Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC
JOURNAL
OF POLISH
AGRICULTURAL
UNIVERSITIES

2001
Volume 4
Issue 2
Series
HORTICULTURE

KOŁOTA E., ŚLĄZAK Z. 2001. THE EFFECT OF CO_2 SUPPLY ON THE YIELDING AND ECONOMIC CONSEQUENCES OF THIS TREATMENT IN GLASSHOUSE CULTIVATION OF TOMATOES **Electronic Journal of Polish Agricultural Universities**, Horticulture, Volume 4, Issue 2.
Available Online http://www.ejpau.media.pl

THE EFFECT OF CO_2 SUPPLY ON THE YIELDING AND ECONOMIC CONSEQUENCES OF THIS TREATMENT IN GLASSHOUSE CULTIVATION OF TOMATOES

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ABSTRACT

The studies conducted in a glasshouse of the Establishment of Horticultural Production (PPO) at Siechnice were aimed to determine the reaction of tomatoes grown on mineral wool to CO_2 enrichment of the atmosphere and to calculate the profitability of applying this treatment in wholesale production. The studies used liquid gas accumulated in pressure containers. After being evaporated, the gas was carried in liquid form to plants by means of a system of PE pipes. The studies adopted three levels of CO_2 content in the glasshouse atmosphere, namely 0.06-0.08% with ventilators closed, 0.04-0.05% with ventilators slightly opened, and 0.03-0.04% with ventilators fully opened.

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The results showed that CO_2 enrichment used in the conditions of wholesale production of glasshouse tomato increased the commercial yield of the fruit from 38.1 to 45.5 kg/m^2 (by 19.4%). A positive effect of CO_2 enrichment of the atmosphere was most clearly revealed in the case of the very early yield, which was gathered from the middle of May and which increased by 50% during the period of 3 years.

The influence of CO_2 enrichment on the economic cultivation of tomatoes was expressed in the clear profit increased by 22.3%. The proportion of the costs of this treatment in extra incomes obtained owing to CO_2 enrichment of the atmosphere was 16.67%.

Key words: tomato, glasshouse cultivation, CO_2 enrichment, yield, profitability of cultivation

INTRODUCTION

In natural conditions for the majority of plants it is not CO_2 concentration in the atmosphere that constitutes a factor limiting the intensity of photosynthesis. This fact is taken advantage of in glasshouse cultivation, where plants are supplied with carbon dioxide. Within a certain range, doubling CO_2 content in the air also doubles the intensity of photosynthesis, which is of significant importance for the production of biomass [13].

The first Polish experiments on supplying tomatoes with CO_2 conducted by Skierkowski [9] showed that a 0.1-0.15% increase of its concentration in a glasshouse secured an increased yield of fruit by 30% and of the early yield by 80%. A similar range of CO_2 concentrations in the cultivation of this plant is also recommended by Libik et al. [7], Sowiński [11]. Libik and Repelewicz [6]. According to Mortensen [8], the optimum CO_2 concentration for the majority of plants is slightly lower and is placed within the range between 0.06-0.09%. On the other hand, Cydendambajew [2] points out that the optimum CO_2 concentration is related to the stage of tomato growth and is equal to 0.06-0.08% in the phase of seedlings production, and 0.1-0.15%, when the plants are fully developed. CO_2 enrichment of plants can also be profitable in summer with open ventilators, the aim of which is to keep its concentration at the level up to 400 ppm [10]. This refers especially to no soil cultivation, where in the afternoon the level of CO_2 can decrease below 100 ppm, which is the value below the compensation point.

Apart from an increase of the fruit yield, especially the early yield, another effect of CO_2 supply is an increase of sugar content in the fruit and a considerable drop of acids concentration and – resulting from it – improvement of organoleptic valours [6]. At the same time attention is drawn to the fact that profitability of this treatment is conditioned by other factors, including the light, air humidity, fertilization and temperature, which should be by 2-3°C higher that in cultivation of plants that are not enriched [3, 6].

Despite encouraging results of studies on CO_2 enrichment this treatment did not arouse much interest in horticultural practice. It began to be used only in the 1980's in West European countries, and lately also in Poland, especially in cultivation on inorganic subsoils. A possibility of using CO_2 free from impurities in the compressed form in cylinders, improvement in the equipment for dosing and controlling the concentration as well as greater air-tightness of glasshouse construction contribute to the popularity of enriching plants with CO_2.

The purpose of the studies was to determine the effect of CO_2 application on the production and economic effects of glasshouse wholesale production of tomatoes.

