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AN AUTOMATIC SYSTEM FOR MEASUREMENTS OF GAS EXCHANGE AND ENVIRONMENTAL FACTORS IN A FOREST STAND, WITH SPECIAL REFERENCE TO MEASURING PRINCIPLES

PERTTI HARI, MARKKU KANNINEN, SEPPO KELLOMÄKI, OLAVI LUUKKANEN, PAAVO PELKONEN, RAIMO SALMINEN and HEIKKI SMOLANDER

SELOSTE:

METSIKÖN KAASUAINEENVAIHDON JA YMPÄRISTÖTEKIJÖIDEN AUTOMAATTINEN MITTAUSJÄRJESTELMÄ

A system for measuring the net photosynthesis, transpiration and environmental factors within the canopy and ground cover vegetation is described. In the planning of the system equipments are built to simulate the interaction between plant and environment and the rates and amount are strictly distinquished. This principle has led to the development of new measuring procedures and to the construction of the system. The system operates continuously through out the growing season in a young Scots pine *(Pinus sylvestris* L.) stand at the University of Helsinki Forestry Field Station in Central Finland. The installation includes three infared gas analyzers and 15 trap-type, pneumatically operated assimilation chambers. Two analyzers are used for CO_2 measurements and the one for H_2O. A data-logging unit controls the system and carries out the measurements of the readings of the sensors of photosynthesis, transpiration, light intensity outside the canopy, light climate inside the assimilation chambers, and dry and wet temperatures from selected points. These measurements are shown digitally and automatically punched onto paper tape.

INTRODUCTION

The rapid development of electronics and automatic data processing techniques has enabled more advanced and versatile ecological studies to be carried out in the field of forestry. Present-day electronic equipment enables continuous monitoring of numerous ecological variables in the field throughout the growing season. The large amount of data produced has to be analysed by automatical data processing techniques. The utilization of this approach creates new alternatives and makes it possible to avoid too great a dependence on laboratory measurements. Succesful research, however, requires different methods because plant metabolism and growth can only be evaluated by observing them from many different points of view. When the new technical opportunities are utilized in ecological research the measuring principles should be carefully analyzed. Especially the amounts and rates should be distinquished from each other and the unique interaction between plants and environment should be taken into consideration.

At the present time there are several projects being carried out (cf. NICIPOROVIC 1968, SCHULZE 1972, Swedish Coniferous . . . 1973/1974, LOUWERSE & EIKHOUDT 1975 STRAIN and HIGGINBOTHAM 1976), in which the metabolism and growth of ecosystems are being studied. In Finland a monitoring station for forest ecosystems has been developed during the last six years. The project has been financed by the Department of Silviculture and Forestry Field Station of the University of Helsinki, and the Academy of Finland. The purpose of the monitoring station is to utilize the new opportunities generated by modern techniques in the field of ecology.

THE MEASURING SYSTEM

General description

A data-logging unit supplied by Nokia Electronics controls the measuring system. This unit collects and measures the data and punches it on paper tape. The flexible programming of the data-logger makes it possible to carry out various ecological experiments at the same time.

There are altogether 20 gas sampling units including tubing and valves. Fifteen of them are used with assimilation chambers (Fig. 2) and five for measuring the reference CO_2 and H_2O concentrations of the outside air with an IRGA-apparatus. The assimilation chambers are each closed for periods of one hundred seconds. The CO_2 and H_2O concentrations inside the cuvette are mea-

