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Chermnykh, L. N.

Kosobrukhov, A. A.
Institute of Soil Science and Photosynthesis USSR Academy of Sciences

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EFFECT OF ENVIRONMENTAL FACTORS ON OPTIMUM TEMPERATURE AND PHOTOSYNTHETIC INTENSITY OF PLANTS ADAPTED TO VARIOUS CONDITIONS

L. N. CHERMNYKH and A. A. KOSOBRUKHOV

Institute of Soil Science and Photosynthesis, USSR Academy of Sciences, Pushchino, Moscow Region, USSR

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CHERMNYKH L. N. and KOSOBRUKHOV A. A. *Effects of environmental factors on optimum temperature and photosynthetic intensity of plants adapted to various conditions.* BIOTRONICS **16**, 1–11, 1987. Effects of short-term light of various intensities, CO_2 and temperature changes on the reaction of photosynthetic apparatus of cucumber plants grown for a long time at various levels of irradiation and temperature were studied. A shift of photosynthetic optimum temperature towards higher temperatures was observed with increase in light intensity. Temperature control is more efficient within a range of light intensities, limiting a linear part of photosynthetic light curve. For the plants grown at higher irradiation levels the maintenance of the optimum temperature provided more efficient utilization of the light of low intensities by them. At all the levels of irradiation an increase of growing air temperature of plants by 5°C led to a shift of the photosynthetic optimum temperature by 1°C towards higher temperature. The plants grown at 15°C had a higher photosynthetic rate as compared with those grown at other temperatures. Low rates of CO_2 uptake were observed at a temperature of 30°C. An increase of CO_2 content up to 0.1% at irradiation of 70 W/m^2 insignificantly affected the rates of CO_2 uptake as compared with natural concentration. Simultaneous rise of the irradiation level and temperature provided an increase of CO_2 positive effect on photosynthesis. The result indicates that it is necessary to control temperature regime taking into account CO_2 concentration in the air and the preceding light and temperature conditions of plant growth.

Key words: *Cucumis sativus* L.; cucumber plant; photosynthesis; photosynthetic optimum temperature; growing condition; irradiation; temperature; CO_2.

INTRODUCTION

An increase of plant productivity under simultaneous decrease of energy spent on their growth on sheltered ground is mainly connected with the maintenance of the optimum values of the controlled environments. The necessity of temperature control together with a change in the irradiation level is mentioned in many papers (*8, 10, 11, 12*). Some authors used the intensity of apparent photosynthesis as a

