EFFECTS OF SWINE FARROWING HOUSE AIR AND MINERAL NUTRITION ON *CUCUMIS SATIVUS*, L.

by

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INTRODUCTION

Swine farrowing houses, which shelter sows and their litters for up to five weeks after birth, are kept at an average temperature of 80°F (3). These units are continuously ventilated in order to replenish the supply of oxygen and remove potentially toxic gases and humidity. During this process, heat, humidity, carbon dioxide and possible other gases are being wasted that could be utilized in other production systems. In an earlier study, Day et al. (12) found CO_2, H_2S, CH_4 and possibly NH_3 in a totally slotted floor swine building with under floor pits. In addition to the gases mentioned above, Merkel et al. (32) found a complex mixture of volatile organic intermediates within enclosed swine buildings.

Greenhouses used to grow vegetables, flowers and other plants are generally heated by fossil fuels which are, excluding labor, the greatest operating expense of a commercial greenhouse (31). These fossil fuels, in addition to releasing heat, are also used to generate CO_2 in order to raise the normal ambient greenhouse levels of CO_2 (5). It has been well documented that the ambient atmospheric level of CO_2 may vary from 200 to 400 ppm (9,17,35) and these low levels may limit photosynthesis (7,18,28,35). Plants grown in CO_2 enriched greenhouses exhibit increased yield and quality (51). Therefore, swine producers with greenhouses utilizing the waste heat and enriched CO_2 from attached farrowing units could benefit from lower fuel costs and increased production.

Various reseachers have studied the feasibility of using waste sources for heat and carbon dioxide enrichment. Haukeness et al. (20) used the heat and CO_2 from turbine exhaust gases for the production of greenhouse tomatoes. The exhaust gases were passed between the inner and outer layers of a double-layered, polyethylene-covered greenhouse. This resulted in greenhouse CO_2 levels of 1200 to 3000 ppm.

In a similar study, Eisa et al. (14) used scrubbed diesel exhaust for CO_2 enrichment of greenhouse vegetables. In this experiment the heat from the diesel exhaust was not utilized.

Dekorne (13) trapped heat in passive solar collectors inside a greenhouse and used rabbits caged under hydroponic tanks to increase CO_2 levels to 700 to 800 ppm. His adult California and New Zealand breed rabbits produced about 40 g of CO_2 per day. In addition to the products of respiration, the composting rabbit manure provided an undetermined amount of CO_2 as well as nitrogen in the form of ammonia.

A crop that has not been grown very much in Kansas and may respond well to a greenhouse environment using the air from a swine farrowing house is the European greenhouse cucumber. Unlike field grown cucumbers, which are grown both for pickling and fresh market use, the European greenhouse cucumber is grown only in a greenhouse and exclusively for the fresh market. The long slender fruit, 32 to 42 cm in length, has tender bright skin and crisp flesh. The fruit can be eaten without peeling and is considered to be superior in eating quality to the U.S. type cucumber. The most popular varieties are parthenocarpic (set fruit without fertilization) and gynecious (44).

In the U.S., the European greenhouse cucumber appears to offer more potential for market development than any other greenhouse-produced vegetable. It is a relatively new product, untried by most potential customers, and can be differentiated from competitive crops more readily than any other greenhouse produce (25). Demand, however, for all fresh cucumbers in the U.S. in 1976 was only 3.4 lb per capita (26).

Expected yield of European greenhouse cucumber, taking environmental variables into consideration and using a plant population of .83 m^2/plant (12,000 plants/ha), is approximately 23 kg per plant (271 t/ha). These values are equivalent to 300 to 600 g of fruit per week (24).

The total world production in 1977 exceeded 5,000 ha, of which 3,200 ha were in the United States, Canada and Western Europe. The remaining 2,600 ha were located in Eastern and Southern Europe (44). Along with lettuce and tomato, cucumbers (all greenhouse types) were rated as one of the most important greenhouse crops produced world-wide (11). In Canada alone, over 60% of the Ontario greenhouse acreage was being devoted to cucumbers (29).

European greenhouse cucumbers were developed in the Netherlands and belong to the family Cucurbitaceae and genus Cucumis. It is a member of the common cucumber species C.sativus, L., which is indigenous to India where it has been cultivated for at least 3,000 years (50).

Because cucumbers are a semi-tropical crop, the culture of European greenhouse cucumber requires conditions of high temperature, humidity, light, fertilizer and moisture (21). The plants also have been shown to respond well to CO_2 enrichment (40). Cucumbers are sensitive plants, and conditions other than favorable can cause reduction in growth and yields (24).

The objectives of this study were:

1. To evaluate the effect of different rates of a complete soluble fertilizer on the growth and yield of two varieties of European greenhouse cucumbers grown in the exhaust air from a swine farrowing unit.

2. To evaluate the effects of swine farrowing house air as a source of carbon dioxide on cucumber seedling top growth for dry weight, first true leaf area and true leaf number.

LITERATURE REVIEW

Carbon Dioxide Enrichment of Cucumber

Gastra (18) determined that at 0.03 % CO_2, photosynthesis in cucumber is almost independent of leaf temperature, while at high concentrations the rate is strongly affected by temperature. He concluded that as CO_2 concentrations and temperature increase, photosynthetic activity also increased.

According to Wittwer (51), CO_2 enrichment resultedin an increase in yield, improved quality and accelerated maturity in all vegetable crops tested. Crops currently adapted for greenhouse culture were especially responsive when grown under low light conditions.

In another study, Wittwer (52) found that leaf numbers for cucumber plants were greatly increased at higher CO_2 levels (1000 ppm). Also enhancement of green color resulted when either the light intensity or the CO_2 concentration was increased. The vegetative growth increases in cucumber plants from added CO_2 were equally as great as lettuce and tomato. The most striking difference, however, was that during the first 60 days of growth the number of pistillate flowers was approximately doubled for both Burpee hybrid and Butcher's Disease Resister varieties. No difference occurred in the number of staminate flowers.

