THE EFFECT OF AN ENRICHED LEVEL OF CO_2 ON FLOWERING AND FRUITING OF THE PECAN

By

J. DAN HANNA

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1966

Submitted to the faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
July, 1967

THE EFFECT OF AN ENRICHED LEVEL OF CO_2 ON

FLOWERING AND FRUITING OF THE PECAN

Thesis Approved:

Herman A. Kimmichs
Thesis Adviser

W R Kays

N N Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks and appreciation to all who assisted, advised, or otherwise aided in the completion of this research and thesis.

Indebtedness is especially expressed to Professor Herman A. Hinrichs for his personal interest and constant, willing and unselfish guidance throughout the course of this study.

Indebtedness is also expressed to Professor W. R. Kays, Head, Department of Horticulture for his genuine encouragement and thoughtful cooperation and assistance in preparing this manuscript.

Acknowledgment is due Harold Davis, Superintendent, Pecan Research Experiment Station, for his assistance in setting up the experiments and collecting data.

Sincere thanks and gratitude is expressed to my wife, Marie, for her encouragement, assistance and patience during the entire study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In the United States, edible nuts usually rank seventh in value among all evergreen and deciduous fruit crops, exceeded only by citrus, apple, grape, peach, pear and strawberry (4). The pecan is by far the most valuable of the edible nuts. During the ten year period from 1956 to 1965, total farm value of pecans produced in the United States varied from a low of $32,000,000 to a high of $67,000,000 (30).

The pecan industry has not developed, however, to its full potential, due particularly to the erratic bearing habit of the pecan tree. During the ten years, 1956 to 1965, fluctuation in pecan production has ranged from 70,800,000 pounds to 251,100,000 pounds (30).

Profits from the pecan orchard are dependent on the production of consistently good crops of high quality. While there are a number of factors which adversely affect pecan yields, probably the two more important causes are (a) low vigor of the trees, and (b) early defoliation of the trees (27). Both of these factors may be related to photosynthesis.

Many studies have pointed to the apparent relationship between vigor and fruiting of individual shoots. Moderately vigorous vegetative growth has been shown to be essential for maximum fruitfulness (5, 9, 13, 15, 18, 27, 29).

It is generally recognized that the leaves of a pecan tree synthesize all or nearly all of the primary carbohydrate material from which the more complex carbohydrates and proteins are formed.

Hinrichs (15) has shown that early defoliation prevented pistillate flower bud initiation and greatly affected the number of catkin buds initiated. Since carbon dioxide assimilation during photosynthesis is the major source of carbon for carbohydrate synthesis in higher plants, it might be expected that CO_2 enrichment would increase total photosynthate and consequent flower bud initiation and development. This effect has been shown for a variety of flowering plants. The work herein reported was undertaken to determine the role of CO_2 enrichment in the initiation and subsequent flowering of the pecan.

The objectives of this study are:

(a) to determine the effect of CO_2 enrichment on the number of pecan pistillate and catkin flowers,

(b) to determine the effect of CO_2 enrichment on current shoot growth of the pecan, and

(c) to determine the optimum period for CO_2 enrichment in relation to flower formation in pecans.

CHAPTER II

REVIEW OF LITERATURE

Problems associated with the formation of pistillate flowers, the setting, sizing, filling and maturing of the nuts are of major concern to pecan growers (9). Since pistillate flower formation must precede all other crop production and crop maturing problems, it is necessarily of foremost importance.

In all plants important changes take place as the life cycle progresses. The pecan, (Carya illinoinsis K. Koch), grows and comes into bearing slowly. Most varieties under good management require four to seven years to begin bearing and seven to twelve years to produce commercial crops (4). In 1930, Crane (5) of the United States Pecan Field Station, Albany, Georgia, found that the heaviest annual crops were produced when the trees were in their early "teens" and before they had attained considerable size. Production tended to decline thereafter. Crane also found that some orchards over a period of time showed a decline in production, others a production which was fairly stationary with possibly a tendency toward biennial production and still other orchards showed a consistent increase in the production of nuts.

Irregular bearing has long been a problem with pecans. Trees usually bear every other year, but in some instances bearing is extremely erratic, i.e. less than biennial (15). Gourley and Howlett (14) reported that Sachs, who was one of the first to concern himself with

the problem of determining the causal agent or agents of flower-bud differentiation, concluded that flower formation was the result of a "flower forming substance developed by the leaves which diffused to the buds in the leaf axils and there induced flower formation."

Klebs, in the review of Gourley and Howlett (14), concluded that the supply of available nutrients, particularly nitrogen, and light intensity as it affects the production of carbohydrates, were the controlling factors in determining whether the plant would remain vegetative or form flowers.

In 1905, Fischer, as reported by Gourley and Howlett (14), after studying the effects of CO_2 upon growth and flowering, concluded that when the supply of carbohydrates was relatively high in proportion to available nitrogen flowers were differentiated. In 1916, Fischer went so far as to place the question of flower formation on the basis of a definite ratio between carbohydrates and nitrogen.

Kraus and Kraybill (19), working with the specific problem of fruit setting in tomato, classified plants in four groups based on differences in the relative nitrogen and carbohydrate content of the plants. These classes are primarily of value in presenting the relationships between nitrogen and carbohydrates in the plant, and its response to fruiting. Gourley and Howlett (14) further adapted the use of these classes to flowering and fruiting of the apple.

Sitton (27) observed that production of pecans is very closely associated with vigor, and equated vigor and pecan production with shoot length. Gossard (13) suggested that the best growth range for a pecan tree would provide sufficient vigor to annually produce eight-inch terminal shoots. These should be capable of producing pistillate

flowers in the current year and blossoming shoots the following year. Isbell (18) concluded that the diameter of shoots and number and quality of leaves should also be indicative traits regarding production. Crane (5) found a large variation in shoot growth rate and amount of shoot growth occurring on the same tree, with shoot length generally decreasing as tree age increased. Isbell (18) in 1928, and Ambling (1) in 1951 reported that within each variety there appears to be an optimum shoot length range for optimum fruit production. Ambling also found, with the exception of the Stuart variety, that 50% of the non-productive shoots fell within the productive shoot length range of each variety. Taylor (29) found in Oklahoma that Stuart fruited best over a relatively short range of shoot lengths, and that 33% of the non-fruiting shoots occurred within the fruiting range. From these observations, it would appear that factors other than shoot length are indicative of and responsible for production.

Smith and Waugh (28) found that in a year when no nut crop was produced and vegetative growth was limited by drouth, starch content of pecan roots was at a very high level. The following year, intensive spring growth and blossoming of the trees occurred, with a concurrent depletion of starch content. With the heavy nut set which occurred, starch content did not increase during the summer and fall. The nut crop the following year was very light. Davis (7), working with sugar prune, encountered similar results, and concluded that storage carbohydrates may be essential for fruit-bud differentiation or that other factors may cause fruit-bud differentiation because of their relationships to the storage carbohydrates.

Finch (9) pointed out that there appeared to be rather wide differences in the relative speed or rate of the disappearance of starch in the previous years wood which are associated with the growth of the different types of shoots the current season. In fruiting shoots, starch was remarkably less abundant than in non-fruiting shoots.

Crane (5) emphasized the importance of the leaf area of the individual shoot and its relation to the ability of the shoot to produce pistillate flowers. Food materials synthesized by the leaves were proportional to their size, structure and ability to function photosynthetically which in turn is closely related to vigor of the shoot. It is the leaves which influence in a large measure the thickening in diameter of the shoots, the accumulation of elaborated food materials which initiate fruit bud formation and the total yield and size of the nuts.

The removal of a leaf subtending a bud usually prevents the differentiation of pistillate flowers in that bud, even though leaves were present at adjacent nodes (22). Hinrichs (15) found that defoliation on August 15, September 1 and September 15, 1957, prevented pistillate flowers from developing. About 20% of a normal set of pistillate flowers developed when the leaves were removed on October 1, while a normal flower set occurred following the October 15 defoliation. Crane (5) and Sitton (27) obtained similar results. Dodge (8) concluded that most trees had an insufficient ratio of leaves per nut to properly fill the nuts and at the same time provide sufficient plant food to initiate pistillate flowers the following year.

