EFFECT OF SWINE CONFINEMENT AIR, POT SIZE, AND SOIL MIX ON GROWTH AND DEVELOPMENT OF BROCCOLI TRANSPLANTS

by

REGINA EVA MARTIN

Diplom (Agriculture), Justus Liebig University, 1979

A MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

Kansas State University

Manhattan, Kansas

1980

Approved by:

J. K. Greig

Major Professor

CONTENTS

ACKNOWLEDGEMENTS 1

1. INTRODUCTION 2

2. LITERATURE REVIEW 4

2.1 Carbon dioxide 4

2.2 Pot size and spacing 10

2.3 Growing media 12

2.4 Nitrogen uptake and assimilation 13

3. MATERIALS AND METHODS 16

4. RESULTS 22

4.1 Effect of CO_2 22

4.2 Effect of pot size 24

4.3 Effect of soil mix 26

4.4 Comparison of main effects and interaction 27

4.5 Differences between the two experiments 28

4.6 Nitrogen content of the shoot 29

5. DISCUSSION... 40

5.1 Carbon dioxide enrichment................................. 40

5.2 Effect of pot size.. 42

5.3 Effect of soil mix.. 43

5.4 Differences between the two experiments................... 44

5.5 Nitrogen content.. 44

6. Summary and conclusion..................................... 46

REFERENCES 48

APPENDIX 54

VITA 62

LIST OF TABLES

1. Mean environmental conditions during the two experiments. 18

2. Dates of seeding, emergence, transplanting, and harvest for the first and second experiment in the control and experimental greenhouse. 19

3. Pot characteristics. 20

4. Soil analysis. 20

5. Effect of CO_2 and pot size on growth characteristics of broccoli transplants in experiment 1. 30

6. Effect of CO_2 and pot size on growth characteristics of broccoli transplants in experiment 2. 31

7. Relative increase of growth characteristics due to CO_2 enrichment, large pots, and the combined effect of CO_2 enrichment and large pots, compared to no enrichment and smallest pots. (In percent) 32

8. Influence of soil mix on growth characteristics of broccoli transplants grown with and without CO_2 enrichment on two different sowing dates. (Means of all pot sizes.) 33

9. Growth characteristics of broccoli transplants, grown with and without CO_2 enrichment at two different sowing dates. (Means of all pot sizes and soil mixes.) 34

10. Nitrogen content of broccoli transplant shoots. (In % of dry matter.) 35

LIST OF FIGURES

1. Effect of CO_2 enrichment on different plant parts and nitrogen content of the shoot dry matter. (Means of two experiments, four pot sizes, and two soil mixes.) 36

2. Effect of pot size on dry weight accumulation of broccoli transplants, grown with and without CO_2 enrichment of the atmosphere. (Means of two experiments and soil mixes.) 37

3. Effect of pot size on stem diameter of broccoli transplants, grown with and without CO_2 enrichment of the atmosphere. (Means of two experiments and soil mixes.) 38

4. Effect of pot size on leaf number of broccoli transplants grown with and without CO_2 enrichment of the atmosphere. (Means of two experiments and soil mixes.) 39

THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

THIS IS AS RECEIVED FROM THE CUSTOMER.

ACKNOWLEDGEMENTS

I wish to express my appreciation to my Advisor and Major Professor Dr. J. K. Greig for his guidance and advice throughout my graduate study and for suggesting this research. Dr. R. A. Keen, Professor of Horticulture, and Dr. P. P. Wong, Professor of Plant Physiology, served in my committee and put in ideas and help for this work.

Jim Hartford and Allan Johnson more than once prevented my plants from desiccation. Without the help of my husband Dennis Martin, and my friends Marie Helena Kurmann, Denis Leylavergne, Mark Curry, and Roland Hertrich I would never have finished taking pictures, measuring stems, counting leaves, and washing roots.

Dr. C. K. Spillman, Professor of Agricultural Engineering, generously allowed me the use of the computer of the Department of Engineering to edit this manuscript, which provided me a decent draft at any time and prevented me from typing the final version all over again.

Dr. T. A. Fretz, Head of the Department of Horticulture, and Dr. C. W. Marr, Professor of Horticulture, read drafts of this thesis and helped with editorial advice. Dr. Marr's expert help in preparing visual aids contributed to my successful defence of this thesis.

Professors Dr. W. Gruppe, Head of the Department of Fruit Science, and Dr. M. Zoschke, Head of the Department of Crop Science at Justus Liebig University, supported my plans to become an Exchange student at Kansas State University.

Last, but not least my husband Dennis and my parents Eva and Hans Schoenberg were a steady source of encouragement and support during my absence from home.

I am very grateful to all those people.

1. INTRODUCTION

Broccoli (Brassica oleracea L. var. italica) also called sprouting broccoli, Italian broccoli, calabrese, or Italian calabrese, is an important commercial crop and of increasing interest for home gardens, fresh market, and freezing industry. In the last ten years the production of processing broccoli has doubled, while that grown for fresh market outlets has tripled. In 1978 27,640 hectares (68,300 acres) were grown in the US, the major portion of it in California, but some production also occurred in the Eastern, Southern, Midwestern and Northwestern States (72).

Broccoli is an annual cole crop and can be grown from seeding to maturity in 60 to over 140 days (71). It can be direct seeded or transplants can be grown in the greenhouse or coldframe for later field setting. Direct seeding is a good method to obtain close spacings for once over harvest for the freezing industry, if the climatic conditions are favorable. However, good stands are not consistently obtained because of unfavorable weather conditions (7). A safer method to obtain a good plant stand is transplanting greenhouse grown seedlings. This method also allows early crops before high temperature reduces yield and quality of this cool season crop. The seedlings can be started five to six weeks before the field is workable, and then transplanted to the field. Commercially succesful broccoli production depends on an inexpensive and satisfactory method of transplant production.

Broccoli has been grown to a limited extent in Kansas for several years. Commercial plantings in larger acreage have been established by direct seeding in July for fall harvest in September and October. In order to expand acreage for spring plantings, transplants should be set in the field in late March to early April. The plants will then be ready for harvest before high temperatures occur.

Since good quality transplants are necessary for early crop production, experiments were conducted on those factors that affect transplant growth and development. The objectives of this research were:

- to evaluate the effect of supplementary CO_2 (as a by-product of swine finishing operations),
- to evaluate pot size or plant spacing,
- to evaluate soil mixes,
- to make a preliminary analysis on the effect of the above factors on nitrogen content of selected plant parts.

2. LITERATURE REVIEW

2.1 Carbon dioxide

Considerable research on CO_2 enrichment of the atmosphere and its promotion effect on plant growth has been conducted since the beginning of this century (13, 15, 45, 61, 62, 74, 75, 77). CO_2 has to be considered a plant nutrient and it has been shown previously that CO_2 enrichment of the atmosphere, "air feeding" of plants, as FISCHER (20) called it, increases plant growth.

Physiological effects of CO_2 enrichment. Probably the main mechanism by which CO_2 enrichment of the atmosphere affects plant growth is by increasing photosynthesis. Increased net assimilation and photosynthetic rates under elevated CO_2 levels were found by different researchers (5, 15, 23, 24, 25, 26, 33, 37, 57, 59). Greater CO_2 uptake is possible because of an improved diffusion gradient for CO_2 between the surrounding atmosphere and leaf interior (40).

Different products of photosynthesis and different translocation patterns of these products are another factor of increased growth in CO_2 enriched plants (40). Sucrose and starch were found in increased amounts in plant leaves when exposed to increasing CO_2 concentrations (5, 33, 52, 57). Those additional photosynthates supply energy and carbon skeletons for biosynthesis of metabolic compounds. The increased assimilate supply can be utilized by the plant to enlarge the leaf itself (15), or it can be translocated to demanding sinks, such as the growing tip, roots, or fruits.

Another reason for increased plant growth has been suggested by GOLDSWORTHY (27). Improved plant growth is brought about not so much by increased photosynthesis, but by reduced photorespiration, which reduces the wastage of CO_2, and thereby improves the efficiency of photosynthesis. Reduced photorespiration is induced directly by CO_2 through reduction of glycollate formation. Glycine and serine, which are involved in photorespiration, were found in smaller amounts in CO_2 enriched plants (5, 57).

At low light intensities increased CO_2 concentration of the atmosphere leads to lowering of the light compensation point (32). Mutual compensation of light and CO_2 is possible to a certain extend, especially in low light intensities, and similar growth increase can be obtained when either light or CO_2 is increased (36, 41, 77).

CO_2 concentration affects stomatal aperture. Decreasing stomatal aperture with increasing CO_2 concentration was observed in soybeans (62), white clover (54), lettuce, and cocklebur (*Xanthium pennsylvanicum*) (40). Tomatoes responded with a small decrease in stomatal opening to higher CO_2 concentration (38). Smaller stomatal opening increases leaf resistance (38, 40), but the resistance to water vapor increases more than the resistance to CO_2 and CO_2 can still diffuse sufficiently when stomata are nearly closed (18). Diffusive resistance is also increased by greater leaf thickness, which occurs in plants grown in CO_2 enriched atmosphere (24, 45, 52). Decreasing stomatal aperture leads to decreased transpiration and such water consumption (18). On the other hand nutrient uptake might be restricted by reduced transpiration. But increased energy from photosynthesis again could increase active nutrient uptake and assimilation. Also mentioned by ENOCH et al. (18) is the possibility, that reduced transpiration hinders heat control through evaporation.

Very high CO_2 levels over a prolonged period of time can cause damage to the plant, such as leaf rolling and starch accumulation in leaves and chloroplasts, which leads to chloroplast destruction as found in tomato plants grown under increasing CO_2 levels up to 2200 ppm (52). Faster aging of the plants occurs because the photosynthetic apparatus is strained more (15).

CO_2 effect on vegetative plant growth. Plants of various species, age, and stage of development respond differently to increasing CO_2 concentration and utilize the additional assimilates not all in the same manner.

The effect of CO_2 on seedlings and young plants, which are still in the vegetative stage, is different than on flowering or fruiting plants in the generative stage, or on mature plants that are developing storage organs, like potatoes or radishes. In general, the effects of CO_2 enrichment on plants in their vegetative stage are increased fresh and dry weight, leaf size, stem diameter, and number of leaves. Growth is accelerated and increases progessively in the young plant. The highest growth rate increase with CO_2 enrichment is obtained in early stages of development (15). Younger leaves have a higher rate of CO_2 absorbtion (10) and the promoting effect of CO_2 on leaf growth declines with leaf age (33).

Active leaf area is a result of plant age, light, and CO_2. Increased CO_2 concentration brings about an increase in active leaf area, which enables the plant to utilize the ambient light better. Larger active leaf area brought about by higher CO_2 concentrations and/or high light intensity can eventually cause plants to suffer more from water stress than plants grown under normal CO_2 concentration (41).

Leaf area, dry weight per cm^2 leaf area, leaf, stem, and total fresh and dry weight, and total dry matter content of tomato seedlings was significantly higher in plants grown in atmosphere of 1200 to 1500 ppm CO_2 compared to plants grown in non enriched air. Furthermore the plants had one to two leaves in a more advanced stage of development and appeared to be ready for transplanting six to eight days earlier. Anthocyanin development in leaves of plants grown in CO_2 enriched atmosphere indicated either buildup of carbohydrates in the leaves, or nutrient deficiency (44).

Considerably greater fresh weight of flower seedlings (petunia, ageratum, marigold) grown in a growth chamber with 1000 ppm CO_2 for two weeks was found by KRIZEK et al. (46). In addition plants grown in CO_2 enriched atmosphere flowered earlier. Combined application of higher temperature, light, and CO_2 resulted in greater fresh weight and earlier flowering.

HARDH (28) reported increased height, weight, and number of leaves in young cucumber and tomato plants grown in atmosphere enriched with 2000 ppm CO_2, and increase in weight of lettuce plants. Celeriac, however, responded only slightly to CO_2 concentrations of 1000 and 2000 ppm. All CO_2 treated plants had a well developed root system compared to the non-enriched plants.

