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Multichannel measuring system for profile monitoring of CO_2 concentration in cultivation equipment

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Abstract. A multichannel measuring system MMS-05 for continuous and synchronized profile monitoring of the CO_2 concentration in cultivation installations is described. The system guarantees the performance of vertical and horizontal gradient measurements and registration of CO_2 concentration in a greenhouse. Experimental studies with 6 cultivars of greenhouse tomato plants performed for testing the system show that the fluctuations in CO_2-profiles, and respectively the CO_2 concentration in the greenhouse, follow a time dependant pattern with a pronounced decrease during the midday hours 10 a.m. ÷ 6 p.m. when CO_2 concentration reaches 160 ÷ 180 μmol mol^{-1}. During the night, as a result of plant and soil respiration, the CO_2 concentration rises to 450 ÷ 500 μmol CO_2 mol^{-1}.

Keywords: CO_2 gradient, greenhouse, measuring system, plant

INTRODUCTION

One of the major factors forming the yield is photosynthetic CO_2 assimilation [4,6,12]. The problem of CO_2 uptake by plants and keeping an optimal CO_2 concentration is particularly apparent in greenhouse conditions because of the real possibilities for optimization of the photosynthetic process in them [1,5,13,14,17].

In greenhouses with closed ventilation there is a lack of air movement that is typical of natural conditions [3,15]. Photosynthesis, plant and soil respiration as well as the relative air immobility in the greenhouse volume determine the presence of vertical and horizontal gradients in CO_2 concentration [1]. These gradients are more apparent when the intensity of the photosynthetic active radiation (PhAR) and the area of the leaves of plants increase [2].

The multichannel system MMS-05 is designed for synchronous profile monitoring and registration of CO_2 concentration in the air volume of cultivation equipment. It is a further development of the measuring system ASP-02 [8] by which a series of investigations of the horizontal and vertical gradients in CO_2 concentration in polyethylene greenhouses with tomato plants were made during 1987 near Cracow, Poland.

DESCRIPTION OF THE MEASURING SYSTEM

The structural scheme of the constructed measuring system is shown in Fig. 1. Eight air accepting probes (AAP1 ÷ AAP8) serve for profile measurements of CO_2 concentration in the air. Their air conductors are switched over to an infrared gas analyser (IRGA) by a system of electromagnetic valves SEMV. The electric output of IRGA is connected to a digital indicator of CO_2 concentration (DI-CO_2) and analogic registering instrument (AR). The latter controls the operating device which switches over the electromagnetic valves SEMV of the 8 channels and a digital indicator DISC displaying the number of the operating pneumatic measuring channel.

The construction of the air accepting probe is shown in Fig. 2. It is a conic corpus 4 with an input filter 6 at its end which serves to prevent penetration of water vapour and dust. The filter 6 is placed between two metal meshes 5 and 7 and is fixed to the corpus 4 by the ring 8 and screws. Through the passing orifice 2 and air line 3 the sampled air is passed to the pneumatic measuring channel of the gas analyser. When the vertical CO_2 profiles are investigated the air accepting probes are mounted to a supporting mast by means of distant consoles 1.

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The construction of the supporting mast with ai accepting probes is shown in Fig. 3. It consists of a duralumin tube with a length of 2700 mm and a diameter of 25 mm and a disk in its base to prevent it sinking into the soil. The top of the mast is fixed with 3 stretchers (not shown in the Fig. 3). By means of distant insertions with consoles the ai accepting probes are mounted on the mast at 8 defined heights (a step of 300 mm between each of them was chosen). To avoid changes in the pattern of the gas exchange field around them they are arranged spirally at intervals o 120°, thus the distance between two neighbouring probes is 610 mm. Moreover, the pneumatic measuring system draws air only from the probe that is connected to the gas analyser.