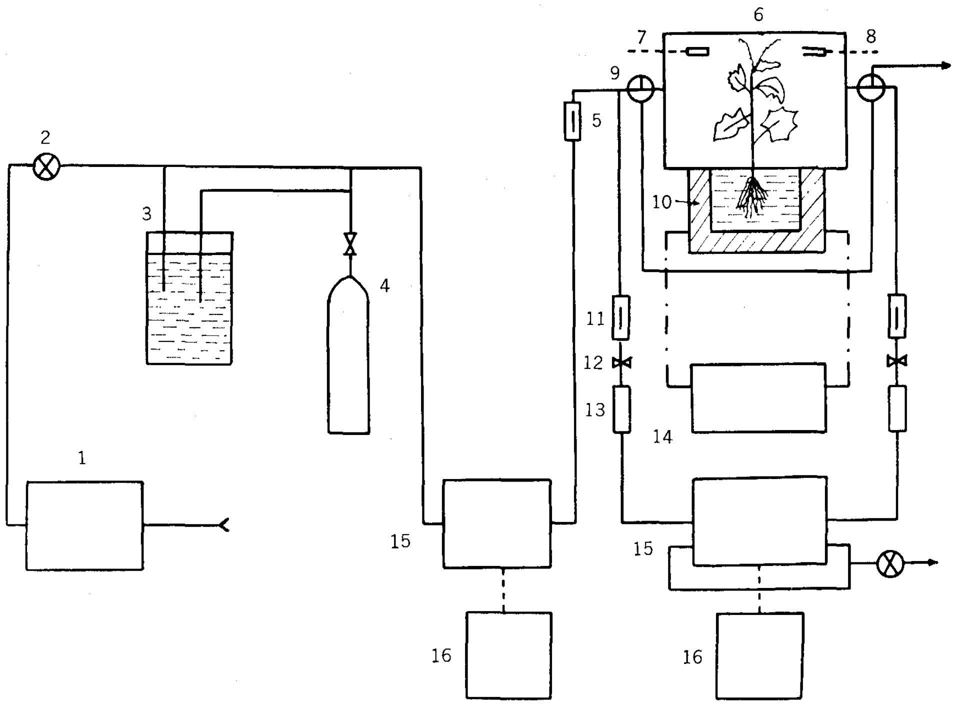

Fig. 1. Schematic diagram of a device for investigating intact plant gas exchange. 1: buffer chamber; 2: pump; 3: tubes for excessive pressure discharge; 4: gas-bag; cylinder with gas; 5: capillary rheometer; 6: assimilation chamber; 7: pyranometer; 8: thermocouple; 9: three-throw taps; 10: root thermostat; 11: rotameters; 12: tap clamps; 13: driers; 14: ultrathermostat; 15: infrared gas analyser; 16: recording potentiometers.

criterion for optimization and at the same time they indicated that it is necessary to take into account adaptation of plants to the environmental factors (*6*, *7*, *11*, *13*). The latter determines mainly the response of plants to environmental factor changing in short-term.

Thus, one can observe a shift of photosynthetic optimum temperature of plants grown under various light regimes (5, *13*). Photosynthetic optimum is shifted towards higher values with an increase in plant growth temperature (*3*, *21*). The change of parameters of photosynthetic light curves of plants adapted to the light of various intensities are well known (*17*, *18*). An increase in temperature and CO_2 concentration leads to a change in the form of light curve i.e. to a rise of plateau level and to a shift of the saturation region towards greater light intensities (*9*, *20*).

Under conditions of short-term multifactor experiment on photosynthetic optimization (*11*, *12*) the plants are constantly adapted to quickly changing environmental conditions (*4*). Therefore, it is not possible to find out the effect of the preceding plant growth conditions on temperature optimum and intensity of photosynthesis. At the same time the study of this problem is necessary for correct determination of plant growth temperature regime.

In the present paper we studied the effect of short-term light of various intensities, temperature and CO_2 increased concentration on photosynthetic apparatus of plants grown for a long period of time at various level of irradiation and temperature.

MATERIALS AND METHODS

Cucumber plants (*Cucumis sativus* L.), Moskovsky teplichnyi hybrid, were grown on water culture with Knop's nutrient solution. According to the experimental variants irradiation was 50,105 and 175 W/m^2, photoperiod—12 h, air temperature day/night—25/20°C. According to irradiation level 8, 12, and 24 arc-mercury discharge lamps DRLF-400 were used per 2.5 m^2 together with ZN-8 incandenscent lamps (300 W•4). Total irradiation was measured with Kozyrev's thermopile (*20*).

At 3–5 leaves stage the plants of each light variant were inserted into an assimilation chamber of a gasometric device of an open type (Fig. 1) consisting of an assimilation chamber, a unit for supplying gas mixture, a unit for control of gas exchange and environmental parameters. The assimilation chamber a disassembling hermetic type. It presents a 22/*l* glass hemisphere placed on a root thermostat. The seal between the base and the chamber is achieved by a microporous rubber gasket and binding screws. The unit for supplying gas mixture consist of a buffer at the input (160 *l* volume), pumps, rotameters and excessive pressure discharge tubes. A gas mixture with a predetermined concentration of CO_2 can be obtained at the output. Air turnover rate can be varied from 0 to 300 *l*/h. Gas flow rate is controlled with the rotameters. The unit of control and registration of CO_2 gas exchange and the environmental parameters consist of Infralit-4 infrared gas analysers, a 12-tracks KSP-4 potentiometer as well as copper-constantan thermocouples and a pyranometer, placed in the assimilation chamber. The device is assembled in KV-1R vegetation chamber that allows to create and maintain various light and temperature regimes to determine gas exchange of plants.