WITTWER and ROBB (77) found marked increase in growth of lettuce, cucumber, and tomato seedlings grown under 1000 ppm CO_2 and 500 footcandles of light, or 400 ppm CO_2 and 1500 footcadles of light. All crops responded with darker green color in increased light or CO_2 concentration. Lettuce and cucumber had increased leaf number when grown in higher CO_2 concentration. Fresh weight of lettuce plants was increased by 50% in 1000 ppm CO_2. Effects of CO_2 on growth became progressively greater with age of seedlings. Higher light intensity and CO_2 concentration combined had an additive effect on seedling growth.

KRIZEK et al. (47) found with cucumber, lettuce, and tomato seedlings, which were grown in the greenhouse for 5-15 days at elevated temperature, light, and CO_2 concentration (2000 ppm), at 16 h photoperiod, that temperature and CO_2 were limiting factors for dry weight production. CO_2 had a more pronounced effect when light and temperature were also at higher levels . A stimulatory influence of the controlled environment treatment on vegetative growth and reproductive development was observed, which persisted when the seedlings were transplanted to the greenhouse, or moved outdoors.

In young tomato plants supplementary light was found to be more efficient than CO_2 enrichment in reducing propagating time (8). Light treated plants were 10 days earlier, CO_2 plants only a few days. No consistent improvement of growth rate with CO_2 during 3 years was observed, indicating that the response to additional CO_2 is variable.

PETTIBONE et al. (63) reported progressively increasing growth of lettuce and okra plants with increasing CO_2 concentration from 400 to 1000 ppm. Stem diameter in okra plants was increased by a factor of 1.7 in 1600 ppm CO_2 compared to 400 ppm.

Other researchers found an increase in root-top ratio in radishes (43), sugarbeets, barley, kale (23), bean and tomato (74) grown in elevated CO_2 concentration, which indicates that root growth is promoted more than shoot growth by supplementary CO_2.

With CO_2 enrichment other growth factors should be maintained at optimum levels. Those levels themselves are elevated with CO_2 enrichment, more mineral nutrients and water are necessary, the optimum temperature is higher (74).

<u>CO_2 sources</u>. Differenct sources have been used for CO_2 enrichment of the greenhouse atmosphere. Chemical CO_2 production has been used experimentally by SMALL and WHITE (67) by reacting sodium bicarbonate with sulfuric acid. Currently burning of hydrocarbons (propane, kerosene,) and natural gas (methane) is a common practice in commercial use of CO_2 enrichment in greenhouses (4, 29, 68). HAUKENESS et al. (30) experimented with exhaust gases from turbines fired with natural gas. Pure CO_2 in liquid (bottle) (29) or solid (dry ice) form (2, 63) are rather expensive sources for commercial greenhouse operations (48, 58). Carbonated water has been used with intermittent mist propagation of cuttings (56), and for chrysanthemum and lettuce production (9).

CO_2 production from biological processes were proposed by SMALL and WHITE (67) by fermentation of organic matter in the greenhouse. High application of manure, as practiced in conventional cucumber culture, can raise the CO_2 concentration of the ambient air from 2700 ppm (45) to 5000 ppm (77). Mulching can increase the CO_2 levels of the ambient air. With polyethylene mulches concentrations of 670 ppm could be obtained under the mulch. But the yield increase of the studied plants was mainly due to temperature increase under the mulch (35).

Air from animal confinements can be used as cheap CO_2 source and as means to utilize a form of wastage occurring in animal production operations. DEKORNE (17) used rabbits, which were kept in the greenhouse, for CO_2 enrichment. Respiration of the animals and decomposition of the manure increased the CO_2 level in the greenhouse up to 800 ppm. In experiments cucumbers and tomatoes were grown in greenhouses supplied with air from a swine confinement building (50, 69), and the CO_2 concentration in the greenhouse reached 1500 ppm. The air of a swine building contains, besides other gases and volatiles, considerable amounts of CO_2 and traces of ammonia (16, 55).

2.2 Pot size and spacing

Transplant quality depends, among other factors, on spacing. Crowding will cause plants to become weak and spindly. On the other hand spacing which is wider than necessary for good quality transplants is uneconomical for the transplant producer. Plants express a plasticity in vegetative growth as a reaction to changing environmental conditions. Grain plants, for instance, react with increasing tiller production to decreasing plant density. Plants like lettuce (or broccoli transplants) have less vegetative plasticity towards plant density, they may just react with an increased leaf number. Therefore, these plant species must be planted in precise patterns for optimum utilization of space (51). According to FLETCHER (22) broccoli transplants grown in flats require a minimum space of 2x2 inches (5x5 cm). Plants should be spaced so that the leaves of one plant do not touch those of another one.

Tomato transplants grow taller and produce more leaves with increasing pot size, whereas wider spacing within one pot size reduces plant height and leaf number. Final yield of fruit after field setting is dependent on pot size and spacing of transplants (42).

Transplanting seedlings (cauliflower) into pots or soilblocks soon after emergence promotes lateral root growth and production of a strong root system, because the tap root is injured during the transplanting process. Subsequently, roots of potgrown transplants are less injured during field planting and are better able to survive under unfavorable post transplanting conditions in the field. Seeding directly into the pot on the other hand results in an uneven plant stand (60).

Volume and diameter of the pots influences growth of onion transplants, successive growth in the field, and final yield, but height of pots is less influencing (73). Conditions of light and N-nutrition during the early period of plant growth affect subsequent development of plants, mainly through their effect on transplant size, as reported for cauliflower by SKAPSKI and OYER (66). Very large transplants are undesirable because of early buttoning in cauliflower (66) and broccoli (1).

Cauliflower plants grown under low level of nitrogen had a 3.3 fold greater fresh weight, and 1.7 fold greater stem diameter when grown in 26 cm^2 (4 in^2) spacing compared to 6.45 cm^2 (1 in^2) spacing. The relative increase was considerably less under high N-level (66). The maximum stem diameter of cauliflower transplants should be 5 mm, the maximum fresh weight 5 g.

Growth of tomato seedlings grown in small pots is inhibited when their root density exceeds 0.2 g dry weight per 100 ml of soil, and depressed vegetative development continues even after field transplanting (53). Higher and earlier yields were obtained from pot raised lettuce transplants as compared to direct drilled or bare-root transplanted plants (21).

2.3 Growing media

A suitable growing medium is important for the successful production of vegetable transplants in the greenhouse. Pure topsoil is not ideal for indoor plant production, because of lack of good physical condition and unsuitable content of mineral nutrients (12, 22).

FLETCHER (22) suggests that a good soil mix does not bake or crust, holds moisture, has a pH of 6.0 to 6.8, and produces plants with good root systems. He suggests mixes that contain one- to two-thirds topsoil, combined with peat, sand, or vermiculite.

For raising vegetable seedlings (tomato, cucumber, cauliflower, kohlrabi) sand-peat mixtures in the ratio of 3:1, 2:2, or 1:3, or peat alone can be used succesfully instead of soil compost (12). Different compost-soil mixtures for potting cauliflower transplants are suggested by NIEUWHOF (60). A difference in weight of cabbage transplants and tomato seedlings was found by HOMNA (34) between soil and sand grown transplants, where the soil grown transplants were larger. Root weight was larger in soil for tomatoes, but similar in soil or sand for cabbage. HAWORTH and CLEAVER (31) found seedlings of lettuce, onion and carrot grown in John Innes compost (a soilless, loam based compost medium) to be smaller and with a lower K content than those grown in sand, which was fertilized with a nutrient solution.

2.4 Nitrogen uptake and assimilation

Nitrogen uptake from the growing medium and incorporation into metabolic compounds (assimilation) requires energy. Nitrogen uptake can be seen as a function of intracellular nitrate concentration, and the net nitrate uptake depends on intracellular nitrate consumption (= N assimilation) (49). N-uptake is photosynthetically controlled, since photosynthesis supplies the carbohydrates necessary to generate the reducing power for N-assimilation, and they supply the carbon skeletons for biosynthesis of amino acids.

Young rice and wheat plants increase uptake of nitrate with increasing duration of illumination, and thereby photosynthesis, and have a higher nitrogen content in shoot and root (19).

Nitrite reduction is connected with the photosynthetic electron transport, which supplies the electrons to reduce NO2. High temperatures and light intensities enhance the conversion of NO_3 to NH_4, because nitrate reductase is most active when photosynthesis and respiration are at high rates and provide reduced NADH and ferredoxin. When the reduction of NO_3 to NH_4 occurs in the leaves, it can be a competitor for energy with CO_2 reduction (65). CO_2 reduction requires two electrons and 478 kJoule per mole, NO_3 reduction requires 8 electrons and 347 kJoule per mole (6).

CO_2 is directly necessary for functioning of nitrate reductase, as found in radish and corn seedlings (70). Thus, CO_2 enrichment could have a positive effect on N-uptake and assimilation. However, MASTERSON and SHERWOOD (54) found a slight decrease in N content of the dry matter in white clover and pea plants, and lower nitrate reductase levels in leaves of nitrogen fertilized clover plants, which were grown in 1200 ppm CO_2 concentration of the atmosphere, compared to plants grown under normal CO_2 level, indicating a reduced uptake of mineral nitrogen,

<u>Foliar N-absorbtion</u>. PORTER et al. (64) found in studies with corn seedlings, which were exposed to 1 to 20 ppm labeled NH_3, that plants can absorb NH_3 from the atmosphere through their leaves. The amount absorbed (microgram ^{15}N per cm^2 leaf surface) in 24 hours, increased with increasing NH_3 concentration. Most of the plant N was bound in proteins (ethanol insoluble fraction) and 2% of the total nitrogen in the corn tops originated from the ^{15}N-ammonia. Green plants may cleanse the atmosphere from NH_3, and also meet part of their N requirement from foliar absorbtion of atmospheric NH_3. HUTCHINSON et al. (39) suggest from experiments with soybean, sunflower, corn, and cotton seedlings, that field crops might satisfy up to 10% of their total N requirement by NH_3 uptake.

Atmospheric NH_3 opens the stomata and thus might lower the diffusive resistance to CO_2 (77), which would reverse the effect of CO_2 increasing diffusive resistance (See 2.1). Phytotoxic concentration of ammonia in the atmosphere is 10 ppm (3).

Nitrogen can furthermore be absorbed in organic form such as urea or amino acid (76).

3. MATERIALS AND METHODS

This study was conducted at the Kansas State University Swine Research Farm. Greenhouses, 6.0 x 7.3 m, with a wooden frame work, were covered by two layers of "Monsanto 602" polyethylene. The space between the two layers was air inflated by a small fan. The houses were east-west oriented, and one of them, referred to as "experimental house", was attached with its back wall to the south wall of a swine finishing building. The other one, the "control house", was attached to another farm building in the same manner.

The temperature in the greenhouses was held at a minimum of 16 C with forced air from a gas heated furnace. The air was distributed through a perforated polyethylene tube, which was attached overhead along the north wall of the houses. When the temperature in the greenhouses reached about 30 C, ventilators at the gable ends began to operate.

In the experimental house exhaust air from the cool swine finishing building was blown into the greenhouse at a rate of 680 m^3 per hour during daylight hours (69). Temperature and relative humidity were maintained at similar levels in both houses. They were measured and recorded by thermohygrographs, which were placed at ground level in the center of each greenhouse.

The CO_2 concentration of the greenhouse atmosphere was measured at different occasions with a MATHESON-KITAGAWA gas detector with tubes for carbon dioxide.

It was suspected that the swine house air contained ammonia, which might influence plant growth independent of the CO_2 content. In order to detect NH_3 small flasks (5ml), containing 1 ml of 1N H_2SO_4 were placed in the greenhouse on two occasions to absorb any ammonia present. The samples were analyzed by the method described by CHAYKIN (11), but no ammonia could be detected.