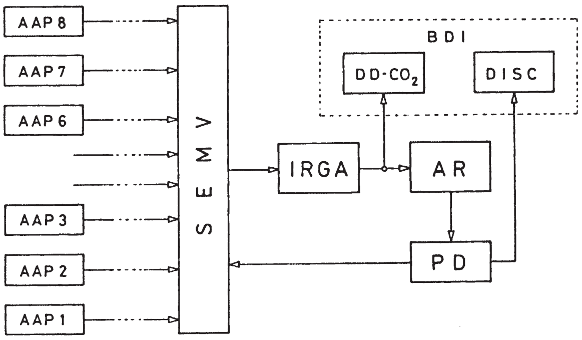

Fig. 1. Structural scheme of the multichannel measuring system for investigating the gradient of CO$_2$ concentration in greenhouses. AAP1 ÷ AAP8 – air accepting probes, SEMV – system of electromagnetic valves, IRGA – infrared gas analyser, DD-CO$_2$ – digital display of CO$_2$ concentration, AR – analogic registrator, PD – processing device, DISC – digital indicator of the switched channel, BDI – block of digital indication.

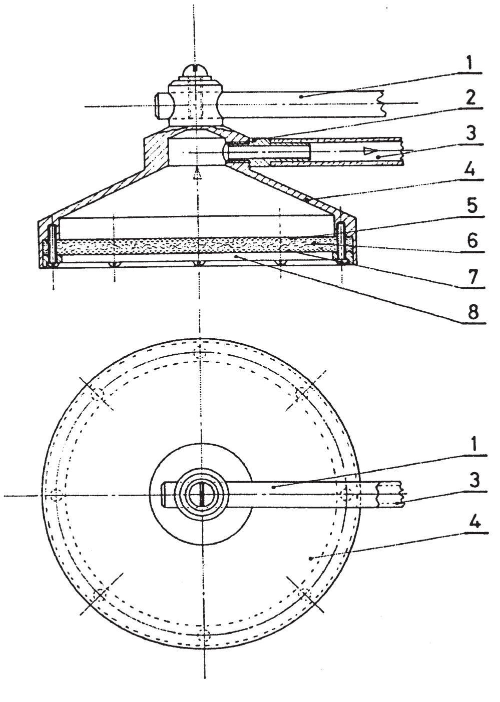

Fig. 2. Construction of the air accepting probe: 1 – distant console, 2 – passing orifice, 3 – flexible air line, 4 – corpus of the probe, 5 and 7 – metal meshes, 6 – input air filter, 8 – metal ring.

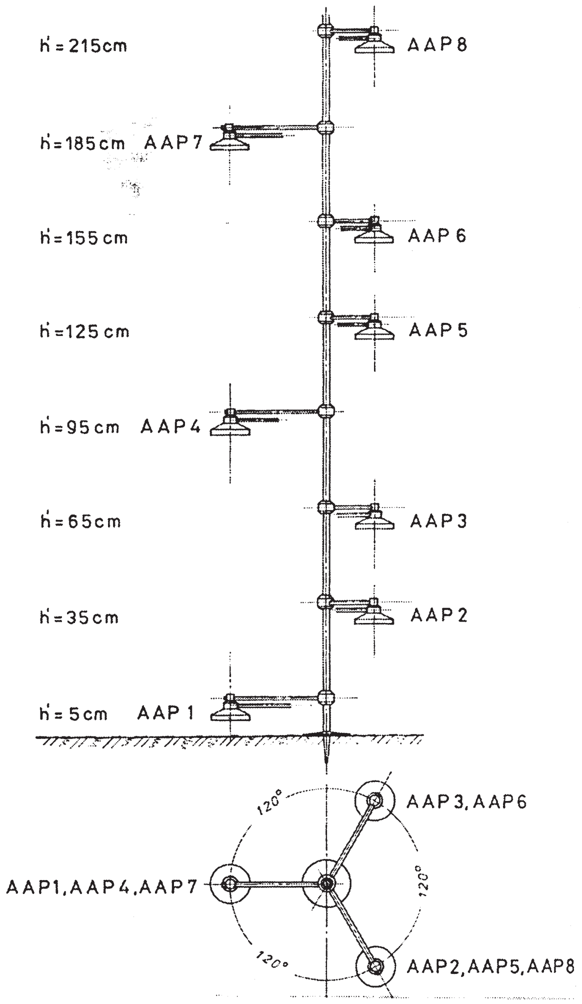

Fig. 3. Construction of the supporting mast with air accepting probes. AAP1 ÷ AAP8 – air accepting probes, h – height of the air accepting probes AAP1 ÷ AAP8.

