FRIDAY MORNING SESSION

December 6, 1968

The Friday morning session convened at 8:30 a.m. in the Ontario Room of the Royal York Hotel. Mr. Roy Forster served as moderator.

MODERATOR FORSTER: This mornings program covers the area of controlling the environment around the plant. Dr. Donald Krizek of the Phyto-Engineering Laboratory at Beltsville, Maryland will present our first paper entitled "Controlled Environments for Seedling Production."

CONTROLLED ENVIRONMENTS FOR SEEDLING PRODUCTION

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INTRODUCTION

The plant propagator has long been interested in ways to accelerate seedling development through proper manipulation of the environment. A number of researchers and commercial growers have reported on this subject in the Proceedings of the Plant Propagators' Society during the past seventeen years.

Conditions during germination and early seedling development exert a profound influence on the subsequent fate of the plant. Methods for improving these conditions, therefore, are of considerable importance to the propagator.

The recent development of plant growth chambers and other controlled-environment facilities affords today's grower a unique opportunity to control environmental factors previously neglected or poorly controlled.

In the past, controlled environment chambers were only available to the researchers (20). Although this is no longer the case (6, 9, 19), the literature on controlled-environment effects is still largely confined to non-economic plants. To fill this void, we have been studying the controlled-environment responses of various horticultural species at Beltsville. These studies were conducted in experimental plant growth chambers at the USDA's new Phyto-Engineering Laboratory during the past two years.

This paper contains a brief description of the experimental system used in the Phyto-Engineering Laboratory and some

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preliminary suggestions on the cultural and environmental factors required for accelerated seedling production.

Although most of our research has been conducted on bedding plants (13, 14, 15) and vegetables (14), we have also successfully grown forage plants and a number of woody plants under controlled environments.

A brief description of this work appeared recently (1, 5, 11, 13, 14, 15). Detailed studies are in preparation and will be reported elsewhere.

EXPERIMENTAL SYSTEM USED IN THE PHYTO-ENGINEERING LABORATORY

Our experimental system (11) is unique in the degree of environmental control possible. Not only can we control photoperiod, light intensity, day and night temperature, and relative humidity, but also atmospheric composition of carbon dioxide and oxygen, air velocity, the composition of nutrient solution, the duration and frequency of nutrient additions, and to a limited extent, the quality of light.

Our basic system consists of a large (12′ x 16′) cold room used as a walk-in growth room, with a number of small (2′ x 2′ x 2′) experimental plant growth chambers constructed out of plexiglass (¼″ clear). These 2-foot cubicles have a 6-inch plenum on opposite ends. A 4-inch circular hole is located on the end walls of each plenum chamber. A fan is located on one end to pull either recycled or ambient air through the chamber. Carbon dioxide in gaseous form is introduced through the air input. Between each plenum and the growth area is a plexiglass wall with holes drilled 1 inch apart to provide for a laminar flow of air (11).

Temperature and humidity are precisely controlled by means of commercially available environmental controllers (AMINCO-AIRE units[4]) modified for day and night control (11). Carbon dioxide level is controlled by means of a specially designed CO_2 control system (2), involving an infra-red analyzer and a series of solenoids and pumps that regulate the flow of gas into the chambers. Lamp banks are held above the small growth chambers and provide a combination of 2000-2500 ft-c of fluorescent and incandescent light.

Our studies at Beltsville, during the past two years, with a wide range of economic plants under controlled environments indicate that present-day textbooks on plant propagation are inadequate. There are few if any guidelines for germinating or growing seedlings of commercially important plants under controlled environments (20).

Despite differences in response of various species to controlled-environment treatment, there are certain preliminary recommendations that we can make. Since most of our con-

[4]Mention of a trademark name or a proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable

trolled-environment studies have focused on the optimum requirements for seedling development (5, 13, 14) rather than for germination (15), our recommendations for germination are only tentative. A great deal more work must be done before we can offer precise suggestions on germination and much still remains to be learned about optimum environments for seedling development.

ACCELERATED GERMINATION AND SEEDLING DEVELOPMENT

Cultural Requirements: The successful production of bedding plants, vegetables, or nursery crops depends upon a number of factors. One of the most important requirements is to have high quality seed. Another important requirement is to use a germination medium that has a small amount of fertilizer and is light and porous. Although well-drained, it should be capable of retaining adequate moisture. There are now many prepared mixtures of peat and vermiculite commercially available, which are excellent for seed germination and do not require sterilization.

