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Final Report

On

A Preliminary Research Plan For Development of a Photosynthetic Link in a Closed Ecological Life Support System

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DISCUSSION

I. Requirements of Photosynthetic Processes

1. General Considerations

The use of higher plants in a closed ecological life support system for long duration space missions involving relatively large numbers of people is one possible solution to logistical problems inherent in such missions. For example, crop plants have the potential capacity to close the loops or cycles for CO_2, O_2, water, and waste as well as the capacity of producing food for humans and food for animals, if present. The combination of so many vital functions - removing CO_2 and replenishing O_2 in the atmosphere, purifying water through transpiration, processing waste nutrients (minerals and nitrogen) and producing food - along with the asthetic and psychological value of plants in such an environment is an additional argument for this solution.

While the potential benefit of using higher plants in a CELSS in space missions is apparent, the research necessary to develop and test this system may produce spin-offs in technology applicable to partially closed, high intensity food production systems useful on earth and to basic discoveries in plant science that might allow advances in food production technology within ongoing, long-term crop improvement programs.

While it is true that conditions necessary for plant growth are rather well known, they have been defined within the limits of the terrestrial environment. In a CELSS the atmospheric composition/ pressure, light quality/ intensity/ duration, relative humidity, temperature, gravity, root medium, nutrient levels and possibly other environmental factors may be varied from terrestrial norms and may be controlled. No one can fully assess the opportunity of this fact or the problems that may arise.

The approach to planning and developing both the habitat for a long term space mission and CELSS should be by integrated systems design. All component and subsystem interactions should be considered at the same time. While it is not practical that experiments be done to study all requirements for plant growth simultaneously, there is an equivalent approach in the needed plant research. A computer simulation model of plant growth and yield should be developed or adapted to this program to serve as an integrating tool for the plant research. The Biosystems Engineering Group at Texas A&M University has developed such models and their involvement with the CELSS is proposed in any future contract. It is critical that such a model not simply be a mathematical extension of how plants behave under known conditions. Rather, a useful model must include a mathematical expression of how the subsystems of the plant work and thus be mechanistically correct. Only in such circumstances can a model be used to predict behavior under conditions never before tested. Computer simulation models should be used to identify needed information and to integrate the total plant research effort.

In the plant science area two types of efforts are needed. First, questions must be answered in the area of basic plant physiology. These are questions relative to photosynthesis, geotropism and such like. The second area is plant growing systems and topics in that area range from crop selection and breeding to integrating all available and acquired information into a set of conditions and operations. Given a set of conditions and operations, engineers can then design a facility to supply these conditions and allow the operations.

2. Requirements of Photosynthetic Organisms

Illumination: The decision between natural and artificial illumination is primarily one of engineering considerations. Plants can be grown under either type of radiant energy, but whether the use of natural illumination is possible depends on engineering considerations such as: window area necessary, structural strength of large window areas, damage from meteorites, insulating capacity of window material against harmful radiation, heat exchange capacities of window material, proper orientation of windows toward sun, absence of sunlight when in earth or moon shadows, etc. If a CELSS must be rotated to provide an artificial gravitational field to allow normal plant development (there is no firm basis to say that plants will grow in the absence of such a field), then the orientation of "windows" to the sun becomes more of a problem. These problems may make the use of natural light unfeasible. In addition, the effects of space levels of cosmic and ultraviolet radiation on plants is not known. Consequently, the amount of shielding required to protect plants is not known; however, studies on increased UV radiation effects on plants are underway at the University of Florida under NSF sponsorship. If artifical illumination is used in a CELSS there will be a need to evaluate the newer artifical sources and to examine the possibility of managing plant development (i.e., flowering, etc.) by manipulating light quality. There are several engineering problems relative to selection of the type of light source (life span, intensity/energy use relationships, heat output, etc).

Growth Media: In addition to water and CO_2 plants require N, P, K, S, Mg, Fe, Ca, Cu, Mo, Zn, Mn, B, Cl. Further, the symbiotic bacteria of legumes require Co and plants commonly are exposed to and utilize Na. The latter six elements above readily become toxic when present in supraoptimal concentrations. The pH of the growth medium preferably should be between 5-7 to allow uptake of the salts. The medium must also furnish support and oxygen. It is possible to grow plants with their roots in mist chambers, hydroponic solutions, inert or artificial media or soil. In a CELSS over long periods of time the growth medium will become an important problem. It is very difficult to maintain the pH and salt balance in nutrient solutions, and they also offer a means of rapid transmission of plant disease organisms, primarily bacteria and fungi, as well as toxic chemicals. The weight and stability of inert media must be considered along with the accumulation of trace elements (toxic) in the growth medium (a problem noted in Russian tests). On the other hand, if some form of hydroponics is employed it will provide an avenue for treating plants through their sensitive root systems with plant growth regulators employed to control development (eg., flowering, etc.). It seems desirable that some buffering capacity be included in the medium. The root medium becomes more critical when recognized that it will presumably be receiving processed human waste and waste water. The waste management / plant nutrient interface will require considerable study.