An infrared gas analyser ‘INFRALYT-IV’ [16] was used for the measurement of CO_2 concentration in the air. According to technical requirements, the air passed to the measuring cell of the analyser must have a constant temperature, pressure and flow rate and must be purified from dust and water vapour [16]. To respond to these requirements some additional elements are included.

The diagram of the multichannel measuring system MMS-05 is shown in Fig. 4. The system ensures continuous profile monitoring and registration of the CO_2 concentration in 8 points of the greenhouse. By means of electrical pumps EP1 ÷ EP8 the air sample enters through the air accepting probes AAP1 ÷ AAP2. The flow rate and the pressure in each channel is regulated individually by needle valves ID1 ÷ ID8 and by included barbotage bottles B1 ÷ B8. The channels are commuted consecutively to the gas analyser by means of electromagnetic valves EMV1 ÷ EMV8 controlled by the processing device PD and a digital display (DISC) shows the number of the switched channel. The common gas track of the eight channels is used for removing the water vapour and mechanical impurities. Initially, drying is done by condensation of the vapours in an electrical cooler (Peltier element, connected to a power block PB) and the water vapour is collected in a condensate vessel CV. The final drying is performed using a chemical dryer CD (a column with $CaCl_2$). Behind a fine filter FF the sample airflow enters through a capillary orifice CO into the gas analyser IRGA. A flow rate of $40\ l\ h^{-1}$ is controlled by the gas flow meter GFM connected with pressure equalizer PE. The measured CO_2 concentration is displayed on a digital voltmeter DV-CO_2 type V-628 with 3.5-digits (Meratronik, Poland) and a registering electronic motor-compensator REMC [11]. The last controls the processing device connected with the decoding block PD-DB for commutating the eight air accepting probes AAP1 ÷ AAP8.

The possibility for the periodical test of the gas analyser calibration is ensured in the MMS-05 system. This is done by 3-way valves TV1 and TV2 by which gas with standard CO_2 concentration and pure nitrogen from the gas cylinders GC1 and GC2 is supplied through reducing valves RV1 and RV2. The digital voltmeter V-628 is used for precise control of the zero-drift of the analyser and the corresponding standard CO_2 concentration.

For registering of the measured CO_2 concentration a 12-channel electronic registering motor-compensator of type EMC [11] is included. The range of the instrument is