In the same study, Wittwer (52) reported that historically large quantities of organic materials and animal manure have been used in the greenhouse culture of cucumber. The release of CO_2 from these materials may reach large proportions with accompanying benefits to growing crops. Above normal levels of CO_2 reduce the size of stomatal apertures or openings. Decaying manure, however, supplies ammonia as well as CO_2. Ammonia at low doses, keeps stomatal apertures open in the presence of abnormally high levels of CO_2.

Klougart (25) determined that CO_2 enriched cucumber plants exhibited an increase in dry matter, sugar, vitamins and color pigments as well as improvements in storage quality and young plant rooting capacity. He found that increased light helped develop a larger productive leaf area and plants in outer rows or benches produced 15-25 % more than the inside. His results showed that CO_2 enrichment resulted in a 24 % increase in unit leaf area and a 74 % increase in yield.

Aoki et al. (4) measured the dry matter production and rate of photosynthesis under CO_2 enrichment. Dry matter production was greatest at 1200 ppm and 2400 ppm enrichment, however, this decreased with the duration of enrichment. The rate of net photosynthesis of cucumber leaves was effective at the beginning, but as the enrichment continued the rates at the higher CO_2 concentration rapidly decreased to below that at normal CO_2 concentration.

Newton (34) observed that supplementary CO_2 increased the growth rate of the cucumber variety Butcher's Disease Resister by increasing both net assimilation rate and leaf expansion. It increased areas of individual leaves by increasing their growth rate before they emerged from the terminal bud. Growth rate after emergence was unaffected by CO_2 concentration. Total leaf area per plant, the total number of leaves and the number of expanded leaves was generally larger for treated than untreated leaves. Areas of the first leaf of treated plants were larger than those of untreated plants. This agreed with the work of Bollas et al. (6), who also found increased leaf growth of cucumber plants when grown with above normal CO_2 concentrations.

Hopen (22) grew cucumber seedlings at atmospheric CO_2 levels of 350, 450, 500, 1250, 1350 and 2150 ppm. CO_2 enrichment increased fresh and dry weights, plant heights, internode development, leaf size, number of fruit developed and leaf starch concentration. The benefit per unit of CO_2 was largest at the lower levels of enrichment. Plants grown to fruiting (42 days) developed a greater number of marketable fruit and larger fresh and dry weights at 1350 ppm than 450 ppm CO_2. Fruit numbers were increased only at 1350 ppm.

Krizek et al. (27) studied cucumber seedlings grown in a growth chamber with high temperature regime (30/24 deg C), light intensity (43.1 klx), CO_2 enrichment (2000 ppm), a 16 h photoperiod and fertilized 4 times daily. After 15 days, plant weight was 2 to 4.6 times as much as those grown in the growth chamber under standard conditions (24/18 deg C, 21.5 klx and 400 ppm CO_2) and 10 to 25 times those grown in the greenhouse in 24/18 deg C, no supplementary lighting and 350 ppm CO_2. Leaf expansion was also greatly enhanced. The most striking effects of CO_2 enrichment were precocious flower bud formation and extensive growth of the lateral buds.

In a study by Enoch et al. (15), cucumber plants were grown in ambient atmosphere CO_2 concentrations of 300 ppm and at elevated levels of 900, 1500 and 3000 ppm during winter and early spring in 10 unheated greenhouses on the coastal plain of Israel. CO_2 enrichment averaged 7 h/day between the end of November and the second half of April. Cucumber cv. Elem grown at 3000 ppm yielded 26 % more over the whole picking season than those grown at 300 ppm. Yield during the first month of picking was doubled by both a 3 and 10-fold increase in CO_2 concentration.

Mineral Nutrition of Cucumbers

Wittwer (52) concluded that fertilizers containing nitrogen must be applied earlier and in larger quantities when cucumbers are grown with CO_2 enrichment. Plants grown in CO_2 atmospheres 3 to 5 times normal responded to watering and fertilizer even in mid-winter.

Cheng (10) reported that different phosphatic fertilizers vary in their ability to prevent or enhance Mn toxicity. He found that low Mn and high P are more beneficial to growth than high Mn and low P. He determined that the optimum balance of the two elements was 105 ppm P and 0.5 ppm Mn. For Wisconcin SMR 18 variety, the optimim fertilization rates per hectare were 30 kg N, 45 kg P and 30 kg K.

Voogt and Sommeveld (41) researched Mn requirements on peat substrates. They found that the highest yields were obtained with applications of 25 to 50 g $MnSO_4 \cdot H_2O$ per m^3. Larger rates of application caused yield reduction and severe Mn toxicity symptoms.

Ward (47) reported that Mn deficiency in cucumbers may cause a characteristic yellowing of the lower and middle leaves. To correct this deficiency he recommended applying magnesium sulfate as a spray at 5.3 kg/550 L H_2O.

In another study, Ward (46) observed that severe calcium deficiency was associated with top leaf tissue of 0.20 % calcium or less. Fruit showed symptoms of proportionate stunting, center and stem-end constriction in Burpee hybrid and a progressively darker green color in Sporu variety. Mild symptoms were difficult to recognize.

Ward (48) determined the total nutrient absorption of cv. Burpee hybrid was equivalent to 408 kg N, 92 kg P, 550 kg K, 237 kg Ca and 57 kg Mn per hectare. These figures formed the basis for the estimation of a practical fertilizer schedule. Ward (49) observed that as the plant aged, N and K decreased in percentage, Ca and Mg increased and P stayed relatively constant. Overall, K was the predominant element in terms of quantity.

Zurbicki (53) reported that plant mineral nutrition is greatly affected by temperature conditions, humidity, duration and intensity of sunshine. Variation in mineral nutrition of plants grown in a greenhouse and open air, may be attributed mainly to differences in relative humidity of the air, and consequently, in transpiration. He found that plants grown in open air were higher in N, P_2O_5 and CaO, while those grown in a greenhouse were higher in K.