Environmental Factors: Effects of environmental factors on plant growth and development have been extensively researched but mostly within the context of terrestrial limits. Most data are from open systems and under natural lighting. Once we depart from the limits of terrestrial environments the interrelationships of the various environmental factors are less well known.

Temperature. General temperature ranges or optima for plant growth are known, but they may be different when other environmental components shift. Temperature has generally not been an environmental component that has been manipulated as a management tool. For example, some plants are photoperiodic at one temperature range and not at another. At Texas A&M University Williams and Morgan have recently shown that a shift of the thermoperiod (day/night temperature cycle) out of phase (½ to 2½ hrs) with the photoperiod caused sorghum to flower like a non-photoperiodic plant. Also at TAMU Powell earlier showed that the rings in cotton fibers are the result of day/night temperature cycles rather than light/dark cycles. He further demonstrated that constant temperature caused abnormal flower development and shedding in cotton. Thus, it appears that two important questions must be answered relative to temperature: (a) what levels and variations or cycles are necessary to sustain plant growth and development, (b) to what extent may temperature be used as a management tool (to promote flowering, bulb or tuber formation, etc.).

Photoperiod. Many plants are photoperiodic, requiring either short days or long days to flower, while others will complete their life cycle in continuous light. Since the CELSS supposes food production for a rather complete, varied diet, it is apparent that fruit, tuber, bulb and other complex, developmental stages must be accomplished by some of the crops in the CELSS. Another photoperiod-related problem is that the human requirement for plant-released O_2 is constant, thus the photosynthetic system cannot be "turned off" part of the day. It would be possible to have opposite photoperiod schedules in different chambers so that some have lights on while others have lights off. It is known that photoperiodism is genetically controlled and within given crop species considerable variation exists in photoperiod requirements. Thus, one aspect of the photoperiod question is a careful selection of the species and varieties to be used in the CELSS. The mixing of different species, or different developmental stages (i.e., conveyor system of production, frequent planting and harvesting), the need for photoperiod exposures to achieve certain developmental events in essential species unavailable in day neutral lines all are significant plant research topics or design considerations. Both temperature and photoperiod influence transpiration rates (stomates often close at night), and since the CELSS will presumably cycle water through plants to be subsequently recovered from the atmosphere, this relationship must be considered.

Gravitational Field. Plants are geotropic organisms. Their roots grow down and shoots grow up in response to gravity. Further, there are gravity-related mechanisms that control branch angles, leaf orientation, and other behaviors. The orientation and special shape of the plant plus polar (directional, i.e., basepetal) movement of certain plant hormones contributes to differentiation processes, (for example, developmental of vegetative buds into reproductive buds in some cases). The entire process of hormonal regulation is related to gravity through the polar transport system for auxin (indole acetic acid) and, possibly to a more limited extent, for gibberellins. Whether or not the development of polarity within a embryo depends upon the presence of gravity is not known, but that is a possibility. What is known about gravitional effects on plants is limited to changing their horizontal position, growing them on klinostats and a few brief experiments in biosatellites. There is no scientific basis to propose that plants can grow in the weightless state nor to determine the fraction of earth gravity that will substitute, allowing acceptable growth and development. How well an artificial gravitational field achieved by centrifugal forces will substitute for earth gravity is unknown. This is clearly one of the most critical topics in the CELSS package. Several questions must be answered including: (a) screening candidate crop species on klinostats to determine sensitivity of complex developmental processes (flowering, fruit growth, seed development, tuberization, bulb formation, etc.) to gravity "cancellation" via rotation, (b) test means to circumvent low or zero-gravity with plant growth regulator applications (auxin transport inhibitors, etc.), (c) examine gravity effects on basic hormone systems such as auxin transport and ethylene synthesis, (d) examine gravity effects on production of toxic substances by plants (CO, NO, etc.) and on major metabolic systems (respiration, etc.).

Atmospheric Composition. In a CELSS it will be possible to alter the conventional terrestrial atmosphere by reducing the pressure or changing the levels of O_2 or CO_2. The effect of reduced pressure on plant growth has not been extensively studied; plants grow at high altitudes but interpretation of the effect of reduced pressure is not possible because of other factors such as temperature extremes, water stress, cosmic radiation, and mechanical stress (wind). Plants require CO_2 and O_2 in the atmosphere, and it is well established that they respond with increased growth to increased CO_2 levels. Operational CO_2 levels in past space flights are well above earth atmospheric levels. However, the tolerance of plant species to elevated CO_2 levels, especially life-cycle-long exposures, is known to vary and must be examined for candidate crop species for a CELSS. Oxygen inhibits photosynthesis, especially in C-3 type plants which have only the Calvin Cycle - type chloroplast (C-4 plants have higher temperature optima for photosynthesis, higher light saturation levels for photosynthesis, higher tolerance to oxygen and the capacity to reduce concentrations of CO_2 below those that C-3 plants can absorb if the CO_2 supply is limited; there are not too many C-4 crop species, corn, sorghum and sugar cane being the best known). It follows that a reduction in the level of O_2 might promote photosynthesis in C-3 plants and this has been demonstrated in closed chamber atmosphere modification experiments at DuPont's Experimental Station. However, in their tests the reproductive stage of development was inhibited by reduced O_2 levels. Relative humidity is another atmosphere-related condition which has important effects on plant growth. High relative humidity increases leaf size and reduces thickness in some species. It will reduce transpiration and thus the speed of cycling of water through the plant component of the water cycle in a CELSS. High relative humidity will have developmental effects, such as inhibiting anther dehiscence (opening of the anther to allow pollen dispensal), and will promote microorganism growth. Relative humidity levels should be studied in conjunction with other work on environmental factors. It will be desirable to study the responses of candidate species to variations in atmospheric composition, minaly total pressure, O_2 and CO_2 partial pressures, and relative humidity. It is quite possible that human needs will set the atmospheric conditions, but the plant optima in a closed system need to be known.