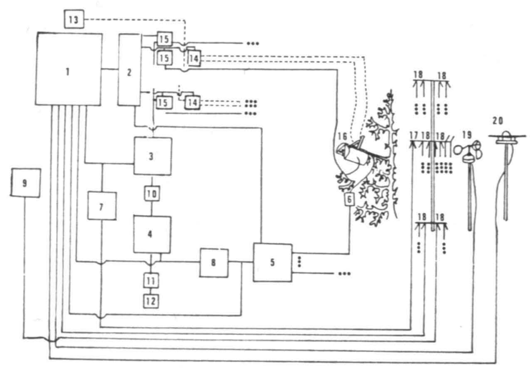

Fig. 1. A block diagram of the measuring system. Control signal (thick line), measurement signal (medium line) and gas conduction tubing (thin line). The numbers refer to the following pieces of equipment: 1. datalogging unit, 2. relay-unit, 3. IRGA apparatus for H_2O, 4. IRGA apparatus for CO_2, 5. central unit of ELP, 6. summing amplifier, 7. millivolt recorder for the output of URAS H_2O) and for the difference between dry and wet temperatues, 8. millivolt recorder for the output of URAS (CO_2) and that for one ELP, 9. potentiometer for temperature measurements, 10. ice bath, 11. flow meter, 12. membrane pump, 13. compressor, 14. magnetic switch for compressed air, 15. magnetic switch for gas to be analysed, 16. cuvette, 17. two pairs of thermocouples for measuring the difference between dry and wet temperatures, 18. thermocouples for measuring dry wet temperatures, 19. apparatus for measuring wind velocity, 20. KIPP-solarimeter.

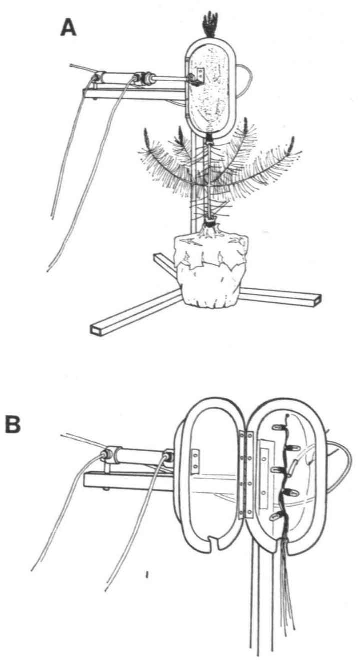

Fig. 2. A. A closed gas exhange chamber
B. An open gas exhange chamber in which five silicon diodes of the ELP are visible.

sured one second before the cuvette is opened. The concentrations are compared with the respective values for the air outside the cuvette. The sample units are measured in sequence. The unit where measurements are to be made is selected by an on-off-type magnetic valve. Opening and closing of the cuvettes is controlled pneumatically. Timing of the measuring sequence is controlled by the data-logger.

The cuvettes can be connected to the gas analyzers by nylon or copper tubing. However, we have found that copper tubing has to be used for monitoring transpiration as the water adsorbing properties of the nylon tubing affect the results. In order to avoid condensation of water vapour in the tubes they are heated.

The measured variables

Our system has been built to monitor the CO_2 and H_2O exchange of plants and the environmental factors which affect these processes. An open measuring system with trap-type cuvettes is used. This system has been found to operate reliably in the rigorous field conditions of Central Finland.

The following parameters of the ecosystem are measured (cf. Fig. 1):

- photosynthesis (URAS)
- transpiration (URAS)
- total radiation (Kippsolarimeter)
- the radiation in PhAR units (LAMBDA LI-185)
- the radiation utilizable in photosynthesis (ELP-equipment) (cf. HARI *et al.* 1976)
- ambient temperature (two pairs of wet and dry thermocouples)
- cuvette temperature
- wind velocity

The measuring interval used is 100 s. Thus in 24 hours 864 measurements are carried out. When all 20 gas sample units are used, it is possible to make 43 measurements of photosynthesis and transpiration from one sample unit each day. However, during the night, IRGA measurements are not reliable due to the variation in ambient CO_2 concentration. Thus between 30 and 40 reliable measurements are made in one day. The analysers are arranged in series so that the gas samples first pass to the URAS for H_2O measurements, then through an ice bath to stabilise the water vapour concentration and finally to the second URAS for CO_2 measurement.

The wet and dry temperatures are measured at three different levels in the stand. One pair of thermocouples is placed in the open area next to the stand at a height of two meters. The thermocouples are placed inside small glass capillary tubes in order to stabilize rapid variations in temperature.

The radiation utilizable in photosynthsis is measured by a piece of equipment called ELP (cf. HARI *et al.* 1976). There are five photo-voltaic cells in every cuvette. The output of the cells simulates the dependence of the photosynthetic rate on the light intensity. After taking the sum of the outputs of the cells the ELP-equipment integrates it over time while the cuvette is closed. The relationship between the output of the ELP and potential photosynthesis is adjusted so that it is linear. The relationship between light intensity and the output of ELP is thus curvilinear.

Quality control of the system

In order to control the operating of the system and to guarantee the reliability of the results, photosynthesis, transpiration, temperature and light intensity are monitored by means of millivolt recorders. We have found that it is very useful to use two-pen recorders for monitoring interdependent variables such as photosynthesis and light, transpiration and the difference between wet and dry temperature etc. Any descrepancy in the recorded curve can be seen at a glance. This has been found to be a really effective method of controlling the system.