In our initial work, we germinated our seed in the greenhouse for 7 to 10 days on a "hot pad" under mist (5, 13). To speed seedling development, we have since begun to germinate our seed directly in the growth chamber (15) or in a special propagation unit that provides 2000 ft-c of fluorescent and incandescent light.

In most of our studies, herbaceous seedlings are kept in the growth chamber for 2 weeks and woody plants for at least 4 weeks. To observe carry-over effects of controlled-environment treatment we transplant a portion of these plants into larger pots and move them to a long-day bench in the greenhouse.

Environmental Requirements: The minimum requirements for seed germination are adequate moisture, suitable temperature, sufficient oxygen, and, for some seed, a certain amount of light. Any one of these factors may prove to be a limiting factor in germination.

For optimum germination and seedling development, seed should be germinated in a growing room (3, 4) or propagation chamber or directly in the growth chamber (15). This facility should be equipped with adequate heating and refrigeration to maintain satisfactory temperature control and have high enough light and temperature to stimulate germination and obtain accelerated seedling development. Provisions should also be made for adequate soil moisture and nutrition, and a moderate relative humidity (60 to 65%). Where possible, the atmosphere should also be enriched with carbon dioxide (1000 to 2000 ppm). The quality and duration of light will of course depend on the species grown; but 16 to 24 hours of illumination with fluorscent light supplemented by a small amount of incandescent light (10 to 20 per cent by wattage) has sufficed for germinating and growing most species. These recommendations will be discussed briefly below.

Moisture and Nutrition

To provide adequate moisture during germination, we water by sub-irrigation methods when germinating in our propagating chamber, and by surface methods when germinating directly in the growth chamber.

We add either distilled water or 0.5 gm/liter (ca. 1 oz./15 gal) of 20-20-20 water soluble fertilizer during the germination period and until the first true leaves begin to expand. Depending upon the kind of seedling, we then add either 0.5 gm/liter or 1.0 gm/liter of fertilizer. We fertilize the plants 4 to 6 times a day (14, 15). Solution is applied until it drips from the bottom of the pots. By using nutrient solution with each watering, we are able to maintain optimum nutrient levels — essential if maximum benefits of elevated light, temperature, and carbon dioxide are to be realized.

Relatve Humidity

We normally control relative humidity in our growth chamber at 60 to 65% for both day and night (5, 11, 14, 15).

Temperature

Our studies certainly show the importance of elevating day and night temperatures above those normally used. The need to elevate temperature is particularly great if the greatest stimulation from CO_2 enrichment is to be achieved (1, 14, 15). The benefits of CO_2 enrichment are much greater at 30 C (86 F) day temperature than at 24 C (75 F) (15).

Light

The use of artificial light in indoor propagating structures for germinating seeds and rooting cuttings has long been advocated (3, 17, 18). The major problem in artificial lighting in propagating structures is to obtain sufficiently high light intensity without running into severe heating problems, and to obtain a proper balance of light quality (7).

Our own studies suggest that the growth of many horticultural species may be greatly accelerated by growing them under at least 16 hours of high intensity light in the growth chamber (Table 1.) We use 2000 to 2500 ft-c of cool-white-fluorescent light (CWF) and supplemental incandescent light (I) in most of our experiments. This intensity of light has proved satisfactory for germination and seedling development of nearly all species that we have studied (1, 5, 13, 14, 15).

The optimum light intensity for seedling growth is yet to be determined.

The minimum light requirement for stimulating germination of petunia, birch, and other plants that we have studied is unknown. It is possible that only a few brief flashes of

Table 1. Comparative growth responses of petunia, ageratum, and marigold seedlings 14 days after start of light treatment in the greenhouse and in the growth chamber Mean of 3 plants per treatment.

Environmental Treatment[1])	Petunia cv. Pink Cascade		Ageratum cv Blue Blazer		Marigold cv Golden Jubilee	
	Fresh Weight Tops (mg)	No of Nodes	Fresh Weight Tops (mg)	No. of Nodes	Fresh Weight Tops (mg)	No of Nodes
Greenhouse						
1. Natural Days (ND)	32	4.7	25	3.0	523	3.0
2. ND + 8 hr CWF (250 ft-c)	54	5.0	63	3.0	750	3.0
Growth Chamber						
3. 16 hr CWF (2500 ft-c)	285	8.3	298	4.3	2919	4.3
4. 16 hr (CWF + I) (2500 ft-c)	1417	11.3	895	5.0	6377	5.0
Increase Over Control	44 x	6.6	36 x	2.0	12 x	2.0

[1]) Plants treated January 27 to February 10, 1967

red light or light of some other wave length may be all that is required. Kincaid (10), according to Mayer and Poljakoff-Mayber (16), found that only 0.01 second of sunlight was needed to stimulate germination in tobacco. He even found moonlight to be effective.