Temperature dependences of photosynthesis were examined for 2–3 h at light intensities of 14, 25, 50, 70, 105, 140, 210, 280 and 350 W/m^2. Temperature was increased from 15–20°C to 35–40°C at a rate of 0.1–0.2°C per min (*1*). At the end of the experiment the area of plant leaves was determined with a polar planimeter. Light-curves were plotted by the photosynthetic rate at the points of optimum temperature curves, obtained at various light intensities. The experiments were replicated 4–5 times.

RESULTS AND DISCUSSION

Photosynthetic temperature curves of plant adapted to various light growth conditions differed in the position of optimum temperature and in the value of the photosynthetic rate. An increase of irradiation while plotting photosynthetic temperature curves led to a shift of optimum temperature towards higher temperatures independing of the preceding conditions of plant growth (Figs. 2A, B, C). Smooth indistinct peak is characteristic for photosynthetic temperature curves at low light intensities. At high levels of irradiation temperature curves had a distinct peak.

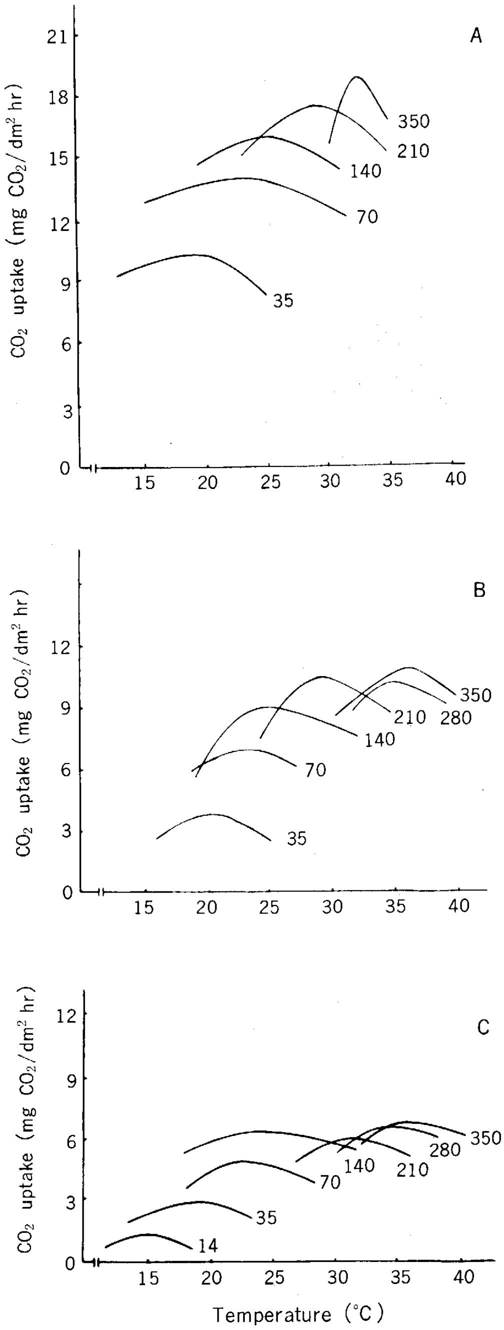

Fig. 2. Photosynthesis temperature curves of cucumber plants at various irradiation (W/m^2); A: plants were grown at 175 W/m^2, B: at 105 W/m^2, C: at 35 W/m^2.