The initiation of pistillate flowers occurs only if the nutritional conditions in the bud are favorable in the early spring when growth

starts (27). The growth of new shoots and leaves and the initiation and early development of pistillate flowers is accomplished from food materials stored from the previous growing season. Apparently, the period of September and October is the time during which storage of food materials must be made for the initiation of pistillate flowers the following season. It is also during this time that development and filling of the kernels occurs. These processes require large amounts of food materials, and demands of the developing kernel are supplied before there is appreciable storage of food materials (27).

Gossard (13) found that nitrogen was used to a great extent in the manufacture of foods that are used in the growth of stems and leaves, while less nitrogen and a higher proportion of carbohydrates was used in the formation of flower buds and nuts. Either too much or too little nitrogen reduced the amount of flower bud formation. Maximum nut production in any one year usually depletes the food reserves to such a low level that little, if any, pistillate flowering occurs the following year (13).

The time of application of fertilizer and the time when nutrient materials become available from decaying cover crops often determines the time when shoot growth is most rapid (27). This in turn affects the manufacture of foods used in filling nuts and building up food reserves, and so it influences the regularity of bearing.

Crane (5) stated that the soils of the pecan belt are generally low in organic matter and nitrogen, and stressed the importance of returning to the soil the greatest possible tonnage of organic matter each year.

Carbon is one of the nutrient elements recognized as essential to plant life. It is utilized by plants in the form of the oxide, CO_2, or as the bicarbonate ion, HCO_3^- (26). Its value to the growing plant is directly related to its use in photosynthesis. A plant utilizing the energy of sunlight by means of chlorophyll converts carbon and water first to a simple sugar, sucrose, and then to other compounds utilized in its normal metabolism (26).

Wittwer and Robb (31) speculated that in the primordial world the CO_2 concentration in the atmosphere was 10 to 100 times that of today. Plants then grew rapidly and through photosynthesis fixed most of the CO_2. It was laid down as oil, gas, coal and in beds of carbonate. Finally, the equilibrium of today arrived. Now plant growth is restricted because the supply of CO_2 is limiting.

Studies of the CO_2 content of the air have been published over the last 200 years. "Ordinary" air contains approximately 0.03 percent CO_2, or 3 parts in 10,000 by volume (31). The optimal CO_2 content of the air for photosynthesis is far above the usual atmospheric content (20). As reported by Chapman, Gleason and Loomis (2), DeSaussure showed diurnal variations in the CO_2 content of field air as early as 1816, and interpreted them as due principally to photosynthesis and respiration. Chapman, Gleason and Loomis (2) showed a build-up of CO_2 near the ground on still nights due to respiration of plants and soil organisms. They also found a daytime drop in CO_2 concentrations to a low of about 25 percent below "normal" just after noon.

Norman (25) pointed out that a crop of corn which will yield 100 bushels per acre requires 20,000 pounds of CO_2. Thus at the "normal" CO_2 atmosphere level the plant must process 33,500 tons of air to

procure 2 3/4 tons of carbon for the crop. Terrestial plants use approximately 15 billion tons of CO_2 per year from the atmosphere (25). In land plants the atmosphere is the only important source of CO_2 (23). Carbon dioxide released in respiration may be utilized in photosynthesis without ever leaving the plant, but under conditions favorable for photosynthesis this does not constitute a very large fraction of the total used (23).

All of the CO_2 used by green plants reaches the chloroplasts as dissolved CO_2, carbonic acid, or one of the salts of the latter (23). The rate of entrance of CO_2 through the stomates is largely in proportion to the aggregate area of the stomatal pores, diffusing through the stomates at a rate approximately fifty times as fast as it diffuses into an efficient absorbing surface (23). The supply of CO_2 to the plant from the atmosphere is dependent upon its level at the cell surface within the stomatal cavity (17).

A considerable part of the CO_2 utilized by plants in many habitats may be released locally as a result of "soil respiration," i.e., in the respiration of soil microorganisms (23). Such a release of CO_2 is especially pronounced in well fertilized soils, soils rich in organic matter, and many forest soils (23, 10).

The rate of photosynthesis is directly influenced by concentration of CO_2, however, other factors such as light, also impose a direct effect. Light requirement for maximum photosynthesis is increased by increasing the CO_2 level (31). Higher levels of CO_2 will partially compensate for a lack of sunlight in midwinter production of greenhouse crops (3). Chapman and Loomis (3) have shown that photosynthesis varies directly with the CO_2 concentration at levels present in the field. As

CO_2 levels are increased, photosynthesis becomes more temperature sensitive (11). Mortimer (24) found in beans, sugar beets and barley that increasing the CO_2 level from 0.25 to 2.0 percent favored the conversion of assimilated $C^{14}O_2$ into sucrose rather than serine and glycine.

Wittwer and Robb (31) suggested that CO_2 levels in plant growing atmospheres in greenhouses maintained substantially above the "normal" should favor growth. In the review of Wittwer and Robb (31), Brown and Escombe in 1902 had negative results in a series of experiments conducted on plants when CO_2 was supplied at a concentration of approximately 1100 ppm. There was downward curling of the leaves, inhibition of flowering and abortion of buds. They concluded that an increase of CO_2 of only 2 to 3 times the normal would result in the "speedy destruction of nearly all flowering plants." In the review of Wittwer and Robb (31), Demoussy attributed the results of Brown and Escombe to impurities in the CO_2 and secured results from CO_2 enrichment at 1500 ppm of up to 262 percent increase in plant weight.

Cummings and Jones (6) in 1918 reported the first experiments in the United States on plants enriched with CO_2. They secured an increase in yields of pods and seeds in peas and beans. No details were given on CO_2 levels. Early work was hampered by frequent toxic impurities in the products of combustion exhausted into the plant growing structures.

Fuller (10) has pointed out that within forests, on grasslands and in riverbottoms CO_2 concentrations at or near the soil level may be two to three times above the "normal." Levels of CO_2 over muck soils are also higher and may account, in part, for the high yielding potential of such areas (16).

Wittwer and Robb (31) conducted the first detailed research with enriched levels of CO_2 applied to greenhouse-grown food crops in the United States. Average yield increases, expressed as fresh weights, approximated 70 percent for the 1963 winter crop of 3 varieties of leaf lettuce. Yields of marketable fruit during the first 110 days of harvest for nine tomato varieties showed an average increase of 43 percent for enriched CO_2 (800 to 2,000 ppm) over the control plots (125 to 500 ppm). Reproductive development as well as vegetative growth was accelerated. During the first 60 days of growth of two varieties of cucumbers the number of pistillate flowers on plants in CO_2 enriched plots was approximately double the number produced on plants in check treatments.

Rose plants grown in an enriched (1,200 to 2,000 ppm) CO_2 atmosphere for two years averaged 8.0 roses per plant during a 3 month period (January through March), while control plants averaged 5.0 roses (21).

Goldsberry (12) found an increase in production of dry matter of carnations when the CO_2 concentration was increased from 200 to 550 ppm. The 550 ppm level showed slightly greater yields and earlier production.

Higher yields and better quality crops from the use of extra CO_2 confirm the long recognized value of animal manures and organic mulches since these materials provide a natural source of CO_2.

CHAPTER III

METHODS AND MATERIALS

Stuart pecan trees planted in the spring of 1961 on the Pecan Research Experiment Station near Sparks, Oklahoma were used in the tests. Ten trees were selected and paired as closely as possible for each treatment with reference to uniformity in size, vigor and rootstock. In treatment 1 the trees were grafted on Niblack seedling rootstock, in treatment 2 they were grafted on Indiana seedling rootstock, in treatment 3 they were grafted on Mahan seedling rootstock, in treatment 4 they were grafted on Hayes seedling rootstock, and in treatment 5, one tree was grafted on Dodd seedling rootstock and the other was grafted on an unknown seedling rootstock.

Two identical structures were used in each treatment to control air movement and limit gas diffusion. Each four-sided structure consisted of 2 inch by 2 inch pine frames 10 feet by 10 feet square and 14 feet high, lightly braced and covered with 4 mil polyethylene film. The structure could be quickly assembled around each test tree. There was a 2 foot open space left at the bottom of the structure for ventilation. Panel frames constructed with 2 inch by 2 inch pine, 2 feet by 10 feet in size and covered with plastic, were used to adjust the opening in the top of the structure to allow enough air circulation to control the temperature and prevent leaf scorch in the trees. Identical panels were used at the lower openings to prevent rapid loss of CO_2 and

thus maintain concentrations. One of the structures is shown in Figure 1 in place around one of the test trees.