Carbon Dioxide

The practical applications of CO_2 enrichment for accelerating production of various horticultural crops under greenhouse conditions are well known (8, 12, 21). Relatively few investigators or growers, however, have used young seedlings. To date, only a few studies on CO_2 enrichment of horticultural plants have been done under completely controlled environments.

Recent experiments in our experimental growth chambers indicate that the growth and development of a number of horticultural species may be stimulated greatly by growing them under controlled environments at 1000 ppm of CO_2 (5, 11). Petunias grown under these conditions and at 2000 ft-c cool-white-fluorescent light, 80 ft-c of incandescent light, at a day

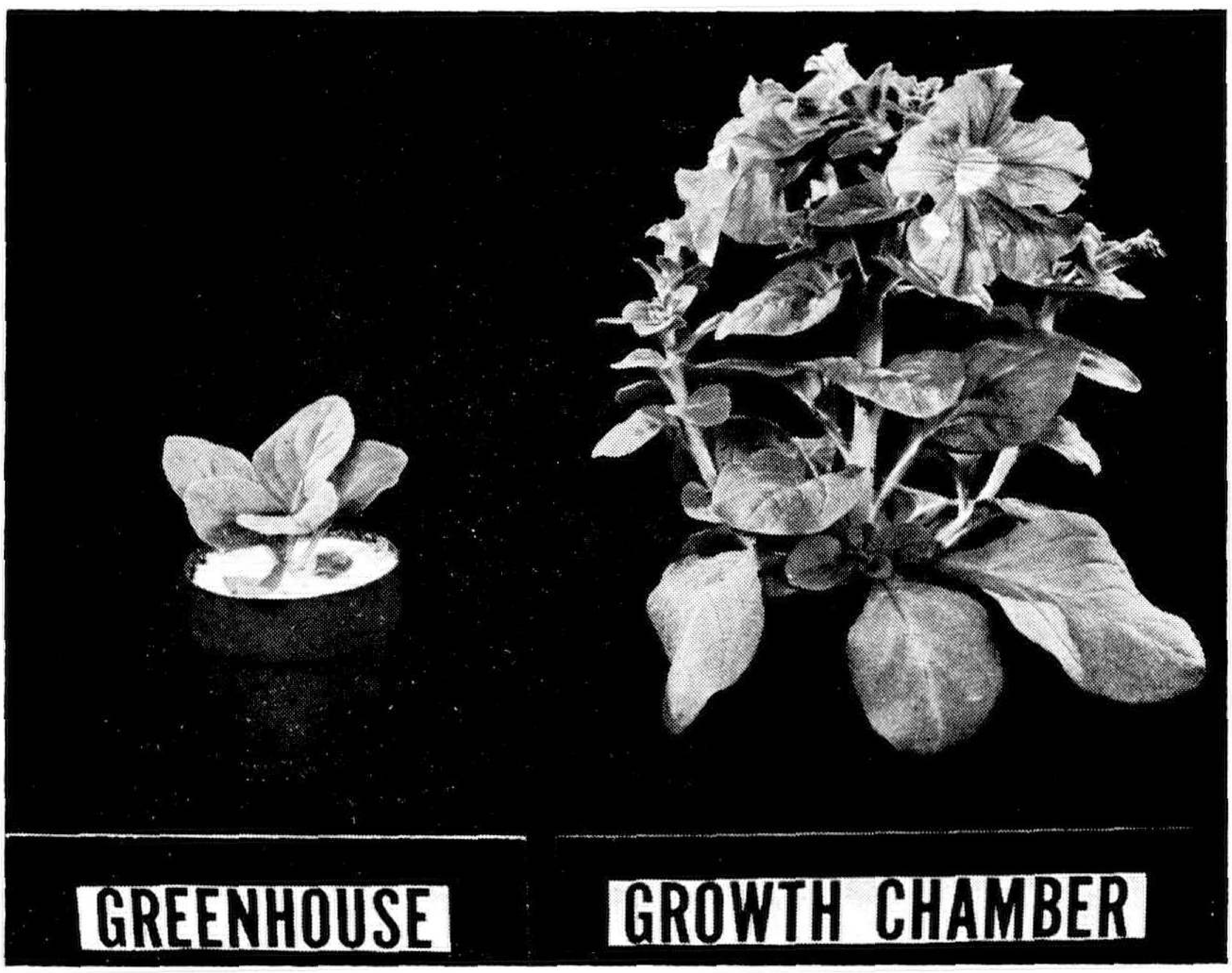

Figure 1. Comparison of petunia (cv. Pink Cascade) plants 5 weeks after planting seed. Plant on left was grown in the greenhouse under natural days at ambient CO_2. Plant on right was grown from seed in the growth chamber for 18 days under controlled-environment conditions at 2000 ppm CO_2 and then transferred to the greenhouse.