Management of Photosynthetic Processes. This consideration includes what can be called the entire crop growing system. It includes such considerations as the spacial arrangement of plants (layering, interplanting, separating species into different compartments, "conveyor belt" production) and thus location of light sources, root medium containers and support, if needed. It also includes management consideration such as planting schedules and techniques. Will seed be stored or produced on board? It may be feasible to use tissue culture for clonal propagation of seedlings which would be transplanted into growing beds thus circumventing the need for seed. Such techniques are now used with many ornamental species and are well suited to a programmed, frequent planting schedule. Tissue culture could be a useful management technique and should be evaluated. It seems likely that serial plantings to maintain plants in all stages of development will be a desirable technique because it will provide for continuous food production and uniform labor needs; however, this management technique may be complicated by needs to modify photoperiods or temperature to facilitate certain development events (flowering, etc.). Harvesting can be programmed relative to planting schedules, but the details of requirements will depend on crops to be employed. Since photosynthesis rates decline near maturity, it will be necessary to harvest promptly to maintain the atmosphere cycling capacity of the vegetation. Another management consideration is whether variations in nutrient levels will be desirable to manipulate crop development. In terrestrial agricultural environments, plants are exposed to a decreasing gradient of nutrient levels during the crop season, while in "artificial" systems nutrients can be replenished continuously. This represents a management option that should be examined. Plant wastes will have to be disposed of in a manner to recycle the CO_2, N and minerals. This will be more of a problem in a closed system because

be considered. The toxic principle released by the algal cultures in the Russian test represents another consideration. Trace elements may accumulate in the root medium to toxic levels. The management of trace elements, especially with the presumed interference between human waste and plant nutrients, is an area that needs consideration. The Russians listed this as a major problem identified in their closed system experiment. Another management consideration is the requirement for pollination of flowers to produce some of the food products and seeds for subsequent plantings. A CELSS will have neither natural wind or insects. Plants vary in their pollination requirements from self pollinated to wind pollinated to obligatory insect cross-pollinated. Tomatoes are produced in greenhouses with special efforts to promote self pollination via hand held vibrators and growth regulators that promote parthenocarpic fruit set (growth and development of fruit without fertilization). This management consideration will have to be evaluated in terms of the crop species selected.

Ecological considerations: There are certain ecological considerations related to the culture of several species in one growth chamber because of the possiblility of differences in optimal environmental requirements for several plant species. This might allow competition, if interplanted. Thus, there is a series of questions on plant density, canopy configuration, layering, etc. that is common to the agronomist/horticulturist. Further, the microorganism interactions also have a ecological dimension. These relationships will have to be considered in the total plant research effort.

Summary: It is possible to summarize the requirements for plant growth and interpret them relative to a CELSS. That analysis is as follows:

The basic requirements of plant growth are:

(1) Carbon in the form of CO_2

(2) Hydrogen and oxygen in the form of H_2O and O_2

(3) Radiation between the wavelengths 400 and 700 nm

In the photosynthetic process, the carbon, hydrogen and oxygen are combined to form glucose, and excess oxygen is evolved. This process takes place in leaves:

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\ O_2$$

The leaves export most of this glucose to other parts of the plant, where it is converted into new plant biomass, including new leaves. The composition of this biomass varies, but a typical example might be:

$$1\text{g}\ C_6H_{12}O_6 + 0.10\text{g}NO_3^- + 0.003\text{g}SO_4^= + 0.12\ \text{g}O_2 + 0.034\text{g other minerals}$$
$$\longrightarrow 0.65\ \text{g new biomass} + 0.34\text{g}CO_2 + 0.27\text{g}H_2O$$

This equation shows that:

(1) Plants recycle some of their own carbon, hydrogen and oxygen

(2) Many other chemical elements are required, in amounts up to 20% of the plant biomass. These include: nitrogen, phosphorus, potassium, sodium, calcium, magnesium, sulfur, zinc, manganese, copper, boron, molybdenum, iron.

Concentrations of these elements in the soil medium must be properly balanced. The pH of the soil must be in the range 4 to 6.