The CO_2 was distributed throughout the tree by using a Linde CO_2 regulator, model RXAH-056P and 50 feet of 1/4 inch plastic tubing which was perforated at 6 inch intervals with 1/64 inch holes for 35 feet of its length. The plastic tubing was arranged in a spiral coil covering the upper 2/3 of the enclosed tree canopy. Liquified CO_2 in cylinders containing 50 pounds were used, and were weighed to determine the amount of CO_2 used. Figure 2 shows the distribution arrangement.

Five treatment dates were selected, with the first occurring on May 30, 1966, just before catkin fall. Succeeding treatments were initiated at 1 month intervals, with the exception of treatment 3, which was delayed 4 days by floodwaters from Quapaw Creek which inundated the area.

Carbon dioxide was introduced to the leaf atmosphere of one tree of each pair from 10:00 A.M. to 4:00 P.M. for a ten day period while the control tree received no additional CO_2. The CO_2 concentration of the tree leaf atmosphere of the tree receiving additional CO_2 was approximately 600 ppm. At the termination of each treatment period, the structures and equipment were dismantled and removed.

Records were obtained on air temperature inside and outside each enclosure; rainfall; pounds of CO_2 used; and total hours of introduction of CO_2. During periods when analyzing CO_2, cloud cover and wind velocities were recorded. The analysis of CO_2 content was made one day in each treatment period per structure and in one tree which had not been enclosed. Samples were taken of the air within the tree canopy at various locations to determine the uniformity of CO_2 concentration. An

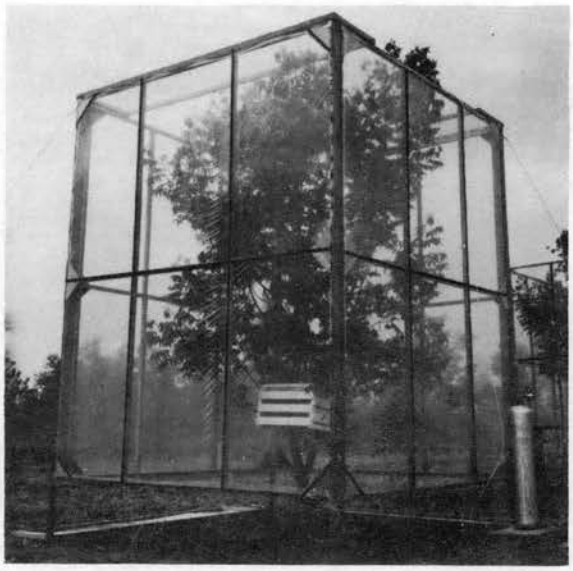

Fig. 1. View of Plastic Structure in Place Around the Tree

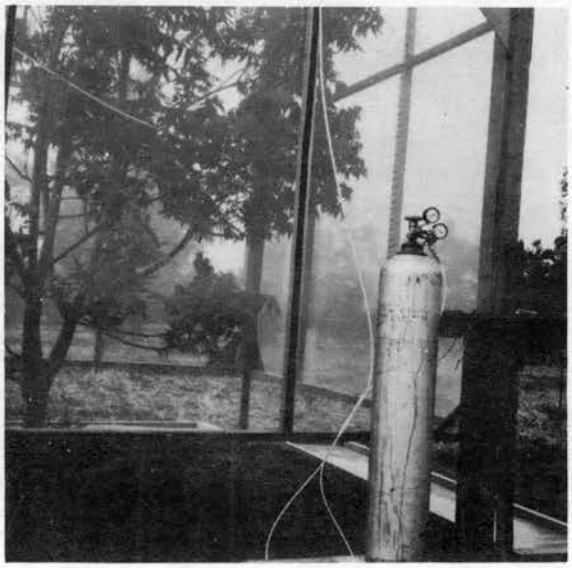

Fig. 2. View of CO_2 Distribution Equipment

MSA Universal Tester using CO_2 detector tubes No. 85976 was used to determine the CO_2 concentrations. Air samples were also collected in polyethylene bags and analyzed using a Beckman L/B Infrared Analyzer, Model 15A, to check and correlate the MSA kit at the start of the tests.

At the start of each treatment, 100 current shoots on each tree were selected at random and labeled with white 1 inch by 1 1/4 inch waterproof tags using light nylon string. Each shoot was measured for length of current growth at that time.

Test trees were grown on Port Silt Loam on the southwestern portion of the station. No fertilizer was applied. Soil management consisted of clean cultivation during the summer months and a cover crop during the winter and spring months. Under this system, the trees maintained good foliage until the close of the growing season. Low temperatures in April delayed development until later than normal. Killing frost occurred on November 1, 1966.

Nuts were harvested from 8 of the 10 trees in 1966. These were analyzed and compared with nuts from 3 additional non-enclosed trees.

Tagged shoots from each of the ten test trees were measured for length and recorded during the winter months. In addition, the diameter of each shoot at the base of the new growth and at the fourth node from the apex was measured and recorded.

On April 18, 1967, the number of buds which initiated catkins on each shoot was recorded for all trees in the tests. The number of shoots which initiated pistillate flowers was observed and recorded on May 3rd and 4th, 1967. Since treatment 5 consisted of different rootstocks, one additional non-treated tree was observed and pistillate flower development was recorded. The enriched tree in treatment 5

was grafted about 3 feet higher than the other treatment trees, and the extra tree was also grafted in the same manner.

CHAPTER IV

EXPERIMENTAL RESULTS

In the investigations herein reported, the differences in shoot length and shoot diameter response, flowering response and nut quality of the pecan to an increased level of CO_2 content of the surrounding atmosphere for five different periods of the growing season were measured and evaluated.

Treatment 1 was started on May 30, 1966, but due to difficulties in adjusting the regulator, the CO_2 concentration was not raised to the desired level, and the test was continued for 1 additional day for a total of 11 days of CO_2 introduction. The first day, 18 pounds of CO_2 was introduced, and thereafter an average of 23.6 pounds of CO_2 was required to maintain the approximate concentration desired. Treatment 2 (June 30 to July 9) required 23.75 pounds of CO_2 per day for the ten day treatment, treatment 3 (August 3 to August 12) required 24.6 pounds per day, treatment 4 (August 30 to September 8) required 25.6 pounds per day and treatment 5 (September 30 to October 9) required 24.8 pounds per day to maintain the approximate 600 ppm level.

Hourly variation of CO_2 concentrations in each structure for one day of each treatment period as well as cloud conditions through the day are shown in figures 3 through 7.

Daily rainfall totals were obtained from May to October from the Pecan Research Station records. Monthly rainfall totals were 1.41

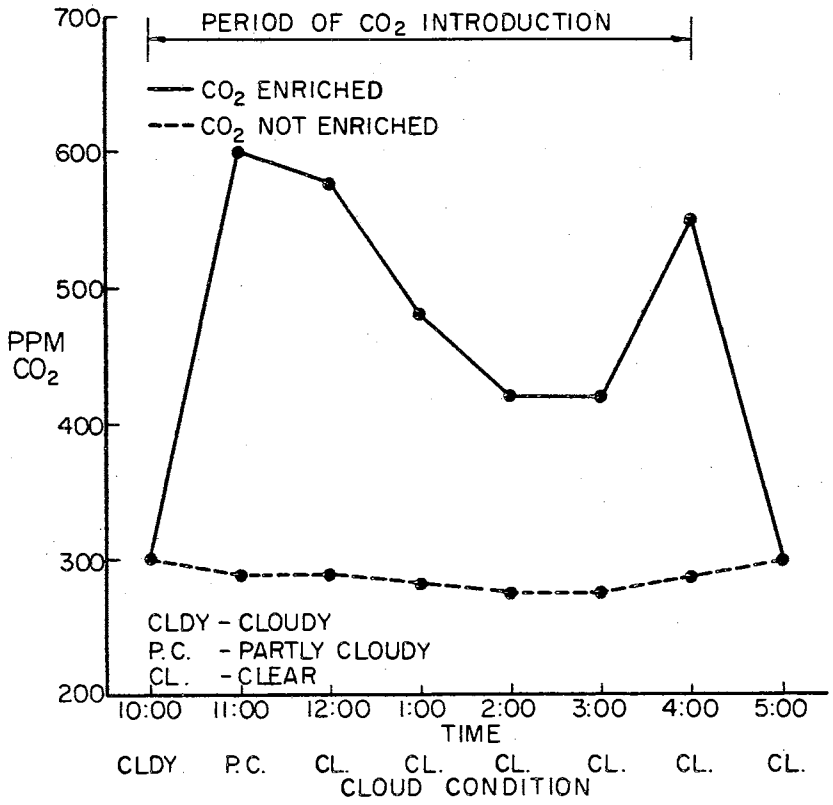

Figure 3. Variation in Hourly CO_2 Concentrations Inside the Canopies of the Two Trees in Treatment 1 on June 8, 1966. Cloud conditions are also indicated.

