Intermittent CO_2 enrichment and analysis of dry matter accumulation and photoassimilate partitioning in tomato

Enriquecimento intermitente de CO_2 e análise do acúmulo de massa seca e da partição de fotoassimilados em tomateiro

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Abstract

To assess dry matter (DM) accumulation and photoassimilate partitioning in tomatoes grown under different CO_2 concentrations an experiment was conducted in a randomized complete block design with 12 repetitions, and two tomato hybrid cultivars cultivar (cv.) Andrea and Alambra. CO_2 enrichment was intermittent (no enrichment during 10:30a.m. to 4:00p.m.), and provided by a compost pile, with gas concentration ranging from 600 to 750 $\mu l\ l^{-1}$. The CO_2 enrichment only changed DM partition and accumulation of the stem in the cv. Alambra, leaving the other variables in both cultivars insensible to the treatment. DM accumulation was higher in protected environments compared with the field conditions. The cultivar Andrea accumulated 786.39 g of DM pl^{-1} in the CO_2 enriched environment, 815.49 g pl^{-1} in the protected environment and 637.41 g pl^{-1} in the field. The cv. Alambra accumulated 766.68 g of DM pl^{-1} in CO_2 enriched environment, 824.35 g pl^{-1} in the protected environment and 592.44 g pl^{-1} in the field. The greatest sink of photoassimilates were the fruits, which accumulated 59%, 63% and 72% of the plant DM in the CO_2 enriched environment, in the protected environment and in the field conditions, respectively.

Key words: *Lycopersicon esculentum*; tomato, carbon dioxide; dry matter.

Resumo

Para avaliar o acúmulo de massa seca (MS) e a partição de fotoassimilados em tomateiro cultivado sob diferentes concentrações de CO_2, foi conduzido um experimento no delineamento em blocos casualizados com 12 repetições e as cultivares (cv.) híbridas de tomateiro Andrea e Alambra. O enriquecimento com CO_2 foi intermitente (não havendo enriquecimento no período das 10 h 30 min às 16 h) pela utilização de pilha de compostagem como fonte do gás, cuja concentração variou de 600 µl/lt a 750 µl/lt durante o período matinal. O enriquecimento com CO_2 alterou somente a partição e o acúmulo de MS de caule na cv. Alambra, permanecendo as demais variáveis, em ambas as cultivares, insensíveis ao tratamento. Houve maior acúmulo de

MS nas plantas cultivadas nos ambientes protegidos comparadas às do campo. A cv Andrea acumulou 786.39 g/planta de MS no ambiente protegido + CO_2 (AP + CO_2), e 815.49 g/planta no ambiente protegido normal (AP normal) e 637.41 g/planta no campo. A cv. Alambra acumulou 766.68 g/planta de MS no AP + CO_2, 824.35 g/planta no AP normal e 592.44 g/planta no campo. O maior dreno de fotoassimilados foram os frutos, que acumularam 59%, 63% e 72% da MS das plantas nos AP + CO_2, AP normal e campo, respectivamente.

Palavras chave: *Lycopersicon esculentum*; tomate, dióxido de carbono, massa seca.

Introduction

The total output of a plant is called the organic production, and the ratio between the mass of the commercial and the organic production is termed the harvest index (Huhn, 1990). The harvest index reflects the partitioning of the product of photosynthesis between the commercial and the vegetative parts of the plant. The ability of the plant to provide high productivity is determined by its ability to produce high levels of photosynthate and / or direct efficiently a large part of these to the organs of commercial interest (Faville et al., 1999).

The concentration of carbon dioxide (CO_2) in the crop atmosphere has an effect on the activity of Rubisco, and may alter the net photosynthesis of the plant, and consequently, the accumulation and transport of carbohydrates, as well as the total production of dry mass (DM). Woodrow et al. (1987) demonstrated that CO_2 enrichment affected both the source and the sink, and the partitioning of carbohydrates into different plant organs (stem, roots and leaves). These authors observed that tomato seedlings grown in environments enriched for CO_2 had a greater biomass, an advantageous trait for providing better plant establishment and initial growth in the field. It was also observed that the DM accumulation in shoots and in the roots increased, as well as the DM of the leaves (81% higher than in the non-enriched environment)

In a study conducted by Nederhoff (1994) in tomatoes grown in the summer, the concentration of CO_2 appeared not to have a direct effect on the allocation of biomass to different plant organs. However, according to the author, the enrichment of CO_2 in tomato plants may increase fruiting, and the allocation of DM to the fruits. Considering this, the aim of this study was to verify the partitioning and the accumulation of DM in tomato plants grown in a protected environment with an without intermittent CO_2 enrichment, and also in the field.