MATERIALS AND METHODS

General

This three part study was conducted in two wood-framed, double-layered polyethylene greenhouses attached to the south side of two farrowing units at the Kansas State University Animal Science Swine Unit, Manhattan, Kansas. The greenhouses were both: 3.7 m wide by 6.1 m long; positioned with a 60 degree roof slope to the south; equipped with a thermostatically controlled exhaust fan that operated above 32^{o}C; and outfitted with an irrigation system composed of 3/16 in (0.48 cm) "spaghetti tubes" connected to 1/2 in (1.27 cm) PVC pipe operating at line water pressure and activated by a clock timer.

A minimum temperature of 23^{o}C was provided by a forced-air natural gas furnace in the control greenhouse, and a force-air propane gas furnace in the experimental greenhouse. Temperature and relative humidity were monitored in both greenhouses with a hygro-thermograph. Carbon dioxide concentrations registered in parts per million were taken at 8 a.m. before the ventilators opened by using a Matheson-Kitawgawa Model No. 8014-400 toxic gas detector using low range (100-7000 ppm) detection tubes.

In the experimental greenhouse, air was drawn through a duct connected to the south side of a 29 stall farrowing unit and into the greenhouse by a fan operating at 11.32 m^3/min (400 cfm) above 21^{o}C and 19.81 m^3/min (700 cfm) at and below 21^{o}C. The control house was not treated with farrowing house air.

All data was subjected to analysis of variance to test treatment components and interactions. Means from significant F tests were seperated by Duncan's Multiple Range Test at the .05 level.

Experiment I: CO_2 Enrichment and Mineral Nutrition of 'La Reine' European Greenhouse Cucumber

One month prior to planting, a soil sample was taken of the silt loam soil in the ground beds in each house. Methyl bromide was used to fumigate all beds, the soil was prepared by roto-tilling, and sphagnum peat moss and ammonium nitrate were incorporated into each bed to achieve medium fertility. The amount of ammonium nitrate and the report of soil fertility are listed in Table 1.

Table 1. Report of soil fertility and amount of ammonium nitrate applied to beds for Experiment I.

	Experimental Greenhouse		Control Greenhouse	
	North Bed	South Bed	North Bed	South Bed
Soil pH	5.5	5.8	5.3	6.1
Organic Matter (%)	3.35	3.60	3.40	3.60
Effective $CaCO_3$ (lb/acre)	4000	4000	6000	2500
Available N (ppm)	26.8	2.8	37.5	17.4
Available P (lb/acre)	177	160	175	126
Exchangeable K (lb/acre)	500	388	500	382
Ammonium nitrate applied (g/bed)	50	162	0	94

Seeds of "La Reine" European greenhouse cucumber were planted in "Jiffy-Mix" media in 7.6 cm (3 in) peat pots on February 28, 1978 in the Horticulture research greenhouse. On March 14 the plants were transplanted to the control and experimental greenhouses at the Swine Unit where they were placed in 5.5 m long by 1.2 m wide by 30 cm deep ground beds, 12 plants per bed and 2 beds per greenhouse. Spacing was 97 cm apart within rows and 91 cm between rows, resulting in .88 m^2 area per plant. Plants were watered every third day with the irrigation system. Whitefly and red spider mites were controlled with the application of resmethrine (5-Benzyl-3-furyl) methyl 2,2-dimethyl-3-(2-methylpropenyl) cyclopropanecarboxylate, and Kelthane 35 (1,1-bis(chlorophenyl)-2,2,2-trichloroethanol) respectively, applied as a spray every other week.

Experimental design consisted of 4 blocks per house with 4 treatments per block assigned at random using a random number table. The treatments were 3 rates (1 rate = 5.6 g fertilizer dissolved in 100 ml water) of complete soluble fertilizer composed of 20% total nitrogen, 20% phosphoric acid, 20% soluble potash, 0.0005% manganese, 0.1000% iron, 0.0500% zinc, 0.0500% copper, 0.0200% boron and 0.0005% molybdenum applied at different times of the week as listed in Table 2.

Table 2. Treatment application rates in grams per plant of 20-20-20 soluble fertilizer in Experiment I.

	Treatments		Total Fertilizer/week	
	Rates*	Times/week	g/plant	kg/ha
1:	1X	1	5.6	63.6
2:	1X	2	11.2	127.2
3:	1X	3	16.8	190.8
4:	3X	1	16.8	190.8

*1X rate = 5.6 g 20-20-20 soluble fertilizer disolved in 100 ml water.

The "umbrella" system (12) was used to prune developing plants by training them up twine to a horizontal pipe two meters overhead and then removing the growing points after the first leaf above the pipe. A small loop of twine around the pipe and the main stem below the top leaf was used to prevent the plant from slipping down the twine. At a very early stage, all side shoots were removed except for two near the top of the plant, which were trained over the pipe and allowed to grow down. The growing points of these two shoots were removed about one meter from the ground. Fruit was prevented from developing on the main stem up to one meter from soil level (29).

Fruits were harvested when they were a minimum of 28 cm in length and a diameter of 4 cm (36,39), and observations were recorded by plant for number of marketable fruit, number of culls and fruit weight. At the end of the growing season (June 16, 1978), a soil sample was taken from each bed and analyzed for pH, effective $CaCO_3$, available phosphorous, exchangeable potassium, manganese, zinc, iron, copper and soluble salts. Leaf samples, three at the top of the main stem per plant, were taken for chemical analysis of the tissue. Leaf tissue was dried to a constant temperature at $65^{o}C$ in an oven and ground in a Wiley mill using a stainless steel # 20 mesh screen. Tissue analysis was performed by the Kansas State University Soil Fertility Laboratory for N, P, K, Ca, Mg, Mn, Zn and Cu. A sulfuric acid digest was used to prepare the ground tissue for analysis of N, P and K, using a 30% H_2O_2 solution as a catalyst; whereas the assay for Mn, Ca, Mg, Mn and Cu used a perchloric acid digest with a 1:1 dilution ratio. N and P were then read on a Technicon Autoanalyzer II while the remaining elements were ascertained by using a Perkins-Elmer Model 390 atomic absorption spectrophotometer.