MATERIALS AND METHODS

The studies were conducted at the Establishment of Horticultural Production Siechnice near Wrocław, in the conditions of wholesale production of glasshouse tomatoes, where in 1991 this vegetable started to be cultivated on mineral wool with computer control of the climate, fertilization and irrigation. Beginning with 1997, plants were enriched with carbon dioxide, which was supplied to the glasshouse atmosphere.

PPO Siechnice uses a prolonged method of tomato cultivation, where seed sowing is performed on December 10-15, while the seedlings cultivated in blocks are planted from mats to mineral wool 40 days after the sowing date and plant density is 2.4 plants per 1 m^2. Plants are led in one stem and the topping takes place at the beginning of September. Large scale introduction of biological methods of protecting plants from greenhouse while fly and red spiders made it possible to use bumble-bees for plant pollination. The fruit are picked 3 times a week. The final harvest was joined with closing down the plantation is in the middle of December.

Plant enrichment is conducted throughout the period of tomato cultivation on a permanent place, with the use of liquid CO_2. The whole system of enriching the greenhouse atmosphere in this gas is comprised of the following:

- pressure containers POLKOMAT 16 or 25, where liquid CO_2 is stored, and a system of ventilator evaporating dishes with the efficiency of 1500 m^3/h for vaporizing this gas;
- a system distributing gas CO_2 to particular greenhouses by means of PCV pipes with ø50 mm;
- a system distributing and dosing CO_2 in particular greenhouses. The distributing wires are made of PCV pipes with ø40 and 32 mm, while the dosing elements are made of PE pipes with ø20 mm, with an opening of ø1.5 mm every 8 m., placed along the plant rows. The working pressure in the distributing pipes is 1.6-2.0 bars, and in the dosing wires 0.5 bar;
- a steering system, the function of which is to obtain a definite level of CO_2 in the greenhouse. Its most important element is an analyzer of gas concentration of PRIVA Company. It cooperates with PRIVA CD 750 computer steering the whole process of tomato production.

Three levels of CO_2 content were adopted in the greenhouse atmosphere in the production of tomato:

- 0.06-0.08% with ventilators closed completely,
- 0.04-0.05% with ventilators opened up to 5%,
- 0.03-0.04% with ventilators opened > 10%.

CO_2 dosing was used in the spring period between 9.00 am.-3.00 pm, and in the summer and autumn periods between 7.00 am-5.00 pm.

The total area of tomato cultivation under the studies was 4 ha every year. The results obtained in 1994-1996 helped to estimate the yielding of plants that were not enriched, while the results from 1998-2000 were achieved with CO_2 enrichment. The year 1997 was not considered in the studies because the cultivation was damaged by flood.

The mean weekly yield of fruit from the whole period of tomato yielding was used to evaluate the commercial yield. An analysis of price tendencies on the greenhouse vegetables market was the basis to distinguish the very early and early yields. On the basis of the data from all the examined years, the very early yield, calculated since the first permanent reduction of

prices for fruit, was considered to mean all the crops gathered in the period up to the 19th week of the calendar year. On the other hand, the early yield was considered to mean the crop gathered since the above time until the next reduction of prices in the third ten days' period of June (a period of 19th-25th weeks of the year).

In the economic estimation – on the basis of weekly crops of fruit signifying the means for the years with and without CO_2 enrichment and the market prices of the year 2000 – the gross income from tomato cultivation was calculated. Besides, the costs of enrichment were worked out and they consisted of the price of CO_2 purchase, the cost of leasing the tanks and evaporating dished, amortization, expenditure of electrical energy, the costs of services, repairs and maintenance. These data were used to calculate the economic indexes, namely the index of profitability and the relative costs of CO_2 enrichment in relation to additional incomes achieved after the treatment was introduced.

From among the weather data the paper chose to present only the measurements of insolation as a factor that is not controlled in greenhouse cultivation (table 1). Calculating the mean monthly insolation in the years 1994-1996, when the plants were not enriched, and in the years when they were (1998-2000), it can be stated that it was slightly higher for the tomatoes that were not enriched. This means that when the other elements of greenhouse micro-climate was kept on the same level year by year, an increased yield of fruit in the years with CO_2 enrichment was solely the effect of this treatment.