Materials and methods

The tomato cultivars cv. Andrea & cv. Alambra both of indeterminate growth, were cultivated in the autumn-winter of 2006, in the Federal University of Viçosa, Viçosa, MG, Brasil. We employed two protected environments (non-acclimatized plastic covers over arches, 24 m x 7.5 m, with a height of 2.4 m), with retractable side curtains. The treatments were designated: AP + CO_2 being the protected environment that received CO_2 enrichment, AP normal being the protected environment with no enrichment, Coverage of the protected environment was achieved using a low density polyethylene with a thickness of 150 μm. We used a randomized block design with 12 repetitions. Spacing was 1.10 m x 0.6 m between the rows and between plants respectively. Each plot had five plants with the three central plants being considered useful.

During cultivation the internal environment was managed through openings in the lateral curtains, so avoiding excessive temperatures during the hottest parts of the day. The protected environments remained with the side curtains open from 10.30am to 16.oopm in order to avoid overheating.

Plants were staked using a vertical thread, with between one and eight node. Apical pruning as not performed, eliminating only the vegetative growth, with the elimination of inflorescences above the eight node.

Localized drip irrigation was applied through drippers, with management based on lysimeters with constant water table level installed in the protected environments and in the field (Bernardo, 1995). Fertilization was performed according to a previous soil nutrient analysis, and the fertilization recommendations for tomato crops. Fertilizer used was: 35 t/ha of cattle manure and 400 kg/ha of P_2O_5 at planting. Divided between planting and coverage, the following fertilization was employed: 160 of/ha de N and 100 kg/ha of K_2O in the AP + CO_2 and in the field, and 70 kg/ha of K_2O + CO_2 in the AP normal. The coverage fertilization was performed through fertigation, weekly, parceling up the total amount of N and K according to the number of weeks of the crop cycle.

The enrichment with CO_2 in the two protected environments was initiated one week after transplanting the seedlings, using compost heaps as the source of CO_2. The CO_2 concentration during the morning was monitored with a CO_2 sensor (IRGA, model GMW20, Vaisala) and ranged between 600 and 750 μl/lt.

At the end of the crop cycle, plants were collected and separated into stems, and leaves, and dried in a forced ventilation oven at 70 °C until they reached constant mass, with subsequent weighing of dry mass. The fruits obtained in a weekly harvest were also dried in the oven to obtain the total DM of the fruit, added to the dry mass of each of the plants. The data collected were subjected to analysis of variance and the Tukey test ($P < 0.05$) in the program, System for Statistical and Genetic Analysis (SAEG) (Ribeiro Junior, 2001).

Results and discussion

Considering the cvs. Andrea and Alambra, it was observed that both produced a similar quantity of DM, both between cultivation environments and among parts of the plants. When considering the proportion of DM in different plant organs, it was observed that, in general, most DM allocation to the fruits was independent of the cultivar and the growth environment. (Table 1).

Table 1. Partitioning of photoassimilates (%) between parts of the plant of the tomato varieties, cvs. Andrea & Alambra cultivated in protected environments (AP + CO_2, AP normal) and in the field.

Crop environment	Stem DM / total DM		Leaf DM / total DM		Fruit DM/total DM	
	Andrea	Alambra	Andrea	Alambra	Andrea	Alambra
AP + CO_2	22 a*	16 a	33 ab	25 a	45 b	59 b
AP normal	18 ab	13 b	35 a	24 a	45 b	63 b
Field	17 b	11 c	24 b	16 b	59 a	72

* Means followed by the same letter in the column do not differ significantly in the Tukey test ($P < 0.05$).
AP + CO_2 = Treatment enriched with CO_2. AP normal = treatment with no CO_2 enrichment.

In the cv. Andrea grown in AP + CO_2 there was a difference in the partitioning of DM between aerial organs of the plant, with highest values for the fruits, followed by the leaves and stems. In AP normal the partition was similar, with a small reduction in stem DM and an increase in leaf DM. In the field portioning presented the same trend, however, a small reduction in allocation to the stem and leaves, and an increased allocation to the fruits was seen (Table 1).