Carbon dioxide readings were taken once at the beginning of the experiment in the control greenhouse and at weekly intervals in the experimental greenhouse. The number of sows housed in the farrowing house was also recorded at this time.

Experiment II: CO_2 Enrichment and Mineral Nutrition of 'Toska 70' European Greenhouse Cucumber.

Seeds of 'Toska 70' European greenhouse cucumber were planted in "Jiffy-Mix" in 8.9 cm plastic pots on November 11, 1978 in the control and experimental greenhouses at the Swine Unit. On December 1, 1978 the seedlings were transplanted to 15.14 L (4 gal) plastic pots containing a peat-lite soil media (8) as listed in Table 3.

Table 3. Composition of 1 m^3 of peat-lite soil media.

Material	Quantity
Sphagnum peat moss	0.5 m^3
Horticultural perlite	0.5 m^3
Pulverized limestone	5.7 kg
$MgSO_4 \cdot H_2O$	0.3 kg

The potted plants were placed in rows 97 cm apart and 91 cm between rows, 6 pots per row, 24 pots per house with .88 m^2 area per plant. The plants were watered every third day using the irrigation system. White fly and fungal diseases were controlled with resmethrin, and benomyl (methyl 1-(butyl carbmoyl) -2 benzimidazolecarbamate) respectively, applied as a spray every other week.

Experimental design consisted of 4 blocks per house with 4 treatments per block assigned at random using a random number table. The treatments were 3 rates (1 rate = 5.8 g of fertilizer dissolved in 100 ml water) of complete

20-20-20 soluble fertilizer with micronutrients (compostion listed above in Experiment I) applied at different times of the week as listed in Table 4.

Table 4. Treatment application rates in grams per plant of 20-20-20 soluble fertilizer in Experiment II.

Treatments			Total Fertilizer/week	
	Rates*	Times/week	g/plant	kg/ha
1:	1X	1	5.8	65.9
2:	1X	2	11.6	131.8
3:	4X	1	23.2	263.6
4:	2X	3	34.8	395.4

*1X rate = 5.8 g 20-20-20 soluble fertilizer disolved in 100 ml water.

Developing plants were pruned using the "umbrella"system (12) as described in Experiment I. Fruits were harvested when they were a minimum of 28 cm in length and 4 cm in diameter. Observations were recorded by plant for number of marketable fruit, number of culls and fruit weight. At the end of the growing season (April 8,1979), the soil media in each pot was tested for soluble salts content using a Solu Bridge Model 15A.

Experiment III: CO_2 Enrichment and Soil Media Effects on 'Slice Master Hybrid' Cucumber.

In both the experimental and control greenhouses, seeds of 'Slice Master Hybrid' cucumber were planted in 8.9 cm plastic pots containing treatments of "Jiffy-Mix",or the peat-lite soil media described in Experiment II, Table 3, but without the addition of $MgSO_4 \cdot H_2O$. Experimental design for each greenhouse consisted of a randomized block of 48 plants with 3 replications per treatment and 8 plants per replicate. This study was repeated 4 times by growing the plants from seed for 30 day periods. The individual plants' true leaf number and estimated true leaf area were recorded. Estimated leaf area was determined by measuring the length of the leaf by the maximum width and multiplying by a factor of 0.73. This factor was determined by measuring 10 cucumber leaves for area using first a planimeter and then the "length by width" method. The corresponding area from the planimeter procedure was then divided by the area of the "length by width" method resulting in a mean factor of 0.73. The resulting factor gives a fairly accurate estimate of the leaf area for rapid comparison of treatments (1,16,33,37). Plants were then cut off at soil level, the tops dried to a constant weight of 65^{o}C in a forced air oven, and weighed.

Carbon dioxide readings were taken every 15 days from the first planting and one reading was taken for ammonia concentration in the experimental greenhouse. The same method was used for ammonia as CO_2, except that ammonia detection tubes were used. Outdoor light intensities, reported in Langleys, were obtained from the Kansas State University Physics Department, and were recorded as the mean for each day of the growing season.

RESULTS and DISCUSSION

Experiment I: CO_2 Enrichment and Mineral Nutrition of 'La Reine' European Greenhouse Cucumber.

The carbon dioxide concentration in the control house registered 300 ppm, the normal ambient level. In the experimental greenhouse, the concentration averaged 1000 ppm over the 15 week growing period and varied from 300 ppm with no swine present in the farrowing house to 1500 ppm with 28 sows and their young, as listed in Table 5. Variations in readings were primarily due to the wind opening the ventilator louvers and air leaks in the greenhouse covering.

Table 5. Weekly carbon dioxide readings expressed in ppm in the experimental greenhouse and number of sows in the farrowing unit for Experiment I.

Date (1978)	CO_2 ppm	Sows*	Date (cont.)	CO_2 ppm	Sows*
3/ 6	1500	11	5/ 5	300	0
3/17	1300	15	5/12	300	0
3/24	1000	18	5/19	600	6
3/31	1000	28	5/26	1200	16
4/ 7	1300	28	6/ 2	1300	21
4/14	1500	27	6/ 9	1300	21
4/21	1000	8	6/19	1300	21
4/28	400	4			

*This figure indicates the number of sows and does not include the offspring, which averaged 8 pigs to the litter.

