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EFFECTS OF LONG-TERM CO_2 ENRICHMENT AND ENVIRONMENTAL CHANGE ON FRUIT CROPS

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A series of simulation experiments was conducted to explore ecophysiological responses of strawberry, pepino, apple and calamondin plants (representing herbaceous, semi-woody, deciduous and evergreen woody fruit crops, respectively) to the long-term atmospheric CO_2 enrichment and major environmental changes. The elevated ambient CO_2 at a suitable level upto 600 ppm could efficiently improve leaf photosynthetic function, enhance biomass and carbohydrate production, increase water and macronutrient use-efficiency, and promote plant growth and fruit productivity. Herbaceous, semi-woody and younger plants were more sensitive to a high CO_2 concentration in the air than woody and older fruit trees. An appropriate CO_2 fertilization could be a strategic contermeasure for scientific-practical and effective application in plastic tunnels and greenhouses for sustainable development and effective management in fruit crop production.

Key words: atmospheric CO_2 enrichment, environmental change, fruit crop, strawberry, pepino, apple, calamondin, plant ecophysiology.

Introduction. CO_2 in the earth's atmosphere is an essential raw material for plant photosynthesis in fruit crop production. The atmospheric CO_2 concentration has been continuously increasing from 280 ppm since the start of the Industry Revolution to the present level of more than 400 ppm. This worldwide long-term CO_2 enrichment is a major driving force for the global warming, as well as more and more frequent and severe weather or climate extremes and significant changes in environmental conditions. It has become an important problem of concern in plant ecophysiology and pomology, and will further deeply influence plant growth and productivity of fruit crops in the future. Thus, it is necessary to comprehensively study and strategically tackle this emerging complex issue for sustainable development and effective management of future fruit crop production.

Aim of Research. This study included a series of systematic and exploratory simulation experiments, and was aimed to a) investigate major ecophysiological responses of representative fruit crops to the effects of long-term atmospheric CO_2 enrichment and environmental changes, and b) to develop scientific-practical strategies suitable for sustainable development and effective management of fruit crop production in the future.

Methods. The research work was carried out mainly in the Institute of Fruit and Vegetable Crops at the University of Bonn, Germany from 1994–1997. Experimental treatments were designed to include both direct effects of different CO_2 levels at 300, 450, 600, 750, and 900 ppm under normal environmental conditions in fruit crop production and the combined effects of ambient, doubled and tripled CO_2 levels at 350, 700, and 1050 ppm including various major environmental factors of high/low temperatures, light intensity, photoperiod, drought/waterlogging, soil salinity/pH, macronutrient deficiency, and air pollutants of O_3, UV, respectively. Strawberry (*Fragaria × ananassa*), pepino (*Solanum muricatum*), apple (*Malus domestica*), and calamondin (*X Citrofortunella mitis*) were selected as four representative types of fruit crops (i.e., herbaceous and semi-woody fruit plants, deciduous and evergreen fruit trees) for the trial materials. Potted plants were placed in the closed or open-top plant growing chambers and exposed to controlled environmental conditions for the simulated experiments either in the laboratory or in the fields.

Research focused on studies of 1) leaf photosynthetic functions (chlorophyll content and fluorescence, stomatal conductance, intercellular CO_2 concentration, photosyntheric gas exchange, rates of photosynthesis, transpiration, dark respiration and ethylene release as well as photosynthetic water-use efficiency, etc.) [5, 14, 15, 17, 19, 20, 22]; 2) plant growth analyses (leaf number, area, growing rate, specific weight, area ratio and weight ratio; shoot/runner/daughter plant number, length, diameter and growing rate; root number, dry weight, biomass increment, root/shoot ratio; and plant net assimilation rate, relative growth rate and daily biomass gain, etc.) [1, 6, 8, 12]; 3) biomass productivity (dry matter increment, daily gain rate, allocation, proportion and production efficiency of the whole plant, etc.) [1, 7, 9, 13]; 4) water consumption (water potential in the leaves, daily consumption, water use index, water-uptake/-use efficiency of the whole plant, etc.) [1, 7, 11]; 5) carbohydrate productivity (starch, glucose, fructose, sucrose and sorbitol contents, proportion, accumulation, distribution and their production efficiency of the plant, etc.) [2, 10]; macronutrient utilization (N, P, K, Ca and Mg contents, proportion, distribution and their uptake/use efficiency of the whole plant, etc.) [3, 17, 18, 21]; and 6) fruit production (crop productivity, flower number, fruit size, weight and yield, ripening period and fruit quality, etc.) [4, 6, 16].

Results. In this paper, we only summarize direct effects of the long-term ambient CO_2 enrichment and different CO_2 concentrations on strawberry, major ecophysiological responses of the trial fruit crops to the elevated atmosperic CO_2 levels, and development of scientific-practical strategies suitable for application of CO_2 fertilization in future sustainable fruit crop production. For more detailed information and relevant results can be refered to the listed references.

Direct effects of long-term CO_2 enrichment on strawberry. The simulation experiments consistently showed that high ambient CO_2 concentrations:

a) decreased chlorophyll content, photosynthetic efficiency, transpiration rate and stomatal conductance of the plant leaves;

b) raised their intercellular CO_2 concentration and photosynthetic water-use efficiency;

c) and accelerated leaf senescence and ethylene release of the trial strawberry plants.

At the same time, both ambient CO_2 level and leaf age influenced its chlorophyll fluorescence parameters and gas exchange rate in plant photosysthesis. Ambiente CO_2 enrichment also significantly promoted plant growth and development by increasing leaf area, specific leaf weight, dry mass production and accumulation, runner/daught plant growth, root development, as well as net assimilation rate and relative growth rate of the strawberry plants.