In the cv. Alambra, DM partitioning showed similar behavior. In the AP + CO_2 there was a greatest accumulation of DM in the fruits, followed by that of the leaves and stems, also observed in the other environments (Table 1).

The DM accumulation in the stem, leaf and total plants of the cv. Andrea was higher in the environment AP + CO_2 and AP normal, compared to the DM of plants cultivated in the field (Table 2). Considering the mean DM accumulation of the plants in - AP + CO_2 and AP normal, it was observed that the stem, leaf and total DM were respectively 68.1%, 56.5% and 79.6% higher than the equivalent DM of plants grown in the field. The accumulation of Fruit DM in the cv. Andrea did not differ between crop environments, with a mean of 368 g/plant.

The cv. Alhambra differed to the cv. Andrea in the accumulation of stem DM, though, in general, the same trend of greater DM in AP + CO_2 and AP normal was seem. Comparing the accumulation of stem DM between crop environments, a greater mass was observed in AP + CO_2 followed by AP normal and field (Table 2). The accumulation of leaf and total DM was similar in the treatments AP + CO_2 and AP normal, being greater than for plants grown in the field, 101.2% and 79.4%, respectively. The fruit DM accumulation in the cv. Alhambra was similar in both protected environments. However it was 21% higher in the AP normal compared with the field.

Enrichment with CO_2 only altered the partitioning and the accumulation of stem DM in the cv. Alambra, with the other variables insensitive to the treatment. This may be related to the exposure time of the enrichment. Although the period of greatest photosynthetic activity is in the morning, Calvert & Slack (1975) report that the ideal for the cultivation with CO_2, enrichment is for the crop to be exposed to high concentration throughout the day. Under this scenario the researchers obtained the best physiological response.

The daily management of the curtains was necessary because after 10.30am, the temperature inside the greenhouse exceeded 30 °C, and there was no cooling system. It is possible that physiological problems occur in tomatoes above 30 ºC, such as a decrease in viability and germination rate of the pollen (Sato et al., 2002); increased photorespiration (Hall & Keys, 1983) and a reduction on the fixation of carbon dioxide (Feller et al., 1998).

Considering the differences among the crops in the protected environment and in the field, the results of this study are concordant with those of other researchers which analyzed the partitioning of photoassimilates and production in tomato plants in similar situations Cockshull et al. (1992) obtained 69% fruit DM, 12.9% for stems and 18.1% for leaves. Scholberg et al. (2000) found for the cv. Agriset 761, cultivated in the field a DM (g/plant) of stems, leaves and fruits of 92.7, 134 and 253 respectively, representing 19.35%, 27.97% and 52.81% of the total DM of the plant, respectively.

Fayad et al. (2001) obtained a DM of 406.3 g/plant de MS for the aerial parts of the cv. Santa Clara, cultivated in the field, at 120 days after transplanting, with accumulated DM in stems, leaves and fruits being 14%, 33% and 51% of the total DM produced by the plant. In the hybrid EF-50 cultivated in a protected environment, total plant DM production was 397.9 g, distributed as 5% stem, 25% total leaf, and 68% fruits. By analyzing tomato growth, Heuvelink (1995) found that of the total DM produced by the cv. Counter, cultivated in a protected environment during the summer period, 60% was allocated to fruits, 28% to leaves, and 12% to stems.

Analyzing the relationship between leaf and fruit DM, it can be seen that for the cv. Alambra, grown in AP + CO_2, each gram of leaf DM resulted in a production of 2.40g of dry fruit. In AP normal production was 2.61 g, and in the field 4.40 g of DM of fruit for each g of DM leaf. For the cv. Andrea, each gram of leaf DM in AP + CO_2 produced 1.35 g of fruit DM. In the treatment AP normal production was 1.34 g of fruit DM per gram of leaf DM, and in the field it was 2.41g It can be observed also that the plants cultivated in the field had a greater production efficiency than those cultivated with the treatments AP + CO_2 and AP normal. However, it must be considered that the collection of plants for drying and acquisition of DM was made at the end of the crop cycle, and even with all the effort made against disease control, plants grown in the field were subject to loss of leaf area and even stem. This was not observed in plants grown under the AP + CO_2 and AP normal treatments. Thus, the loss of DM of plants cultivated in the field should be considered for the comparison of production efficiency of plants grown in protected environments and those grown in the field.