Because the furnaces and exhaust fans were controlled by thermostats, the temperatures were generally the same for both greenhouses. The average nightly relative humidity, however, was approximately 12% higher in the experimental greenhouse than the control. This was primarily due to the humid air coming through the duct from the farrowing house. The average monthly nightly relative humidity is listed in Table 22 in the Appendix.

No yield data was available for the control greenhouse for the entire growing season. Plants grew poorly and were stunted, yielded no market quality fruit, and leaves were necrotic and chlorotic with very short internodes. This problem was not observed in the experimental greenhouse, which had the same soil, fertilizer treatments, temperature and watering regimes; therefore air pollution from the natural gas furnace was suspected. Several sources (23,41,43,45) reported similar plant symptoms caused by ethylene and carbon monoxide, which are the result of incomplete combustion, especially with a natural gas furnace.

In the experimental greenhouse, there was no significant difference between fertilizer treatments in the number of marketable fruit, fruit weight and number of culls as listed in Table 6 and 16. Treatment 1 of 5.6 g of fertilizer per week, although not significantly different from the other treatments, had the highest overall yield and was within the range of 7.5 g per week that was recommended by Ward (47).

Tissue analysis of the three top leaves of the main stem of each plant for N, P, K, Mn, Ca, Mg, Zn and Cu content, resulted in no significant differences between fertilizer treatments regardless of greenhouse effect, as reported in Tables 7, 17 and 18.

Table 6. Effects of Different Rates of 20-20-20 Fertilizer on Mean Fruit Weight (kg), Marketable Fruit Number and Fruit Culls per Plant for Experiment I.

Treatment[1]	Fruit Weight	Mkt. Fruit Number	Fruit Culls
1: 1X rate 1 time /week	10.3 a*	17 a*	0.3 a*
2: 1X rate 2 times/week	9.0 a	16 a	1.0 a
3: 1X rate 3 times/week	9.7 a	17 a	1.0 a
4: 3X rate 1 time /week	8.6 a	16 a	0.3 a

*Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.5 level.

[1]1X rate = 5.6 g 20-20-20 fertilizer disolved in 100 ml water.

Table 7. Effects of Different Rates of 20-20-20 Fertilizer, Regardless of Greenhouse Effect, on Mineral Content of Cucumber Leaves for Experiment I.

A. Content of Nitrogen, Phosphorous, Potassium and Calcium (per cent)

Treatment[1]	N	P	K	Ca
1: 1X rate 1 time /week	4.69 a*	0.48 a*	2.11 a*	3.23 a*
2: 1X rate 2 times/week	4.54 a	0.61 a	2.27 a	3.63 a
3: 1X rate 3 times/week	5.08 a	0.68 a	2.80 a	2.85 a
4: 3X rate 1 times/week	4.52 a	0.50 a	2.40 a	3.72 a

B. Content of Manganese, Magnesium, Zinc and Copper (ppm)

Treatment[1]	Mn	Mg	Zn	Cu
1: 1X rate 1 time /week	138 a*	708 a*	129 a*	11 a*
2: 1X rate 2 times/week	141 a	728 a	85 a	12 a
3: 1X rate 3 times/week	167 a	687 a	87 a	10 a
4: 3X rate 1 time /week	160 a	725 a	110 a	11 a

*Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.5 level.

[1]1X rate = 5.6 g 20-20-20 fertilizer disolved in 100 ml water.

The effects of the experimental greenhouse environment compared to the control greenhouse, regardless of fertilizer treatments, showed a significant increase in N, P and K for the plants from the control greenhouse; Ca and Mg increased for plants from the experimental greenhouse; and no significant difference for Mn, Zn and Cu for either house as listed in Tables 8, 17 and 18.

Table 8. Effects of Experimental and Control Greenhouses, Regardless of Fertilizer Treatments, on N, P, K, Ca (per cent), Mn, Mg, Zn and Cu (ppm) Content in Leaves of Cucumber in Experiment I.

Greenhouse	N	P	K	Ca	Mn	Mg	Zn	Cu
Experimental:	4.25 a*	0.44 a*	1.98 a*	3.95 a*	154 a*	829 a*	78 a*	11 a*
Control:	5.16 b	0.70 b	2.80 b	2.77 b	149 a	595 b	127 a	11 a

*Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.5 level.

Soil tests of the beds in both greenhouses, listed in Table 9, reported no great difference between the beds in either house, therefore, the differences in the tissue analysis probably can be attributed to the suspected air pollution problem in the control greenhouse. The lower leaves of the plants in this greenhouse were generally defoliated, which could have a tendency to create an imbalance in the translocation of mineral nutrients, and perhaps give a false indication of the tissue content when compared to the healthy plants in the experimental greenhouse. The elemental content of the leaf tissue from the experimental greenhouse was not deficient when compared to the results of other reseachers (19,30 38,48).

Table 9. Report of soil fertility for soil beds in both greenhouses for Experiment I.

	Experimental		Control	
	North Bed	South Bed	North Bed	South Bed
Soil pH	5.5	5.7	5.7	5.7
Effective $CaCO_3$ (lb/acre)	2500	2500	2500	3000
Available P (lb/acre)	177	200	160	151
Exchangeable K (lb/acre)	500	473	500	379
Mn (ppm)	61	56	45	55
Zn (ppm)	3	3	2	2
Fe (ppm)	82	76	97	83
Cu (ppm)	3	3	2	2
Soluble Salts (millimhos/cm)	1.12	.75	1.3	1.25

Experiment II: Carbon Dioxide Enrichment and Mineral Nutrition of 'Toska 70' European Greenhouse Cucumber.

A little more than a month after transplanting, the furnace in the control greenhouse malfunctioned. This resulted in the freezing of all plants, and no yield data for comparison with the experimental greenhouse was recorded.

In the experimental greenhouse, there was a considerable difference among fertilizer treatments in regards to yield as listed in Table 10 and 19. For fruit weight, there was no significant difference between Treatments 1 and 2, and 1 and 3, but a significant difference between Treatments 2, 3 and 4. For marketable fruit number, there was a significant difference among treatments, with Treatment 2 having the most fruit at 20 per plant. For fruit culls, only Treatment 2 had any culls recorded, and was significantly different from the other treatments.