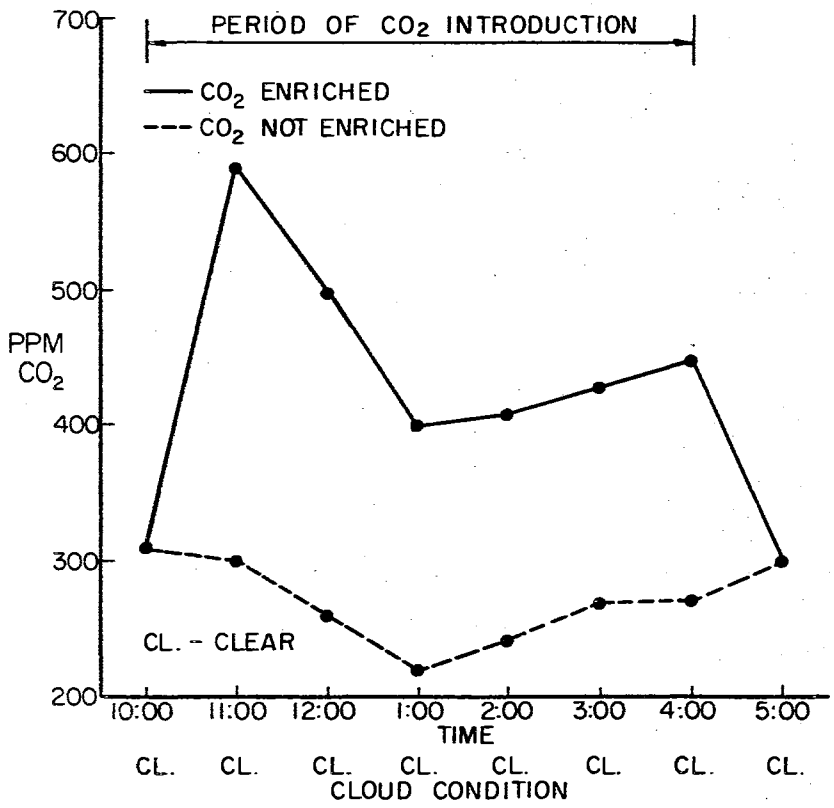

Figure 4. Variation in Hourly CO_2 Concentrations Inside the Canopies of the Two Trees in Treatment 2 on July 3, 1966. Cloud conditions are also indicated.

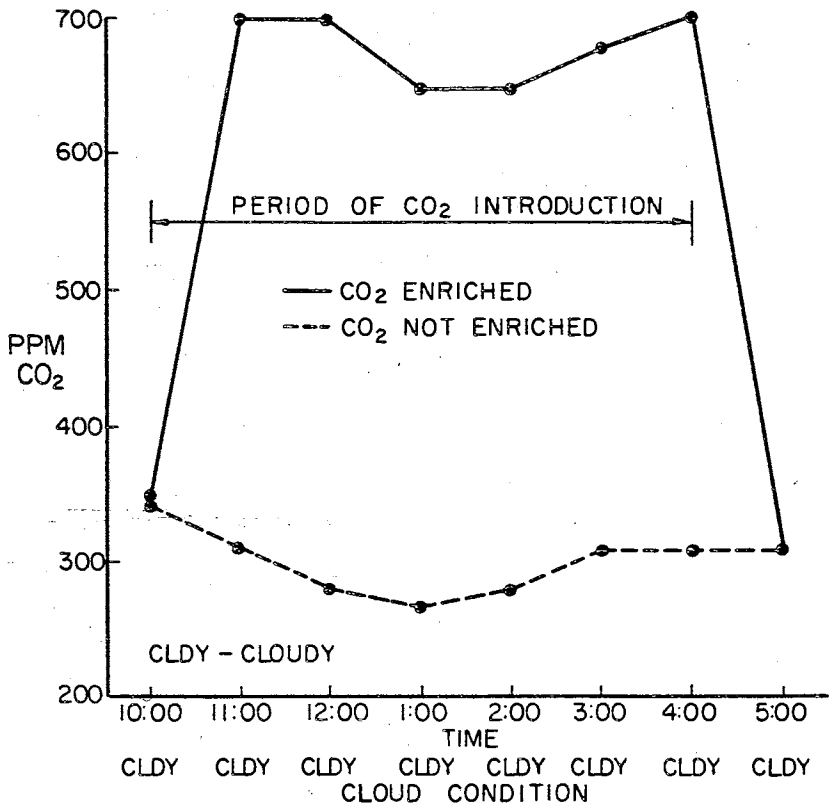

Figure 5. Variation in Hourly CO_2 Concentrations Inside the Canopies of the Two Trees in Treatment 3 on August 4, 1966. Cloud conditions are also indicated.

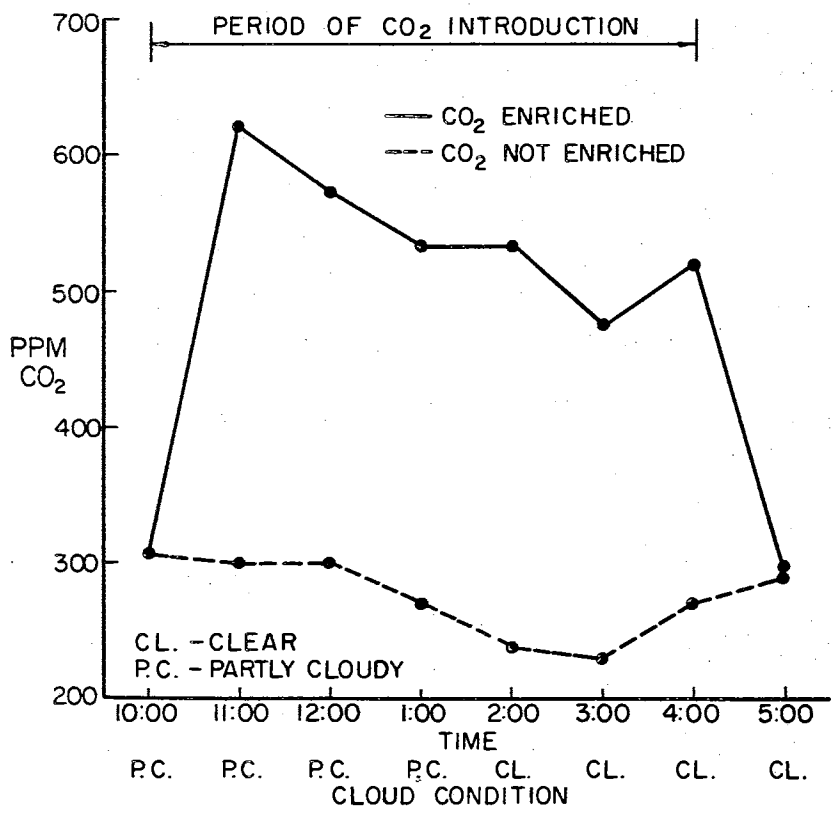

Figure 6. Variation in Hourly CO_2 Concentrations Inside the Canopies of the Two Trees in Treatment 4 on September 3, 1966. Cloud conditions are also indicated.