temperature of 23 C (ca. 73 F) and night temperature of 17 C (ca. 63 F), and 60% relative humidity for 2 weeks, and then transferred to the greenhouse on 16-hour days at 17 C, flowered in 5 to 6 weeks from seed. Those grown continuously in the greenhouse flowered in 9 to 10 weeks. Fresh weight of petunia, ageratum, and marigold seedlings, taken after 14 days of controlled-environment treatment, were considerably greater than those of seedlings grown under ambient CO_2 conditions in the greenhouse (5, 11).

By direct seeding in the growth chamber, enriching the atmosphere to 2000 ppm CO_2, raising the day temperature to 30 C (86 F) and the night temperature to 24 C (75 F), and increasing the applications of fertilizer, even more dramatic results were obtained (1, 14, 15). Branching was increased; flower initiation was greatly accelerated; and carry-over effects were even more striking (Fig. 1).

BENEFITS OF ACCELERATED CULTURE

Although the economics of controlled-environment production of seedlings remain to be established for various crops, the advantages of using these facilities should more than compensate the grower for his initial investment.

(1) The grower will profit by having seedling production on a scheduled basis. (2) By means of accelerated culture, his growing times will be reduced as well as his labor costs. (3) The consumer will profit by being able to buy superior plants with larger leaves; sturdier stems; greater branching; and earlier, larger, and more abundant flowers.

Our studies provide convincing evidence that optimum seedling growth can best be obtained when all of the critical environmental factors are controlled simultaneously (1, 5, 14, 15).

There is much that we do not know but the road ahead looks promising. At last the researcher and the grower have the means to manipulate the environment to its greatest advantage.

LITERATURE CITED

1. Bailey, W. A.; D. T. Krizek; and H. H. Klueter. 1968. Controlled Environment and the Genies of Growth. p. 2-12. In The Yearbook of Agriculture 1968. *Science for Better Living*. U. S. Government Printing Office, Washington, D. C.
2. ——————; H. H. Klueter; D. T. Krizek; and N. W. Stuart. 1968. CO_2 systems for growing plants. ASAE Paper No 68-319. Paper presented at Summer Meeting, Amer. Soc. Agr. Eng.
3. Canham, A. E. 1964. *Electricity in Horticulture*. MacDonald, London. 199 p.
4. —————— 1968. The application of artificial lighting in commercial horticulture. Paper presented at the Second International Meeting on Applications of Electricity in Agriculture and Horticulture, Silsoe; England. April 1-6, 1968. Commission Internationale du Genie Rural. Section IV Agricultural Electrification. 22 p.
5. Cathey, H. M. 1967. Photobiology in horticulture. *Proc. XVII Int. Hort. Cong.* 3:385-391.