The large amount of data which is obtained is analysed in Helsinki using a UNIVAC 1108 computer. Thus a further means of controlling the system is provided. The paper tapes are transported once a week to Helsinki where the data is immediately checked. At this stage it is possible for instance to obtain the daily patterns of photosynthesis, light and temperature. The necessary feedback is thus supplied to the field station. Further analysis of the data

is carried out during the wintertime. Computation of the data will also be possible at the Forestry Field Station in 1978 after a new PDP computer has been installed there.

DISCUSSION

Design principles

Design of the measurements are carried out in close connection with the analysis of the data obtained. This principle has led to construction of new measuring principles and equipment (cf. HARI *et al.* 1975 and HARI *et al.* 1976). The basic biological parameters are the rates of various metabolic processes. These rates depend on the environment and the internal state of the trees. Special care is paid to the adequate measurement of environmental factors affecting the metabolic process monitored.

Either metabolic rates or its integrals during prolonged periods can be measured. If the metabolic rate can be measured then this is preferable. If the rate is impossible or technically difficult to measure then data concerning the integrals can be utilized in the analysis. Then special care have to be paid on the possible nonlinear relations between rates and environmental factors. For this reason all the meteorological methods can not be applied in ecological studies without modification.

Technical aspects

We have paid special attention to developing a system which will operate reliably in the climatic conditions prevailing in Central Finland (the station is located at a latitude of 61° 51' N) where the annual temperature range is about 60° C. In winter the depth of snow is usually over 0.5 m. So far, we have been able to operate from the end of March till the end of October. In the near future, if necessary, it will be possible to carry out continuous monitoring all year around.

A simple cuvette design has been chosen for the sake of reliability. It has the following advantages: 1) most of the necessary equipment can be placed in the instrument cabin, and 2) it is cheap compared with more complicated types (JARVIS *et al.* 1971), 3) the result of measurement is an integral for the 100 second period of photosynthetic or transpiration rate. The cuvette, however, is still rather flexible in use. With only slight modifications, it can be used for monitoring the photosynthesis and transpiration of various types of trees, dwarf shrubs, mosses and lichens.

The system of sequentially selected sampling units has proved to be very effective. By multiplexing the measurements (as presented in Fig. 1) one channel of the data logger can be expanded to several measuring points. Thunderstorms rose a serious problem, because lightning which strikes near to the measuring cables induces a high voltage which may cause damage to the sensitive instruments. An additional trouble for electrical instruments is caused by the wet field conditions. It is difficult to protect all the electrical circuits against water. Despite these troubles the system has proved to work reliably in the field conditions and it has been considered as a useful tool in the studies of forest ecology and regeneration. A list of papers of the Primary Production Group at the Department of Silviculture, University of Helsinki is enclosed in the Appendix.

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SELOSTE:

METSIKÖN KAASUAINEENVAIHDON JA YMPÄRISTÖTEKIJÖIDEN AUTOMAATTINEN MITTAUSJÄRJESTELMÄ

Artikkelissa esitellään metsikön puuston ja pintakasvillisuuden nettofotosynteesin ja haihdunnan mittausjärjestelmä. Mittausjärjestelmää suunniteltaessa on simuloitu kasvin ja sen ympäristön välisiä vuorovaikutussuhteita, mikä on ollut perusperiaatteena järjestelmää rakennettaessa ja uusia menetelmiä kehitettäessä. Mittauslaitteisto toimii läpi kasvukauden, ja siihen kuuluu kolme infrapunakaasuanalysaattoria ja 15 paineilmalla toimivaa mittauskammiota — kyvettiä. Analysaattoreista kaksi mittaa kyvetteihin sijoitettujen kasvien tai kasvinosien hiilidioksidivaihtoa ja kolmas haihduntaa. Erityisesti tähän tarkoitukseen konstruoiduilla laitteilla mitataan kyvettien valoilmastoa sekä haihduntaolosuhteita. Lisäksi seurataan normaaleja ympäristön meteorologisia muuttujia. Koko mittausjärjestelmän keskeinen laite on tietojenkeruuyksikkö, joka ohjaa mittaustapahtumaa, lukee eri mittareiden tulokset ja tallettaa tiedot reikänauhalle tietokoneella tapahtuvaa jatkokäsittelyä varten.