months during which the photocells are in use; in the case of output voltage the period is longer (5 to 6 months).

The amplifier. The difference in the photocurrents coming from the measuring and control photocell is amplified by means of a two-stage differential d.-c. amplifier (v. Fig. 6). The voltage generated by the photocells across the load resistance of several hundred kiloohms is supplied to the grids of the tubes in the first balanced pentode stage (V_1 and V_2). The load resistors of the first stage were experimentally chosen so as to balance the deviations existing between the photovoltaic cells P_1 and P_2. Gain in the first stage may be regulated by means of the variable resistor R_2. In this way it is possible to get a suitable reading of the meter for a given area.

The second cascade (V_1 and V_2) provides a low output impedance. The bridge connection again guarantees independence of fluctuations in the supply.

To make the drift of the amplifier as low as possible, the supply voltages


A
R3
R4
V1
V2
V3
V4
R1
R5
a
B
R10
R11
M
R2
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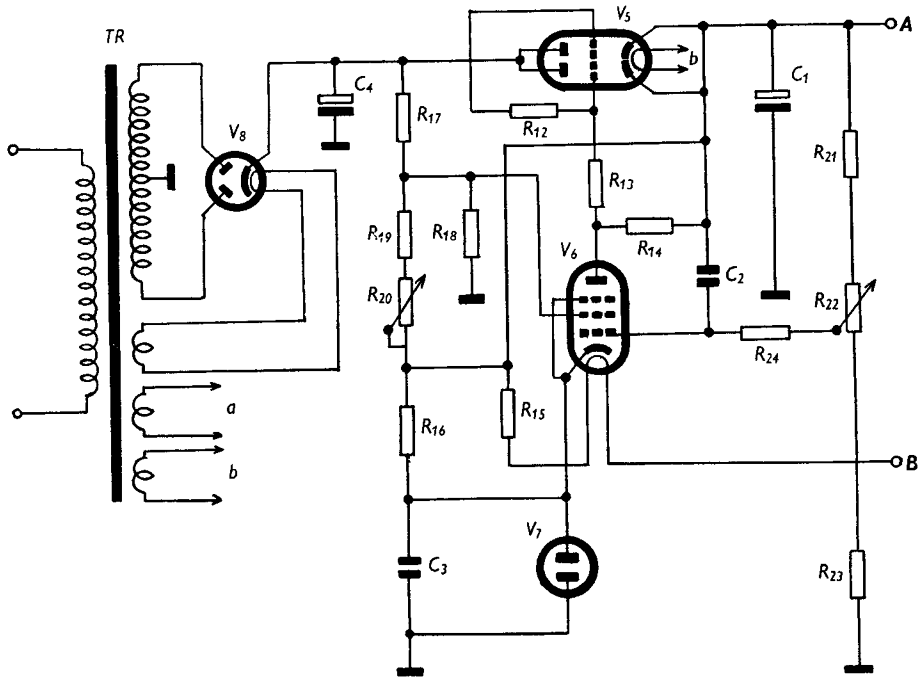
R7
R8
R9
P1
P2


TR
V5
A
b
C4
C1
V8
R17
R12
R21
R13
R19
R18
R14
V6
R20
C2
R22
R24
a
R15
R16
b
B
V7
C3
R23

for both stages and the heating current for the tubes of the first stage are provided with an efficient electronic voltage stabilizer. In addition the heating current of tubes V_1 and V_2 is stabilized by the resistors R_{10}, R_{11} and R_{15}.

The electronic stabilizer is governed by the error of the output voltage (voltage divider R_{21} to R_{23}, control grid of tube V_6) and by the error of unstabilized input voltage through the compensating circuit (voltage divider $R_{16} + R_{20}$, screen grid of V_6). Constant reference voltage is provided by the glow-tube, operating at 75 volts. Heating current of the amplifier (V_6) is derived from the stabilized supply. The stabilizer described delivers the voltage necessary for operation of the amplifier with a high stability (stabilization coefficient at about 2,000) if the input voltage varies between —20 to +10%.

The power supply is of normal type with a full-wave rectifier (V_8).

Putting the instrument into operation. Firstly, it is necessary to find the proper operation point of the stabilizer. For this purpose the amplifier is disconnected at points A and B and is replaced by a variable resistor (R_S — 600 ohms); suitable measuring instruments are connected as shown in Fig. 7. The variable resistor R_{21} is adjusted to approximately its middle position. The output voltage of the stabilizer is brought to 162 to 164 volts by adjusting the potentiometer R_{24} and the output current is adjusted to 72 to 75 milliamperes varying the voltage of the substitute load R_S. Input voltage is then varied by means of a variable voltage transformer between the limits of —20 to +10% from the normal mains voltage and the meter V_2, connected in series with a compensating battery, is read. The resistance of the variable resistor R_{21} is progressively varied (with simultaneous correction of output voltage through adjustment of the potentiometer R_{24}) until a state is reached in which the variations of input voltage exercise a minimal effect on the output voltage of the stabilizer.