Note also that:

Leaves cool themselves by evaporative cooling. About 300g of water is evaporated for every gram of CO_2 taken up. If the water is not available, growth stops and most plants die in a matter of days. 100% of the water must be recycled through the plants.

Since the water that is evaporated is pure, the mineral salts build up in the soil medium and this also stops growth.

Differences in the potential of the water between soil medium and atmosphere largely determine the rate of evaporation, and these differences can be controlled. However, without gravity there might be no roots to take up the water and essential nutrients.

Toxic compounds and biological pathogens enter plants very easily, either from the soil medium or from the atmosphere. Plants have very few defensive mechanisms, and diagnosis of problems is difficult in most cases.

Relevance to Closed Life Support Systems

(1) Plant growth requires more than the provision of the carbon dioxide, water and light that are needed for photosynthesis.

(2) The other nutrient requirements are generally known, but keeping them in balance in a closed system for several years is likely to prove difficult.

(3) Toxic compounds will accumulate, and many of them will not be familiar to plant pathologists. New systems for identifying and dealing with such problems in a spacecraft will have to be developed.

II. RECOMMENDATIONS

A. Data Base Accumulation and Use

1. Relevant Literature

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Fong. F., 1975. Phospholipid metabolism in bean leaves (Phaseolus vulgaris). Ph.D. Dissertation, University of California, Riverside.

Fong, F., J. Peters, C. Pauling, and R. L. Heath. 1975. Two mechanisms of near ultraviolet lethality in Saccharomyces cerevisiae: a respiratory capacity dependent and an irreversible inactivation. Biochim. Biophys. Acta 387:451-460.

Jacobson, B. S., F. Fong and R. L. Heath, 1975. Carbonic anhydrase of spinach: studies on its location inhibition and physiological function. Plant Physiol. 55:468-474.

Fong, F. and R. L. Heath. 1975. Phospholipid metabolism in ozone treated bean leaves. Plant Physiology 56S:5.

Fong, F. and R. L. Heath. 1974. Phospholipid metabolism in ozone treated bean leaves. Plant Physiology 53S:31.

3. Literature Searching (Machine), Cataloging and Re-Call Methods.

A comprehensive literature search could be the objective of a specific study. Key words should be identified for each of the major areas outlined on pages 71 to 74 of the Research Topics section which follows. Relevant computerized bibliographies such as the Chemical Abstracts and others should be searched. The references should then be screened for applicability and placed into a computer under a key word and author program.

B. Research Topics

1. Introduction

Many of the research questions related to developing a Closed Ecological Life Support System are also related to the ongoing research programs of the Land Grant Universities. The Texas Agricultural Experiment Station has relevant research programs and support is available from other colleagues who are associated with the University system but who are not TAES staff. A joint research effort of Johnson Space Craft Center and the Texas A&M University group is proposed as one approach to answer the questions critical to development of a CELSS. Obviously, the questions and areas identified here are the basic part of the plan and could be attacked effectively by other groups. It is, however, the opinion of the study team that there would be an advantage of a research plan utilizing a team of scientists currently interested in questions of plant physiology, crop productivity and crop ecology.

The TAMU group has identified the major questions they feel must be answered. Several scientists have been identified who are interested in working on these questions. Pre-proposals by individuals and small teams are enclosed to show willingness to participate, competency, facilities and some ideas on approaches. There is considerable overlap between some of the individual proposals; however, these problems can be worked out with additional time. In particular, it would be possible to involve people on algal problems, human nutrition and food preparation, and other questions if such seems desirable.

2. Proposed Research Programs

a) Selection of the crops to be grown in the CELSS based on considerations of human nutrition and food preference, production efficiency, compatibility (size, etc.) and related practical considerations. The development of selection criteria would be a team effort, and since subsequent studies might eliminate some selections, more species would have to be selected than would be used initially. The horticulturists involved in this area would begin a breeding program to identify and adapt varieties to the conditions of the CELSS. They would also develop the cropping system(s) to be used, including planting and harvesting schedules and all details of management. The use of tissue culture as a propagation technique would be tested.

Tentative Investigators: Dr. Creighton Miller, Dr. John Larsen, Dr. Roberta Smith.

b) Determination of Plant Root Medium and Nutrition Provisions. This effort would test and select an appropriate root culture medium. Another effort would be to test waste (human and plant) management systems as sources of plant nutrients. Ways to monitor and regulate nutrient levels would be developed and trace element questions would be studied.

Tentative Investigators: Dr. David A. Zuberer, Dr. Richard W. Weaver, Dr. L. R. Hossner.

c) Determination of the optimal environmental conditions for growth of plants in a CELSS. This study would focus on both those requirements for photosynthesis and those for complex phases of growth and development. The research would use candidate plant species and varieties selected in the crop selection and breeding project (number A above).