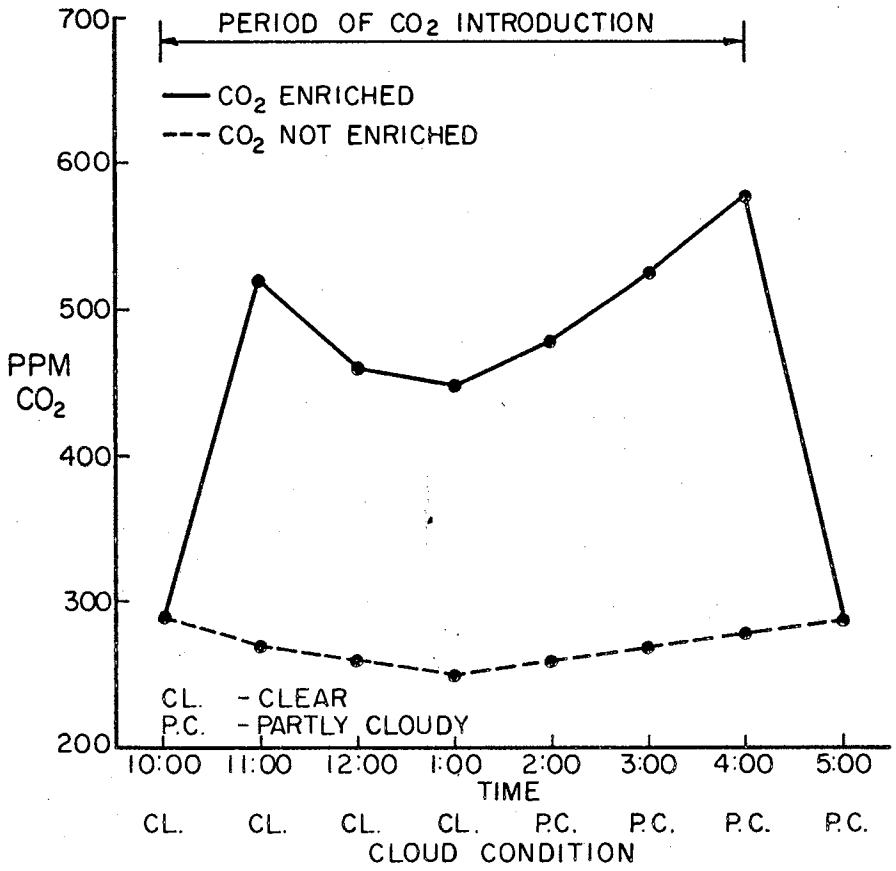

Figure 7. Variation in Hourly CO_2 Concentrations Inside the Canopies of the Two Trees in Treatment 5 on October 4, 1966. Cloud conditions are also indicated.

inches in May, 1.04 inches in June, 8.20 inches in July, 9.0 inches in August, 3.47 inches in September and 0.53 inches in October.

Minimum and maximum air temperatures for the period of each test inside and outside each structure are reported in Table 1. No substantial differences occurred.

Growth Response

Growth response to CO_2 enrichment as shown by increase in current shoot length during the remainder of the growing season is recorded in Table II. Substantial variation occurred only in treatment 2, while response in the other treatments varied and differences were small. Minor differences were also noted in the amount of secondary or late growth, but no trend was apparent.

Growth response to CO_2 enrichment was also expressed as mean stem diameters recorded at the base of the current shoot and at the fourth node from the apex (Table III). No substantial differences were apparent, but the largest increase in diamter was shown by treatment 2.

Growth response to CO_2 enrichment as indicated by the average number of terminal area shoots forced in the spring of 1967 per 1966 shoot is recorded in Table IV. Again, no growth trend was evident.

Flower Response

Pistillate flower initiation was enhanced in all treatments. The data as shown in Tables V and VI indicates a substantial increase in pistillate flower initiation for CO_2 enrichment over that of the paired, non-enriched tree in treatment 5 (September 30 to October 9), and smaller increases for each of the other four treatments. With the

TABLE I

A COMPARISON OF THE MINIMUM AND MAXIMUM TEMPERATURES INSIDE EACH ENCLOSURE AND OF THE OUTSIDE AIR DURING FIVE PERIODS OF CO_2 ENRICHMENT AT THE PECAN RESEARCH EXPERIMENT STATION, SPARKS, OKLAHOMA IN 1966

	Date of Treatment	Temperatures in Degrees Farenheit					
		Enriched Enclosure		Non-Enriched Enclosure		Outside Air	
		Low	High	Low	High	Low	High
1.	5/30 to 6/9	56	93	57	96	56	94
2.	6/30 to 7/9	65	103	65	103	65	101
3.	8/3 to 8/12	63	98	61	97	60	96
4.	8/30 to 9/8	59	91	57	90	53	90
5.	9/30 to 10/9	38	90	39	88	37	90

TABLE II

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON CURRENT SHOOT LENGTH

	Date of Treatment	Average Increase in Shoot Length	
		Enriched	Non-Enriched
1.	5/30 to 6/9	4.524 inches	4.426 inches
2.	6/30 to 7/9	2.269	.625
3.	8/3 to 8/12	.566	.700
4.	8/30 to 9/8	.370	.343
5.	9/30 to 10/9	.257	.327

TABLE III

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON THE AVERAGE DIAMETER OF CURRENT SEASON GROWTH

	Date of Treatment	Average Stem Diameter			
		At Base		Between 4th and 5th Node	
		Enriched	Non-Enriched	Enriched	Non-Enriched
1.	5/30 to 6/9	.816cm	.858cm	.467cm	.472cm
2.	6/30 to 7/9	.977	.877	.542	.488
3.	8/3 to 8/12	.878	.934	.506	.491
4.	8/30 to 9/8	.951	.959	.497	.502
5.	9/30 to 10/9	.878	.909	.543	.552

TABLE IV

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON THE AVERAGE NUMBER OF TERMINAL AREA SHOOTS FORCED THE FOLLOWING YEAR

	Date of Treatment	Average Number of Shoots Forced Per Terminal	
		Enriched	Non-Enriched
1.	5/30 to 6/9	2.46	2.50
2.	6/30 to 7/9	2.87	2.61
3.	8/3 to 8/12	2.34	2.55
4.	8/30 to 9/8	2.62	2.58
5.	9/30 to 10/9	2.34	2.72

TABLE V

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON THE PERCENT OF 1966 SHOOTS PRODUCING PISTILLATE FLOWERS IN 1967

	Date of Treatment	Percent of 1966 Shoots Producing Pistillate Flowers		
		Enriched	Non-Enriched	Non-Enriched Non-Enclosed
1.	5/30 to 6/9	15.05	9.46	
2.	6/30 to 7/9	3.05	.0	
3.	8/3 to 8/12	10.75	4.12	
4.	8/30 to 9/8	15.96	.0	
5.	9/30 to 10/9	32.64	3.06	12.00

TABLE VI

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON THE PERCENT OF NEW SHOOTS PRODUCING PISTILLATE FLOWERS IN 1967

	Date of Treatment	Percent of New Shoots Producing Pistillate Flowers		
		Enriched	Non-Enriched	Non-Enriched Non-Enclosed
1.	5/30 to 6/9	7.80	5.12	
2.	6/30 to 7/9	1.23	.0	
3.	8/3 to 8/12	4.93	2.06	
4.	8/30 to 9/8	7.55	.0	
5.	9/30 to 10/9	20.30	1.25	4.30

exception of treatment 1, each of the following treatments showed a gain in pistillate flower initiation over the preceding treatment(s). Two of the non-enriched trees, those in treatments 2 and 4, initiated no pistillate flowers on the tagged shoots.

Pistillate flower initiation on an extra non-enriched, non-enclosed tree which was grafted in a similar manner to the enriched but enclosed tree of treatment 5 is also recorded in Tables V and VI. This tree had a higher pistillate flower initiation percent than the non-enriched tree of treatment 5, but did not approach the percent of pistillate flower initiation of the enriched tree in this treatment.

Catkin flower bud initiation and development was also affected by CO_2 enrichment. This response is shown in figures 8 through 12 and in Table VII. The average number of catkin buds forced per shoot on April 18, 1967, was greater in all treatments, but especially so in treatments 1, 2, 4 and 5. Treatment 3 showed only a small gain in catkin formation. Carbon dioxide addition did not change the shoot length range on which catkin initiation occurred.

Catkin growth as well as foliage apparently was stimulated by CO_2 enrichment. Catkin size was observed to be larger and catkin emergence was earlier on enriched trees in all five treatments. Foliage was observed to be heavier in the spring of 1967 in treatments 1, 2, and 3 on the CO_2 enriched trees.