← Fig. 6. Diagram of the electronic part of the instrument. Scheme is drawn corresponding to the Czechoslovak norms.

R_1	430 kΩ/0,25 W	R_{15}	800 Ω/50 W
R_2	6·8 kΩ	R_{16}	16 kΩ/2 W
R_3	180 kΩ/1 W	R_{17}	1·3 MΩ/0,25 W
R_4	240 kΩ/1W	R_{18}	47 kΩ/1 W
R_5	430 kΩ/0,25 W	R_{19}	52·6 kΩ/1 W
R_6	43 kΩ/1 W	R_{20}	10 kΩ
R_7	51 kΩ/1 W	R_{21}	106 kΩ/1 W
R_8	100 kΩ	R_{22}	4·7 kΩ
R_9	47 kΩ	R_{23}	82 kΩ/1 W
R_{10}	800 Ω/50 W	R_{24}	560 kΩ/0,25 W
R_{11}	75 Ω/15 W		
R_{12}	330 Ω/0,25 W	C_1	40 μF
R_{13}	330 Ω/0,25 W	C_2	9100 pF
R_{14}	10 MΩ/2 W	C_3	0,07 μF
		C_4	40 μF

V_1—V_8 see text

P_1—P_2 to photoelements

V_1, V_2, V_6 — 12 Ж1Л may be substitued e. g. by RV 12 P 2000

V_3, V_4 — 6C65 could be substitued by 6SN7 or E CC 40 etc.

V_5 — 6H5C a valve of rather solitary construction; might be substitued by two valves of the type PL 36 connected as triodes.

V_7 — CT'2C equivalent to VR 75 or any other glow tube with Vstab. = 75 V, $I_{max.} = 40$ mA, $I_{min.} = 5$ mA, $R_{i\,max.} = 180\ \Omega$.

V_8 — 5 Ц4 C equivalent to 5Z4.

The amplifier with the photocells is then connected. The variable resistors R_8 and R_9 are adjusted in approximately their middle position. With weak illumination of the photocells, R_3 and R_4 are experimentally adjusted so as to bring the deflection of the meter near zero. Finally, residual asymmetry, zero position and gain are adjusted by means of R_8, R_9 and R_2 respectively. The gain of the amplifier is chosen so as to bring direct readings of the meter into simple relation to the area of the objects measured (e. g. when 2 cm^2 corresponds to 20 divisions of the scale).

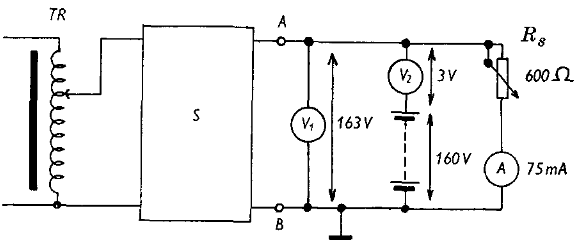


Fig. 7. Circuit for adjusting the voltage stabilizer.

C a l i b r a t i o n o f t h e i n s t r u m e n t. Calibration is carried out by inserting pieces of black paper (circular or square) with area of 1 to 150 cm^2 into the measuring channel and noting the readings of the meter. An advantage of the instrument is that it is possible to choose the gain of the amplifier so that the maximum area measured would cause a full deviation of the mater, i. e. a unit of area will correspond to a definite number of divisions.

Another method of measurement can be adopted, reminiscent of weighing on an ordinary balance: the objects whose area is to be measured are placed in one channel and round or square pieces of black paper of known area are placed in the other until the meter returns to zero.

A c k n o w l e g e m e n t

The authors wish to express their thanks to Dr. I. Šetlík (Košice) and J. Čatský (Praha) for their friendly help in preparing the manuscript.

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Прибор для измерения площади листьев

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Резюме

В статье авторы описывают новый тип фотоэлектрического планиметра для измерения площади листьев. Планиметр основан на абсорбции крайнего красного и близкого инфракрасного илучений, и поэтому его показания мало зависят от толщины и окраски листьев. Конструкция оптической части аппарата довольно проста. В планиметре имеются два оптических канала: один измерительный, в который вкладываются листья, и другой, контрольный (эталонный), который компенсирует колебания в силе потока света, вызываемые изменениями напряжения в сети. Поток света в обоих каналах переменяется в электрические импульсы при помощи серебряносульфидных фотоэлементов. Различие между напряжением измерительного и эталонного фотоэлементов усиливаются при помощи чувствительного дифференциального усилителя постоянного тока, собранного по баллансной схеме. Для обеспечения стабильности нуля все анодные цепи этого усилителя и накальные цепи первого каскада питаются от электронного стабилизатора. Коэффициент усиления можно менять и тем самым легко можно установить цену деления шкалы прибора. Сходное устройство обоих каналов позволяет, кроме прочего, применить метод измерения, аналогичный взвешиванию на весах: в контрольный канал вкладываются квадраты или кружки с известной площадью, пока указатель прибора не находится на нуле. При помощи планиметра нельзя измерять большое количество объектов одновременно, так как ось канала должна проходить через измеряемый объект.