It would consider both yield and nutritional quality. Conditions to be studied include atmospheric pressure, atmospheric composition (O_2/CO_2 levels), light quality/intensity, photoperiod/thermoperiod, temperature and relative humidity. The relationship of environmental conditions to transpiration and the water cycle would be determined. Tentative Investigators: Dr. C. R. Benedict, Dr. K. J. McCree, Dr. R. D. Powell, Dr. R. J. Newton.

d) Determination of the effects of reduced or zero gravity on growth and development processes such as root growth and development leaf orientation, flowering, fruit growth, tuberization, bulb formation, etc. The effect of reduced gravity on auxin transport and ethylene production would be studied. Air pollution questions related to higher plants and algae in a closed system should be investigated. Tests would be conducted using chemical growth regulators to circumvent effects of low gravity and to achieve other management effects such as flower induction, fruit set, etc. The low gravity studies would involve klinostats, experiments in Space Shuttle flights, and approaches developed from those two experiences. Candidate crop species will be screened in this project. Tentative Investigators: Dr. A. S. Garay, Dr. F. Fong, Dr. P. W. Morgan, Dr. R. D. Powell.

e) Microorganism - phytopathological studies on how to protect plants from disease organisms, how to monitor the microbiological status of the system, the possibility of including desirable microorganisms in the system and the possible human disease aspects of plant pathogens. Tentative Investigators: Dr. R. S. Halliwell, Dr. Ray D. Martyn, Dr. R. E. Pettit, Mrs. Ruth A. Taber, Dr. M. P. Grisham.

f) Computer simulation modeling of plant growth and crop yield. This is a strong part of the total effort tieing together engineering and biological testing. It will allow recognition of needed information as well as prediction of individual plant and total system behavior under selected conditions.

Tentative Investigators: Dr. Don W. DeMichele, Dr. John Goeschl, and others.

NASA PROJECT INVOLVEMENT

Creighton Miller
John E. Larsen

Potential Areas

1. Determination of which vegetable crops would be most appropriate for growth in space flight - both from a human nutrition and preference standpoint, would be a logical starting point. Also, the identification of crops which can most easily tolerate environmental conditions encountered in space travel, with particular emphasis on production efficiency per unit of available growing area and time would constitute an integral part of the crop selection process.

2. Following resolution of point 1, extensive testing should be undertaken to determine the most efficient varieties of the selected crops. Such factors as maturity rate, yield, and nutritional value must be considered in this determination.

3. Once the plupiological and other parameters which limit efficient crop production under space flight conditions have been identified, a breeding program(s) should be initiated to develop varieties tailor made for growth under these conditions. Varietal choice is of the utmost importance, as production efficiency must be the prime consideration.

4. The effect of environmental conditions encountered in space flight on seed germination, flowering, fruit development and other parameters must be investigated.

5. Cropping systems for space flight is an additional area which must be investigated. Root media, as well as sequential planting and intercropping are examples of facets which must be considered in the total cropping system.

Problem

Rapid clonal propagation of food plants to produce uniform plants of predictable quality, and thereby bypassing the time involved for sexual seed production and its variation.

Objectives

Plants chosen for space lab use will need to have *in vitro* culture methods developed if they do not already exist.

Modification of *in vitro* techniques to zero gravity growth conditions will need to be studied.

Methods to minimize energy input into the culture environment (photoperiod, light quality, temperature) for maximal production of plantlets will be examined.

Storage methods for germplasm *in vitro* will be studied.

Proposed Principal Investigator

Roberta H. Smith
Assistant Professor, Plant Physiology
Department of Plant Sciences

Facilities available

Plant Tissue Culture Laboratory

a. Medium preparation facilities

b. Aseptic transfer air flow hoods

c. Culture room, incubators, and orbital shaker platforms

Related Research

Rapid clonal propagation of pecan trees, kalanchoë, nandina

Tissue culture of cotton for somatic cell genetics research.

Anther culture of sorghum for haploid or homozygous diploid plants.

Problem

Microorganisms have been well documented to be of extreme importance in diverse ecosystems because of their participation in biological decomposition of wastes, transformation of essential plant nutrient (particularly N and P), plant disease and many other processes. Because of this versatility microbial processes might be integrated into the design of the closed ecology life support system to provide useful inputs for other CLSS components.

Research Questions

Can soil microorganisms be exploited so as to provide enhancement and or stability of essential biological processes such as solid waste and waste water treatment and food crop production within closed ecosystems.

Can plant productivity in closed ecosystems be enhanced through colonization with selected microbes specifically those capable of fixing atmospheric dinitrogen (N_2) and/or producing plant growth regulators.

Can the Rhizobium-legume symbiosis be exploited within the closed ecology life support system i.e. can CO_2 removal and nutrient recycling be coupled to protein production.

Can plant disease within the closed ecosystem be controlled with biological agents.

Proposed Prinicipal Investigators

David A. Zuberer
Assistant Professor, Soil Microbiology
Soil & Crop Sciences Department

Richard W. Weaver
Associate Professor, Soil Microbiology
Soil & Crop Sciences Dept.