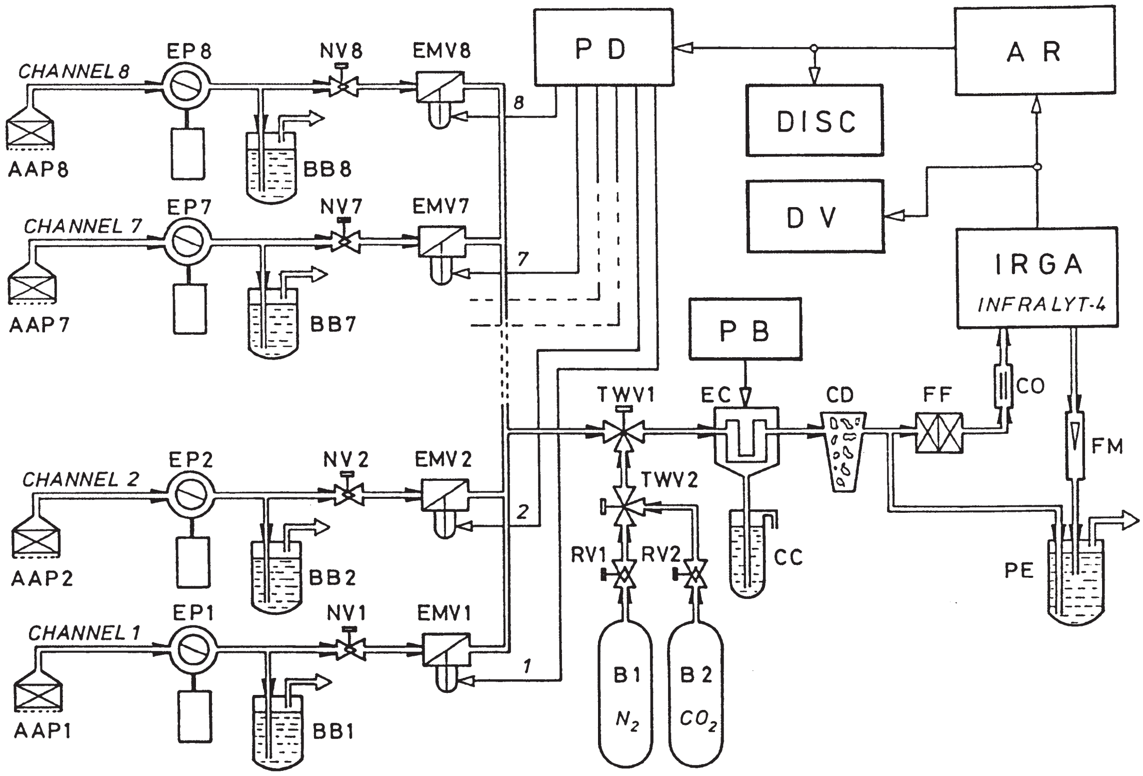

Fig. 4. Principal scheme of the multichannel measuring system MMS-5. AAP1 ÷ AAP8 – air accepting probes, EP1 ÷ EP8 – electrical pumps, NV1 ÷ NV8 – needle valve, B1 ÷ B8 – barbotage bottles, EMV1 ÷ EMV8 – electromagnetic valve, EC – electrical cooler, CD – chemical dryer, PB – power block, FF – fine filter, CO – capillary orifice, FM – flowmeter, PE – pressure equalizer, DV – digital voltmeter, AR – analogic registrator, PD – processing device, IRGA – infrared gas analyser, DISC – digital indicator of the switched channel, CC – condens container, TWV1, TWV2 – three-way valve, RV1, RV2 – reducing valve, B1 – bottle with N_2, B2 – bottle with CO_2.

1.000 V with an accuracy of ±0.25% of the measuring part and ±0.5% for the registering, the width of the diagram band is 250 mm moving with 20 mm h^{-1}.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental studies with the multichannel system MMS-05 for synchronous gradient measurements of the CO_2 concentrations were carried out in the greenhouse of the N. Poushkarov Institute of Soil Science and Agroecology, Sofia [7]. It is of the block type steel-glass greenhouse with dimensions 101 x 36 m and a mean height of 2.9 m. The soil surface occupied by tomato plants was 3220 m^2. The heating system of the greenhouse is constructed using steel tubes with a 75 mm diameter placed horizontally at heights of 30, 60 and 90 cm above the soil level ensuring the circulation of hot water. The natural ventilation is achieved by 9 lines of air inputs placed on the greenhouse roof.

An experiment with 6 cultivars of greenhouse tomato plants (Karmelo, Marone, Luxena, Marlena, Torena and Nivena) was carried out. The plants were grown in plots with Alluvial-Meadow soil and Smolnitsa (Vertisol, FAO), the crop density was 3.3 plants per m^2. The fertilization was performed according to the accepted technology for greenhouse vegetable-growing. The uniform soil humidity was ensured by drop irrigation using the Drossbach system.

For control of CO_2 quantity emitted by soil respiration [7] in the greenhouse the constructed measuring system described in [9] was used. It consists of a gas-accepting soil probe connected to a gas analyser and registering instrument.

The major microclimatic parameters limiting the photosynthesis process in the greenhouse were measured using a 6-channel measuring system AIS-01 [10]. It controls the following parameters: PhAR, CO_2 concentration, and air temperature in the greenhouse. The diurnal course of the three main parameters during a spring day (20 April) is shown in Fig. 5. The concentration of CO_2 and air temperature were measured in plant cover at a height of 90 cm above the ground.