Environmental conditions. The environmental conditions in both greenhouses during the experiments are given in Table 1. The values for the daily mean temperature were obtained by the sum of the temperature at 7:00, 14:00, and 2 times 21:00 hours, divided by 4. The temperature summation was obtained by summation of the daily mean temperature over the experimental period (seeding to harvest). Mean relative humidity per day was obtained by the sum of daily minimum and maximum value of percent humidity divided by two. The data of daily radiation were obtained from the Department of Physics, KSU, Manhattan. The radiation summation is the sum of daily total radiation over the experimental period. No significant difference in the daily mean temperature between the two houses occurred in the first experiment; however, in the second experiment the mean temperature in the experimental house averaged 1 C higher than in the control house.

Table 1: Mean environmental conditions during the two experiments.

	Experiment 1*		Experiment 2**	
	Control	CO_2	Control	CO_2
Temperature (C)	18	18	22	23
Temperature summation (C)	936	936	858	897
Relative humidity (%)	61	58	67	64
Daily radiation (cal/cm^2)	283	283	475	475
Radiation summation (cal/cm^2)	14,716	14,716	18,525	18,525
CO_2 concentration (ppm)	300	1000	300	650

*2/13 to 4/5
**4/11 to 5/20

The incoming exhaust air from the swine house served as CO_2 source. Its CO_2 content varied depending on weather conditions and number and weight of pigs present in the swine building. During warm and sunny days the curtains in the swine house were pulled up and the greenhouse was ventilated so that the CO_2 content in the greenhouse reached almost normal levels on those days. With closed curtains and ventilators not operating the CO_2 concentration in the experimental greenhouse reached nearly 1600 ppm. During the first experiment 151 pigs with an average weight of 77 kg were in the finishing house, and 162 pigs of 41 kg respectively during the second experiment. In the second experiment the average CO_2 concentration in the experimental greenhouse was 350 ppm lower than in the first experiment. This was due to higher outside temperatures and therefore higher ventilation rates in the greenhouse, and eventually smaller size pigs.

<u>The experiments</u>. The study was conducted on two different sowing dates (first and second experiment) in spring 1980. Seeding, transplanting,

and harvesting dates are listed in Table 2. Seeds of the early broccoli hybrid "Green Comet" were planted into flats containing equal parts of jiffy mix and sand in the first experiment, jiffy mix alone in the second, and were placed on the ground floor of each greenhouse for germination.

Table 2: Dates of seeding, emergence, transplanting, and harvest for the first and second experiment in the control and experimental greenhouse.

	Exp. 1	Exp. 2
Seeding	2/13	4/11
Emergence	2/20	4/14,15*
Transplanting	2/27	4/21,22*
Harvest	4/5	5/20
No. of days from seeding to harvest	52	39

* First date = control, second date = experimental

The seedlings were transplanted into flats with plastic pots of four different sizes (Table 3) when they were still in the cotelydone stage 14 days after seeding in the first experiment, and 11 days after seeding in the second experiment.

Table 3: Pot characteristics.

Size	Length x width cm x cm	height cm	surface area cm^2	volume cm^3	pots per flat
1	3.8 x 3.8	5	14.4	72.2	72
2	5.6 x 4.8	5	26.9	134.4	36
3	6.0 x 6.0	5	36.0	180.0	32
4	7.8 x 5.6	5	43.7	218.4	24

Two soil mixes were used:

1 = equal parts of sandy loam and perlite

2 = equal parts of sandy loam, perlite, jiffy mix, and sand.

The analysis of the two media is given in Table 4. Both soil mixes had a medium good fertility and varied only slightly in their nutrient content and pH.

Table 4: Soil analysis.

Soilmix	pH	Organic matter %	Available phosphorus kg P/ha	Exchangable potassium kg K/ha	Available nitrogen ppm N
1	7.4	4.6	126	1488	61.9
2	7.1	3.9	140	1310	43.5

The plants were watered as needed and measured when they had reached field transplanting size (about six-leaf stage), 52 days after seeding in the first experiment, 39 days in the second.

The experimental design for both experiments was a 4x2x2 factorial (4 pot sizes, two soil mixes, and with and without CO_2 enrichment), with four replications of 10 plants, completely randomized within each greenhouse.

Determination of growth. The following parameters (growth characteristics) were measured on the plants to make inferences about the vegetative growth: stem diameter, leaf number, dry weight of the whole plant, top, roots and dry weight per node. Nitrogen content of the top dry matter was determined.

Stem diameter was measured on the fresh plants, directly under the first true leaf, or its scar. The number of true leaves was counted, including the ones that dropped. For dry weight determination the plants were cut off at soil level, and the roots were washed and dried seperately from the tops in a forced air oven at 65 C. Dry weight per node was estimated by dividing the top dry weight by the number of leaves present at harvest.

The nitrogen content of plants grown in pot sizes 2 and 4 of all treatments was determined in the SoiL Science Laboratory of KSU by digestion of the dry sample with concentrated H_2SO_4 and H_2O_2, and subsequent colorimetric determination of total nitrogen in an ammonia-salicylate complex.

All data were analyzed statistically by analysis of variance at 5% level of significance.

4. RESULTS

4.1 Effect of CO_2

Transplant growth was promoted considerably by CO_2 enrichment of the atmosphere. However, the different plant parts were affected in different magnitude (Tables 5, 6, 7).

The greatest effect of CO_2 enrichment was on shoot dry weight. Increase in top dry weight was approximately 150% greater than that of the control plants, in both experiments (Table 7). The absolute difference between CO_2 plants and controls was smallest in the smallest pots and greatest in the largest pots (Tables 5 and 6). Plants of the smallest pots in the CO_2 house were not significantly different in top dry weight from plants grown in the largest pots in the control house in both experiments.

Root dry weight was affected less than top dry weight by supplementary CO_2. Root dry weight of plants grown in the experimental greenhouse increased 94% in the first experiment, 67% in the second compared to the control plants (Table 7).

The rate of increase in total dry weight (top + roots) was intermediate between top and root weight increase. Total dry weight of plants grown in the experimental house was 2.4 times as great as that of the control plants.

Because of different promotion of top and root growth by CO_2 the top-root ratio was greater in the CO_2 enriched plants, top growth was promoted more than root growth.

The growth parameter affected in fourth order by CO_2 enrichment was dry weight per node. It was doubled by CO_2 enrichment in both experiments (Tables 5, 6, 7).

Leaf number and stem diameter, an average of both experiments, were increased in the same order of magnitude (45%) by CO_2 enrichment. However, the increase in stem diameter was more consistent in both experiments, 44% (1.3 mm) in the first, 47% (1.6 mm) in the second experiment, than leaf number, which increased 33% (1.6 leaves) in the first experiment, 56% (2.3 leaves) in the second, regardless of pot size (Table 5, 6, 7).

The promotion of the different plant parts by CO_2 enrichment is presented in a polygonal diagram (Fig. 1).

Some general observations on transplant growth in CO_2 enriched atmosphere should be considered. CO_2 enriched plants exhibited a darker green color, and had larger, thicker leaves. In the experimental greenhouse the ground was covered earlier by the plants than in the control house.

On the other hand CO_2 enriched plants wilted more rapidly under water stress conditions than the control plants. The control plants appeared more sturdy, which means a closer ratio of stem diameter and internode length. They were less susceptible to injury during handling, the leaves did not break as easily as in the CO_2 treated plants.

4.2 Effect of pot size

Pot size in this experiment was equivalent to spacing, because all pots had the same height, they were rectangular, and connected at their edges to form a uniform surface without spaces between the individual pots.

There was a significant difference in all growth characteristics between plants grown in pot size 1 and 2, and between 2 and 4. Differences between plants grown in pot size 2 and 3, and also in some cases between pot size 3 and 4 were not always significant (Tables 5 and 6). This occurred because the surface area available per plant (= pot surface) between pot sizes 2 and 3, and between 3 and 4 was less than between pot size 1 and 2, or between 2 and 4 (Table 4). The number of plants per unit area (plant density) in pot size 1 was two times that of pot size 2, 2.25 times that of pot size 3, and three times that of pot size 4. In other words plant density decreased progressively from the smallest to the largest pots.

The increase in growth was approximately proportional to the increase in surface area available to each plant (Fig. 2, 3, and 4). However, in pot size 3, a square shaped pot, a less pronounced increase in dry weight accumulation occurred (Fig. 2).

Dry weight accumulation was the greatest effect of increasing pot size. Total dry weight was tripled in pot size 4 compared to 1 in the first experiment (Table 5). In the second experiment it was doubled in the control plants, but 2.3 times higher in the CO_2 treated plants (Table 6).

Top dry weight was about three times higher in pot size 4, as compared to pot size 1 in the first experiment, and two times greater in the second. The difference in top dry weight between plants grown in the largest and the smallest pots was 396 mg per plant in the control, and 902 mg per plant in the CO_2 treated plants in the first experiment, 250 mg and 861 mg in the second experiment respectively (Tables 5 and 6).

Root dry weight was influenced in about the same order of magnitude as top dry weight. In the mean of all treatments root dry weight of plants grown in pot size 4 was three times as great as of plants grown in pot size 1 in the first experiment, and two times as great respectively in the second experiment (Table 7).

Top-root ratio did not change with increasing pot size due to the comparable relative increase in root and top weight mentioned before (Tables 5 and 6). An exception in the first experiment was pot size 2, where root growth was more promoted, which resulted in a lower top-root ratio.

Average dry weight per node was affected in the second order by pot size. The control plants in the largest pots had a 2.5 times greater weight per node, but the CO_2 plants had a 2 times greater weight per node than the plants of the respective smallest pots (Table 5). In the second experiment, the node weight of the plants grown in the largest pots was about 1.8 times as great as of plants grown in the smallest pots in the control and in the experimental house (Table 6).

Stem diameter was increased in third order by increasing pot size. The difference in stem diameter between the largest and the smallest pots was 1.2 mm in the control, and 1.9 mm in the CO_2 enriched plants (about 50%) in the first experiment, and 0.8 mm and 1.4 mm respectively (about 30%) in the second experiment. Differences between pot sizes 3 and 4 in the control house were not significant in both experiments (Tables 5 and 6).

The number of leaves per plant increased the least with increasing pot size. The relative increase was greater in the first than in the second experiment. Plants in the largest pots had 1.4 more leaves in the control, 1.6 more leaves in the CO_2 plants, compared to the plants of the smallest pots in the first experiment (Table 5). Only differences between pot sizes 1 and 2, and between 2 and 4 were significant in the CO_2 treated plants. In the second experiment the difference between pots 1 and 4 was 0.6 leaves in the control plants. In the CO_2 treated plants the difference between the largest and the smallest pots was 1.1 leaves (Table 6). Relative increases in leaf number of plants grown in the largest pots compared to plants grown in the smallest ones were about the same for control and CO_2 treated plants, 30% in the first experiment, 19% in the second (Table 7).

4.3 Effect of soil mix

Of the three limiting factors, examined (CO_2, pot size, and soil mix), the two different soil mixes resulted in the smallest differences in transplant growth.

However, in the first experiment, significant, and in the plant stand visible differences between plants grown in the two media occurred in the control house. Total, top, and root dry weight of the control plants grown in soil mix 2 was increased by almost 30% compared to plants grown in soil mix 1. Dry weight per node was increased by 16% in soil mix 2. Stem diameter was increased by 13% in both, control and CO_2 treated plants. Leaf number was increased by 9% in the control plants (Table 8).

In the second experiment a slight decrease in the different growth characteristics was observed in plants grown in soil mix 2 (-2% to -13%) which was significant only in the case of stem diameter. and not visible in the plant stand (Table 8).

4.4 Comparison of main effects and interaction

In Table 7 the relative effects of CO_2 enrichment compared to the control, large pot size compared to small, and the combined effect of largest pot size plus CO_2 compared to smallest pot size without CO_2 enrichment are presented.