Facilities Available

Two laboratories equipped for research in the areas of environmental microbial ecology and soil microbiology with emphasis in plant microbe interactions, biological nitrogen fixation, and utilization of agricultural and urban wastes.
Controlled Environment Plant Growth Chambers
Mass Spectrometer for ^{15}N studies.
Gas chromatographs for acetylene-reduction assays for nitrogen fixation.

Soil Microbiology research projects or areas: (1) Aspects of biological nitrogen fixation in the Rhizobium-legume symbiosis and associative nitrogen fixation in grasses.

(2) Ecology of free-living nitrogen fixing bacteria in aquatic and terrestrial habitats.

(3) Exploitation of beneficial processes of soil microoganisms, such as release of plant nutrients from waste products, control of plant disease and transformations of essential plant nutrients.

F. Fong

Problem

* To remove unidentified air pollutant(s) formed by the algal production unit so that it could be integrated with the plant production unit.

Research Questions

* What are the effects of this unkown pollutant(s) on plant growth and development?

* What are the gaseous by-products of algal cultures and are they phytotoxic?

* How can these pollutants be removed from the air or their production eliminated?

Proposed Principal Investigator

Franklin Fong
Assistant Professor (Plant Physiology)
Plant Sciences Department
Texas A&M University

Facilities Available

Controlled environment and general biochemistry laboratory (872 ft^2)
(room 419, Plant Sciences Building)
Contains: 3 semi-closed, glass walled test chambers for plant response studies.

Chamber specifications:
- 2.2m x 1.2m x 1.2m high
- artificial light (up to 17.5 watts/m^2)
- air temperatures 5-30° C
- humidity controls
- photoperiod controls

On going air pollution research projects:

a) ozone and sulfur dioxide inhibition of plant growth and development

b) biosynthesis of ethane and lipid peroxidation products in stressed plants

Problem

Management of ecological relationships between plants and microorganisms in space.

Within limited space maximum plant yield and product quality will be critical. Plant growth can be significantly influenced by the presence or absence of beneficial or harmful organisms. The introduction of certain microorganisms into a closed system could significantly improve waste decomposition, recycling of nutrients, crop yeild, and product quality. Interactions between such organisms may be significant. Also, the need to recycle organic plant residues will require an understanding of microbial ecological systems.

Research Questions

1. Are the seeds and/or cuttings used to establish farms in space initially free of microorganisms? Do they need to be free? If so, what methods would be employed to guarantee this? If not, what organisms would be allowed?

2. Would it be advisable to inoculate plant growth media in space with beneficial microorganisms - or will a purely chemical system suffice?

3. What microorganisms would be beneficial to add to growth media to improve plant health?

4. Will beneficial microorganisms maintain their beneficial qualities over an extended period of time?

5. Is it possible to actually add such organisms without any accompanying organisms, since many have never been grown in pure culture?

6. Are there certain combinations of beneficial organisms that would accelerate plant growth and yield higher quality products.

7. What kind of system could be devised (in cooperation with engineers) to add organisms at specific concentrations? How critical will such concentrations be? What kind of sampling techniques will be needed?

8. What will be the survival time for any such introduced organisms under the space environment? Will it be necessary to periodically re-inoculate growth media? What effect will solar radiation have on them?

9. After harvest will it be appropriate to add microbes to break down residual plant parts for re-use or will chemical digestion be preferred?

10. What kinds of microbes known to have cellulolytic and other enzyme systems would be <u>safe</u> to add for this purpose?

11. What methods could be used to test for microbial contamination or effectiveness of decontamination in a space greenhouse?

12. Will mutations be a problem? Will it be necessary to grow organisms under a simulated space environment in order to check for this? If so, what kind of markers can be used?

13. Will plant stress stimulate or encourage various introduced organisms to become pathogenic?

Proposed Principal Investigators

Robert E. Pettit
Associate Professor
Department of Plant Sciences

Ruth Ann Taber
Research Scientist
Department of Plant Sciences

Facilities available

The Department of Plant Sciences and Texas Agricultural Experiment Station has the following equipment available for use: microscopes (light and electron), incubators, growth chambers, greenhouses, transfer chambers, refrigerators, microtechnique equipment and equipment for chemical extractions in supportive laboratories and departments.

Problem: Maintaining pathogen-free plant systems in space

In order to maintain actively growing plants over long periods of time in a closed system such as a space station, it is paramount that any known or potential phytopathogens be excluded from the system. It is perhaps axiomatic that the result of many scientific man years of research and development could be devastated by the introduction of plant pathogens into the system. With this in mind, the following questions and research avenues are proposed for investigation:

1. The exclusion of phytopathogens will require extensive programs developed in the following areas:

   A. Production and certification of pathogen-free plant material whether it be seed, vegetative plant parts, transplants, plantlets derived from plant tissue culture techniques, etc. This will also require means of maintaining the plants free of pathogens.

   B. Elaborate quarantine and decontamination policies and procedures to prevent the accidental introduction of phytopathogens. Media of potential introduction include (1) contaminated new plant material, (2) contaminated personnel as shifts and crews are rotated, and (3) contaminated equipment and supplies.