6 Commonwealth Scientific and Industrial Research Organization. 1962 *Proceedings of a Symposium on Engineering Aspects of Environment Control for Plant Growth.* Melbourne, Australia 266 p.
7 Hartmann, H T. and D E Kester. 1959 *Plant Propagation Principles and Practices* Prentice-Hall, Englewood Cliffs, N. J. 559 p
8 Holley, W. D. 1968 CO_2 enrichment for flower production. ASAE Paper No. 317 10 p Paper presented at Summer Meeting, Amer Soc Agr. Eng
9. Hudson, J. P. 1957. *Control of the Plant Environment* Proc. Fourth Easter School in Agricultural Science. University of Nottingham Butterworths, London 240 p
10 Kincaid, R. R. 1935. Effects of certain environmental factors on germination of Florida cigar-wrapper tabacco seeds Tech. Bul. 277 University of Florida, Agr. Exp Sta. 47 p (Cited by Mayer and Poljakoff-Mayber, 1963)
11 Klueter, H. H ; W. A. Bailey; H. M. Cathey; and D T. Krizek. 1967 Development of an experimental growth chamber system for studying the effects of major environmental factors on plant growth. ASAE Paper No 67-112 18 p Paper presented at Winter Meeting, Amer. Soc Agr. Eng.
12 Kretchman, D W and F S Howlett. 1968. CO_2 enrichment for vegetable production. ASAE Paper No 68-316. 21 p Paper presented at Summer Meeting, Amer. Soc. Agr. Eng
13 Krizek, D T ; H. M. Cathey; H. H. Klueter; and W. A Bailey. 1967. Escalating the growth and development of F_1 hybrid annuals by use of controlled environments Abstract Amer Soc Hort. Sci. Meeting
14 ——————; W. A. Bailey; and H H Klueter. 1968a Accelerated growth of seedlings and precocious flowering under controlled environments at elevated CO_2, light, and temperature. Plant Physiol 43 (Suppl) :S-32.
15. ——————; ——————; and ——————: 1968b. Benefits of carbon dioxide enrichment and direct seeding of F_1 hybrid annuals under controlled environments. Abstract Amer. Soc. Hort Sci Meeting
16. Mayer, A. M and A Poljakoff-Mayber 1963. *The Germination of Seeds.* Pergamon Press, New York. 236 p.
17. Stoutemyer, V. T and A. W Close 1946 Rooting cuttings and germinating seeds under fluorescent and cold cathode lighting Proc Amer. Soc. Hort. Sci. 48:309-325.
18 —————— and ——————. 1953. Propagation by seedage and grafting under fluorescent lamps Proc Amer Soc Hort. Sci 62:459-465
19. Thimann, K. V. (Chairman, NRC Panel on the Plant Sciences) 1966 *The Plant Sciences, Now and In the Coming Decade; A Report on the Status, Trends, and Requirements of Plant Sciences in the United States.* NRC Pub 1405 Washington, D C. 167 p.
20 Went, F. W (ed) 1957 The *Experimental Control of Plant Growth.* Chronica Botanica, Waltham, Mass 343 p.
21 Wittwer, S H and W Robb 1963. Carbon dioxide enrichment of greenhouses for food crop production. Econ Bot. 18 (1):34-56

MODERATOR FORSTER: Thank you very much, Don.

JIM WELLS: How was the growing medium saturated six times a day? You also mentioned a relation between light intensity and reduction in diseases, would you elaborate on that a little?

DON KRIZEK: We tried various methods of watering the plants to keep them turgid and push them to their maximum. For our system the most convenient method was to use small capillary tubes attached to a tygon line which was run to a supply tank which was connected in turn to a series of time clocks and solenoid valves to control the water flow. With respect to reducing disease, I don't feel qualified to answer this, but I do believe that if the plant is healthy, it can withstand the attack of many pathogens which a weaker plant might not be able to withstand.

PETER VERMEULEN: Is it essential to use a synthetic mix?

DON KRIZEK: No it is not. We started out by using regular composted soil but the quality varied so much from one batch to another that we went to a synthetic mix to have more uniformity. We have obtained excellent results with this peat-lite mix.

RALPH SHUGERT: In your opinion, would the check plants catch up with the *Betula* which were grown under optimum conditions and were considerably larger than those of the check, if both were planted out into a transplant bed?

DON KRIZEK: We are in the process of running such studies now but based upon what we have done thus far with herbaceous plants, there is no reason not to expect that woody plants started under controlled-environment conditions would not also maintain their lead in growth over check plants provided that nutrition or some other factor did not become limiting.

KNOX HENRY: You reported working with 2000 ppm CO_2 but, in some work we have been doing, 1200 ppm seems to be about the maximum that is necessary. I wonder if you would comment on this.

DON KRIZEK: The optimum CO_2 would depend to a large degree on the light, temperature, and other factors which you may be using. At lower temperatures, particularly, you may well be saturating your system at 1200 ppm of CO_2.

PAUL READ: Have you looked at growth regulator effects and interactions with your other factors?

DON KRIZEK: Not as yet. There are many environmental interactions that we need to examine before we begin studies on growth regulator effects and chemical and environmental interactions, although these certainly need to be done.

MODERATOR FORSTER: In continuing our interest in controlling the plants environment, I'd like to introduce to you now a fellow Canadian, Mr. Joe Molnar who is interested in plant propagation and CO_2 work.

CARBONIZED MIST IN PLANT PROPAGATION

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Introduction:

The propagation of horticultural plants is an important aspect of the nursery and bedding plant industry. Many species and cultivars are difficult or impossible to propagate from

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