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INFLUENCE OF ATMOSPHERIC CARBON DIOXIDE ENRICHMENT ON THE PRODUCTION AND BIOCHEMICAL COMPOSITION OF ROOTS OF SWEET POTATO

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ABSTRACT

Sweet potato **(Ipomoea batatas** (L.) Lam., 'Georgia Jet') plants were grown in open field plots and open top chambers at CO_2 concentrations of 354, 431, 506, and 659 $\mu l l^{-1}$ during May to August, 1984. The plants were harvested at 92 days of growth and the different plant parts were separated. The number of tubers per plant increased significantly with an increase in CO_2 concentrations. However, the density, volume, and mean length of US #1, 2, canner, cull or jumbo roots did not show any significant differences with elevated CO_2 concentrations. Starch content in sweet potato roots increased significantly in plants grown at 431 and 506 $\mu l l^{-1}$ CO_2. The percentage of sucrose, soluble amino acids, and proteins decreased with an increase in CO_2 enrichment and were most noticeable at 659 $\mu l l^{-1}$ CO_2 atmosphere.

INTRODUCTION

Global concentration of atmospheric carbon dioxide (CO_2) is steadily increasing due to rapid industrialization, deforestation and consumption of fossil fuel. It has been predicted that CO_2 concentration in the atmosphere will be doubled from its present level by the year 2025 (Clark et al. 1982). Strain and Cure (1985) catalogued the responses of increased concentrations of carbon dioxide in different food crops yet, limited information is available on root and tuber crops. Although CO_2 enrichment effects in sweet potatoes have been investigated in phytotron (Bhattacharya et al. 1985) as well as in open top chambers (Biswas et al. 1986), these reports demonstrated that the production of foliage and roots increased in response to CO_2 enrichment at the earlier stages of growth of plants. At maturity, the increase in the production of sweet potato roots was not proportional with increased concentrations of carbon dioxide in the atmosphere. It is not known from the available data whether CO_2 enrichment affects qualitative or quantitative changes in the biochemical composition of sweet potatoes or any other crop plants. Sweet potatoes are extensively grown in southern United States as well as in the tropical, sub-tropical and warm-temperate regions of the world as one of the major sources of carbohydrates, proteins and vitamins for livestock and human consumption. We therefore considered of interest to investigate the effects of CO_2 enrichment on the production and biochemical composition of roots of sweet potatoes in open top chambers under environmental conditions.

MATERIALS AND METHODS

Field Site: The experiment was conducted in the Summer 1984 at the Tuskegee **University's George** Washington Carver Agricultural Experiment Station, Alabama. The soil was a Norfolk sandy loam (Typic Paleudult), with a pH ranging from 6.2 to 6.9. The specific field used for the experiment was flat, but slightly sloped to the northeast.

Experimental Design and Field Layout: Sweet potato plants were exposed to five treatments in a randomized block design with three replicate blocks. The five treatments consisted of an open field plot with no chamber and four chambers with CO_2 levels of 354, 431, 506 and 659 $\mu l l^{-1}$. A randomized block design was used because the higher end of the field was somewhat better drained than the lower end. The blocks were arranged in rows running perpendicular to the direction of the slope. This design assured a random distribution of the replicates with respect to soil drainage.

Planting and Assembly of Chambers: Sweet potato plants (**Ipomoea batatas** (L.) Lam. 'Georgia Jet') that were three months old and about 20-25 cm in length were obtained from the South Macon County Sweet Potato Cooperative, Inc., Tuskegee, Alabama. The plants were transplanted into the field by hand, with the help of wooden stakes, on May 21, 1984. Plants were placed about 30 cm apart in rows that were about 90 cm apart. The rows were raised about 20 cm above the surrounding soil. The chambers were assembled and placed on the field during the period of May 23-27. There were two rows of 10 plants inside each chamber. From May 28 to June 7 necessary adjustments were made in the CO_2 dispensing and monitoring systems. Dispensing and monitoring of CO_2 in the chambers began on June 8 (see Figs. 1-4 and Biswas et al. 1985 for details).