On the basis of photosynthetic curves the plot were made for characterizing both a shift of the photosynthetic optimum temperature upon irradiation change during the experiment and the effect of plant growth light regime on photosynthetic optimum temperature (Fig. 3A). At low light intensities a shift of photosynthetic optimum temperature was greater than at higher ones. Thus, for the plants, adapted to

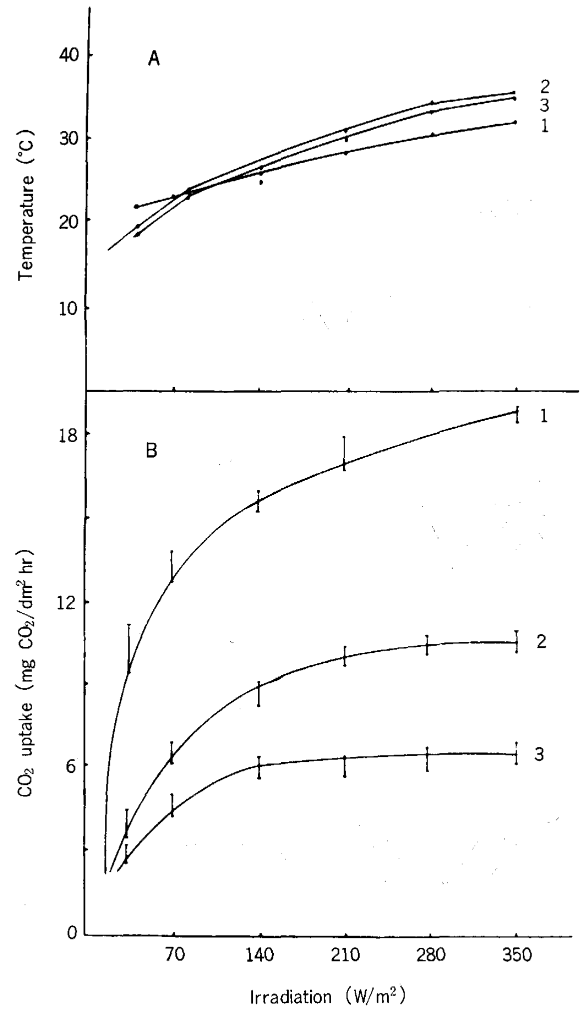

Fig. 3. A: Optimum temperatures for photosynthesis at various irradiation levels (W/m^2); B: Photosynthesis temperature curves of cucumber plants plotted according to the photosynthetic rate values at the optimum points of photosynthesis temperature curves. 1: plants were grown at 175 W/m^2, 2: at 105 W/m^2, 3: at 35 W/m^2.

105 W/m^2, an increase of light intensity from 14 to 70 W/m^2 resulted in a rise of optimum temperature by 6°C, i.e. 1.1°C per 10 W/m^2. Within a range of 70–210 W/m^2 a shift of photosynthetic optimum temperature was 0.7°C per 10 W/m^2.

An increase of light intensity during plant growth from 35 to 105 W/m^2 led to a shift of photosynthetic optimum temperature towards higher temperatures. Similar change of optimum temperature was observed for the plants grown under natural light (*5*). However, these investigations were carried out at saturating light intensity. The effect of light conditions of plant growth on photosynthetic optimum temperature depended on the intensities of short-term light. In our experiments, photosynthetic optimum temperature of the plants grown at 175 W/m^2 was higher at lower light intensities, and was lower within a range of 70–350 W/m^2 than that of the plants, adapted to 35 or 105 W/m^2 (Fig. 3A). In other words, the way of changing the curves of photosynthetic optimum temperature depended on light intensity while plotting photosynthetic temperature curves and light conditions of plant growth.

Light curves plotted according to the values of photosynthetic rate at the points of optimums of photosynthetic temperature curves are given in Fig. 3B. A considerable effect of plant growth light regime on a dip angle of a linear part of photosynthetic light curve as well as on the level of light saturation plateau can be seen. Thus, for the plants grown at 35 W/m^2 an increase of CO_2 uptake was observed under the light conditions lower than 140 W/m^2. A further enhancement of irradiation level did not result in an increase of photosynthetic rate. For the plant grown at 105 W/m^2 we observed a shift of the saturation level towards greater light intensities as well as a higher level of plateau as compared with the plants grown at 35 W/m^2. CO_2 uptake was increased 1.8-fold on the saturation plateau. Photosynthetic saturation plateau was not observed for the plants adapted to 175 W/m^2 of light intensity.