Nut Quality Response

Quality of the nuts produced on the test trees in 1966 was relatively poor due to the short growing season, but considerable variation did occur among the eight trees in the tests from which pecans were

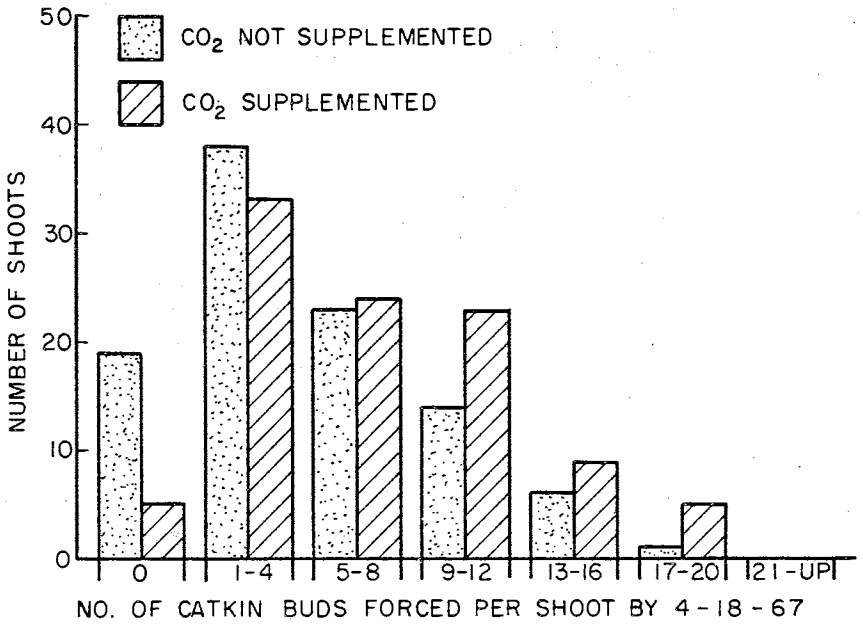

Figure 8. The Effect of Normal and Supplemental Levels of CO_2 Applied May 30 to June 9, 1966 on Catkin Emergence of 6 Year Old Stuart Pecan Trees

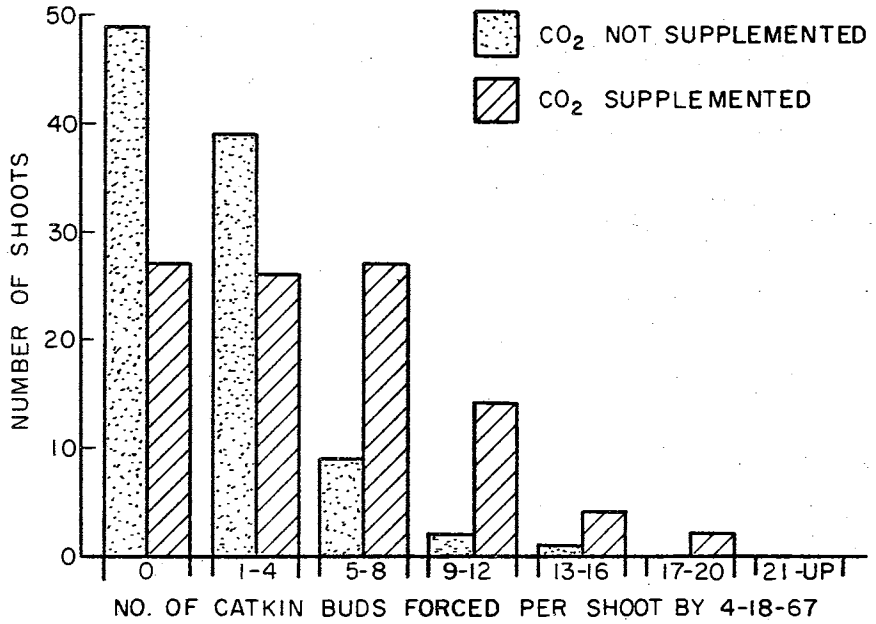

Figure 9. The Effect of Normal and Supplemental Levels of CO_2 Applied June 30 to July 9, 1966 on Catkin Emergence of 6 Year Old Stuart Pecan Trees

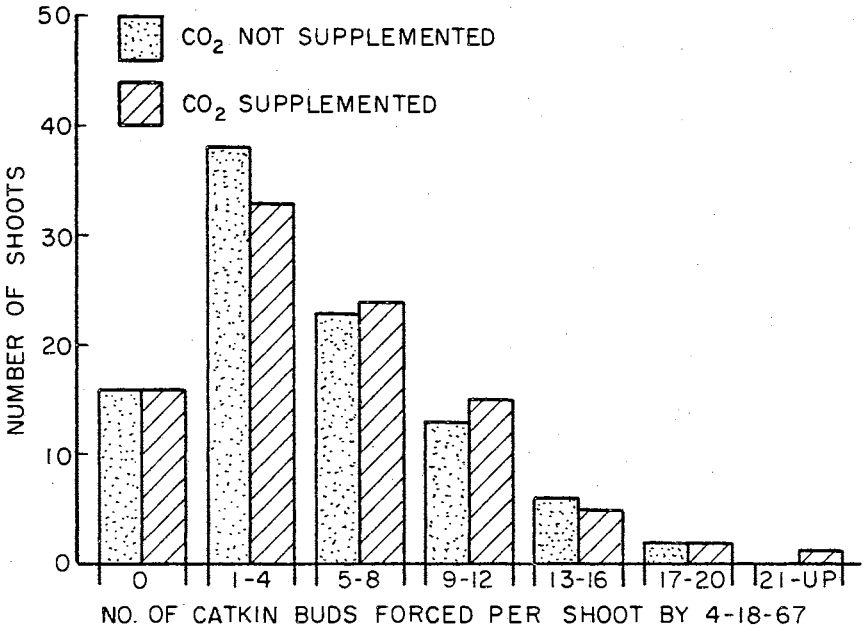

Figure 10. The Effect of Normal and Supplemental Levels of CO_2 Applied August 3-12, 1966 on Catkin Emergence of 6 Year Old Stuart Pecan Trees

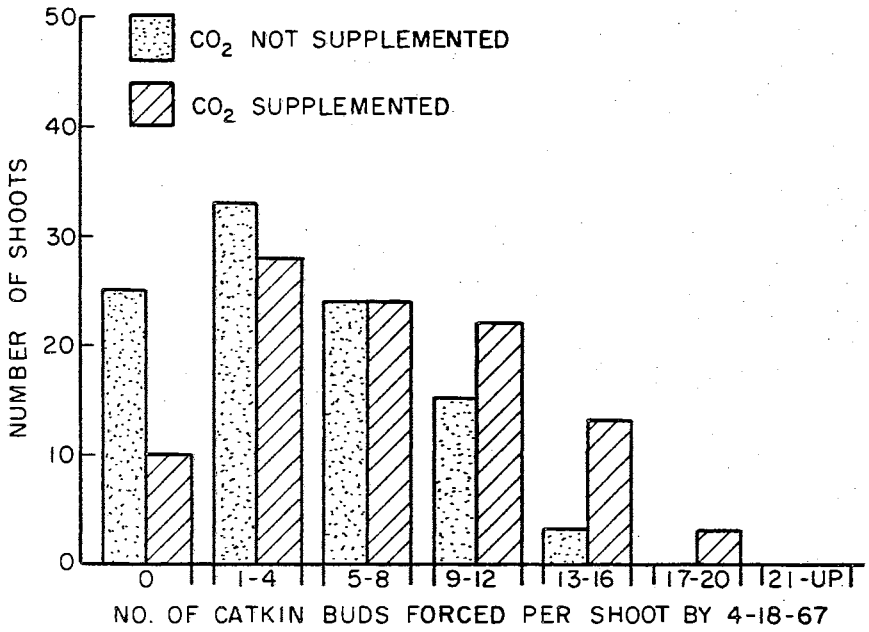

Figure 11. The Effect of Normal and Supplemental Levels of CO_2 Applied August 30 to September 8, 1966 on Catkin Emergence of 6 Year Old Stuart Pecan Trees