Maintenance of the Crop: Water was applied to the field by drip irrigation as necessary to supplement natural rainfall. There was little rainfall in the first part of the growing season, and irrigation was needed frequently. During the second part of the growing season, the rainfall was more than average, consequently no irrigation water was provided. Fertilizer was applied at the rate of 15 kg of nitrogen, 15 kg phosphorus and 22.0 kg of potassium per ha, based on soil tests. One-half of the fertilizer was applied in bands along the rows at the time of planting; the other half was side-dressed four weeks after planting. Weeding in and around the chambers and open field plots was done manually.

Problems with insects were minor; thus no insecticide was used. Nematode counts were taken at the middle and at the end of the growing period. Nematode counts were insignificant.

Harvest of Sweet Potato Roots: The sweet potato roots were harvested during August 17-29. Roots were dug from the same ten plants in each plot that were used in the vegetative harvest. The roots were placed on a board, lightly rinsed with water in order to remove clumps of soil adhering to the roots, then air-dried outdoors for 10 to 15 minutes. The fresh weight, diameter, length, and volume were taken for each individual root. Any roots which were odd-shaped were noted. Diameter was taken with calipers at the greatest dimension measured at right angles to the longitudinal axis. The length was taken at the greatest dimension measured in a line between points at each end. Volumes are measured by the displacement of known amounts of water in several different size graduated cylinders and beakers. The total fresh weight and number of roots, as well as the mean length, diameter and volume of the roots, were calculated for each plot. Individual root fresh weight and volumes were used to calculate the density of each tuber.

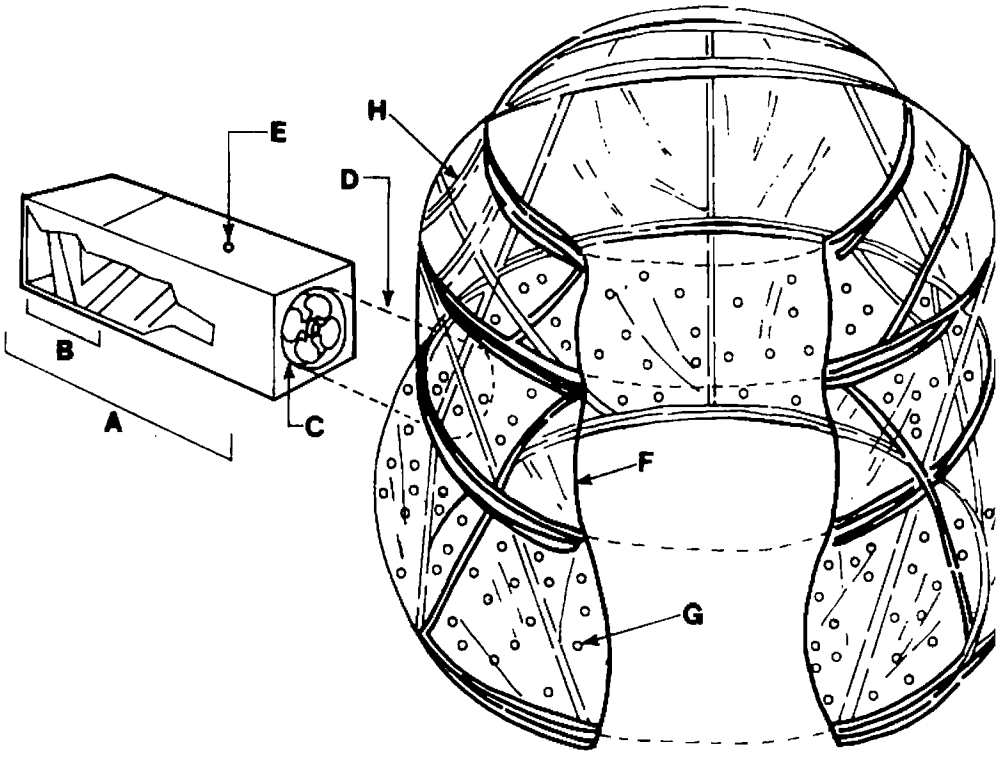

Fig. 1. Diagram of open top chamber. This chamber consists of an aluminum frame covered with clear polyvinylchloride film. A. Plenum box; B. Louvers, screen and fiberglass particulate filters; C. 0.5 HP axial fan; D. Connecting duct; E. CO_2 inlet; F. Upper panel; G. Double walled lower duct panel with perforated inner wall; H. 45 frustum panel.