In the first experiment the overall effect of largest pots compared to smallest was greater than the effect of CO_2 enrichment over no enrichment (control). In the second experiment the effect of CO_2 was overall greater than the effect of larger pot size, except on root growth (Table 7).

The combined effect of CO_2 enrichment and large pots was greater than one would expect assuming additive effect of pot size and CO_2. A synergistic effect occurred when both factors were combined, which was especially striking on dry weight development of the plants. The effect was less pronounced on stem diameter development, and smallest on leaf number.

The influence of soil mix was neglectable compared to the effect of pot size and CO_2.

4.5 Differences between the two experiments

Small, but significant differences between the two experiments occurred in stem diameter, top-root ratio, and dry weight per node of plants grown in either greenhouse, in leaf number of the control plants, and in root dry weight of the CO_2 enriched plants (Table 9).

CO_2 enrichment resulted in a consistent plant response in the two experiments, allthough CO_2 concentration was lower in the second experiment. The effect of increasing pot size on transplant growth was less pronounced in the second experiment; dry weight accumulation increased only half as much in the largest pots compared to the smallest than in the first experiment (Table 7). Differences between the two soil mixes did not exist in the second experiment as occurred in the first experiment. There even was a tendency of the effect being reversed (Table 8).

In the second experiment, plant stand was considerably less uniform than in the first experiment, which is also expressed in a greater mean square of the error (Appendix ANOVA). This was probably due to the different germination medium used in the second experiment (pure jiffy mix vs. equal parts of jiffy mix and sand). During transplanting the roots of the seedlings grown in pure jiffy mix were damaged more than seedlings grown in jiffy mix and sand, because the latter seperated more easily.

4.6 Nitrogen content of the shoot

Shoots of 64 dry transplants, grown in pot sizes 2 and 4 (second smallest and largest pot size) in both soil mixes, with and without additional CO_2 were analyzed for total nitrogen content .

The most striking difference occurred between plants grown in CO_2 enriched atmosphere. The N content of the CO_2 plants was 2.5 to 4 times higher than in the control plants.

Significant differences between pot sizes existed only in the first experiment in the CO_2 treated plants. The plants in the larger pots had a higher N content.

In general, there was no significant difference between soil mixes 1 and 2. However, soil mix 2 tended to cause a higher N content of the plants, especially in the first experiment. A difference between first and second experiment occurred in the CO_2 treated plants, but not in the control plants (Table 10).

Table 5: Effect of CO_2 and pot size on growth characteristics of broccoli transplants in experiment 1.

Parameter	Enrichment treatment	Pot size* 1	2	3	4
Stem diameter (mm)	Control	2.6	3.2	3.5a	3.8a
	CO_2	3.6	4.5b	4.7b	5.5
Leaf number	Control	4.1	4.6	5.1	5.4a
	CO_2	5.4a	6.5b	6.7bc	7.0c
Total dry weight (mg)	Control	236	467a	597a	740b
	CO_2	605ab	1257c	1291c	1714
Top dry weight (mg)	Control	187	356a	475ab	583b
	CO_2	506b	1013c	1079c	1418
Root dry weight (mg)	Control	48	112a	122a	158
	CO_2	100a	245	212	297
Top root ratio	Control	4.0a	3.2b	3.9a	3.7ab
	CO_2	5.1c	4.1a	5.1c	4.8c
Dry weight per node (mg)	Control	48	82a	102ab	122b
	CO_2	112b	183c	189c	237

All means within a parameter are different at 5% level of significance, except means followed by the same letter.

* For desription of pot sizes see Table 3.

Table 6: Effect of CO_2 and pot size on growth characteristics of broccoli transplants in experiment 2.

Parameter	Enrichment treatment	Pot size* 1	2	3	4
Stem diameter (mm)	Control	3.0	3.3	3.6a	3.8a
	CO_2	4.3	4.9	5.3	5.7
Leaf number	Control	3.8	4.1a	4.0a	4.4
	CO_2	5.8	6.1	6.6b	6.9b
Total dry weight (mg)	Control	350a	481ab	535b	684c
	CO_2	758c	1016	1306	1744
Top dry weight (mg)	Control	286a	386ab	437bc	536cd
	CO_2	649d	865	1125	1510
Root dry weight (mg)	Control	64	95a	97a	148b
	CO_2	109a	152b	181	234
Top root ratio	Control	4.5a	4.0ab	4.5a	3.7b
	CO_2	6.0cd	5.8d	6.2cd	6.5c
Dry weight per node (mg)	Control	80a	100ab	114bc	133cd
	CO_2	151d	188	224	287

All means within a parameter are different at 5% level of significance, except means followed by the same letter.

* For description of pot sizes see Table 3.

Table 7: Relative increase of growth characteristics due to CO_2 enrichment, large pots, and the combined effect of CO_2 enrichment and large pots, compared to no enrichment and smallest pots. (In percent)

Parameter	CO_2 over control		Pot size 4 over 1		Pot size 4 + CO_2 over pot size 1 - CO_2	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Stem diameter	44	47	48	27	111	90
Leaf number	33	56	32	19	70	82
Total dry weight	139	136	191	119	626	398
Top dry weight	151	152	188	119	658	428
Root dry weight	94	67	207	119	519	266
Node dry weight	105	98	124	83	394	259

Table 8: Influence of soil mix on growth characteristics of broccoli transplants grown with and without CO_2 enrichment on two different sowing dates. (Means of all pot sizes.)

Parameter	Enrichment treatment	Exp. 1 Soil* 1	Exp. 1 Soil 2	Exp. 2 Soil 1	Exp. 2 Soil 2
Stem diameter (mm)	Control	3.0	3.4ab	3.5a	3.3b
	CO_2	4.3	4.8	5.1c	5.0c
Leaf number	Control	4.6	5.0	4.2	4.0
	CO_2	6.4a	6.4a	6.3a	6.4a
Total dry weight (mg)	Control	450a	571b	541ab	484ab
	CO_2	1181c	1252c	1196c	1216c
Top dry weight (mg)	Control	354a	447b	440ab	382b
	CO_2	971c	1037c	1030c	1044c
Root dry weight (mg)	Control	96a	124	101a	102a
	CO_2	211b	215b	166c	172c
Top root ratio	Control	3.8a	3.6a	4.4b	3.9a
	CO_2	4.7bc	4.9c	6.2d	6.0d
Weight per node (mg)	Control	82a	95a	113b	100ab
	CO_2	177c	184c	213d	212d

All means within a parameter are different at the 5 % level of significance, except means followed by the same letter.

* Soil 1 = soil/perlite, soil 2 = soil/perlite/jiffy mix/sand.

Table 9: Growth characteristics of broccoli transplants, grown with and without CO_2 enrichment at two different sowing dates. (Means of all pot sizes and soil mixes.)

Parameter	Enrichment treatment	Exp. 1	Exp. 2
Stem diameter (mm)	Control	3.2	3.4
	CO_2	4.6	5.0
Leaf number	Control	4.8	4.1
	CO_2	6.4a	6.4a
Total dry weight (mg/plant)	Control	510a	512a
	CO_2	1217b	1206b
Top dry weight (mg/plant)	Control	400a	411a
	CO_2	1004b	1037b
Root dry weight (mg/plant)	Control	110a	101a
	CO_2	213	169
Top root ratio	Control	3.7	4.2
	CO_2	4.8	6.1
Dry weight per node (mg)	Control	88	107
	CO_2	180	212

All means within a parameter are different at the 5% level of significance, except means followed by the same letter.

Table 10: Nitrogen content of broccoli transplant shoots. (In % of dry matter.)

Pot size*	Soil mix**	Exp. 1 Control	Exp. 1 CO_2	Exp. 2 Control	Exp. 2 CO_2
2	1	1.34ab	3.43c	1.21ab	4.88 e
	2	1.50ab	3.80c	1.08a	4.57de
	Mean	1.42	3.61	1.15	4.73
4	1	1.50ab	4.34d	1.47ab	4.87e
	2	1.76 b	4.31d	1.52ab	5.01e
	Mean	1.63	4.33	1.50	4.94

All means within a parameter are different at the 5% level of significance, except means followed by the same letter.

*Pot size 1 = 3.8x3.8 cm, Pot size 4 = 7.8x5.6 cm.
**Soil mix 1 = soil/perlite,
Soil mix 2 = soil/perlite/jiffy mix/sand.

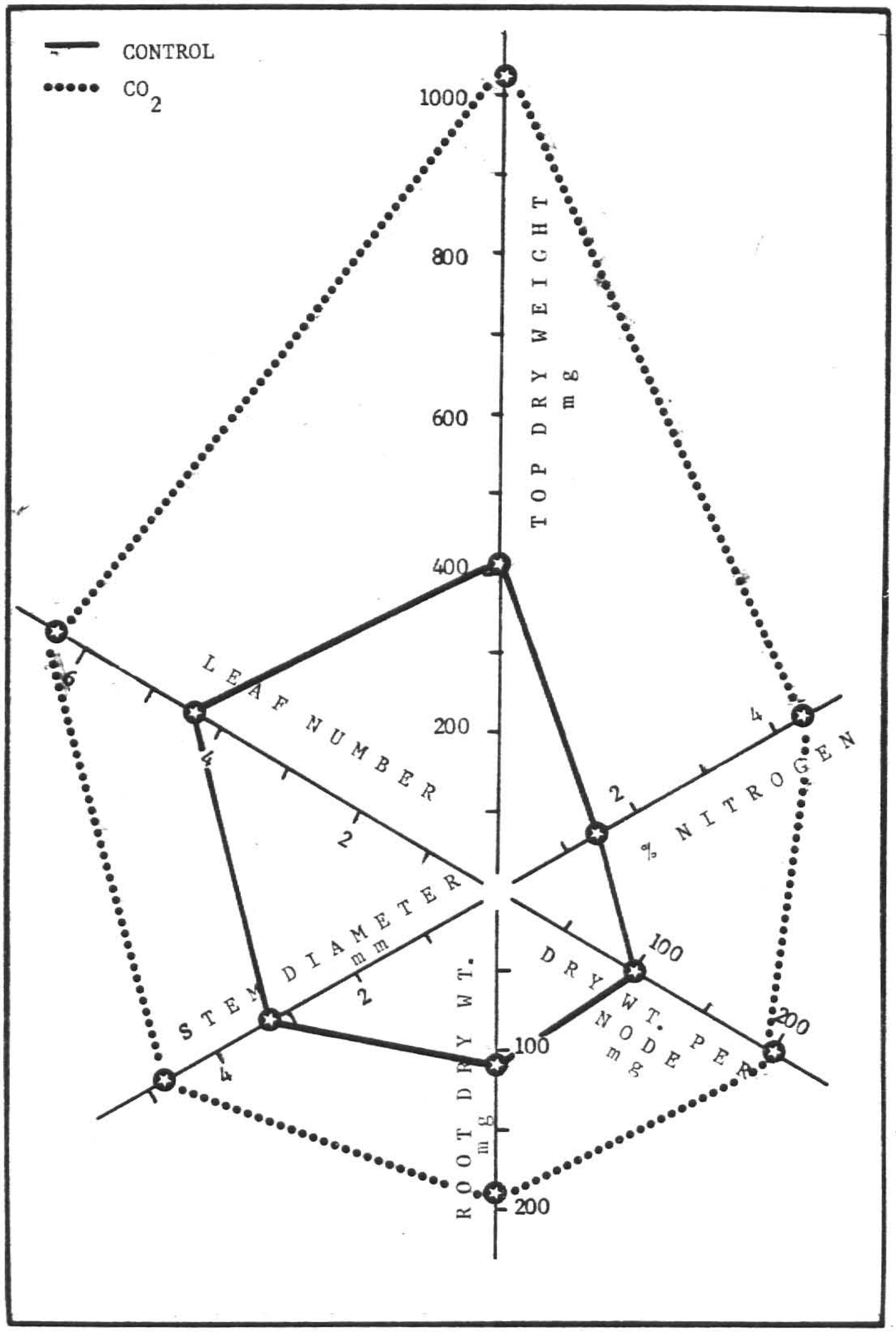

Figure 1. Effect of CO_2 enrichment on different plant parts and nitrogen content of the shoot dry matter. (Means of two experiments, four pot sizes, and two soil mixes.)