Table 10. Effects of different rates of 20-20-20 fertilizer on mean fruit weight (kg), marketable fruit number and fruit culls per plant for Experiment II.

Treatment[1]	Fruit Weight	Mkt. Fruit Number	Fruit Culls
1: 1X rate 1 time /week	5.4 a*b	17 a*	0.0 a*
2: 1X rate 2 times/week	6.5 a	20 b	0.3 b
3: 4X rate 1 time /week	5.0 b b	14 c	0.0 a
4: 2X rate 3 times/week	2.6 c	8 d	0.0 a

*Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the .05 level.

[1]1X rate = 5.8 g 20-20-20 fertilizer disolved in 100 ml water.

By the end of the experiment, all plants in Treatments 3 and 4 had died, most likely due to the high soluble salt content of the soil media as listed in Table 11. Plants in these treatments exhibited excessive leaf margin burn, wilting, degradation of the stem at the soil line, wet soil and poor growth. These symptoms agree with those of Tiessen et al. (40) for high soluble salts damage.

Table 11. Effects of fertilizer treatments on soluble salts content of soil media for Experiment II.

Treatment[1]	Millimhos/cm[2]
1: 1X rate 1 time /week	0.87
2: 1X rate 2 times/week	1.44
3: 4X rate 1 time /week	1.72
4: 2X rate 3 times/week	1.89

[1]1X rate = 5.8 g 20-20-20 fertilizer disolved in 100 ml water

[2]Interpretation (40):

.50 to 1.80	Satisfactory range for established plants but upper range may be too high for some seedlings or sensitive plants.
1.80 to 2.25	Slightly higher than desirable for most plants.

Experiment III: Carbon Dioxide Enrichment and Soil Media Effects on 'Slice Master Hybrid' Cucumber.

Carbon dioxide concentration in the experimental greenhouse registered approximately 1500 ppm each time when tested every 15 days from the first planting date to the last harvest. For the duration of the experiment, the farrowing unit was occupied at full capacity of 29 sows plus their young. A test for ammonia in the experimental greenhouse atmosphere revealed none present at the time of sampling.

For the two soil medias tested, regardless of greenhouse effect, "Jiffy-Mix" produced plants in both greenhouses with significant increases in mean dry weight, first true leaf area and true leaf number of 496%, 614% and 81% respectively, when compared with the peat-lite media, as listed in Table 12 and 20. Because "Jiffy-Mix" contains a starter fertilizer and the peat-lite media contain none, these increases were to be expected.

The peat-lite was prepared without fertilizer in order to indicate whether the plants were receiving any nutrition from gases in the greenhouse atmosphere, such as ammonia or carbon dioxide. Because ammonia was not detected, carbon dioxide in high concentrations (1500 ppm) was most likely responsible for the significant increases in mean plant observations for plants grown in both the peat-lite and "Jiffy-Mix" soil medias in the experimental as compared to the control greenhouse as reported in Table 13.

Comparison of observations between greenhouses, regardless of soil media treatment, resulted in significant increases in the experimental greenhouse in plant mean dry weight, first true leaf area and true leaf number of 280%, 89% and 92% respectively, as reported in Table 14 and 20. These results, primarily due to the enriched CO_2 atmosphere, agree with research on CO_2 done by

Klougart (25) and Krizek (27), where they reported increases in true leaf area; Wittwer (52) and Newton (34), who reported increases in true leaf number; and Aoki (4), Hopen and Ries (22), who found increases in dry weight.

Table 12. Comparison of "Jiffy-Mix" and peat-lite soil medias for plant mean dry weight, first true leaf area and true leaf number for Experiment III.

Soil Media	Dry Weight		True Leaf Area		True Leaf Number	
	grams	% increase	cm^2	% increase	number	% increase
Jiffy-Mix	0.91 a*	496%	53 a*	614%	3.6 a*	81%
Peat-Lite	0.15 b		7 b		1.9 b	

*Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the .05 level.

Table 13. Effects of soil media-greenhouse interaction on mean plant first true leaf area, true leaf number and dry weight for Experiment III.

Media[1]	House[2]	Leaf Area	Media[1]	House[2]	Leaf Number	Media[1]	House[2]	Dry Weight (g)
J	E	67.8 a*	J	E	4.7 a*	J	E	1.43 a*
J	C	38.6 b	P	E	2.6 b	J	C	0.38 b
P	E	11.6 c	J	C	2.4 b	P	E	0.24 c
P	C	3.3 d	P	C	1.4 c	P	C	0.06 d

*Means in the same column followed by the same letter are not sifnificantly different according to Duncan's Multiple Range Test at the .05 level.

[1]For Media: J = "Jiffy-Mix"; P = Peat-Lite.

[2]For Greenhouse: E = Experimental; C = Control.

There was some difference in the observations, regardless of greenhouse or media treatment, for different plant-harvest periods as listed in Table 15.

Only Period IV was significantly different from the other periods for mean plant dry weight; there was no significant difference in first true leaf area; and only Period I was significantly different for true leaf number. For solar radiation, Period IV was significantly different from I and II, but not III. This was due to the days becoming longer during Periods III and IV.

Table 14. Comparison of experimental and control greenhouse environments, regardless of soil medias for plant mean dry weight, first true leaf area and true leaf number for Experiment III.

Greenhouse	Dry Weight		True Leaf Area		True Leaf Number	
	grams	% increase	cm^2	%increase	number	% increase
Experimental	0.84 a*	280%	39.6 a*	89%	3.6 a*	92%
Control	0.22 b		20.9 b		1.9 b	

*Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.5 level.

Table 15. Comparison of plant-harvest periods for plant mean dry weight, first true leaf area, true leaf number and solar radiation for Experiment III.