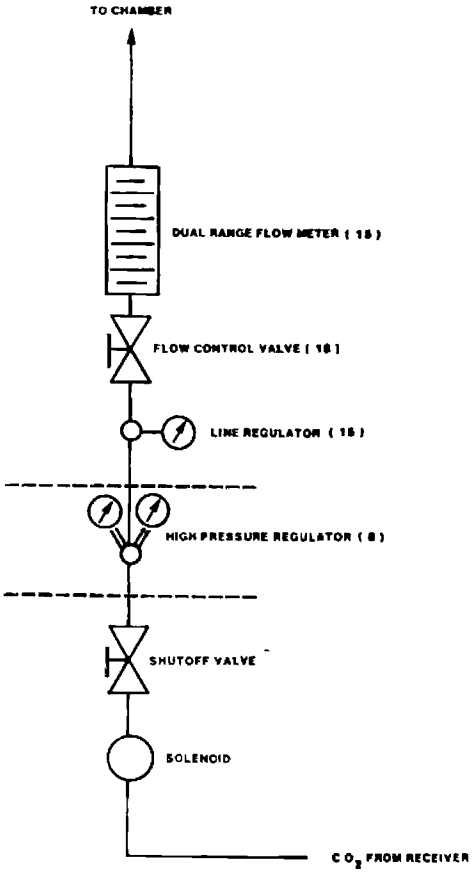

Fig. 2. Diagram of carbon dioxide dispensing manifold. Numbers in parenthesis indicate the number of each type of component in the system. Dotted lines indicate the positions of branches in the gas flow to multiple components.

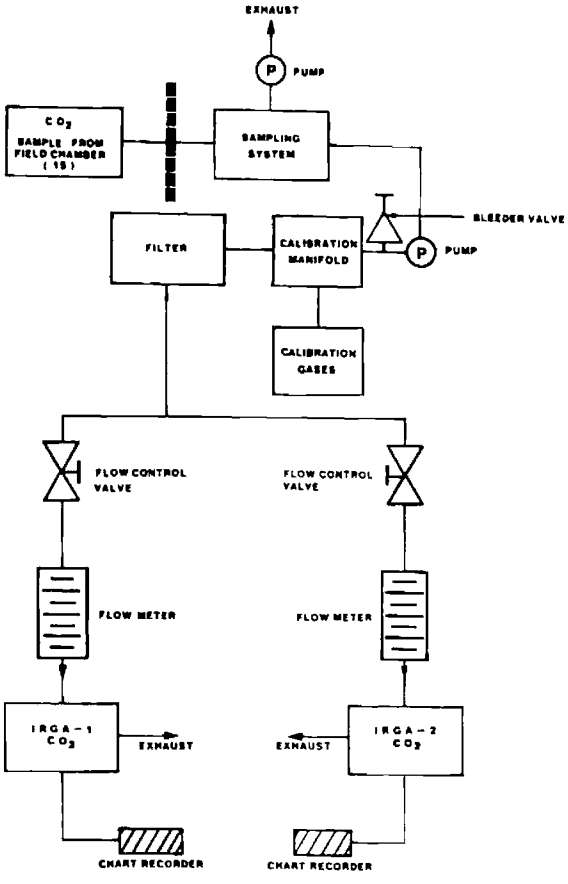

Fig. 3. Diagram of CO_2 sampling pathway. Dotted lines indicate that there are 15 chambers feeding into the sampling system. The sampling systems divert the gas from one chamber at a time to the infrared gas analyzers (IRGAs), while the gas from the remaining chambers is exhaused.