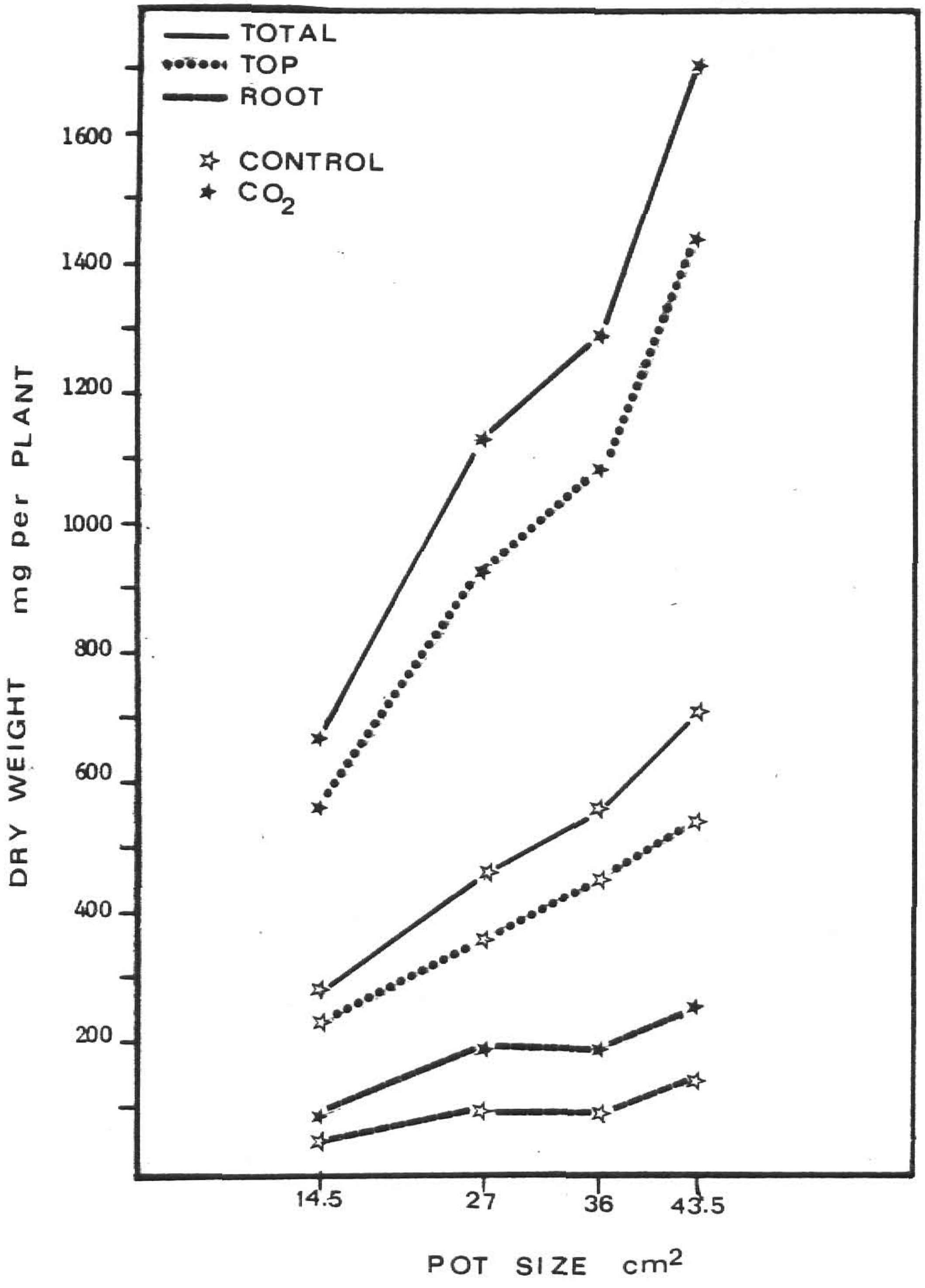

Figure 2. Effect of pot size on dry weight accumulation of broccoli transplants, grown with and without CO_2 enrichment of the atmosphere. (Means of two experiments and soil mixes.)

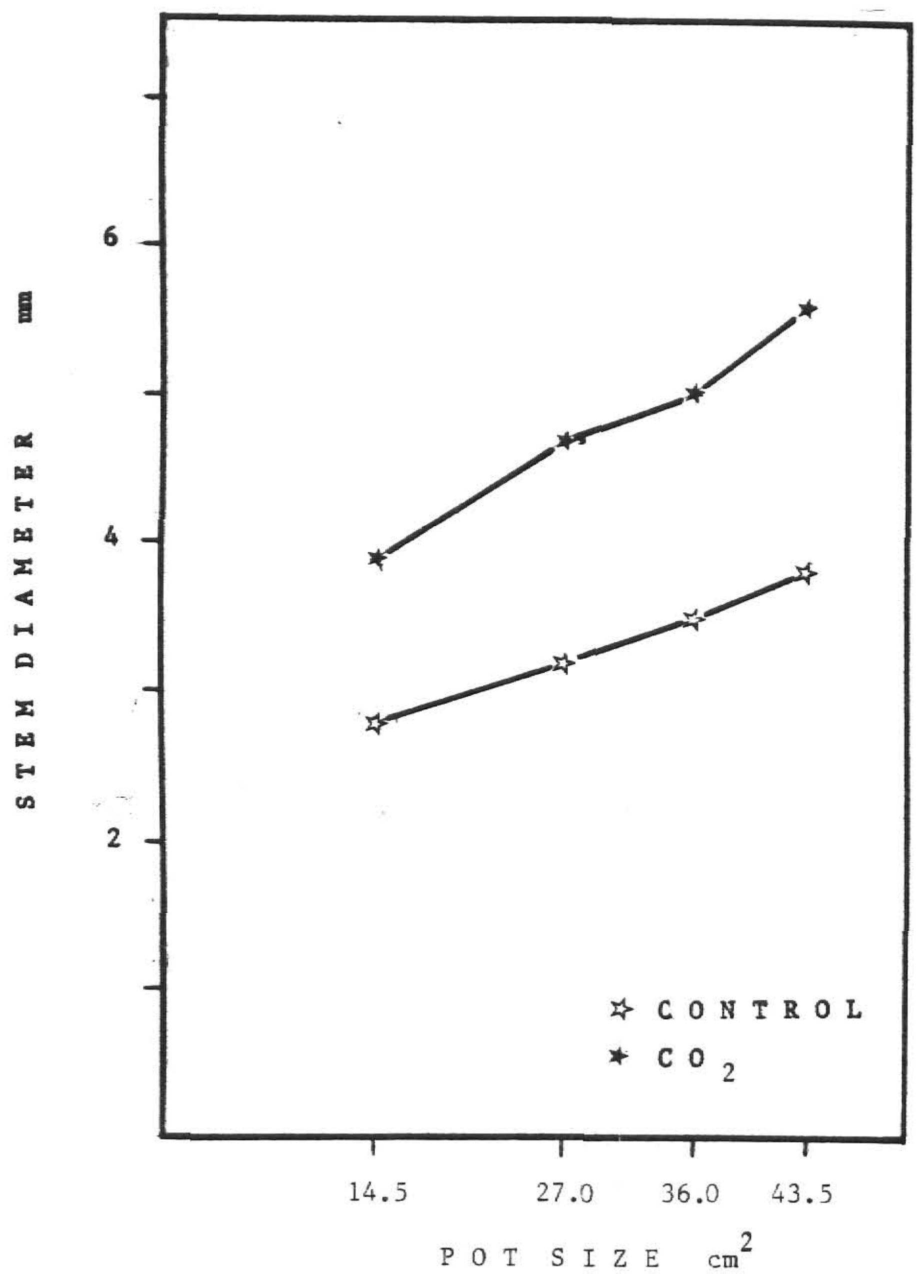

Figure 3. Effect of pot size on stem diameter of broccoli transplants, grown with and without CO_2 enrichment of the atmosphere. (Means of two experiments and soil mixes.)

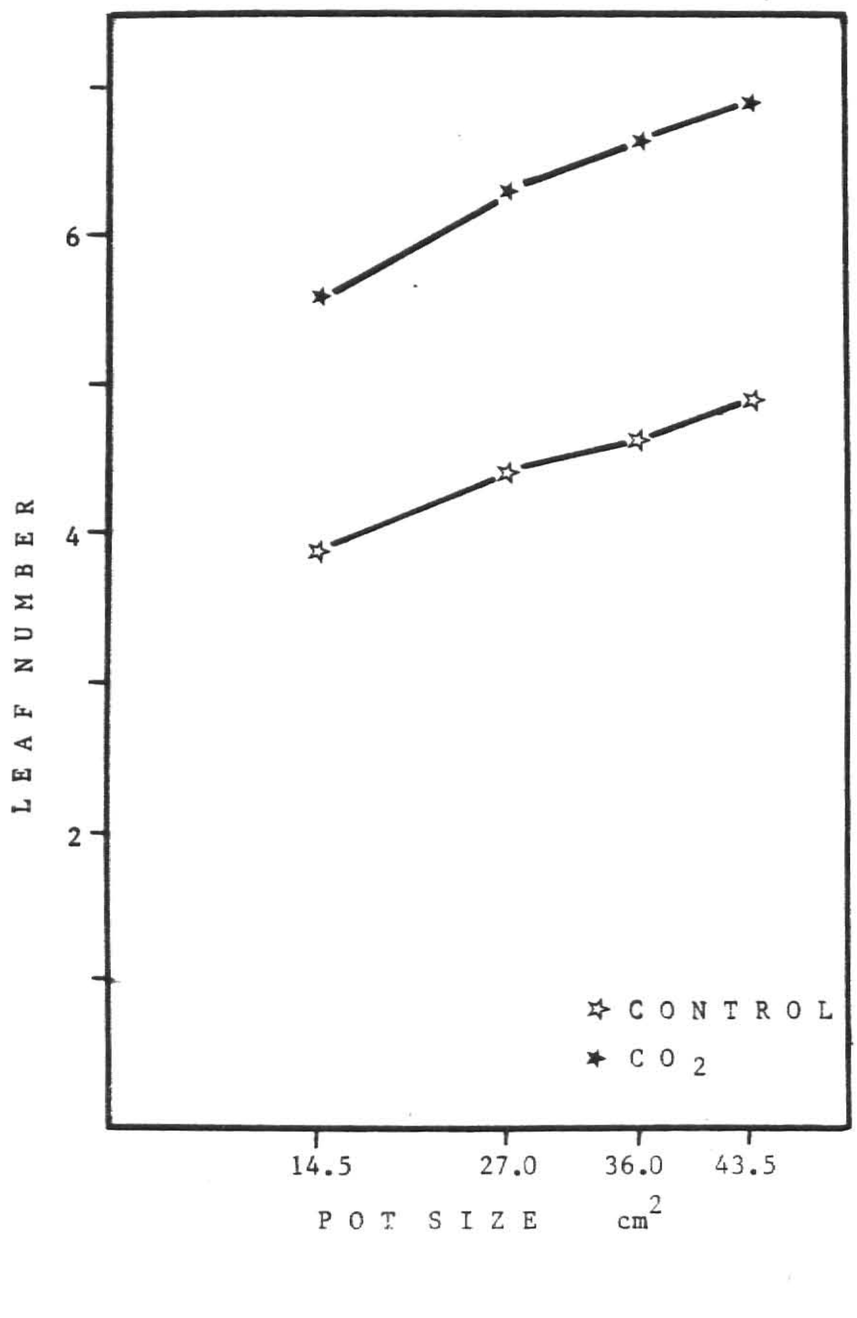

Figure 4. Effect of pot size on leaf number of broccoli transplants, grown with and without CO_2 enrichment of the atmosphere. (Means of two experiments and soil mixes.)