Table 1. Mean monthly insolation during the cultivation of greenhouse cultivation at PPO Siechnice in the years 1994-2000

Specification	Years 1994-1996 without enrichment	Years 1998-2000 with CO_2 enrichment
Mean number of sunny hours in a month	145.37	143.16
Deviation from the mean monthly insolation for the years 1992-2000 in the times	-1.69	-3.90
Deviation from the mean monthly insolation for the years 1992-2000 in %	-1.15	-2.65

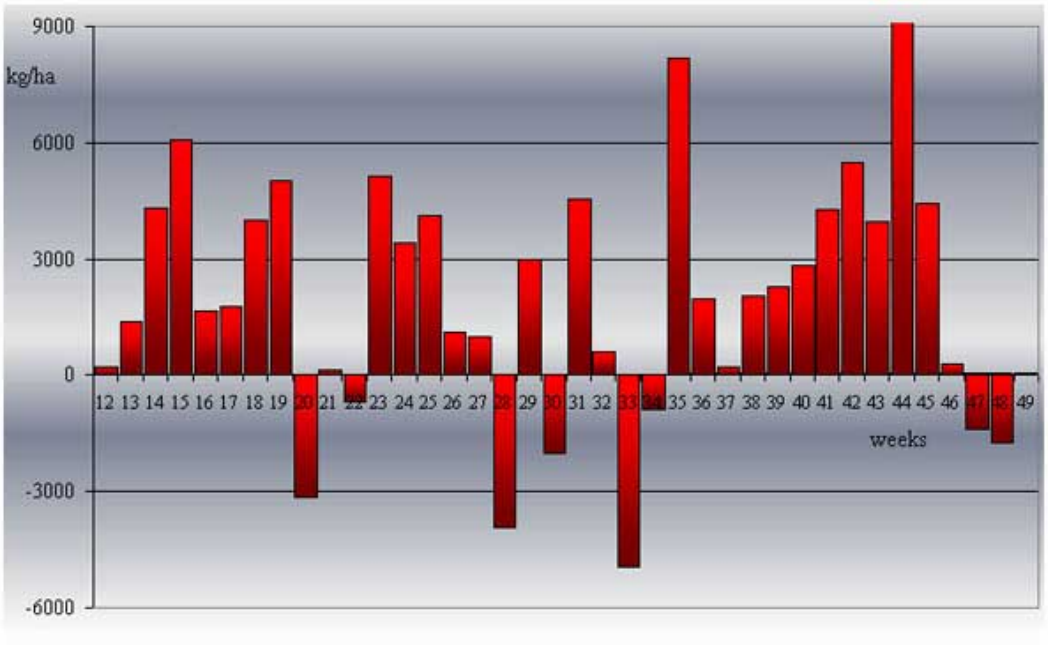
RESULTS

In all the analyzed years the fruit harvest began in the 13th week of the calendar year, i.e. on the first days of April. The year 1999 was an exception because then the beginning of the harvest was a week earlier. In all the examined years very intensive ripening of the fruit and consequently increased crops were observed beginning with the 16th week of the year (third 10-day period of April). The yielding was decreased after 38th-39th week in the variant without CO_2 enrichment, and after 44th-45th week in the variant with CO_2. The harvest was finished after the 48th week that is in the first half of December, independent of the use of CO_2 application.

The results concerning tomato yielding showed slight differentiation in the successive vegetation seasons. That is why they are presented as mean figures for the period of 3 years. It follows from the data in figure 1 that supplying plants with carbon dioxide gave a significantly higher yield, mainly at the beginning of the harvest, between the 13th and 19th weeks of the calendar year. In the successive period the effect of CO_2 enrichment was differentiated; the plants supplied with CO_2 showed both increases and decreases of the yield