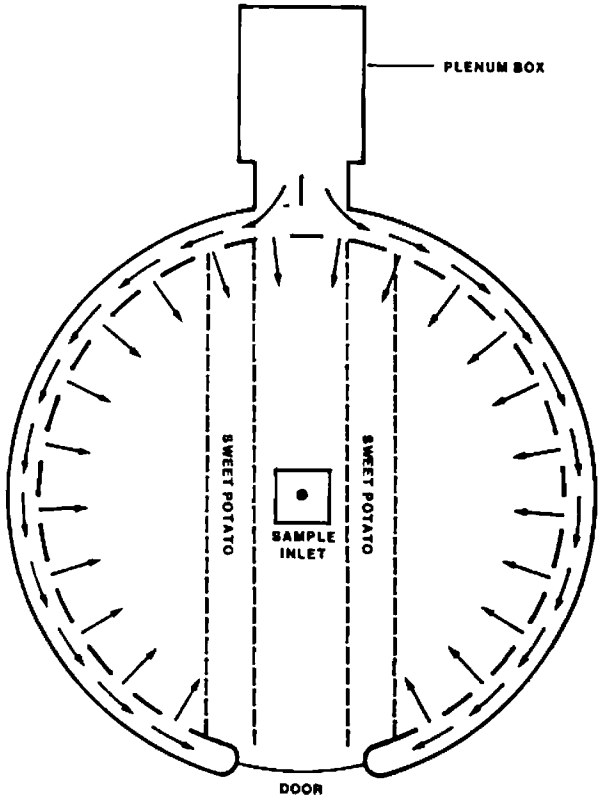

Fig. 4. Cross section of bottom half of open top chamber showing position of sweet potato plants and CO_2 sample inlet.

On August 30, two root samples of each grade from each plot were selected and fresh weights were taken. Jumbo grade roots were present in only 4 plots and were used when available. Each root was cut into slices less than 0.5 cm in width. These samples were placed in paper bags and dried in ovens at a temperature of 55 ± 5ºC.

Root Grades: The individual root measurements for fresh weight, diameter, length, and volume were entered in the computer. A code for odd shaped roots was entered also. The size requirements for each grade generally followed those of the North Carolina Department of Agriculture and Rogers et al. (1983). Based on these size requirements, the individual roots in each plot were placed in a specific grade using SAS (Statistical Analysis System).

The criteria used to place individual roots in a grade are as follows:

Grade (gm)	Length (cm)	Diameter (cm)	Weight (gm)
US #1	4.0 <= length <= 23	4.0 <= diameter <= 9.0	< 1022
US #2		diameter > 3.8	< 1022
Canner		2.5 <= diameter <= 3.8	< 1022
Cull		diameter < 2.5	< 1022
Jumbo			>=1022

Grade 2 roots are similar in size to #1's but fall into another grade due to their being odd shaped.

Statistical Analysis of Sweet Potato Data: Statistical analysis of sweet potato growth data was performed using standard analysis of variance technique (Snedecor and Cochran, 1967) and by utilizing SAS (Statistical Analysis System, SAS Institute, Cary, NC). In the analyses, a complete randomized block design was used with five treatments (four open top chambers at 354, 431, 506 and 659 $\mu l l^{-1}$ CO_2 and the open field plot) in each block. There were three replicate blocks. An analysis of variance was run on all data with the model shown below:

Source	Degrees of Freedom
Block	2
CO_2	4
Error	8
Total	14

Tests for significance were done with the Block * CO_2 error mean square from the ANOVA. This error term had 8 degrees of freedom. The coefficient of variation (CV) was calculated by the ANOVA procedure. The S- (standard error of the mean) was calculated as follows:

$$S\bar{} = \sqrt{\frac{\text{Error Mean Square}}{N}}$$

where N = 3. The LSD (least significant difference) is a test for all main-effect means.