5. DISCUSSION

5.1 Carbon dioxide enrichment

The great promotion of transplant growth brought about by CO_2 enrichment of the atmosphere is in agreement with findings of other researchers, who worked with different crops (18, 28, 44, 46, 47, 63, 74, 77, and others).

Increased dry weight accumulation in shoot and roots indicate a high rate of carbon assimilation (51), which has to be closely related to an increased rate of photosynthesis, since CO_2 assimilation and incorporation require energy, which comes from the light reaction. In the shoot, the additional assimilates obviously were used rather to enlarge the leaves themselves (15), than for the development of additional leaves or increase of the stem diameter, as the data about relative increase of the different plant parts show (Table 7).

A lesser, but still large amount of assimilates is transported to the roots and used for roots dry weight accumulation, compared to the shoot. HARDH (28) also observed a well developed root system in CO_2 enriched vegetable transplants, and increased root weight of tomato and bean plants was reported by WITTWER (74). Greater promotion of shoot than of root growth is reflected in the greater top-root ratio in this study. This is in contrast to the results of other researchers, (23, 74, 75) who found a decrease in top-root ratio (increase in root-top ratio) in other plants. HURD (37) found no change in the proportion of leaf, stem, and root dry weight in tomato seedlings grown in CO_2 enriched atmosphere, which indicates that all plant parts were promoted in the same magnitude by CO_2 enrichment. No change in root weight of tomato seedlings was observed by KRETCHMAN and HOWLETT (44). The reason for relative smaller promotion of root growth than of shoot growth in this study might be the restricted rooting space in the pots. However, root concentration did not reach 2 mg dry roots per cm^3 rooting space, wich was found to be restricting for root growth of tomato seedlings by MASAKI and OHNO (53). With greater root mass more absorbing surface for nutrients is available, and thus further promotion of plant growth is possible by increased nutrient uptake. With increased nitrogen nutrition shoot growth is promoted more than root growth and thus shoot-root ratio increases (65).

Increased number of leaves in plants grown in CO_2 enriched atmosphere occurs frequently (28, 36, 50, 37, 77). However, a comparatively low increase in leaf number (5%) in young tomato plants was found by HURD (37), no increase in leaf number of older kale, sugar-beet, and maize plants was found by FORD and THORNE (23). In this study more light and increased daylength in the second experiment possibly influenced leaf number more than CO_2 enrichment, which is indicated by lower relative increase in the CO_2 enriched plants, compared to the control, because both received the same amount of light. However, in both experiments, the CO_2 enriched plants could develop the same number of leaves theoretically 10 days earlier than the control plants, if one calculates the number of days per leaf from transplanting the seedlings (cotyledone stage) until harvest.

Increased stem diameter in CO_2 enriched plants was measured by PETTIBONE et al. (63). In this study the amount of shoot dry weight the stem had to carry per mm of stem diameter was about twice as much in the CO_2 enriched broccoli plants than in the control plants. This might lead to less sturdy plants, which are more sensitive to environmental influences, like heavy rain or wind.

Increased leaf number and dry weight per node indicate a greater active leaf area per plant, which can be the reason for faster wilting of the CO_2 treated plants, compared to the control plants (41). In combination with the larger root system which can absorb more water this resulted in faster exhaustion of the water reserves in the limited soil volume in this study. Darker green color, increased leaf size and thickness are in agreement with findings of other researchers (24, 45, 69, 77). Increased nitrogen content of the plants also causes dark green color.

5.2 Effect of pot size

Plant growth was greatly promoted with increasing pot size. Transplant size is a reflection of volume of the container, and space per plant. With increasing pot size the individual plant has a larger soil volume, and therefore more rooting space and a greater nutrient reserve available. More space between the shoots reduces mutual shading, therefore competition for light is reduced, and so photosynthesis of the individual plant increases.

The pots with square shape (=3) seemed to increase plant growth relatively less than the rectangular shaped pots (2 and 4), especially dry weight development. This might be due to the fact, that the amount of light the individual plant received did not increase as much, when in row spacing and between row spacing was increased by a small amount than if just one, either in row, or between row spacing was increased by a greater amount, as occurred in the rectangular shaped pots.

Stem diameter and fresh weight of cauliflower transplants grown in flats increased with increasing space per plant (1, 4, and 8 in^2), as reported by (66). KNAVEL (42) found that tomato transplants developed more leaves with increasing container size, but not with increasing spacing within pot size.

In this study plants in the small pots, which represented a closer spacing, eventually suffered from competition for light, especially the CO_2 treated plants, which were large and spindly. In the control house retarded plant growth in the smallest pots might be due to limited soil volume or by limited nutrient supply available to the plants, because the plants were so small that mutual shading should not have had such a great effect.

5.3 Effect of soil mix

Differences in transplant growth between the two soil mixes were small, because the nutrient content of both soils was of comparable order of magnitude (Table 4). Soil mix 2, which contained 1/4 peat in form of jiffy mix, eventually had slightly better physical properties, in form of better water holding capacity, which may have a positive effect under water stress conditions. In addition it did not form a crust on the surface, when dry, as was observed in soil mix 1, the soil-perlite mixture. Otherwise, soil mix 1 might be more preferable, because it is easier to prepare with just two components.

5.4 Differences between the two experiments

Somewhat different response of transplant growth to the different growth factors examined can be explaned by a different combination of the factors light, temperature, humidity, and CO_2 concentration in the second experiment (Table 1).

CO_2 concentration in the experimental greenhouse was higher during the first experiment. The growing period also was longer in the first experiment (52 vs. 39 days), but during the second experiment higher light intensity (475 cal/cm^2 per day vs. 283 cal/cm^2 per day) compensated for lower CO_2 concentration (36, 41). Higher light intensity and temperature were improved conditions for the plants growing in the small pots, but did not have a great effect on the plants grown in the larger pots. Therefore the relative increase in growth in the larger pots compared to the small ones was lower in the second experiment.

5.5 Nitrogen content

Higher nitrogen content of the CO_2 treated plants can be explained in different ways. First, there was some nitrogen in form of NH_3 or other volatile form as component of the swinehouse air, which was taken up and utilized by the plant. Allthough the presence of ammonia was not proved in this study, traces of ammonia in swine confinement air have been detected by DAY et al. (16). Foliar absorbtion of ammonia has been shown in corn seedlings by PORTER (64) and HUTCHINSON et al. (39). Secondly, plants were better able to take up N, either from the soil, or the surrounding air. CO_2 fertilized plants have a higher rate of photosynthesis. As a result, more carbohydrates and other compounds are manufactured, which serve as energy source for the process of nutrient uptake and assimilation. Moreover, the additional carbohydrates supply carbon skeletons for biosynthesis of amino acids (70).

The trend of increasing N content with larger pot size can be explained by the fact that those plants in the larger pots had a higher soil volume, and more rooting space available, and more roots to absorb more N.

Allthough there was a slight difference in available N between the two soil mixes (Table 4), soil mix had no great influence on N uptake. This is in agreement with its influence on other growth characteristics, which was similar in most cases by the two different media.

The difference between first and second experiment in the CO_2 treated plants is somewhat surprising, because the CO_2 concentration in the greenhouse atmosphere was lower in the second experiment than in the first (650 ppm vs. 1000 ppm). Eventually the plants had more energy for N uptake due to higher temperature and higher light intensity in combination with the CO_2 in the second experiment.

6. Summary and conclusion

CO_2 enrichment of the greenhouse atmosphere, with swine confinement air as CO_2 source, greatly promoted growth and development of broccoli transplants. Dry weight accumulation in the shoot was influenced the most and was up to 150% higher than in the non enriched control plants. Root dry weight increased an average of 80%, and so top-root ratio was higher in the CO_2 treated plants, compared to the control plants. Stem diameter and leaf number increased 45% each by CO_2 enrichment. CO_2 enrichment is a suitable cultural method to improve growth and development of broccoli transplants. In this period of high energy cost, supplementary CO_2, which substitutes for light in early spring, might be desirable in transplant production, if better plants can be grown in smaller pots (closer spacings), or in reduced propagation time.

With increasing pot size, transplant size and quality improved, and plants grown in the largest pot size were up to 3 times as big (in terms of dry weight accumulation) as plants grown in the smallest pots. Plants grown in the smallest pots were inferior in quality, in both the control and the experimental greenhouses, due to crowding and/or insufficient nutrient supply. The largest relative growth increase from one pot size to the next bigger one, generally occurred between plants grown in the smallest and second smallest pots. No significant differences in dry weight occurred between plants grown in the two medium sized pots in the control house, and root dry weight was not different in plants grown in either greenhouse. Stem diameter and leaf number increased steadily with pot size. The largest plants resulted from the largest pots, however, in all other pots than the smallest transplants of acceptable quality could be produced.

CO_2 enrichment improved transplant growth in the same order of magnitude as large pot size did. The combination of large pots and CO_2 enrichment had more than additive effect on dry weight accumulation and the plants were more than six times as heavy as the plants grown in the smallest pots without CO_2 enrichment.

The two soil mixes used did not result in a large and consistent difference in transplant growth in the mean of both experiments and all treatments. Either one is suitable for broccoli transplant production.

Nitrogen content in the dry matter of transplant shoots was 2.5 to 4 times as great in the CO_2 treated plants as in the control plants, which was possibly due to improved ability of the CO_2 treated plants to absorb nitrogen from the soil, and foliar uptake of ammonia from the swine house air.

Air from a swine confinement building is an acceptable CO_2 source, where CO_2 concentrations up to 1600 ppm can be reached in the greenhouse atmosphere, and which possibly has the positive side effect of NH_3 enrichment, where ammonia can be absorbed by plant leaves.

REFERENCES

[1] BAGGET, J.R., MACK, H.J. 1970. Premature heading of broccoli cultivars as affected by transplant size. J. Amer. Soc. Hort. Sci. 95: 403-407.

[2] BAILEY, W.A., KLUETER, H.H., KRIZEK, D.T., STUART, N.W. 1970. CO_2 systems for growing plants. Transactions ASAE 13: 263-268.

[3] BERKEL, N. van 1967. Some technical aspects of CO_2 enrichment. Proc. XVII Inter. Hort. Congress 3: 333-341.

[4] ———————— 1975. CO_2 from gas-fired heating boilers - its distribution and exchange rate. Neth. J. Agric. Sci. 23: 202-210.

[5] BISHOP, P.M., WHITTINGHAM, C.P. 1968. The photosynthesis of tomato plants in a carbon dioxide enriched atmosphere. Photosynthetica 2: 31-38.

[6] BLACK, C.C. 1980. Intercellular coordination of carbon, nitrogen and sulfur assimilation pathways in leaves of C4 photosynthesis plants. Paper given at Division of Biology Seminar, KSU, Sept. 26 1980.

[7] BRADLEY, G.A., SMITTLE, D., VOSE, H.H. 1965. Broccoli production practices. Arkansas Farm Research 14 (1): 5.

[8] CANHAM, E. 1974. Some effects of CO_2, air temperature and supplementary artificial light on the growth of young tomato plants. Acta Horticulturae 39: 175-181.

[9] CARPENTER, W.J. 1967. Effect of intermittent misting with carbonated water on the growth of greenhouse chysanthemums and lettuce. Proc. XVII Inter. Hort. Congress 1: 349.

[10] CHAPMAN, H.W. 1951. The absorbtion of CO_2 by leaves of the potato. Amer. Potato J. 28: 602-615.

[11] CHAYKIN, S. 1960. Determination of Ammonia. Analytical Biochemistry 31: 375-382.

[12] CHROBOCZEK, E. 1963. Peat and sand mixtures to replace soil composts for vegetable plant production. Acta Horticulturae 1: 1-2.