The approach used by us to plot photosynthetic light curves allows to find out the correlation between the CO_2 uptake and the photosynthetic optimum temperature (Fig. 3). The greatest rate of photosynthetic optimum temperature changes corresponded to a linear part on the light curve of photosynthesis of the plants adapted to 35 W/m^2 irradiation. At low intensities temperature effect is negligible and a shift of the photosynthetic optimum temperature is related with an increase of CO_2 uptake when irradiation is increased and with an increase of respiration rate when the temperature is raised. Light intensity change within a range of 140–350 W/m^2 did not result in that of photosynthetic rate at an optimum temperature for each irradiation level. At the same time photosynthetic optimum temperature increased with the irradiance. These results are not consistent with the data from Pisek *et al.* (*15*), indicating that at irradiation higher than the saturating value, a shift of photosynthetic optimum temperature towards higher temperatures does not occur. Insignificant change of photosynthetic optimum temperature of the plants adapted to 35 W/m^2 light intensity was found by us only at higher irradiances. This fact suggests that the plants tend to maintain leaf temperature at the level necessary to photosynthesize at a sufficiently high rate. Photosynthetic saturation proves that a further increase of light intensity for these plants is not efficient; the efficiency of temperature increase is thus decreased.

Photosynthetic light curves of plants adapted to high light intensities confirm the data on temperature positive effect on the process of photosynthesis, since at short-term increase of irradiation and correspondingly temperature, its rate was constantly increased.

It should be noted that the maintenance of optimum temperature regime for the plants adapted to high irradiation resulted in a better use of low intensity light by them. It is proved by a great value of the dip angle of the linear part of photosynthetic light curves of the plants grown at high irradiation level. On the contrary, another picture has been usually observed in case when photosynthetic light curves are plotted during one temperature regime (*17*, *19*).

Together with the light factor temperature regime of plant growth has a con-

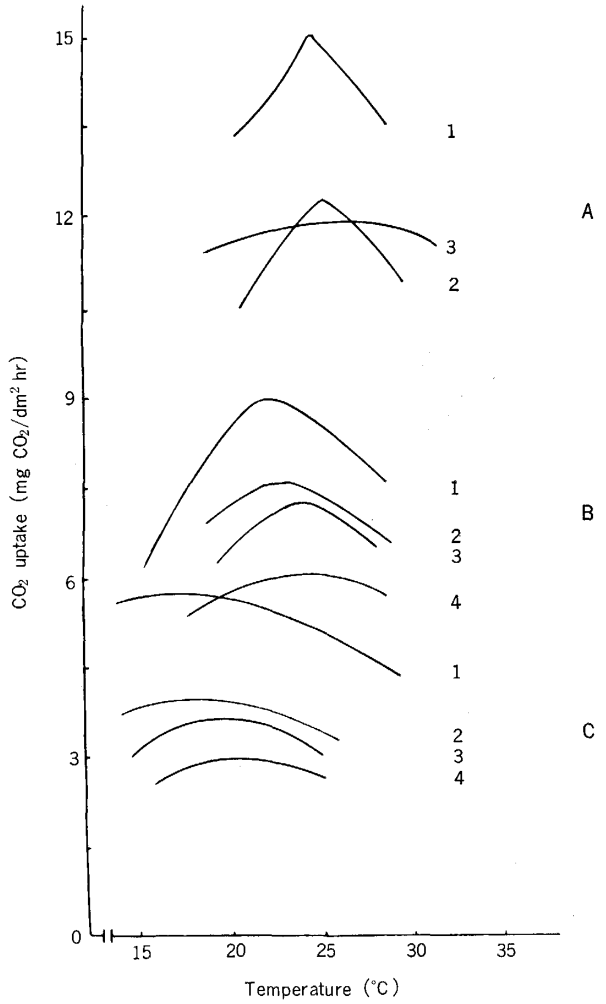

Fig. 4. Photosynthesis temperature curves of the plants grown at various levels of irradiation and temperature. A: plants were grown at 175 W/m^2; B: at 105 W/m^2; C: at 35 W/m^2; 1, 2, 3, 4: plants were grown at 15,20, 25, 30°C, respectively.