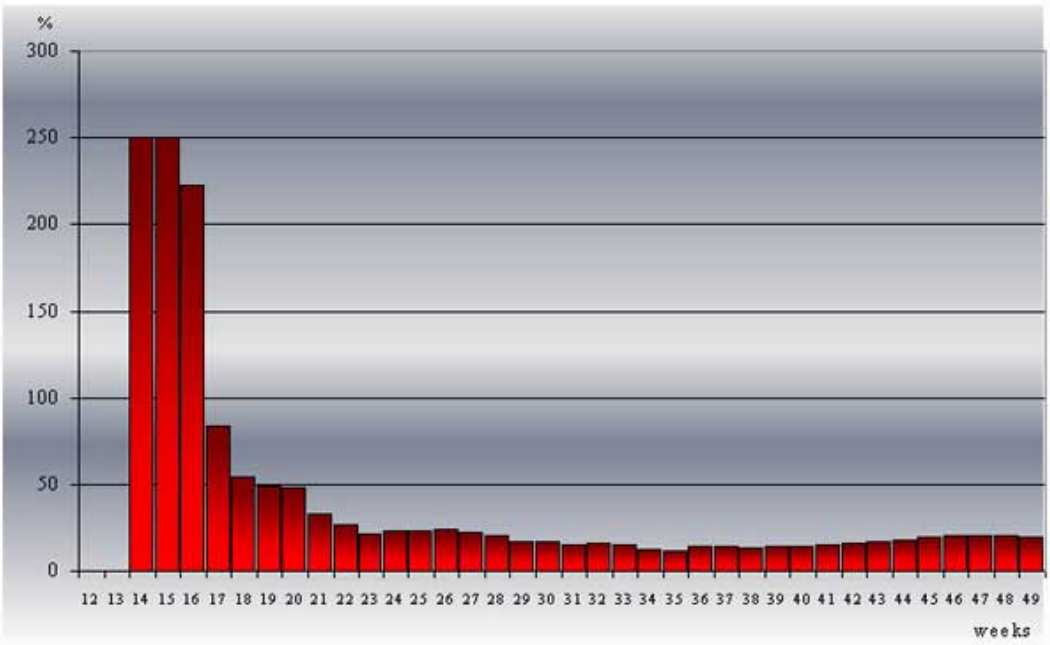
in relation to the cultivation without CO_2 enrichment. In the autumn period, however, the studies again observed high effectiveness of this treatment in the 39th-46th weeks.

Figure 1. Differences in the commercial yield of greenhouse tomato enriched with CO_2 in relation to the cultivation without this treatment, weekly in kg from 1 ha



In sum, percentage increase of the yield calculated from the beginning of the harvest in the successive weeks of the year (figure 2) showed very high efficiency of this treatment during the first 3 weeks of yielding, when it reached 250% in relation to the cultivation without CO_2 enrichment. In the successive 4 weeks the yield was lowered to 30% showing further slow decrease in the summer period and increase in autumn.

Figure 2. Total increase of the commercial yield of greenhouse tomato achieved under the effect of CO_2 enrichment, calculated from the beginning of the crops in successive weeks of the year (in %)



The data contained in table 2 and referring to the whole period of cultivation show that in conversion per 1 m^2, supplying plants with CO_2 caused an increase of the commercial yield of fruit from 38.1 to 45.5 kg, of the early yield from 8.8 to 9.7 kg, and of the very early yield from 5.0 to 7.5 kg. A high, up to 50% increase of the very early yield points at especially high effectiveness of the treatment at the beginning of the cultivation and fruit harvest of tomato. That increase was also significant in reference to the overall commercial yield and it was 19.4%.

Table 2. Effect of plant enrichment with CO_2 on the yielding on greenhouse tomato (kg/m^2)

Successive weeks	Type of yield	Cutlivation without CO_2 enrichment	Cultivation with CO_2 enrichment	Increase of yield under the effect of CO_2 enrichment (in %)
13-19	very early	5.0	7.5	50.0
20-25	early	8.8	9.7	10.2
26-49	the remaining part of the yield	24.3	28.4	16.9
13-49	total commercial yield	38.1	45.5	19.4

It can be stated on the basis of the data from table 3 calculated from the data of the year 2000 that the purchase of CO_2, including the costs of leasing evaporating dishes and tanks, constituted the highest proportion in the costs of plant enrichment. The following important item in the costs was servicing the enriching devices. Its proportion in the total costs was 35.5%. The financial outlays including amortization, repairs and maintenance of the dosing and controlling devices constituted a relatively small percent. The total cost of enrichment per 1 ha of tomato cultivation was determined to be 51 037.20 PLZ, which – with simultaneous increase of the gross income by 306 123.50 PLZ (22.3%) – ensured the clear income of 255 086.30 PLZ from 1 ha in consequence of applying CO_2 enrichment (table 4). High profitability of enriching greenhouse tomatoes with carbon dioxide is proved by the index of relative costs, which is 16.67% and the index of profitability, which reaches 499.80%.