Plant-Harvest Period (1979)	Dry Weight g/plant	Leaf Area cm^2/plant	True Leaf Number	Solar Radiation[1]
I: 1/25-2/23	0.43 a*	29.4 a*	2.1 a*	261 a*
II: 2/8 -3/9	0.53 a	32.7 a	2.9 b	272 a
III: 2/23-3/24	0.48 a	30.2 a	3.0 b	316 a b
IV: 3/9 -4/7	0.68 b	28.9 a	2.9 b	345 b b

*means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.5 level.
[1]Measured in Langleys (one gram calorie per cm^2 of irradiated surface).

Klougart (25) reported that more light developed a larger productive leaf area, although plants may suffer from water stress as increased active leaf area also gives a larger evaporation with higher light intensities. As there was no significant difference between plant-harvest periods for leaf area, especially for the control greenhouse, transpiration may have been a factor because the control greenhouse averaged approximately 10% lower in relative humidity than the experimental greenhouse. This decrease in humidity may have increased transpiration and possibly slowed growth in the control house.

Variation in cloudy and sunny periods may also have been a factor in influencing growth, even though the average solar radiation was higher for a 30 day period. If the sunny days occurred at the beginning of a growth period, with cloudy days following, this may have a tendency to slow growth as well.

The average nightly relative humidity for the duration of the study was approximately 26% higher in the experimental greenhouse than the control. This information, averaged by plant-harvest periods, is listed in Table 23 in the Appendix.

SUMMARY and CONCLUSIONS

Experiment I: CO_2 enrichment and mineral nutrition of 'La Reine' European greenhouse cucumber.

Carbon dioxide concentration of the control greenhouse was an ambient 300 ppm while the experimental greenhouse averaged 1000 ppm and varied from 300 ppm with no swine present to 1500 ppm with 29 swine and litters in the farrowing house during the 15 week growing period. Concentrations tended to vary due to the ventilator being opened by the wind or air leaks in the plastic covering, reducing the experimental greenhouse carbon dioxide content. Yield was not significantly affected by any of the fertilizer treatments. The lowest rate of 5.6 g 20-20-20 per plant per week appeared to be the most cost effective application for good yield. Tissue analysis of the plants in the experimental greenhouse confirmed that there was no nutritional deficiencies among any of the fertilizer treatments applied.

Experiment II: CO_2 enrichment and mineral nutrition of 'Toska 70' European greenhouse cucumbers.

A significant difference was found among fertilizer treatments, with treatment 2 yielding the highest in fruit weight and number. Treatments 3 and 4 were found to be unsatisfactory because of high soluble salt accumulation in the soil media which led to the death of the plants. Research needs to be done with other soil mixes to avoid excess moisture as well as the addition of slow release fertilizer into the media. Work also needs to be done comparing non-carbon dioxide enriched cucumber yield trials with those with CO_2 enrichment.

Experiment III: CO_2 enrichment of 'Slice Master hybrid' cucumber.

Carbon dioxide enrichment in the experimental greenhouse of approximately 1500 ppm, significantly increased plant mean dry weight, first true leaf area and number of true leaves over the control greenhouse, regardless of soil media used. Plants grown in "Jiffy-Mix", regardless of greenhouse, had significantly greater plant mean dry weight, first true leaf area and number of true leaves ofer the peat-lite media. Increases in observations were due primarily to the enriched CO_2 atmosphere in the experimental greenhouse, and not to any other detectable gas, such as ammonia, which was not found in the air. The 30 day plant to harvest periods had little or no significant effect with time as compared to the increase in the the solar radiation with the lengthening days.

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VITA

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A P P E N D I X

Table 16. Analysis of variance of Experiment I: Effect of treatments on marketable fruit number, fruit weight and fruit culls.

A. Marketable fruit number

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	1.729	.975
Blocks	3	2.896	.948
Error	9	24.729	
TOTAL	15		

B. Fruit weight

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	2.150	.833
Blocks	3	.883	.947
Error	9	7.454	
TOTAL	15		

C. Fruit culls

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	.750	.088
Blocks	3	2.417	.004
Error	9	.250	
TOTAL	15		

Table 17. Analysis of variance of Experiment I: Effect of fertilizer treatments and greenhouses on nitrogen, phosphorous, potassium and calcium content of cucumber leaves.

A. Nitrogen content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	.403	.607
Blocks	2	.135	.813
Greenhouses	1	4.914	.015
Trtmt. X Grnhses.	3	.279	.731
Error	14	.641	
TOTAL	23		

B. Phosphorous content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	.054	.111
Blocks	2	.003	.868
Greenhouses	1	.400	.001
Trtmt. X Grnhses.	3	.006	.853
Error	14	.023	
TOTAL	23		

C. Potassium content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	.512	.175
Blocks	2	.841	.075
Greenhouses	1	4.018	.002
Trtmt. X Grnhses.	3	.022	.512
Error	14	.269	
TOTAL	23		

D. Calcium content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	95986237.167	.541
Blocks	2	70077633.000	.461
Greenhouses	1	824033204.167	.024
Trtmt. X Grnhses.	3	169591704.167	.307
Error	14	128314002.381	
TOTAL	23		

Table 18. Analysis of variance of Experiment I: Effect of fertilizer treatments and greenhouses on manganese, magnesium, zinc and copper content of cucumber leaves.