One must consider that, as a function of the training system adopted, the apical pruning with eight nodes may have limited plant production in the AP + CO_2 and no AP normal environments. It is possible that if more nodes were kept on the plant, then there might be increased production, and consequently more efficient productivity of plants in the protected environment. The training system adopted provides greater DM accumulation in the leaf and stem, because the vegetative growth is not limited.

The harvest index of the plants ranged from 45% to 72%. De Koning (1993) reported in an annual crop in a protected environment, 72% of the total biomass was accumulated in the fruits, while Cockshull et al. (1992) found the harvest index of 69% and Scholberg et al. (2000) obtained 58% in field-grown crops. Crops with a higher yield capacity have a harvest index of more than 65%, according to Heuvelink & Dorais (2005). Greater of lesser values may be observed according to the number of bunches harvested and crop management. The harvest index in this experiment was higher for field cultivation than for cultivation in protected environments.

From the proportion of leaf and stem DM (table 2) it can be seen that the vegetative growth was greater in the protected environments. A feature of this crop management is that plants are protected from unfavorable climatic conditions. As the tomato is susceptible to attack by various diseases requiring water collected on the plants surface, the protected environment becomes an cultivation option when a lower incidence of disease is desired. In field cultivation plants are exposed to rain and dew, conditions which are favorable to disease, and which in turn may interfere with the vegetative growth, and also, induce premature senescence of leaves, a fact noted by Scholberg et al. (2000) who cultivated tomatoes in field conditions similar to this study.

Table 2. Dry mass (g/plant) of stem, leaves and fruit, and the total DM of the tomato cultivars cvs. Andrea & Alambra, cultivated in AP + CO_2, AP normal and in the field.

Crop environment	Stem DM		Leaf DM		Fruit DM		Total DM	
	Andrea	Alambra	Andrea	Alambra	Andrea	Alambra	Andrea	Alambra
AP + CO_2	171.6 a*	117.2 a	261.6 a	193.4 a	353.8	466.0 ab	786.4 a	766.7 a
AP normal	152.1 a	102.7 b	283.5 a	199.8 a	380.0	521.9 a	815.5 a	824.3 a
Campo	110.9 b	64.2 c	154.2 b	97.8 b	372.6	430.4 b	637.4 b	592.4 b

* Means followed by the same letter in the column do not differ significantly in the Tukey test ($P < 0.05$).

AP + CO_2 = Treatment enriched with CO_2. AP normal = treatment with no CO_2 enrichment.

Another factor that is possibly related to the greater vegetative growth of plants in the greenhouses is the increase in the diffuse radiation within these environments caused by the plastic covers (Farias et al., 1993). Diffuse radiation is the most effective for photosynthesis, as it is multidirectional and penetrates most effectively into the plant canopy, favoring vegetative growth and development. Radin et al. (2003) observed that tomato plants grown in the field, with greater amounts of photosynthetically active incident radiation (PAR) produced less biomass than plants grown in a protected environment. The authors emphasize that the efficiency of use of PAR was greater in the protected environment compared to the field Papadopoulos & Ormrod (1988) obtained similar results and found that the more efficient use of radiation in protected environments was explained by the larger proportion of diffuse radiation. Aikman (1989) found that increasing the diffuse radiation promoted greater uniformity of radiation within the canopy, causing the lower leaves to increase their efficiency of interception and use of radiation. Therefore, higher efficiency of radiation use could occur as a response to increasing the relative contribution of radiation on shaded leaves, thus increasing the accumulating crop biomass with an increasing proportion of diffuse radiation.

Sinclair & Horie (1989) found that radiation use efficiency varies within one species and that leaves saturated by radiation are less efficient than shaded ones. The more homogenous distribution of solar radiation through the canopy tends to saturate the majority of leaves, generating a greater production of photoassimilates and accumulation of biomass in plants grown in protected environments.

Conclusions

The yield of total Dry Mass (DM), and that of individual parts of the plant, I general, was greater in protected environments than in the field. Intermittent enrichment with CO_2 was only seen to change the allocation of stem DM in the cv. Alambra, with no effect on the accumulation nor partitioning of DM between the leaf, fruit, or total of the cultivars studied. Production efficiency of the cv. Alambra was greater than that of the cv. Andrea, with greater fruit DM for each gram of leaf DM. With intermittent CO_2 enrichment little physiological response was observed in the plants.

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