siderable effect on the temperature curves and photosynthetic optimum (*3*, *15*). Independing of the irradiation level, the plants grown at 15°C had a higher rate of photosynthesis as compared with those of other temperature variants (Fig. 4). On the contrary, at a high temperature of 30°C low rates of CO_2 uptake are observed. This picture, i.e. the rate of CO_2 uptake on the unit leaf area basis, can be related with specific leaf thickness. It results in the discrepancy between CO_2 uptake by a unit leaf area and plant productivity (*14*, *16*).

At all the levels of irradiation an increase of plant growth temperature led to a shift of photosynthetic optimum temperature towards higher temperatures (Fig. 5). A shift of optimum temperature was 1°C when the growth temperature was changed by 5°C. Insufficient shift of photosynthetic optimum temperature grown under various temperature regimes was also discussed in other works (*2*, *15*). It characterizes an insignificant effect of one environmental factor on the value of

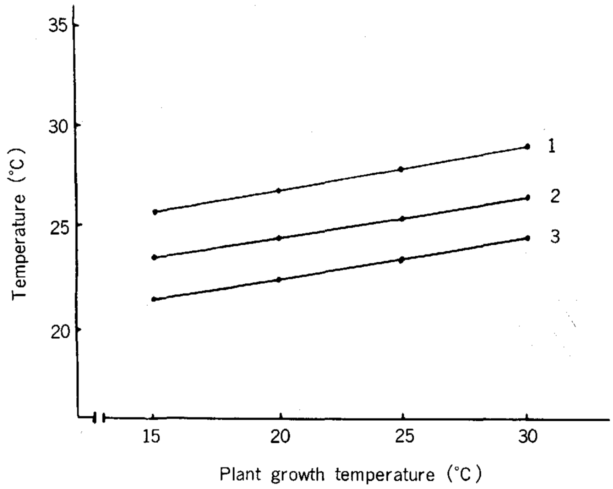

Fig. 5. Photosynthetic optimum temperature of cucumber plants, grown at various levels of irradiation and temperature. Irradiation values of 175, 105 and 35 W/m^2 correspond to 1–3 curves.

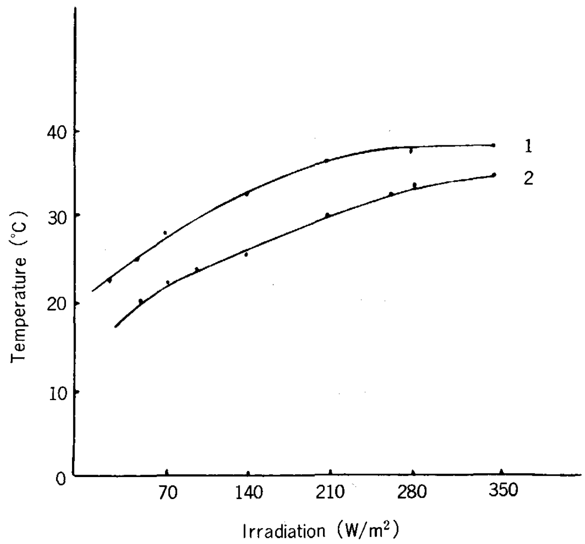

Fig. 6. Photosynthetic optimum temperatures of cucumber plants at natural (2) and increased 0.1% (1) CO_2 concentration in the air. The plants were grown at 35 W/m^2.

photosynthetic optimum temperature. On the contrary, under simultaneous change of environmental factors the total shift of photosynthetic optimum temperature can be about some degrees. The results of our investigations (as well as the data from (5, *13*)) prove that the preceding light and temperature conditions of plant growth affect the optimum temperature and intensity of photosynthesis. Therefore, it is obvious that temperature regime regulation must be carried out taking into account of the preceding effect of the environmental factors on plants.