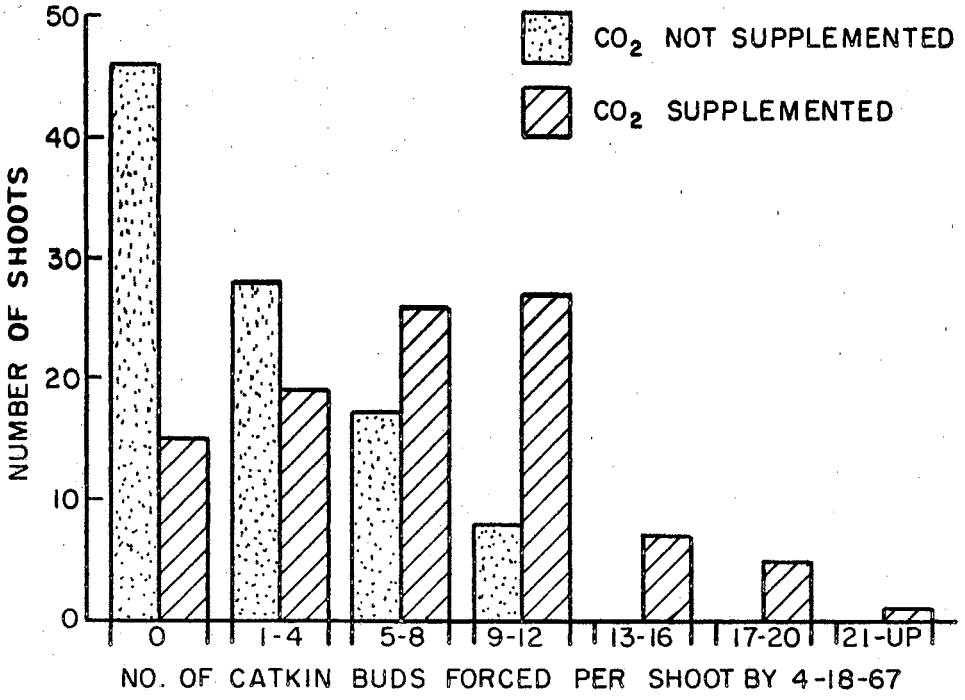

Figure 12. The Effect of Normal and Supplemental Levels of CO_2 Applied September 30 to October 9, 1966 on Catkin Emergence of 6 Year Old Stuart Pecan Trees

TABLE VII

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON THE AVERAGE NUMBER OF CATKINS PER SHOOT ON APRIL 18, 1967

Date of Treatment	Average Number of Catkins Per Shoot	
	Enriched	Non-Enriched
1. 5/30 to 6/9	6.94	4.64
2. 6/30 to 7/9	4.80	1.92
3. 8/3 to 8/12	5.30	5.15
4. 8/30 to 9/8	7.20	4.20
5. 9/30 to 10/9	7.18	4.61

harvested. Results of the analysis and evaluation of nut quality are given in Table VIII. Quality of the pecans from CO_2 enriched trees was generally better than that of the non-enriched trees with the exception of treatment 5. A rating scale varying from 1, for low quality, to 5, for good quality, was used to rate both external appearance of the shell and quality of the pecan meat.

Size of nuts produced on the test trees did not vary consistently between treatments, but shell thickness was less for nuts produced on CO_2 enriched trees in all five treatments. Since no nuts were harvested from two of the non-enriched, enclosed trees, nuts from three non-enclosed, non-enriched nearby trees were evaluated for comparison in these treatments. Inshell nut size was determined by water displacement in ml. and shell thickness was measured at the same location on each nut in inches using a micrometer.

TABLE VIII

A COMPARISON OF THE EFFECTS OF CO_2 ENRICHMENT OF STUART PECAN TREES AT FIVE PERIODS OF THE GROWING SEASON ON THE NUT QUALITY OF THE CURRENT CROP

	Date of Treatment	External Appearance[a]	Kernel Quality[b]	Kernel Percent	Average Nut Size Displacement in ml	Average Number Nuts Per Pound	Shell Thickness in Inches
1.	5/30 to 6/9						
	Enriched	3.8	2.8	46.1	10.6	52.9	.0431
	Non-enriched	2.9	2.0	43.7	11.2	61.9	.0436
2.	6/30 to 7/9						
	Enriched	3.3	1.8	44.6	10.3	71.9	.0431
	Non-enriched	-	-	-	-	-	-
3.	8/3 to 8/12						
	Enriched	3.9	2.9	48.6	10.9	57.6	.0433
	Non-enriched	3.3	2.0	43.8	10.7	64.2	.0437
4.	8/30 to 9/8						
	Enriched	3.7	2.3	46.8	12.0	58.6	.0433
	Non-enriched	2.7	1.4	35.2	11.3	60.9	.0436
5.	9/30 to 10/9						
	Enriched	3.5	1.5	37.2	11.9	60.0	.0439
	Non-enriched	-	-	-	-	-	-
Average 3 non-enclosed trees		3.2	1.8	43.6	11.8	60.8	.0441

[a] External appearance rated 1 (poor) to 5 (excellent)

[b] Kernel quality rated 1 (poor) to 5 (excellent)

CHAPTER V

DISCUSSION AND CONCLUSIONS

The results of this study indicate that short periods of atmospheric CO_2 enrichment at various periods of the growing season can enhance flowering of the pecan the following year. This result is in general agreement with work done on greenhouse floral crops by Lindstrom (21) and Goldsberry (12), and with greenhouse vegetable experiments conducted by Wittwer and Robb (31).

Growth response to CO_2 enrichment expressed as increased stem diameter and increased shoot growth was not evident in this study, as shown by Tables II and III. It is believed that carbohydrates synthesized during the enrichment period were stored as such and not converted to amino acids. This postulation would be indicated by both the lack of growth response and the flowering response of the trees, and in general agrees with the work done by Smith and Waugh (28).

Response of the shoot mean diameters to the short periods of CO_2 enrichment did not indicate sufficient storage of carbohydrates to cause a consistent increase in diameters. No consistent increase was found in the number of terminal shoots forced in 1967, but evidently enough carbohydrates were stored to increase the vigor of 1967 shoot growth and catkin flower formation during the CO_2 enrichment periods of treatments 1, 2 and 3.

Tables V and VI indicate an increase in pistillate flower initiation for all treatments, with a large increase from the September 30 to October 9 period of CO_2 addition. This result correlates closely with Hinrichs' observations on defoliation, in that carbohydrate storage must occur after September 15 in order for pistillate initiation to occur (15). Variations in the number of pistillate flowers between the earlier treatments may be due, in part, to differences in earliness of maturity of the different rootstocks upon which the pairs of trees were grafted. The consistency of variations between trees of a treatment would tend to indicate that the CO_2 enrichment period, even in the earlier treatments, had some residual effect upon carbohydrate storage and consequent pistillate flower initiation.

That pistillate flower initiation is affected by the height of graft placement is indicated by the results of treatment 5, in that the extra non-enriched, non-enclosed tree which was grafted about 3 feet above the ground level had more pistillate flower initiation than the enclosed, non-enriched tree which was grafted at ground level. This effect of earlier maturity for the higher grafted trees does not account for the much larger increase in pistillate flower initiation on the CO_2 enriched tree which was also grafted high.

Two separate effects are shown by CO_2 addition as it affects catkin bud initiation and subsequent development. Table VII indicates an increase in catkin flower development from both early and late periods of CO_2 enrichment. It is believed that the early response of treatments 1 and 2 represent enhanced catkin bud initiation, since these treatments occurred shortly after the catkin buds were formed. However, treatments 4 and 5 also increased catkin flower development, probably

due to increased carbohydrate reserves which stimulated growth from a larger number of previously initiated catkin buds (Figures 8 to 12). This effect is also evident by the increased size and earlier growth of catkins on CO_2 enriched trees.

Nut quality was generally enhanced by all CO_2 enrichment periods except treatment 5. The enhancement was probably due to increased carbohydrate reserves available for filling the nuts. The decrease in quality and maturity of the CO_2 enriched nuts from the September 30 treatment may be due in part to the unusual amounts of rainfall during July and August coupled with more nominal rains in September, and, in part to added reserves of carbohydrates, both of which might contribute to keeping the tree actively vegetative later than normal. Hence more of the carbohydrates were utilized in growth and less in filling the nuts.