Biochemical Estimations: Oven dried roots of sweet potato were used for the estimation of starch, sucrose, soluble amino acid and total proteins by following the methods of Huber and Israel (1982), Jones et al. (1977), Moore and Stein (1948) and Lowry et al. (1951), respectively with some modifications.

RESULTS AND DISCUSSION

Sweet potato plants grown in enriched CO_2 atmosphere under field conditions showed greater increase in root biomass than shoot biomass. A comparison between growth pattern of sweet potato plants at ambient CO_2 in open field plots and open top chambers showed reduced growth of shoots in open top chambers than in open field plots (unpublished data). The decrease in several growth parameters in open top chambers may be attributed to increased rate of moisture loss due to high wind velocity inside the chambers, increased temperature and reduced light intensity (Rogers et al. 1983). However, a significant increase in total root numbers (Table 1) in response to CO_2 enrichment indicates the partitioning of photosynthate from leaves to the roots. The increase of root production with increased concentrations of carbon dioxide in this cultivar is being reported in phytotron study by Bhattacharya et al. (1985). The number, density, mean length and volume in each of the grades of roots did not show any significant differences among US #1, US #2, Canner, Cull and Jumbo' (Tables 1-4). Only Canner roots showed significant variation in mean diameter (Table 5) as compared with other grades of roots. Results on the size and shape of roots of 'Georgia Jet' cultivar as affected by CO_2 enrichment are in agreement with the report of Bhattacharya et al. (1985). It may be mentioned that for marketing US #1 root is more important than all other grades of roots. The deformation of roots in response to CO_2 enrichment needs further investigation in order to understand the ontogeny of roots in this cultivar.

The biochemical composition of roots presented in Fig. 5 indicate that starch concentration in roots increased at 431 and 509 $\mu l l^{-1}$ CO_2 in marked contrast to a decrease in sucrose level at elevated CO_2 concentrations. It would therefore appear, that CO_2 enrichment resulted in the conversion of mono and disaccharides in the formation of starch, decreasing thereby the free pool of carbon available for the syntheses of soluble amino acids and proteins. Bhattacharya et al. (1985) reported an increase in starch content in the leaves of sweet potato (**Ipomoea batatas** 'Georgia Jet') at elevated CO_2 concentrations. Several investigators (Nafziger and Koller, 1976; Finn and Brun, 1982; Mauney et al., 1979) have also reported that CO_2 enrichment increased starch content of soybean leaves but not the sucrose concentrations. However, Finn and Brun (1982) concluded that the addition of photosynthate provided by CO_2 enrichment in soybean leaves was retained as starch because of 'inefficient partitioning into sucrose'. In contrast, additional photosynthate produced in response to elevated CO_2 concentrations in tomato leaves is apparently partitioned between both

Table 1. Effect of different CO_2 concentrations on the total number of roots and the number of roots for each grade of sweet potatoes grown in open plots and within chambers at day 92 harvest, n = 3.

CO_2 ($\mu l l^{-1}$)	Total number of tubers	U.S. #1	U.S. #2	Canner	Cull	Jumbo
354 1/	70 c 1/	21	24	14	10	2
354	67 c	16	27	15	9	0
431	73 bc	22	29	11	11	0
506	93 ab	25	30	19	19	1
659	97 a	28	37	19	12	1
$S_{\bar{x}}$ 2/	6.6	6.6	5.6	2.5	3.5	-
CV (%) 2/	14	50	32	31	49	-
LSD	22	21	18	19	11	-
	S	N.S.	N.S.	N.S.	N.S.	-

1/ This CO_2 value (354) is from the open plot (no chambers) other values are from within chambers. Values for CO_2 are daytime means.

2/ $S_{\bar{x}}$ and CV (%) are from ANOVA.

3/ Within each column, values sharing the same letter are not significantly different at the 0.05 level, according to the LSD test.

Table 2. Effect of different CO_2 concentrations on the density of the different grades of 2 roots of sweet potatoes grown in open plots and within chambers at day 92 harvest, n = 3.