A typical picture of vertical CO_2-profile, obtained by the multichannel measurements system for profile monitoring of CO_2 concentration in greenhouses, is shown in Fig. 6. The measurements by MMS-05 are carried out in the plant cover of tomato plants. The mast with air accepting probes was mounted immediately to the temperature sensor and the probe of the system AIS-01 [10].

The fluctuations in CO_2-profiles, and respectively the CO_2 concentration in the greenhouse, have a temporary character with a pronounced decrease during the midday hours 10 a.m. ÷ 6 p.m. when the CO_2 concentration reaches 160 ÷ 180 μmol mol^{-1}. During the day the sources for CO_2 are soil and root respiration and the biological activity of microorganisms in the soil [7,15]. The emitted CO_2 quantity can not compensate the assimilated by plant cover CO_2 which depends on PhAR intensity and the value of the leaf area index (LAI). During the ventilation of a greenhouse by air exchange with the environment the CO_2 concentration increases but is still lower in comparison with the ambient one (Ca ~ 325 μmol CO_2 mol^{-1}) [7]. During the night, as a result of plant and soil respiration, the CO_2 concentration

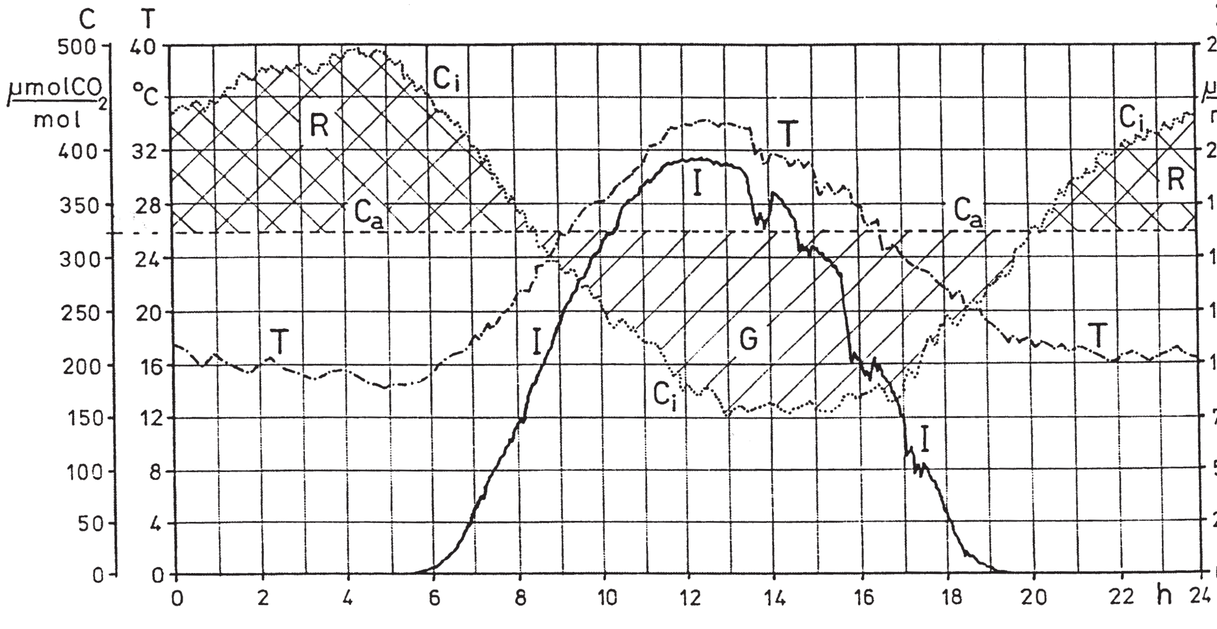

Fig. 5. Diurnal course of the major microclimatic parameters limiting the photosynthetic process registered during a spring day. Ci - CO_2 concentration in the greenhouse middle at height of 90 cm above the soil; I – intensity of photosynthetically active radiation, T – air temperature in the middle of greenhouse, h – hours during the twenty-four-hour period.