[13] DAUNICHT, H.J. 1965. CO_2-Duengung; Entwicklung, heutiger Stand, eigene Versuchsergebnisse. Acta Horticulturae. 2: 86-96.

[14] ———————— 1966. Methods and results of experiments on the effects of the CO_2-concentration on vegetable crops. Acta Horticulturae 4: 116-125.

[15] ———————— 1974. Control of plant growth and development by carbon dioxide concentration. Acta Horticulturae 39: 167-173.

[16] DAY, D.L., HANSEN, E.L., ANDERSON, S. 1965. Gases and odors in confinement swine buildings. Transactions ASAE 8: 118-121.

[17] DEKORNE, J.B. 1975. The survival greenhouse. The Walden Foundation, El Rito, California (165pp.) pp. 75-76.

[18] ENOCH, H.Z., RYLSKI, I., SPIEGELMAN, M. 1976. CO_2 Enrichment of strawberry and cucumber plants grown in unheated greenhouses in Israel. Scientia Horticulturae 5: 33-41.

[19] FARRAHI-ASCHTIANI, S. 1964. Die Naehrstoffaufnahme bei etiolierten und bei unterschiedlich lange belichteten jungen Weizen- und Reispflanzen. Dissertation. Justus-Liebig-Universitaet, Giessen.

[20] FISCHER, H. 1912. Gartenflora 61: 165-168. cit. in DAUNICHT, H. J. 1965. CO_2 Duengung; Entwicklung, heutiger Stand, Eigene Versuchsergebnisse. Acta Horticulturae 2: 86-96.

[21] FISHER, K.J., BURGE, G.K. 1979. Crop establishment methods with lettuce. New Zealand Commercial Grower 34 (11): 28. in Hort. Abstr. 50 (1980): 6216.

[22] FLETCHER, R.F. 1975. Growing vegetable transplants. Pennsylvania State University, Cooperative Extension Service, Circular 562.

[23] FORD, M.A., THORNE, G.N. 1967. Effect of CO_2 concentration on growth of sugar-beet, barley, kale, and maize. Ann. Bot. 31: 629-644.

[24] FRYDRYCH, J. 1976. Photosynthetic characteristics of cucumber seedlings grown under two levels of carbon dioxide. Photosynthetica 10: 335-338.

[25] ———— 1978. The effect of increased CO_2 concentration on photosynthetic rate of leaves of kohlrabi clones (Brassica oleracea var. gongylodes L.). Zeitschrift f. Pflanzenzuechtung 80: 158-161.

[26] GAASTRA, P. 1966. Some physiological aspects of CO_2 application in glasshouse culture. Acta Horticulturae 4: 111-116.

[27] GOLDSWORTHY, A. 1969. Riddle of photorespiration. Nature 224: 501-502.

[28] HARDH, J.E. 1966. CO_2 enrichment in raising young vegetable plants. Acta Horticulturae 4: 126-133.

[29] HARTMANN, H.D. 1967. The effect of CO_2 concentration on headlettuce with special regard to the response of varieties. Proc. XVII Inter. Hort. Congress 1: 467.

[30] HAUKENESS, M.O., MAGINNES, E.A., GREEN, G.H., BROOKS, E.E. 1978. Using the heat and carbon dioxide frome turbine exhaust gases for

the production of greenhouse tomatoes. HortScience 13: 292-293.

[31] HAWORTH, F., CLEAVER, T.J. 1964. Growth and mineral composition of vegetable seedlings. J. Hort. Sci. 39; 34-41.

[32] HEATH, O.V.S., MEIDNER, H. 1967. Compensation points and carbon dioxide enrichment for lettuce grown under glass in winter. J. Exp. Bot. 18: 746-751.

[33] HO, L.C. 1977. Effects of CO_2 enrichment of the rates of photosynthesis and translocation of tomato leaves. Ann. Appl. Biol. 87: 191-200.

[34] HOMNA, S. 1956. Effects of growing medium on the performance of transplants of four varieties of each cabbage and tomato. Proc. Amer. Soc. Hort. Sci. 67: 361-364.

[35] HOPEN, H.J., OEBKER, N.F. 1975. Mulch effects on ambient carbon dioxide levels and growth of several vegetables. HortScience 10: 159-161.

[36] HOPEN, H.J., RIES, S.K. 1962. The mutually compensating effect of carbon dioxide concentration and light intensities on the growth of Cucumis sativus L.. Proc. Amer. Soc. Hort. Sci. 81:358-364.

[37] HURD, R.G. 1968. Effects of CO_2-enrichment on the growth of young tomato plants in low light. Ann. Bot. 32: 531-542.

[38] HURD, R.G. 1969. Leaf resistance in a glasshouse tomato crop in relation to leaf position and solar radiation. New Phytol. 68: 265-273.

[39] HUTCHINSON, G.L., MILLINGTON, R.J., PETERS, D.B. 1972. Atmospheric ammonia absorbtion by plant leaves. Science 175: 771-772.

[40] JONES, R.J., MANSFIELD, T.A. 1970. Increase in Diffusion resistance of leaves in carbon dioxide-enriched atmosphere. J. Exp. Bot. 21: 951-958.

[41] KLOUGART, A. 1967. A look ahead based on research of horticultural plants in Europe. Proc. XVII Inter. Hort. Congress 3: 323-332.

[42] KNAVEL, D.E. 1965. Influence of container, container size, and spacing on growth of transplants and yields in tomato. Amer. Soc. Hort. Sci. 86: 582-586.

[43] KNECHT, G.N. 1975. Response of radish to high CO_2. HortScience 10: 274-275.

[44] KRETCHMAN, D.W., HOWLETT, F.S. 1966. The response of tomato seedlings to CO_2 enrichment. Ohio Agric. Res. and Development Center, Wooster, Research Summary 8: 1-4.

[45] ——————, —————— 1970. CO_2 enrichment for vegetable production. Transactions ASAE 13: 252-256.

[46] KRIZEK, D.T., BAILEY, W.A., KLUETER, H.H., CATHEY, H.M. 1968. Controlled environments for seedling production. Proc. Inter. Plant Prop. Soc. 18: 273-281.

[47] ——————, ——————, ——————, LIU, R.C. 1974. Maximizing growth of vegetable seedlings in controlled environments at elevated temperature, light and CO_2. Acta Horticulturae 39: 89-102.

[48] LAKE J.V. 1965. Carbon dioxide for glasshouse crops. Span 8: 108-110.

[49] LOEPPERT, H., KRONBERGER, W. 1979. Control of nitrate uptake by photosynthesis in Lemna paucicostata 6746. Photosynthesis and Plant Development. R. Marcelle, H. Clijsters, M. van Poucke (Editors), Dr W. Junk bv Publishers. The Hague. pp. 301-308.

[50] LONG, J.E. 1979. Effect of swine farrowing house air and mineral nutrition on Cucumis sativus L. Master's Thesis, Kansas State University, Manhattan, Kansas.

[51] LOOMIS, R.S., WILLIAMS, W.A., HALL, A.E. 1971 Agricultural productivity. Ann. Rev. Plant Phys. 22: 431-468.

[52] MADSEN, E. 1973. Effect of CO_2 concentration on the morphological histological and cytological changes in tomato plants. Acta Agriculturae Scandinavica 23: 235-240.

[53] MASAKI, T., OHNO, H. 1979. [Studies on growth of vegetable seedlings in pots. I. The growth of young tomato seedlings in pots of different sizes for different periods.] Bulletin of the Vegetable and Ornamental Crops Research Station, A Ishinden-Ogoso (Japan), Tsu (1979) No. 5: 81-93. Abstr. in Hort. Abstr. (1980) 50: 4293.

[54] MASTERSON, C.L., SHERWOOD, M.T. 1978. Some effects of increased atmospheric carbon dioxide on white clover (Trifolium repens) and pea (Pisum sativum). Plant and Soil 49: 421-426.

[55] MERKEL, J.A., HAZEN, T.E., MINER, J.R. 1969. Identification of gases in a confinement swine building atmosphere. Transaction ASAE 12: 310-315.

[56] MOLNAR, J.M., CUMMING, J.M. 1968. Carbonized mist in plant propagation. Proc. Inter. Plant Prop. Soc. 18: 281-288.

[57] MORTIMER, D.C. 1959. Some short term effects of increased carbon dioxide concentration on photosynthetic assimilation in leaves. Can. J. Botany 37: 1191-1201.

[58] NELSON, P.V. 1978. Greenhhouse operation and management. Reston Pub. Co., Inc., Reston, Va.

[59] NEWTON, P. 1966. The influence of increased CO_2 concentration and supplementary illumination on growth of tomato seedlings during winter month. Ann. Appl. Biol. 57: 345-353.

[60] NIEUWHOF, M. 1969. Cole crops. Leonard Hill, London.

[61] OEBKER, N.F., HOPEN, N.J. 1974. Microclimate modification and the vegetable crop ecosystem. HortScience 9: 564-568.

[62] PALLAS, J.E. 1970. Theoretical aspects of CO_2 enrichment. Transactions ASAE 13: 240-245.

[63] PETTIBONE, C.A., MATSON, W.R., PFEIFFER, C.L., ACKLEY, W.B. 1970. The control and effects of supplemental carbon dioxide in air-supported plastic greenhouses. Transactions ASAE 13: 259-262,268.

[64] PORTER, L.K., VIETS, F.G. Jr., HUTCHINSON, G.L. 1972. Air containing nitrogen-15 ammonia: foliar absorbtion by corn seedlings. Science 175: 759-761.

[65] SALISBURY, F.B., ROSS, C.W. 1978. Plant Physiology. 2nd Edition. Wadsworth Publishing Company, Belmont, Ca.

[66] SKAPSKI, H., OYER, E.B. 1964. The influence of pre-transplanting variables on the growth and development of cauliflower plants. Proc. Amer. Soc. Hort. Sci. 85: 374-385.

[67] SMALL, T., WHITE, H.L. 1930. Carbon dioxide in relation to glasshouse crops. Ann. Appl. Biol. 17: 81-89.

[68] SOEST, W. van 1967. Practical experience with CO_2 on vegetable growing under glass. Proc. XVII Inter. Hort. Congress 1: 346.

[69] SPILLMAN, C.K., GREIG, J.K., JOHNSON, G.A., HARTFORD, J.R., KOCH, B.A., HINES, R.H. 1980. Solar energy utilization in a greenhouse/animal shelter combination. To be published in Proc. ASAE National Energy Symposium, Kansas City, Mo.

[70] STULEN, I. 1979. Influence of CO_2 on functioning of nitrate reductase in radish (a C3 plant) and corn (a C4 plant) seedlings. Nitrogen Assimilation of plants. 6th Long Ashton Symposium 1977. E.J. Hewitt, C.V. Cutting (Editors) Academic Press. London. pp. 582-588.

[71] THOMPSON, R., TAYLOR, H. 1970. Calabrese for fresh market and processing. Scott. Agric. 49: 166-171.

[72] USDA 1979. Agricultural Statistics.

[73] VIK, J. 1975. [Experiments concerning raising onion transplants in groups.] Research in Norwegian Agriculture 26: 343-361.

[74] WITTWER, S.H. 1967. Carbon dioxide and its role in plant growth. Proc. XVII Inter. Hort. Congress 3: 311-322.

[75] ———— 1970. Aspects of CO_2 enrichment for Crop production. Transactions ASAE 13: 249-251, 256.

[76] ————, BUKOVAC, M.J. 1969. The uptake of nutrients through leaf surfaces. Handbuch der Pflanzenernaehrung und Duengung I/1, H. Linser (Editor), Springer, Wien.

[77] ————, ROBB, W.M. 1964. Carbon dioxide enrichment of greenhouse atmoshperes for food crop production. Econ. Bot. 18: 34-56.

APPENDIX

Analysis of variance (ANOVA): Effect of the treatments on growth characteristics of broccoli plants.