A. Manganese content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	1203.523	.625
Blocks	2	6134.490	.079
Greenhouses	1	127.882	.804
Trtmt. X Grnhses.	3	3341.965	.219
Error	14	2007.331	
TOTAL	23		

B. Magnesium content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	2095.072	.943
Blocks	2	12836.895	.480
Greenhouses	1	325920.427	.001
Trtmt. X Grnhses.	3	44738.597	.086
Error	14	16589.757	
TOTAL	23		

C. Zinc content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	2612.764	.503
Blocks	2	7826.047	.122
Greenhouses	1	14176.620	.053
Trtmt. X Grnhses.	3	919.290	.833
Error	14	3183.420	
TOTAL	23		

D. Copper content

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	2.873	.901
Blocks	2	3.423	.800
Greenhouses	1	.184	.914
Trtmt. X Grnhses.	3	14.022	.453
Error	14	15.118	
TOTAL	23		

Table 19. Analysis of variance of Experiment II: Effect of treatments on marketable fruit number, fruit weight and fruit culls.

A. Marketable fruit number

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	76.555	.0001
Blocks	2	6.583	.006
Error	6	.472	
TOTAL	11		

B. Fruit weight

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	8.242	.001
Blocks	2	.880	.880
Error	6	.371	
TOTAL	11		

C. Fruit culls

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Treatments	3	.083	.454
Blocks	2	.083	.422
Error	6	.083	
TOTAL	11		

Table 20. Analysis of variance of Experiment III: Effect of treatments on first true leaf area, true leaf number and top dry weight.

A. First true leaf area

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Greenhouses	1	210.708	.0001
Treatments	1	1259.984	.0001
Blocks	8	19.941	.583
Time	3	32.021	.282
Time X Grnhses.	3	53.082	.107
Trtmts. X Grnhses.	1	1305.836	.0001
Error	30	24.018	
TOTAL	47		

B. True leaf number

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Greenhouses	1	385.120	.0001
Treatments	1	325.106	.0001
Blocks	8	.094	.723
Time	3	2.188	.0001
Time X Grnhses.	3	1.003	.001
Trtmts. X Grnhses.	1	3.245	.0001
Error	30	4.306	
TOTAL	47		

C. Top dry weight

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Greenhouses	1	300.197	.0001
Treatments	1	447.229	.0001
Blocks	8	.015	.767
Time	3	.136	.004
Time X Grnhses.	3	.002	.163
Trtmts. X Grnhses.	1	2.245	.0001
Error	30	.753	
TOTAL	47		

Table 21. Analysis of variance of Experiment III: Effect of mean light intensities for 30-day plant-harvest periods.

Source of Variation	Degrees of Freedom	Mean Square	Alpha
Plant-Harvest Periods	3	45896.83	.057
Error	116	17859.76	.057
TOTAL	119		

Table 22. Comparison of average nightly relative humidity (%) by month in 1978 for Experiment I.

Month	Experimental Greenhouse	Control Greenhouse
March	78	58
April	78	60
May	80	73
June	90	88

Table 23. Comparison of average nightly relative humidity (%) by plant-harvest periods for Experiment III.

Plt-Hv Periods (1979)	Experimental Greenhouse	Control Greenhouse
I: 1/25-2/23	56	33
II: 2/8 -3/9	58	33
III: 2/23-3/24	62	34
IV: 3/9 -4/7	62	34

EFFECTS OF SWINE FARROWING HOUSE AIR

AND MINERAL NUTRITION ON *CUCUMIS SATIVUS*, L.

by

JOHN EDWARD LONG IV

B.A., University of Kansas, 1972

AN ABSTRACT OF A MASTER'S THESIS

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Swine farrowing houses are continuously ventilated in order to remove potentially toxic gases. In this process, heat, humidity and high concentrations of carbon dioxide are wasted. Rather than vent the waste air to the outside atmosphere, the air was vented into a polyethylene plastic-covered greenhouse on the south side of a farrowing house. Cucumber plants were then grown in the experimental greenhouse containing the farrowing house exhaust, and an identical control greenhouse without the farrowing house air.

The objectives of these experiments were to evaluate the effect of different rates of a complete soluble fertilizer on the yield of two varieties of European cucumbers grown in the exhaust air from a swine farrowing house, and to evaluate the effects of swine farrowing house air as a source of carbon dioxide on cucumber seedlings grown in two soil medias.

In Experiment I, European greenhouse cucumber variety 'La Reine' was grown in soil beds using four rates of 20-20-20 soluble fertilizer applied at 5.6 g one time/week; 11.2 g two times/week; 16.8 g three times/week; or 16.8 g one time/week per plant. It was concluded that there was no significant difference in fruit weight, number or culls between any of the treatments. Yield between the experimental and control greenhouses was unavailable because of poor growth of the plants in the control greenhouse due to suspected air pollution from the furnace. Carbon dioxide concentrations in the Experimental greenhouse averaged 1000 ppm for the 15 week study compared to 300 ppm in the control greenhouse.

In Experiment II, European greenhouse cucumber variety 'Toska 70' was grown in plastic pots containing peat-lite media using four rates of 20-20-20 soluble fertilizer applied at 5.8 g one time/week; 11.6 g two times/week; 23.2 g one time/week; or 34.8 g. three times/week per plant. It was concluded that 11.6 g of fertilizer two times per week gave the most significant increase in fruit weight and number. No yield data was available for the control greenhouse due to a malfunction of the furnace and the consequent freezing of all plants.

In Experiment III, cucumber variety 'Slice Master Hybrid' was grown in both greenhouses from seed in plastic pots containing either "Jiffy-Mix" media, which contained a starter fertilizer, or peat-lite media, which contained no fertilizer. After 30 days, plants were measured for first true leaf area, true leaf number and plant top dry weight. This study was repeated four times. It was concluded that "Jiffy-Mix," regardless of greenhouse, gave significantly greater increases of 496%, 614% and 81% for plant mean dry weight, first true leaf area and true leaf number. The carbon dioxide in the experimental greenhouse, which averaged 1500 ppm for the duration of the study, compared to 300 ppm for the control, gave significant increases of 280%, 89% and 92% for plant mean dry weight, first true leaf area and true leaf number, regardless of soil media used.

On the basis of this study, it can be concluded that excellent growth in cucumbers can be achieved using the exhaust air from a swine farrowing house.