The dependeces characterizing photosynthetic optimum temperature at in-

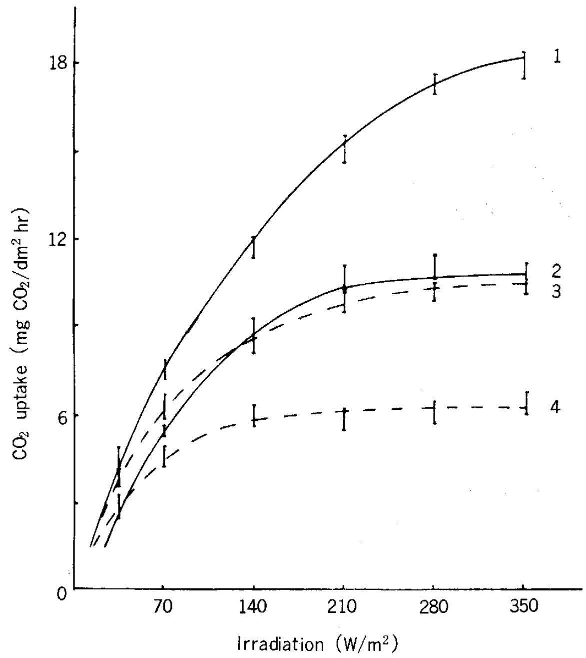

Fig. 7. Photosynthesis light curves plotted according to the photosynthetic values at the optimum points of photosynthesis temperature curves. 1, 2: photosynthesis was measured at increased CO_2 concentration (0.1%); 3, 4: at natural CO_2 concentration. 1, 3: the plants were grown at 105 W/m^2; 2, 4: at 35 W/m^2.

creased CO_2 concentration and various light intensities are given in Fig. 6. An increase of irradiation level from 35 to 210 W/m^2 resulted in a shift of photosynthetic optimum temperature towards higher temperatures. Within a range of 210–350 W/m^2 a shift of the photosynthesis optimum was insignificant.

At an increased CO_2 concentration in the air photosynthetic optimum temperature is 3–6°C higher as compared with the values found at natural concentration of carbon dioxide. Together with the rise in photosynthetic optimum temperature, an increase of CO_2 uptake rate on the one leaf surface unit basis is observed. Photosynthetic light curves plotted according to the photosynthetic rate values at the points of optimums of temperature curves allowed to find out the effect of carbonic acid on photosynthesis at various irradiation levels and optimum temperature (Fig. 7).

An increase of CO_2 content in the air at irradiation up to 70 W/m^2 had insignificant effect on the photosynthetic rate as compared with natural CO_2 concentration. Together with an increase of plant irradiation level a positive effect of CO_2 on photosynthesis was increased. As compared with natural CO_2 concentration a shift of photosynthetic saturation region towards higher light intensities occurred. In the plants grown at 105 W/m^2 photosynthetic saturation was not observed.

Thus, the present results indicate the necessity of temperature regulation taking into account CO_2 content in the air and preceding conditions of plant growth. Positive effect of CO_2 on photosynthesis is increased under simultaneous temperature increase. An increase of CO_2 content in the air is the most efficient at high levels of plant irradiation.

To sum up the reaction of plant on the change of irradiation levels, temperature, CO_2 concentration depend on the value of affecting factors, their combination as well as plant physiological state resulted from the preceding effect of environmental factors on the plants. Under sheltered ground it is necessary to control temperature taking into account CO_2 concentration and the preceding light and temperature conditions of plant growth. Underestimation of this condition can result in a decrease of plant productivity and an increase of energy spent on their growth.

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