CO_2 ($\mu l l^{-1}$)	Density (gm/cm)				
	U.S. #1	U.S. #2	Canner	Cull	Jumbo
354[1/]	1.01	1.03	0.99	0.91	0.97
354	1.05	1.03	1.12	0.88	--
431	1.03	1.00	1.01	0.90	--
506	1.00	1.01	0.93	0.94	0.95
659	0.99	1.00	1.02	0.85	1.08
$S_{\bar{x}}$ [2/]	0.02	0.03	0.07	0.07	--
CV (%)[2/]	0.02	0.03	0.07	0.07	--
LSD	0.08	0.11	0.23	0.24	--
	N.S.	N.S.	N.S.	N.S.	N.S.

1/ This CO_2 value (354) is from the open plots (no chambers); other values are from within chambers. Values for CO_2 are daytime means.

2/ $S_{\bar{x}}$ and CV (%) are from ANOVA.

Table 3. Effect of different CO_2 concentrations on the mean length of different grades or roots of sweet potatoes grown in open plots and within chambers at day 92 harvest, n = 3.

CO_2 ($\mu l l^{-1}$)	Mean Length (cm)				
	U.S. #1	U.S. #2	Canner	Cull	Jumbo
354[1/]	12.9	10.2	8.3	5.3	17.5
354	11.6	10.0	8.6	5.4	--
431	13.2	10.8	7.5	5.3	--
506	13.3	10.0	8.2	6.1	20.0
659	12.4	10.4	8.1	5.4	14.0
$S_{\bar{x}}$[2/]	0.9	0.6	0.8	0.6	--
CV (%)[2/]	11.8	9.2	15.9	19.1	--
LSD	2.8	1.8	2.4	2.0	--
	N.S.	N.S.	N.S.	N.S.	--

1/ This CO_2 value (354) is from the open plots (no chambers); other values are from within chambers. Values for CO_2 are daytime means.

2/ $S_{\bar{x}}$ and C (%) are from ANOVA.

Table 4. Effect of different CO_2 concentrations on the mean volume different grades of roots of sweet potatoes grown in open plots and within chambers at day 92 harvest, n = 3.

CO_2 ($\mu l l^{-1}$)	Mean Volume (cm^3)				
	U.S. #1	U.S. #2	Canner	Cull	Jumbo
354[1/]	304	235	48	13	1375
345	231	197	46	16	--
431	281	207	36	12	--
506	289	174	58	17	1500
659	204	195	47	16	1020
$S_{\bar{x}}$[2/]	34	19	9	2	--
CV (%)[2/]	22	17	32	24	--
LSD	110	63	28	7	--
	N.S.	N.S.	N.S.	N.S.	

1/ This CO_2 value (354) is from the open plots (no chambers); other values are from within chambers. Values for CO_2 are daytime means.

2/ $S_{\bar{x}}$ and CV (%) are from ANOVA.

Table 5. Effect of different CO_2 concentrations on the mean diameter of different grades of roots of sweet potatoes grown in open plots and within chambers at day 92 harvest, n = 3.

CO_2 ($\mu l\,l^{-1}$)	Mean Diameter (cm)				
	U.S. #1	U.S. #2	Canner	Cull	Jumbo
354[1/]	6.3	6.1	3.3 [3/]	1.8	11.1
354	6.0	5.9	3.3^{ab}	2.0	--
431	6.2	5.9	3.1^{bc}	1.8	--
506	6.3	5.6	3.2^{c}	1.8	10.3
659	5.6	5.7	3.1^{c}	2.0	13.0
$S_{\bar{x}}$[2/]	0.3	0.3	0.1	0.1	--
CV (%)[2/]	7.8	8.1	2.2	9.4	--
LSD	0.9	0.9	0.1	0.3	--
	N.S.	N.S.	S	N.S.	

1/ This CO_2 value (354) is from the open plots (no chambers); other values are from within chambers. Values for CO_2 are daytime means.

2/ $S_{\bar{x}}$ and CV (%) are from ANOVA.

