we have a problem of getting the root cuttings to grow. Maybe again, this is a matter of technique.

WEDNESDAY AFTERNOON SESSION

October 6, 1971

MODERATOR RAY HASEK: It gives me great pleasure to introduce a colleague of mine for a good many years, Dr. Tok Furuta, Extension Ornamental Horticulturist, at the University of California, Riverside. And he will talk to us about controlled environment seed propagation. Tok:

THE PHYTOTRONIC ENTERPRISE

TOKUJI FURUTA

University of California
Riverside, California

The room was gleaming white and seemingly sterile. Occasionally a door opened and music from a transistor radio entered from somewhere outside. Otherwise, there was an air of hushed expectation.

The only sound was a gentle hiss as air passed through the adjustable louvers into the room, combined with a faint hum from the lights. This was all the sound that could be heard as women robed in white moved about silently inspecting the rows and rows of white plastic trays. From time to time they would stop to more closely inspect and manipulate one of the living creatures on the white trays.

The room was divided into two parts by a lightproof curtain. Half of the room was brilliantly lit from overhead lights. On the basis of the glow from each lamp one determines that at least two types were used. The other half of the room was dimly lit for part of the time, in darkness the remainder. Every 12 hours, the curtains automatically parted and the lights moved to the dark side.

Through special tubes attached to the trays, water and nutrients reached the tiny creatures. There was no waste, the floor remained spotless. The workers inspected the controls and monitoring devices to be certain the composition of gases and the temperature and relative humidity were within acceptable limits for the creatures to grow vigorously.

Reached through large sliding doors at one end of the room was a smaller room whose walls were lined with shelf after shelf. Over each shelf were fluorescent lights. On the shelves were more of the white trays seen in the larger room.

At the far end, through more sliding doors, was a clean preparation room. Here the trays were prepared before being placed on the shelves in the small room.

Would this be a description of the propagation facilities for seedlings at some nursery in the future? Would there be advantages for the nurseryman, and for the consumer? Can seedlings be propagated this way and still be of high quality?

This description is not of the future. Essentially, it is based on facilities already in operation. At the 1970 meeting of the American Society of Agricultural Engineers, James A. Buck (4) of the General Electric Company presented a paper, "High Intensity Discharge Lamps for Plant Growth Applications," in which the facilities above, a part of a commercial greenhouse vegetable operation, were essentially described.

Some thoughts on terminology: The terminology that has developed to describe facilities for plants is confusing. The following descriptions may be helpful.

> **Phytotrons** are combinations of greenhouses and growing rooms for plants.
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> **Controlled environment** has been used to designate the system of growing plants in rooms or chambers under artificial lights when temperature, composition of the gases, and relative humidity as well as soil moisture and nutrition are controlled. This is usually contrasted to *greenhouse* culture where natural light is used—perhaps supplemented with artificial light, but still natural light is the primary source. In the greenhouse the soil moisture, nutrition, humidity, atmospheric gases and temperature may also be controlled so the environment of the plant is controlled.
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> **Growing rooms** are temperature-controlled, artificially-lighted rooms for growing plants. These rooms are large enough to permit people to enter. Composition of the air may also be regulated.
>
> **Growing cabinets** are smaller than growing rooms and the operator cannot enter.
>
> **Germinators** are rooms or cabinets designed especially to germinate seeds—usually high humidity and rather precise temperature controls are needed.

Focus on the problem. To fully comprehend the subject of germinating seeds and growing plants under controlled conditions, it is necessary to seek answers to the following questions. First, can plants of the desired characteristics and quality be grown in these facilities? Second, what are the phases of plant growth and development that are involved in the system? Third, why would one consider using such facilities? Lastly, what are the benefits and the costs?

When evaluating all data to decide whether these systems are worthwhile, one must remember that different systems of production are being compared. Each individual has somewhat different requirements for the system. Each must of necessity make the analysis because the right system for one may not be right for another.

Can it grow plants? To study plants under controlled conditions, or to be able to rapidly evaluate some conditions, such as the number of seeds that germinate, laboratory workers and research scientists have for many years used cabinets and growing rooms. These have been used to grow plants but generally were too expensive or complicated for practical use. Because the idea worked, adaption to field use followed.

Researchers, nurserymen and greenhouse vegetable growers in Britain and the European continent have studied the use of growing rooms for a number of years (5, 9, 16, 17). Concurrently, procedures were being developed (3), in the U.S. to grow seedlings under fluorescent lights.

There is no question but that seeds may be germinated and high quality young seedlings grown in growing rooms under artificial lights. But what about the benefits to the grower, and to the consumer?