Parameter: Stem diameter

Source of variation	Degrees of freedom	Mean square	Alpha
1. Experiment			
Greenhouse	1	25.685	0.0001
Soil	1	2.908	0.0001
Pot size	3	5.957	0.0001
Greenh.* Soil	1	0.021	0.6145
Greenh.* Pot	3	0.350	0.0092
Soil * Pot	3	0.178	0.1012
Greenh.* Soil * Pot	3	0.020	0.8613
Model	15	3.371	0.0001
Error	44	0.081	
Total	59		
2. Experiment			
Greenhouse	1	40.960	0.0001
Soil	1	0.302	0.0194
Pot size	3	3.260	0.0001
Greenh.* Soil	1	0.090	0.1932
Greenh.* Pot	3	0.282	0.0026
Soil * Pot	3	0.117	0.0927
Greenh.* Soil * Pot	3	0.090	0.1726
Model	15	3.507	0.0001
Error	48	0.052	
Total	63		
1. and 2. Experiment			
Experiment	1	3.121	0.0001
Greenhouse	1	65.427	0.0001
Soil	1	0.720	0.0013
Pot size	3	9.041	0.0001
Model	31	3.440	0.0001
Error	92	0.066	
Total	123		

Parameter: Leaf number

Source of variation	Degrees of freedom	Mean square	Alpha
Greenhouse	1	38.056	0.0001
Soil	1	0.870	0.0001
Pot size	3	5.457	0.0001
Greenh.* Soil	1	0.525	0.0022
Greenh.* Pot	3	0.172	0.0242
Soil * Pot	3	0.100	0.1257
Greenh.* Soil * Pot	3	0.107	0.1086
Model	15	3.982	0.0001
Error	44	0.050	
Total	59		
2. Experiment			
Greenhouse	1	83.038	0.0001
Soil	1	0.150	0.2414
Pot size	3	2.288	0.0001
Greenh.* Soil	1	0.263	0.1233
Greenh.* Pot	3	0.304	0.0470
Soil * Pot	3	0.114	0.3701
Greenh.* Soil * Pot	3	0.002	0.9969
Model	15	6.105	0.0001
Error	48	0.107	
Total	63		
1. and 2. Experiment			
Experiment	1	4.272	0.0001
Greehnouse	1	115.816	0.0001
Soil	1	0.163	0.1551
Pot size	3	7.404	0.0001
Model	31	4.998	0.0001
Error	92	0.079	
Total	123		

Parameter: Total dry weight

Source of variation	Degrees of freedom	Mean square	Alpha
1. Experiment			
Greenhouse	1	737.782	0.0001
Soil	1	13.614	0.0019
Pot size	3	162.888	0.0001
Greenh.* Soil	1	0.932	0.3926
Greenh.* Pot	3	23.338	0.0001
Soil * Pot	3	1.163	0.4340
Greenh.* Soil * Pot	3	0.089	0.9752
Model	15	92.119	0.0001
Error	44	1.250	
Total	59		
2. Experiment			
Greenhouse	1	769.092	0.0001
Soil	1	0.555	0.6595
Pot size	3	125.248	0.0001
Greenh.* Soil	1	2.441	0.3570
Greenh.* Pot	3	32.195	0.0001
Soil * Pot	3	0.971	0.7937
Greenh.* Soil * Pot	3	1.393	0.6885
Model	15	83.594	0.0001
Error	48	2.2823	
Total	63		
1. and 2. Experiment			
Experiment	1	0.059	0.8661
Greenhouse	1	1505.482	0.0001
Soil	1	4.599	0.1395
Pot size	3	283.654	0.0001
Model	31	85.023	0.0001
Error	92	2.070	
Total	123		

Parameter: Top dry weight

Source of variation	Degrees of freedom	Mean square	Alpha
1. Experiment			
Greenhouse	1	538.136	0.0001
Soil	1	9.369	0.0028
Pot size	3	107.707	0.0001
Greenh.* Soil	1	0.266	0.5969
Greenh.* Pot	3	16.736	0.0001
Soil * Pot	3	0.903	0.4182
Greenh.* Soil * Pot	3	0.032	0.9916
Model	15	64.586	0.0001
Error	44	0.937	
Total	59		
2. Experiment			
Greenhouse	1	626.626	0.0001
Soil	1	0.779	0.5507
Pot size	3	89.807	0.0001
Greenh.* Soil	1	2.124	0.3259
Greenh.* Pot	3	28.753	0.0001
Soil * Pot	3	0.957	0.7228
Greenh.* Soil * Pot	3	0.829	0.7648
Model	15	66.038	0.0001
Error	48	2.157	
Total	63		
1. and 2. Experiment			
Experiment	1	1.512	0.3294
Greenhouse	1	1160.845	0.0001
Soil	1	2.547	0.2065
Pot size	3	195.222	0.0001
Model	31	63.285	0.0001
Error	92	1.573	
Total	123		

Parameter: Root dry weight

Source of variation	Degrees of freedom	Mean square	Alpha
1. Experiment			
Greenhouse	1	15.716	0.0001
Soil	1	0.395	0.0021
Pot size	3	5.938	0.0001
Greenh.* Soil	1	0.202	0.0238
Greenh.* Pot	3	0.615	0.0001
Soil * Pot	3	0.051	0.2635
Greenh.* Soil * Pot	3	0.044	0.3255
Model	15	2.555	0.0001
Error	44	0.037	
Total	59		
2. Experiment			
Greenhouse	1	7.290	0.0001
Soil	1	0.019	0.6033
Pot size	3	2.994	0.0001
Greenh.* Soil	1	0.011	0.6913
Greenh.* Pot	3	0.165	0.0801
Soil * Pot	3	0.012	0.9162
Greenh.* Soil * Pot	3	0.093	0.2706
Model	15	1.141	0.0001
Error	48	0.069	
Total	63		
1. and 2. Experiment			
Experiment	1	2.170	0.0001
Greenhouse	1	22.367	0.0001
Soil	1	0.301	0.0199
Pot size	3	8.505	0.0001
Model	31	1.861	0.0001
Error	92	0.054	
Total	123		

Parameter: Top-root ratio

Source of variation	Degrees of freedom	Mean square	Alpha
1. Experiment			
Greenhouse	1	16.752	0.0001
Soil	1	0.006	0.8764
Pot size	3	2.488	0.0001
Greenh.* Soil	1	0.900	0.0543
Greenh.* Pot	3	0.046	0.8971
Soil * Pot	3	0.602	0.0629
Greenh.* Soil * Pot	3	0.371	0.2002
Model	15	1.795	0.0001
Error	44	0.230	
Total	59		
2. Experiment			
Greenhouse	1	60.708	0.0001
Soil	1	2.021	0.0285
Pot size	3	0.698	0.1671
Greenh.* Soil	1	0.483	0.2751
Greenh.* Pot	3	1.423	0.0202
Soil * Pot	3	0.774	0.1337
Greenh.* Soil * Pot	3	0.234	0.6247
Model	15	4.840	0.0001
Error	48	0.396	
Total	63		
1. and 2. Experiment			
Experiment	1	25.090	0.0001
Greenhouse	1	69.716	0.0001
Soil	1	1.079	0.0681
Pot size	3	2.829	0.0001
Model	31	4.131	0.0001
Error	92	0.317	
Total	123		

Parameter: Dry weight per node

Source of variation	Degrees of freedom	Mean square	Alpha
1. Experiment			
Greenhouse	1	12.512	0.0001
Soil	1	0.153	0.0111
Pot size	3	2.487	0.0001
Greenh.* Soil	1	0.015	0.4140
Greenh.* Pot	3	0.169	0.0003
Soil * Pot	3	0.009	0.7288
Greenh.* Soil * Pot	3	0.014	0.5775
Model	15	1.456	0.0001
Error	44	0.022	
Total	59		
2. Experiment			
Greenhouse	1	17.187	0.0001
Soil	1	0.076	0.2928
Pot size	3	2.555	0.0001
Greenh.* Soil	1	0.058	0.3595
Greenh.* Pot	3	0.515	0.0003
Soil * Pot	3	0.024	0.7884
Greenh.* Soil * Pot	3	0.048	0.5499
Model	15	1.825	0.0001
Error	48	0.067	
Total	63		
1. and 2. Experiment			
Experiment	1	1.964	0.0001
Greenhouse	1	29.978	0.0001
Soil	1	0.008	0.6726
Pot size	3	4.988	0.0001
Model	31	1.657	0.0001
Error	92	0.046	
Total	123		

Parameter: Nitrogen content

Source of variation	Degrees of freedom	Mean square	Alpha
Experiment	1	1.732	0.0003
Greenhouse	1	142.057	0.0001
Soil	1	0.066	0.4555
Pot size	1	2.231	0.0001
Model	15	10.131	0.0001
Error	48	0.116	
Total	63		

VITA

Regina Eva Martin was born on May 12, 1955 in Odenthal, Federal Rpublic of Germany. She maturated from Grammar School in 1974 and began the study of Agriculture at Justus Liebig University in Giessen, West Germany, in Fall 1974. During her study she passed agricultural internships on several different farms and Research Institutions. In October 1979 she recieved her degree of Diplom Agricultural Engineer in Plant Production from Justus Liebig University. As an exchange student she enrolled in a Master's program in Horticulture at Kansas State University in Fall 1979.

EFFECT OF SWINE CONFINEMENT AIR, POT SIZE, AND SOIL MIX ON GROWTH AND DEVELOPMENT OF BROCCOLI TRANSPLANTS

by

REGINA EVA MARTIN

Diplom (Agriculture), Justus Liebig University, 1979

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

Kansas State University

Manhattan, Kansas

1980

In a greenhouse experiment the effect of carbon dioxide enrichment of the atmosphere, pot size and soil mix on growth development and nitrogen content of broccoli transplants, sown on two dates (experiments 1 and 2), was studied. The usefulness of swine confinement air as a CO_2 source was evaluated. The CO_2 concentration in the experimental greenhouse ranged from 450 to 1600 ppm (average 1000 ppm) in the first experiment, and from 400 to 1100 ppm (average 650 ppm) in the second experiment. In the control house the CO_2 concentration was approximately 300 ppm. Pots of four sizes (3.8x3.8 cm, 5.6x4.8 cm, 6.0x6.0 cm, and 7.8x5.6 cm) filled either with equal parts of sandy loam soil and perlite (soil 1), or with equal parts of soil, perlite, jiffy mix, and sand (soil 2), were planted with 'Green Comet' broccoli seedlings in the cotyledone stage. Stem diameter, leaf number, total, top and root dry weight, top-root ratio, and dry weight per node were measured when the plants had reached field transplanting size (6-leaf stage). Nitrogen content of the shoot dry matter of plants grown in pot sizes 5.6x4.8 cm and 7.8x5.6 cm of all treatments was determined.

CO_2 enrichment of the atmosphere resulted in great promotion of plant growth, especially dry weight accumulation. Total, shoot, and root dry weight and dry weight per node were increased 137%, 151%, 80% and 101% respectively in the mean of both experiments, as compared to the control plants. Stem diameter and leaf number increased 45% each. Top-root ratio was higher in the CO_2 enriched plants.

With increasing pot size plant growth also increased. Total, shoot, and root dry weight of plants grown in the largest pots were tripled in the first experiment, and doubled in the second experiment, compared to plants grown in the smallest pots. Dry weight per node increased 100%, stem diameter 37% and the number of leaves 25% in the mean of both experiments. Top-root ratio did not change with increasing pot size.

The combined effect of CO_2 enrichment and large pot size resulted in the largest plants. The relative increase in growth of plants grown with CO_2 enrichment in the largest pots compared to plants grown in the control house in the smallest pots, was greater than the sum of CO_2 and pot size effect.

The two soil mixes studied did not result in a significant and consistent difference in transplant growth. Nitrogen content of the CO_2 treated plants was 2.5 to 3.3 times as great as in the control plants.

Overall the results indicate that swine confinement air is a useful source for CO_2 enrichment of the greenhouse atmosphere.