3/ Within each column, values sharing the same letter are not significantly different at the 0.05 level, according to the LSD test.

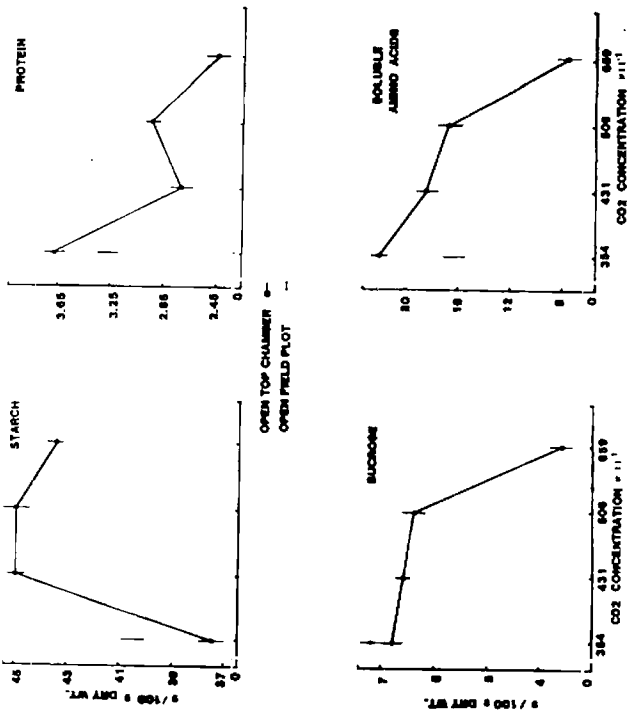

Fig. 5. Effect of different concentrations of carbon dioxide on the biochemical composition of roots of sweet potato at 92 days of growth.

starch and sucrose. It may be stated that CO_2 enrichment of tomato plants results in increased sucrose content and hence increased carbon transport. The regulation of sucrose content in the leaf tissues of soybean appears to be mediated through the activity of sucrose phosphate synthase (SPS). However, results obtained with soybean plants in response to CO_2 enrichment by Huber et al. (1982) support the role of SPS activity but do not confirm causal relation between SPSase and starch/sucrose levels in leaves. Huber et al. (1985) compared the export rate and SPSase activity in leaves of several species including field grown sweet potato (cv Travis). A low activity of SPS in leaves of **Ipomoea batatas** (cv Travis) is indicative of the greater partitioning of carbon into starch than in sucrose biosynthesis. A similar investigation of SPS activity in sweet potato roots is important in order to understand the partitioning of carbon between sucrose and starch in response to increased concentrations of CO_2.

It is interesting to note that both soluble amino acids and proteins (Fig. 5) decreased by increasing CO_2 concentration from 354 to 659 $\mu l l^{-1}$ in the environment, reflecting thereby the low nutritive value of sweet potato roots for human consumption. In this cultivar, CO_2 enrichment has been found to decrease protein-nitrogen contents of leaves and stems significantly at maturity (Biswas et al. 1986). It is, however, difficult at this stage to interpret why protein and soluble amino acid decreased with increased concentrations of carbon dioxide, although some data concerning nitrogen assimilation and CO_2 concentrations are available in soybeans (Hardy and Havelka 1975a; 1975b; Sheehy et al. 1980; Williams et al. 1981, 1982). It was inferred from one of these studies (Williams et al. 1981) that by increasing carbon dioxide concentration from 320 to 1000 $\mu l l^{-1}$ in symbiotically grown soybean seedlings under limited nitrogen supply caused no significant increase in Kjeldahl nitrogen content of plants. According to Huber et al. (1984) all of the extra carbon input due to enhancement of photosynthesis by CO_2 enrichment in soybean (**Glycine max** 'Bragg') was partitioned into starch. Perhaps lack of responsiveness of whole plant nitrogen accummulation to atmospheric CO_2 enrichment is related to the initial partitioning of fixed carbon into starch and subsequent slow mobilization of that carbon for transport to other plant parts.

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