2. Exclusion of known or potential pathogens from plant systems will require virtually sterile growth conditions. The question then arises: "Can plants be grown successfully under sterile conditions?" More and more evidence is accumulating to suggest that plants require a whole array of microorganisms including resident endophytes and mycorrhizal associations. Can these organisms be successfully re-introduced into the system? For example, the nitrofying bacteria which would most probably be used to aid plant growth are aligned closely with the crown gall bacterium. Plasmid transfers and mutations occurring naturally or spawned by radiation sources potentially add to pathological hazards.

3. In a closed system such as a space station, it becomes necessary to recycle all metabolic waste products. The close similarity between many of the normal enteric bacteria of humans and certain plant pathogenic bacteria raises the concern of plasmid transfers between the two groups of bacteria, thereby potentially creating new plant pathogenic bacteria out of normal human intestinal flora and/or creating human pathogens from plant pathogens.

4. The potential always exists that after all precautions are taken, a pathogen(s) could be introduced into the life support system. This would create a dangerous situation since the pathogen would not encounter other competitive microorganisms. Also plant cultivars would most probably be selected for food producing value and growth characteristics under defined conditions and not necessarily for disease resistance.

5. The development of control measures would depend on a knowledge of how conditions of zero gravity or reduced gravitational fields affect the disease cycle of pathogens. Would dissemination, germination, penetration, infection, and reproduction be accomplished in a way similar to the way they occur on Earth? Will genetic systems function normally? Will mutations occur at a different rate? In essence, will our present knowledge and understanding of parasitism and disease control hold true for environmental conditions of a space station? There must, therefore, be a fail-safe method of quick and effective erradication of the pathogen prior to its becoming successfully established. This would entail development of control measures which would be effective against a wide range of pathogenic organisms including such diverse forms as viruses and viroids, bacteria, mycoplasma-like-organisms, fungi and nematodes, yet would not be destructive to the confined environment of the space station. In this area, certainly, the prospects of biological control and radiation need to be investigated.

   In addition to developing the ideal control agent, a means of rapid application would have to be developed.

Proposed Investigators:

Raymond D. Martyn, Jr.
Assistant Professor, Plant Pathology
Department of Plant Sciences

Michael P. Grisham
Assistant Professor, Plant Pathology
Department of Plant Sciences

Project Consultant:

Robert S. Halliwell
Professor, Plant Pathology
Department of Plant Sciences

Facilities Available:

The Plant Pathology section within the Department of Plant Sciences maintains an extensive network of laboratory and greenhouse space and supportive equipment. In addition, the Department has an Hitachi HS7S electron microscope and has access to an HU-11 transmission EM and scaning electron microscope.

Problem:

Plants must be successfully grown from seed to maturity under conditions of low or zero gravity.

Research Questions:

Can grain crop (eg. wheat), root crop (eg. radish) and vegetative crop (eg., lettuce) plants be successfully cultured from seed to maturity under a condition of constant rotation (4 rph) on a vertical klinostat?

What is the effect of zero gravity on the polar transport of auxin? (Proposed experiments in space shuttle flights).

What is the effect of zero gravity on ethylene production and its concomitant effect on auxin transport? (Proposed experiments in space shuttle flights.)

Investigator:

Page W. Morgan
Professor, Department of Plant Science
Texas A&M University

Facilities Available:

Two laboratories more than 1200 square feet for plant hormone research. Small growth rooms for growing test plants. Equipment for extracting, identifying and measuring plant hormones (Liquid and Gas Chromatographs). Isotope counting equipment for transport studies. Supporting greenhouse and cold room facilities.

Related research projects:

(1) Regulation of photoperiodism, height, tillering and other characters by hormones in sorghum.

(2) Interrelationships of auxins and ethylene in physiological processes.

(3) Roles of ehtylene in regulation of plant development (flowering, shedding, leaf shedding, seed germination, fruit ripening, etc.).

A. S. GARAY

These comments are divided into two main parts.

1. Toxic substances in plants
2. Effects of reduced or zero gravity field on:
   A. growth and development
   B. basic metabolism of plants

1. Toxic Substances in Plants

Background: Many organisms, microbia, plants, fungi, and animals including man, can produce toxic gases such as CO, NO or NO_2. In a closed system required by space flight these toxic substances may accumulate and cause serious problems.

Objective: Plants chosen for space flight should be tested for toxic gas production under simulated conditions of space flight.

2a. Effect of Reduced or Zero-Gravity Field on Growth and Development of Plants

Background: The overwhelming majority of our knowledge about how gravity effects plant growth and development comes from experiments in which the normal orientation of plants with respect to gravity is disturbed. It has been suggested as early as 1914 that the curvature responses to gravity might be due to an unequal distribution of the apically produced growth regulating substances. Since that time many experiments proved that gravity effects the production, translocation, and accumulation of different plant growth regulators - both the promoters and inhibitors. It has been observed that the changes are not only quantitative. New types of growth inhibitiors can be produced due to gravitational disturbances. In accordance to that, almost all experiments prove that the inclination of stem from its normal vertical position to a horizontal position causes growth inhibition, and differential growth of buds on the upper and lower side. In some cases even one day in horizontal position caused , 30-35% inhibition of shoot growth. Horizontal position influences flower bud set and differentiation. Larch buds were formed to differentiate into male flowers only if they were oriented horizontally or downward. The buds which were pointing upward were exclusively vegetative.