Table 3. Costs of CO_2 enrichment in the cultivation of greenhouse tomato according to the data from 2000

Amount of the used CO_2 and specification of costs	Value
Amount of used CO_2 (in kg/ha)	66 343.00
Price of CO_2 purchase (in PLZ/ha)	0.33
Costs of leasing tanks and evaporating dishes (in PLZ/kg CO_2)	0.07
Costs of used CO_2 (in PLZ/ha)	26 537.20
Costs of servicing the enriching devices (in PLZ/ha)	18 000.00
Costs of electrical energy (in PLZ/ha)	500.00
Repairs and maintenance (in PLZ/ha)	3 000.00
Amortization of enriching devices (in PLZ/ha)	3 000.00
Total cost of CO_2 enrichment in the cultivation of 1Ha tomato (in PLZ)	51 037.20

Table 4. Basic economic indexes in the cultivation of greenhouse tomato with CO_2 enrichment

Specification	Value
Gross income (in PLZ/ha)	
– with CO_2 enrichment	1 679 826.74
– without CO_2 enrichment	1 373 703.24
Increase of gross income under the effect of CO_2 enrichment (in PLZ/ha)	306 123.50
Clear income achieved under the effect of CO_2 enrichment (in PLZ/ha)	255 086.30
Proportion of CO_2 enrichment costs in the additional gross income (in %)	16.67
Profitability index of enriching plants with CO_2 (in %)	499.80

DISCUSSION

The new technology of production, using the mineral wool as the subsoil, the system of plant fertigation and steering the greenhouse climate of PPO Siechnice made it possible to achieve an increase of the yield of tomato fruit in the prolonged cultivation up to 38.1 kg/m^2, which made the cultivation profitable. Applying CO_2 in plant enrichment, which began in 1995 and is now used in all greenhouse cultivation, was considered to be a condition of further improvement of the productive and economic effectiveness.

The studies conducted in the years 1994-2000 showed that the increase of tomato yield achieved under the effect of supplying plants with carbon dioxide in the conditions of wholesale production was lower in relation to the increase obtained on an experimental scale by Skierkowski [9], Hartz, et al. [4], Libik and Repelewicz [6] and quoted by Sowiński [11].

This can be accounted for both by greater difficulties in achieving the optimum conditions in a huge wholesale object and by the applied CO_2 concentration, which was kept at the level of 0.06-0.08% with closed ventilators, and only 0.03-0.04% with open ventilators, doing away with the deficit of the gas intensively utilized in the process of photosynthesis.

An increase of the commercial yield of fruit from 38.1 to 45.5 kg/m^2 should be considered to be fully satisfying, especially when one considers the fact that the highest increase was observed at the beginning of fructification. It turned out that the increase of the very early yield achieved during the first 7 weeks of yielding (until the middle of May) reached 50%, which – considering very high retail prices – had a significant influence on the application of this treatment. When Libik and Repelewicz [5] applied CO_2 enrichment in the concentration 800 ppm, they found out an increase of the yield of early fruit within the range of 77-98% depending on the year, which has a decisive effect on the financial outcome if one takes into account a 27% increase of the total commercial yield and more favourable price relations at the beginning of the crop. High efficiency of the treatment of CO_2 enrichment at that time can be accounted for by the fact that young plants show a more positive reaction towards the content of this gas in the atmosphere, because in older plants a genetically conditioned drop of photosynthesis intensity takes place [1, 12].

At PPO Siechnice enrichment with CO_2 contributed to higher gross income by 22.3%, which – with relatively low costs of the application of the treatment – gave a very high profitability rate of 499.8%. Hartz et al. [4] also point at high profitability of CO_2 enrichment. They establish its costs at 10% of the total costs of tomato production. On the other hand, Skierkowski [9] found out a 20% increase of the value of the fruit yield in the spring cultivation and no effectiveness of the treatment in the autumn cultivation. It should be emphasized, however, that these results were obtained on traditional subsoil, where no radical drop of the level of CO_2 caused by intensive photosynthesis process in the greenhouse atmosphere takes place.

CONCLUSIONS

Results of the studies conducted in the years 1994-2000 and concerning profitability of enriching greenhouse tomatoes with carbon dioxide point at the following conclusions:

1. CO_2 enrichment on a permanent place on the subsoil of mineral wool gave increased commercial yield of fruit from 38.1 to 45.5 kg/m^2 (by 19.4%)
2. A positive effect of enriching the atmosphere with CO_2 was especially revealed in the case of the very early yield of fruit, which had a decisive importance for the economic profitability. That yield gathered from the beginning of April till the middle of May was for the period of 3 years higher by 50% in relation to the cultivation without enrichment.
3. The influence of CO_2 enrichment on the economic effect of tomato cultivation was shown in increased clear income by 22.3%
4. The rate of relative value of additional costs of CO_2 enrichment was 16.67%, while the rate of profitablity reached the value of 499.8%.

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