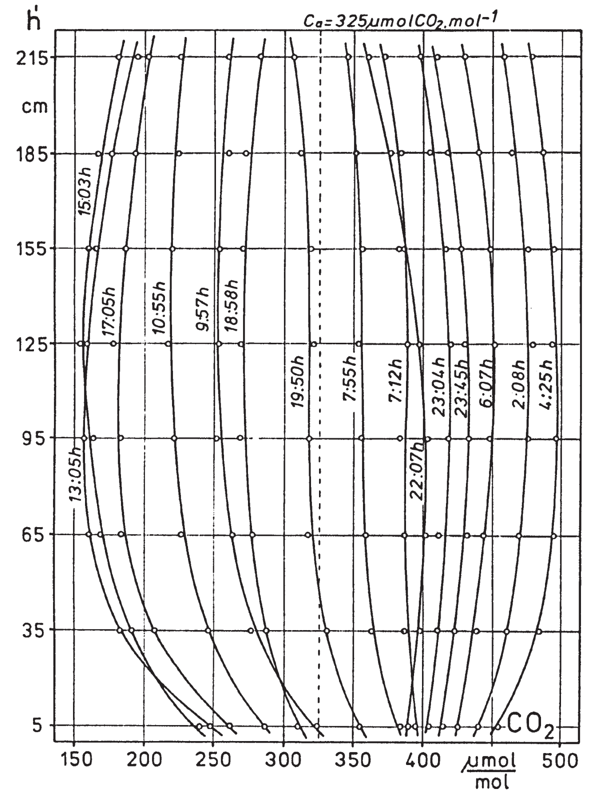

Fig. 6. Typical picture of vertical CO_2-profile in the middle of tomato plant cover (LAI=3.6) during the twenty-four hours.

rises to 450 ÷ 500 μmol CO_2 mol^{-1}. This level of CO_2 is determined by the hermeticism of the greenhouse and the condition of the gasket elements.

Therefore during sunny days, at closed or open ventilation, the insufficiency of CO_2 is a factor limiting the photosynthetic process [1,15] which imposes the necessity of additional enrichment of the greenhouses with CO_2 [7].

The multichannel measuring system MMS-05 allows continuous synchronous monitoring and registering of the gradient of CO_2 concentration. Depending on the position of the air accepting probes one can investigate vertical as well as horizontal profiles of CO_2 concentration in the greenhouse volume or plant cover.

The study of CO_2 profiles in cultivation equipment contributes to clarifying *in vivo* the limitations on photosynthesis as it gives quantitative evaluation of changes in CO_2 level. The fluctuations of the CO_2 profiles in plant cover in the greenhouse can be significantly changed and improved by uniform CO_2 supply by means of a distributing system with perforated plastic tubes or tubes from polyton sheat. The control of CO_2 concentration is realized using a gas analyser system.

During the experimental investigations the multichannel measuring system MMS-05 showed a stable and reliable working regime.

CONCLUSIONS

A multichannel measuring system MMS-05 has been developed for continuous profile monitoring of the CO_2 concentration in cultivation installations. Through the multichannel system one can perform vertical as well as horizontal gradient measurements and registration of CO_2 concentration in 8 points of the air volume.

With increasing PhAR intensity and assimilating leaf area enlargement, as a result of the photosynthetic process, the deficiency of CO_2,and respectively the vertical gradient, strongly increase. The change of CO_2 concentration in the greenhouse has a time-dependent pattern with an emphasised decrease during the midday hours when it reaches values of 150 ÷ 180 μmol mol^{-1}.

The results from the investigation of the diurnal and seasonal course of the CO_2 gradient during the vegetation period can be used for the evaluation of CO_2 budget, and prediction, of the necessary CO_2 quantities for supplying the greenhouse, with the aim to optimize the photosynthetic process for the corresponding stage of the crop.

Experimental studies showed a stable and reliable working regime of the multichannel measuring system MMS-05.

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