There is a direct relationship between light intensity and CO_2 absorption and utilization. This effect is shown in Figures 1, 3, 4, and 5 by the decreased CO_2 utilization during cloudy periods. During periods of clear weather, light intensity was such that the requirements for CO_2 by the tree exceeded the capacity of the CO_2 regulator, and consequently CO_2 concentrations could not be maintained at the 600 ppm level.

This work strongly indicates that if CO_2 enrichment can be effected in the tree leaf atmosphere of the pecan during late September and early October, enhancement of pistillate flowering the following spring can be expected. There appears to be a need for investigating the effectiveness of cultural methods such as mulching and green manuring on

increasing the CO_2 concentration in the field before any recommendations can be made to growers.

CHAPTER VI

SUMMARY

Carbon dioxide enrichment of the leaf atmosphere of one tree in each of five pairs of young Stuart pecan trees was effected at five periods during the 1966 growing season at the Pecan Research Station near Sparks, Oklahoma.

The objectives of this study were to determine: (1) the effect of CO_2 enrichment upon the number of pecan pistillate and catkin flowers initiated and developed, (2) the effect of CO_2 enrichment on current shoot growth of the pecan and (3) the optimum period for CO_2 enrichment in relation to flower formation in the pecan.

Results of this study indicate:

(1) Pistillate flower initiation was enhanced for each tree in which the CO_2 leaf atmosphere was enriched for a ten day period.

(2) Catkin flower formation and development was increased for each tree in which the CO_2 leaf atmosphere was enriched for a ten day period.

(3) The number of terminal shoots forced the following year was not shown to be affected by CO_2 enrichment.

(4) Diameters of the current growth were not affected consistently by CO_2 enrichment.

(5) Current shoot elongation did not respond consistently to CO_2 enrichment.

(6) The optimum period for pistillate flower initiation occurred in treatment 5 (September 30 to October 9).

(7) Nuts occurring on the trees during CO_2 enrichment periods were of better quality on the earlier treatments, but quality was lower in treatment 5.

SELECTED BIBLIOGRAPHY

1. Ambling, H. J. 1959. "Shoot growth and pecan fruiting." Proc. Southeastern Pecan Growers Assoc. 52: 45-48.

2. Chapman, H. W., L. S. Gleason and W. E. Loomis. 1954. "The carbon dioxide content of field air." Plant Physiol. 29: 500-503.

3. _____ and W. E. Loomis. 1953. "Photosynthesis in the potato under field conditions." Plant Physiol. 28: 703-716.

4. Childers, N. F. 1961. Modern Fruit Science. Horticultural Publications. New Brunswick, N. J. 450-468.

5. Crane, H. L. 1930. "Terminal growth in relation to fruiting in the pecan." Nat'l. Pecan Assoc. Bul. 29: 24-32.

6. Cummings, M. B. and C. H. Jones. 1918. "The aerial fertilization of plants with carbon dioxide." Vermont Sta. Bul. 211.

7. Davis, L. D. 1931. "Some carbohydrate and nitrogen constituents of alternate bearing sugar prunes associated with fruit bud formation." Hilgardia. 5: 119-154.

8. Dodge, F. N. 1946. "A study of the degree of filling of pecan nuts as affected by the number produced by the tree." Proc. Amer. Soc. Hort. Sci. 47: 139-146.

9. Finch, A. H. 1931. "Nutritional relations of various types of pecan shoots." Proc. Ga.-Fla. Pecan Growers Assoc. Reprint.

10. Fuller, H. J. 1948. "Carbon dioxide concentrations of the atmosphere above Illinois forest and grassland." The American Midland Naturalist. 39: 247-249.

11. Gaastra, P. 1959. "Photosynthesis of crop plants as influenced by light, carbon dioxide, temperature and stomatal diffusion resistance." Meded. Landbou. Wageningen. 59: 1-68.

12. Goldsberry, K. L. 1963. "The effects of carbon dioxide on carnation growth." Proc. Amer. Soc. Hort. Sci. 83: 753-760.

13. Gossard, A. C. 1954. "Growth and fertilization of pecan trees in relation to regularity of bearing." Proc. Okla. Pecan Growers Assoc. 24th Annual. 24-22.

14. Gourley, J. H. and F. S. Howlett. 1947. Modern Fruit Production. The MacMillian Co. N. Y., N. Y. 62-74.

15. Hinrichs, H. A. 1959. "Erratic bearing." Proc. Okla. Pecan Growers Assoc. 30th Annual. 17.

16. Hopen, H. J. and S. K. Ries. 1962. "Atmospheric carbon dioxide levels over mineral and muck soils." Proc. Amer. Soc. Hort. Sci. 81: 365-367.

17. Inone, E. 1963. "The environment of plant surfaces." Environmental Control of Plant Growth. L. T. Evans (ed). pp. 23-32. Academic Press, N. Y., N. Y.

18. Isbell, C. L. 1928. Growth Studies of the Pecan. Ph.D. dissertation, Michigan State University. 20-36.

19. Kraus, E. J. and H. R. Kraybill. 1918. "Vegetation and reproduction with special reference to the tomato." Oregon Agr. Exp. Sta. Bul. 149.

20. Leopold, A. C. 1964. Plant Growth and Development. McGraw-Hill, Inc., N. Y., N. Y. pp. 26-29.

21. Lindstrom, R. S. 1965. "Carbon dioxide and its effect on the growth of roses." Proc. Amer. Soc. Hort. Sci. 87: 521-524.

22. Magness, J. R. 1927. "Pruning investigations. Second report, studies in fruit bud formation." Oregon Agri. Exp. Sta. Bul. 146.

23. Meyer, B. S., D. B. Anderson and R. H. Bohning. 1960. Introduction to Plant Physiology. D. Van Nostrand Co. Inc., Princeton, N. J.

24. Mortimer, D. C. 1959. "Some short term effects of increased carbon dioxide concentration on photosynthetic assimilation in leaves." Canad. Jour. Bot. 37: 1191-1201.

25. Norman, A. G. 1962. "The uniqueness of plants." Amer. Sci. 50: 436-449.

26. Sauchelli, V. 1965. "Fertilizing the air of crop plants." Ag. Chem. 20: 61.

27. Sitton, B. G. 1941. "Why pecan trees fail to bear." Proc. Tex. Pecan Growers Assoc. 21st Annual. 46-58.

28. Smith, C. L. and J. G. Waugh. 1938. "Seasonal variations in the carbohydrate and nitrogen content of roots of bearing pecan trees." Jour. of Ag. Res. 57: 449-460.

29. Taylor, G. G. 1966. The Relation of Terminal Growth to Fruiting in Pecans. Masters Thesis, Oklahoma State University.

30. "Tree nuts by states." USDA Crop Rept. Bd. Fr Nt 4-1. Aug. 1958 annually through Aug. 1966.

31. Wittwer, S. H. and W. Robb. 1964. "Carbon dioxide enrichment of greenhouse atmospheres for food crop production." Econ. Bot. 18: 34-56.

32. _____ and _____. 1963. "CO_2 does increase yield and quality." Amer. Veg. Grower. 11? 9-11.

VITA

J. Dan Hanna

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF AN ENRICHED LEVEL OF CO_2 ON FLOWERING AND FRUITING OF THE PECAN

Major Field: Horticulture

Biographical:

Personal Data: Born near Ringling, Oklahoma, November 25, 1926, the son of J. D. and Bonnie Lou Hanna.

Education: Attended grade school in Ringling and Waurika, Oklahoma; graduated from Ringling High School in 1944; received the Bachelor of Science degree from the Oklahoma State University, with a major in Horticulture, in May, 1966; completed requirements for the Master of Science degree in July, 1967.

Professional Experience: Entered the United States Army Air Corps in 1944, discharged from reserve status in 1948; taught in Veterans Agricultural Training Program, Ringling High School, 1947 to 1949; engaged in private farming, ranching and horticultural operations from 1949 to 1964; served as graduate research assistant in Oklahoma State University Horticulture Department during the 1966-1967 school year.

Organizations: Alpha Zeta; Alpha Gamma Rho; Oklahoma State University Deans' Honor Roll; Horticulture Club; Oklahoma State University Advisory Council; Oklahoma Pecan Growers Association Board of Directors; Texas Pecan Growers Association; Louisiana Pecan Growers Association; Federated Pecan Growers Associations of the United States, President; National Pecan Council, Board of Directors; Oklahoma Flying Farmers.