Phases of plant growth. While plant development and growth from the onset of germination of the seed until transplanting to the field is a continuous process, taking the viewpoint that three distinct phases of plant development are involved would help to evaluate systems—procedures, equipment, etc.—developed for the culture of plants in growing rooms. These phases are as follows: (1) Germination of the seed, (2) Growth of the small seedling until transplanting, and (3) Growth of the small transplant. Demarcation between these developmental phases is not sharp. Duration of each phase is dependent upon the species and the environmental conditions that prevail.

Each phase has distinct optimum environmental conditions and space requirements. These may vary with plant species and even variety.

In a series of articles in 1969, Cathey (7) reported on the response of seeds of 112 species of plants to different regimes of temperature and light. He divided the responses into nine groups. He found that light inhibited the germination of seeds of some species such as *Vinca rosea* and *Limonium suworowii* (*Statice suworowii*). On the other hand the presence of red light on imbibed seeds was essential or enhanced the germination of many species such as *Petunia* 'Maytime;' *Kalanchoe* 'Tom Thumb;' *Begonia* 'Snowbank' and *Primula* 'Fasbender's Red.' Light intensity of 200 foot candles or less was sufficient; many plants responded to as low as 0.2 foot candles of light energy.

Temperature acted to modify the response to light. Optimum temperatures varied from 55° F. (lupine, *Myosotis,* sweetpea) to 80° F. (mimosa, *Grevillea robusta*).

The optimum environmental conditions for small plants before and following transplanting might be considered to be the same. Obviously, higher light energies are needed than those needed for seed germination. Early research in the U. S. reported minimum light intensities of 500 to 600 foot candles were needed to produce acceptable plants. Following transplanting to small pots, or spaced in flats, British scientists have been working with light intensities of 500 to 1000 foot candles on the plants.

The major difference between the last two phases would be the space needed for the plants. The space requirements for seed germination and growth of the small seedlings would be the same.

These requirements suggest that at least two separate cabinets or rooms would result in the most optimum conditions, efficiency and costs. A small room or cabinet for seed germination could be used. Several cabinets could be used to obtain the best condition for germination of each species. Low light intensity (200 fc), high humidity (65% and over) and temperature varying from 55° F. to 80° F. would be needed. Shelves may be close together. A second and larger room would be used to grow the small plants before or following transplanting to small pots. Higher light intensities (over 500fc) and lower humidity would be a consideration. The necessity of water and fertilization must also be added to the system.

Reasons for commercial usage. Around many nurseries may be rooms not fully utilized, or are used for only part of the year. Converting these to growing rooms would not only more fully utilize them but permit more efficient use of capital. This is a principal reason for commercial usage of growing rooms. Cellars, common storage and refrigerated storages are examples of facilities that can be more fully utilized. If there would be a corresponding release of greenhouse space for crop production, greater benefits would accrue as the released space is put into income-producing crops (4).

Another reason often expressed for use of growing rooms is that plants develop more rapidly and uniformly under these conditions than under greenhouse conditions. This generally is true because of a constant uniform environment and one suited for rapid plant growth. For example, air temperatures are more constant in growing rooms than in greenhouses. And due to the uniform intensity of light while the lamps are on, plants in growing rooms often receive more total light energy during the day than they would in greenhouses under natural conditions.

A third reason advanced for the use of growing rooms for small plants is earlier production, such as flowering or yield of vegetables, or more total production. Again there seems to be general agreement that this is true.

Faster growth. It would be surprising indeed if plants did not grow faster under growing room conditions than under greenhouse conditions. The total concept of using growing rooms is to be able to provide optimum environmental conditions whatever the whims of mother nature.

All factors in a plant's environment—water, nutrients, temperature, light energy, etc.—function together as a subsystem to influence the rate and amount of plant growth. Research scientists at the USDA have found that plant growth can be speeded tremendously by increasing the intensity of all environmental factors. Some of the fastest growth was obtained when the following environment prevailed: air temperature of 85° F. days and 75° F. nights, 16 hours of light at 4000 foot candles of intensity, relative humidity of 65%, 2000 ppm of CO in the air, air movement around the plants constant and four to six applications of water and fertilizer each day. This should be contrasted to research in Great Britain where ambient CO_2 levels were used, temperatures of 70° F. day, 65° F. night, 16 hours of light at 1000 foot candles intensity and air movement at 60 feet per minute.

It appears that plant growth can be speeded tremendously. The cost of providing the escalating environment must be balanced against income to determine practicality.