High CO_2 in the air not only boosted biomass accumulation and daily gain in the plants; but also enhanced biomass-production efficiency and promoted more dry mass partitioning into their leaves and roots, whereas less to the shoots and stems, which in turn affected dry weight ratio and root/shoot ratio of the plants.

It was observed that the enriched ambient CO_2 levels decreased water-uptake efficiency of strawberry roots; but increased total water consumption and water-use efficiency of the strawberry plants. Furthermore, long-term CO_2 enrichment in the air resulted:

a) in more carbohydrate accumulation, especially for starch;

b) raised carbohydrate-production efficiency;

c) but reduced soluble carbohydrate proportions, especially for fructose and sucrose, in the trial plants.

Increased ambient CO_2 concentrations still improved macronutrient-use efficiency of the whole plant; decreased macronutrient-uptake efficiency of its roots, diluted macronutrient content in the plant tissues, and altered macronutrient proportion and distribution in different organs of the strawberry plants.

As consequence, strawberry plants growing at a high level of atmospheric CO_2 achieved earlier times of blossoming, bearing and fruit ripening, higher fruit yield, larger fruit size, better fruit quality, a longer fruit-harvest period and more efficient fruit productivity.

Ecophysiological responses of fruit crops to high CO_2 levels. The experimental results indicated that an ambient high CO_2 concentration enabled all trial fruit crops to achieve a stronger activity in physiological metabolism and environmental suitability and an distinctly improved adaptation to the enforced environmental stresses, mainly by enhancing plant growth, biomass productivity and carbohydrate-production efficiency, as well as the plant water-use and macronutrient-use efficiencies. These effects were evidenced with the raised plant's net assimilation rate, improved macronutrient-use and water-use efficiencies of these fruit crops, promoted plant growth, biomass and carbohydrate production and enhanced plant ecophysiological adaptability to climate change and environmental stresses such as O_3, UV, high/low temperatures, light intensity, photoperiod, drought/waterlogging, soil salinity/pH and nutrient deficiency, etc. This mechanisms would help developing scientific-practical contermeasures for better and effective management of fruit crops under a further elevated ambient CO_2 level in the future.

In addition, the enriched CO_2 effects on the trial fruit crops were more pronounced in strawberry and pepino (i. e., herbaceous and semi-wood fruit plants) than apple and calamondin (i. e., woody fruit trees). In the latter, moreover, deciduous fruit tree (apple) was more ecophysiologically sensitive to the atmospheric CO_2 enrichment than evergreen fruit tree (calamondin). The results suggested that various types of fruit crop species should be taken into consideration of strategic decision in scientific-practical applications for an appropriate level of CO_2 concentration in the future fruit crop production.

Effecting efficiency of raising CO_2 concentrations. It was observed that effecting efficiency of the elevated ambient CO_2 concentrations on the trial fruit crops was more prominent in the range of 300–600 ppm than 600–900 ppm. On the other hand, a too high level of CO_2 in the air (e.g., higher than 900 ppm and some treatments above 750 ppm) caused leaf chlorosis, necrosis, curling, photoinhibition, and even a retarded plant growth. These new findings revealed that it would be necessary to identify and control a suitable level of the ambient CO_2 enrichment for the future scientific-practical applications in proper development and effective management of the protected fruit crop production.

Conclusion. Relatively smaller herbaceous and semi-woody fruit crops (such as strawberry and pepino plants) and younger plants could be more ecophysiologically sensitive to the enriched ambient CO_2 concentrations than higher woody species and older trees (such as apple and calamondin trees). CO_2 fertilization to herbaceous and semi-woody plants would be a scientific-practicable application in protected facilities for development of future fruit crop production. CO_2 enrichment effects on fruit crops could be more prominent and efficient below 600 ppm than above 600 ppm. Up to 600 ppm of CO_2 fertilization would be recommended as strategic countermeasures to be adopted for plastic tunnels and greenhouses for fruit crop production in the the future, particularly in temperate zones and countries.

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ВЛИЯНИЕ ДЛИТЕЛЬНОГО ВНЕСЕНИЯ CO_2 И ЗНАЧИТЕЛЬНЫХ ИЗМЕНЕНИЙ ОКРУЖАЮЩЕЙ СРЕДЫ НА ПЛОДОВЫЕ КУЛЬТУРЫ

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Проведена серия моделирующих экспериментов с целью изучения экофизиологических реакций растений клубники, пепино, яблони и каламондина (представляющих травянистые, полулесные, лиственные и вечнозелёные древесные плодовые культуры, соответственно) на длительное внесение CO_2 и значительные изменения окружающей среды. Допустимый уровень CO_2 (до 600 ч/млн) может эффективно улучшить функцию фотосинтеза листьев, увеличить производство биомассы и углеводов, повысить эффективность использования воды и макроэлементов, а также способствовать росту и продуктивности растений. Травянистые, полулесные и молодые растения более чувствительны к высокой концентрации CO_2 в воздухе, чем древесные и более взрослые плодовые деревья. Использование CO_2 в качестве удобрения может стать стратегической контрмерой научно-практического и эффективного применения в туннельных укрытиях и теплицах для устойчивого развития и эффективного управления производством плодовых культур.

Ключевые слова: обогащение атмосферы CO_2, изменение окружающей среды, плодовая культура, клубника, пепино, яблоко, каламондин, экофизиология растений.