Early imprinting. Environmental influences on young seedlings can persist for many weeks, even when the plant has been removed from that environment. This effect has been shown a number of times (6, 8, 10, 11, 12, 14, 18). The effect may be larger plants, earlier flowering, earlier yield, and more yield. Adverse effects may also be noted.

Often, the nature of the crop determines whether the effect may be adverse or not. For example, Hopkins (10) reported that brief periods of water stress with small tobacco plants delayed flowering (flowering at a higher node). Actually this effect was beneficial because yield was increased due to a change in distribution of leaf surface and the delay of flowering at a higher node.

Where the grower is interested in faster growth and earlier yield, or more total yield, or both, early imprinting could be used to advantage However, where the grower sells plants, the value of early imprinting for faster growth and earlier yield may be open to question. True, the crop will be ready for market in a short period of time. However, if adverse weather caused delays in selling or delivering the plants, would they become overgrown and of poor quality too rapidly? Would the faster growth shorten the shelf life of plants at retail outlets? Both of these are possibilities based on the evidence and must be considered.

Benefits and costs. The benefits of using growing rooms may be listed as follows: (1) faster plant growth, (2) earlier yield or more total yield or both, (3) more uniform plant growth, (4) utilization of under-used or waste space, (5) more predictable plant growth.

To a businessman that starts seedlings and matures a crop—be it flowering or vegetables—these benefits could mean more precise regulation of the crop and an improved income picture. To the businessman that sells small plants, some of these benefits may mean shorter shelf life of the small plants.

The cost of providing these facilities vary with location and environment. In England, some data indicate that the cost per tomato plant was from 4% to 110% more depending upon the system of growing room culture used (15). On the other hand, Buck (4) quotes the vegetable grower as stating that he saved money—"Our anticipated savings...should amount to 0.008 cents for each of two million lettuce seedlings and 0.04 cents for each of 75,000 tomato plants started. We also expect to save over 1,200 man hours of labor..." Both of these facilities did not report the use of elevated levels of CO_2. Because the last facility was utilizing underused refrigerator space already on the premises, it is not clear what costs of building or depreciation of structures was involved. The report by Lingard considered depreciation of the structures as a cost of operation.

The environment to maintain. If you were to construct facilities for germinating seeds and growing young plants, what should be the level of each environmental factor over which control could be exercised? In 1969, a representative of George Ball, Inc. (2) wrote that they were recommending the following conditions for the germination and early culture of bedding plants: (1) Constant day and night temperatures of 65° F. to 70° F.; (2) Minimum light intensity of 500 to 800 foot candles at plant level, using warm white fluorescent tubes as a light source; (3) Lights on for 18 hours per day. No mention was made of CO_2 levels, relative humidity or air movement. Presumably these factors fluctuated naturally.

Scientists working at the USDA (13) suggested that the optimum environmental system had the following characteristics: (1) air movement of 100 feet per minute; (2) day temperatures of 80° F. to 85° F. and night temperatures of 70° F. to 75° F.; (3) relative humidity of 65 per cent; (4) light intensity of 100 foot candles for germination and 2000 foot candles for growing; (5) light duration of 16 hours; (6) light source of cool white fluorescent tubes and incandescent bulbs (10% of wattage); (7) CO_2 levels of 400-500 ppm for germination and 1000-2000 ppm for growing.

In the facilities described by Buck (4) the following conditions prevailed: (1) Constant air movement, velocity not stated; (2) constant temperature of 70° $\pm$ 5° F.; (3) light intensity of 4000 foot candles; (4) light duration of 12 hours; 5) light source a combination of high pressure sodium and metal halid lamps.

As previously mentioned, growing rooms in Britain have from 500 to 1000 foot candles of light at a temperature of about 70° F. Light duration was generally 16 hours. Fluorescent tubes are the most common light source.

Several considerations should be kept in mind for these facilities. First, germination rooms require less light than growing rooms. A maximum of 200 foot candles would be sufficient for germination while growing rooms should have a minimum of 500 to 1000 foot candles of light at plant level.

Second, germination rooms require higher humidities than growing rooms. A level of 60-65% should be sufficient for growing rooms.

Third, maximum effect of elevated CO_2 levels is obtained only under high light intensities—over 1500 or 2000 foot candles of light. Elevated temperatures during the light hours are important.

Fourth, the length of lighting for best growth is somewhat dependent on light intensity. Buck (4) stated that they found as good growth with 12 hours of light at 4000 foot candles as 16 hours of light at 2000 foot candles. Other reports indicate the same. Light intensity high enough to make 12 hours of lighting sufficient has some practical advantages in efficient use of lights.

Fifth, light source is relatively unimportant to plants as long as the proper color balance is maintained. Light source does influence cost of installation and operation.

In the final analysis, each situation must be analyzed on its own merits depending on the desires of the manager. Guidelines for minimum conditions might be drawn up, but these may not be the most efficient for the particular situation.

Some engineering considerations. Buck (4) presented the ideas that went towards designing and building a growing room for commercial conditions Only one level of plants were to be grown, and a light intensity of 4000 foot candles was desired. High intensity gas discharge lamps were used. Use of fluorescent lights would require many lamps and mounting them close together. Also some difficult lamp temperature requirements were imposed, requiring a complicated air handling system. Still, the fluorescent lights would have been less expensive to install.

Passing the air over the lamps and exhausting at the bottom of the room help to cool the lamps, and to heat the air. Outside air can be used to cool the room whenever outside air is below growing room temperature. However, this would complicate the task of maintaining elevated CO_2 levels. Excess heat from the lighted growing room might be used to heat other facilities such as the germination room.

Burning the lights constantly and moving them from one room to another each 12 hours would make maximum use of this expensive facility—and increase the life of the bulbs in the process. Control of photoperiod may be by means of low intensity lights in the dark room.

British research workers have developed ideas to have more than one layer of plants in a growing room. Tiered mobile benches are placed between banks of lights. The concept seems to hold much promise.

Separate seed germination rooms should be provided. Ideally, three rooms are needed—a germination room, a growing room for small plants in the seed flats and a growing room for the plants in small pots or packs. The latter two rooms may be combined without serious difficulty.

In conclusion. The widespread use of separate germination and growing rooms for seedlings will depend upon the costs and benefits that accrue to the producer. There is no question on the ability of producing quality plants, of obtaining faster growth and of the effects of early imprinting. Recent technological developments make these facilities practical.

Whether greenhouses will be completely replaced by these facilities is questionable. Under some conditions, greenhouses will be replaced. More likely these facilities will be part of a well organized system of production for plants that include greenhouses and outdoor facilities as well as growing rooms and germination rooms.

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MODERATOR HASEK: Thank you, Tok. Any questions?

RALPH SHUGERT: Tok, I was wondering, in researching this did you run across anything in the use of lights for breaking double dormancy in seeds? I'm thinking of genera like *Vibernum* and *Tilia,* which, for a commercial man, seed dormancy presents quite a problem. Has anyone done any experimental work in lighting to break double dormancy?

TOK FURUTA Well, frankly, no because I wasn't looking for that aspect. I don't recall any information I've seen on this particular aspect. Seed is generally responsive to light only after it has imbibed water and is getting ready to germinate This is just removing one block of germination. Now, when you're talking about double dormancy—this may be caused by inhibitors or something else like this. I don't know. It's questionable in my mind whether light would have any effect on both aspects of double dormancy.

MODERATOR HASEK: We are to have a panel on our next segment, which is on seed handling. We will start with Gene Baciu.

PROLONGING SEED LIFE

EUGENE BACIU

Mistletoe Sales, Wholesale Seeds
Santa Barbara, California

Seeds of short life have presented problems for the nurseryman for centuries. In the days of the sailing ships, expeditions were made to gather plants from all over the world. Many of these plants had to be grown in containers on the ships and, in most instances, it took years to transport these plants to Europe and other countries. The steamship helped tremendously in transporting the plants that bear short-lived seeds. Then came the airplane and now we have jets that can transport the seeds from any place in the world to the grower in a few hours. Of course, at times it has taken up to six weeks to get them out of Customs. I have had seed received from Thailand by Customs on August 2 which were not released until September 16, resulting in very poor germination. I was unable to get a reason from Customs for their refusal to release my shipment. Perhaps some work could be done with Customs to shorten this period of time.

Resulting from our changing habits of living, we have developed a desire for small plants to be available at any time of the year. Now the problem is a method of prolonging the life of seeds so that we may reach this goal.

During the past several years, I have been working with moisture and temperature control methods and have had some success with the following seeds. *Dizygotheca elegantissima* seed viability is usually 8 to 10 days. With the right amount of moisture and temperature control, (35° F.), the viability has been increased to 6 months with 90% germination *Syzygium paniculatum* (*Eugenia myrtifolia*) retains its viability for about one week; now with refrigeration the seed can be kept about two months. At the end of this time, remove the seed from cold storage and germinate them, just enough for the seed to crack. Then return them to the refrigerator at a temperature of 34° to 38° F. By doing this we have added 6 more months to the life of *Syzygium paniculatum*, for a total of 8 months. *Magnolia grandiflora* has been a