The data concerning the growth rate of plants rotated on a horizontal klinostat are often contradictory. Several authors observed growth inhibitions; others noted growth stimulation. This discrepancy might be caused by differences in the rates of rotation. Flowers of Gladiolus developing on klinostat display radial symmetry instead of a dorziventral one. It is a strange fact that although a large body of experimental data prove that plant development is regulated by gravity we can hardly make any predictions concerning the effect of long lasting zero-gravity field. The experiments in biosatellites shows some correspondance to results obtained by klinostats; however, it should be kept in mind that klinostats do not provide a zero-gravity field but only a continuous symmetric reorientation of field direction. Weightlessness may have special effects such as the pollen abortion of TRADESCANTIA, increased peroxidase activity in wheat seedlings, faster growth of SALMONELLA, etc. The above have been observed in a two day flight!

Objectives: All plant-candidates for space flight should be checked first on klinostates for their complex developmental process such as flowering, fruit set and growth, seed production, tuberization, bulb formation and dietetic value of their edible parts. It should be checked whether or not the eventual disruptive effect of zero-gravity field can be circumvented by chemical means or environmental manipulations. In a second stage of experiments, observations must be made in biosatellites.

2b. Effect of Reduced or Zero-Gravity Field on Basic Metabolism of Plants

Background: It has been observed that gravity-compensation by klinostat is accompanied by an increased metabolic activity such as a rise in CO_2 output, rapid phosphorylation, etc. This compensation-induced enhancement of metabolism appears not to be channeled into growth of shoot, which is actually inhibited in most cases.

Objectives: Study the uncoupling of growth and basic metabolism in klinostat experiments. These may give us a method for succesful manipulation of space-craft plants and selective of proper varieties.

Problem

Maintaining the proper balance of nutrient elements to produce healthy plants in a solution culture is difficult under the best of conditions. The medium is only slightly buffered. Rapid changes in pH, micronutrient, and micronutrient concentrations can occur when the system is supporting actively growing plants.

Research Questions

1. Can a lightweight slurry system be developed that will provide substantial buffering capacity to the nutrient culture system to better control pH and nutrient balance?
2. Human wastes contains many of the nutrient elements required for the growth and reproduction of plants. Can waste material be effectively utilized in a buffered slurry culture system to supply a major portion of the nutrient requirement of plants?

Proposed Principal Investigator

Dr. L. R. Hossner
Professor of Soil Fertility and Chemistry
Texas A&M University
College Station, TX 77843
(713) 845-3814

Facilities Available

Laboratory and greenhouse space is available in the Soil and Crop Science Department. Equipment for monitoring nutrient concentration that is presently available includes electronic equipment, atomic absorption spectrophotometer, emission spectrophotometer and scanning UV spectrophotometer.

Projects

Recent projects which relate to the proposed problem are as follows:

Salt index values of potassium phosphate fertilizers and its relation to germination and early plant growth of field crops.

Sewage disposal on agricultural soils: chemical and microbial implications.

Soil phosphate equilibria and utilization in diverse Texas soils.

Characteristics of coatings formed on the epidermis of rice. (*Oryza sativa* L.) plants as affected by Fe and manganese additions.

Movement and efficiency of applied phosphorus to rice in flooded soil.

Problem

* Plants must translocate photosynthetic products

Research Questions

* What is the effect of low gravity on photosynthate translocation and partitioning in plants?

* How does the manipulation of photoperiod, temperature, and oxygen partial pressure affect translocation of photosynthate?

Proposed Principal Investigator

R. J. Newton
Assistant Professor, Plant Physiology
Department of Plant Sciences

Facilities Available

Controlled environment laboratory:

1. artificial light up to full sunlight
2. controlled air temperature, humidity, and carbon dioxide concentration
3. 200 square feet

Equipment available:

Radio-gas-chromatograph for monitoring photosynthetic products and translocation

Research Projects:

1. water stress effects on photosynthate translocation and sink metabolism
2. carbohydrate metabolism as related to dormancy and germination in aquatic weeds

Problem:

Photosynthesis requires specific environmental conditions to be optimal and to maintain plant growth and development over a prolonged period.

Research Questions:

What is the effect of reduced pressure on the plant and what is the optimum gas mixture under reduced pressure?

What are the effects of reduced gravity on the plant?

What are the effects of both photoperiod and thermoperiod and humidity?

How can pollination, required for fruit development, be accomplished without wind or insects?

Different approaches are required to answer these questions. Chambers are available and can be readily constructed to study the pressure problem and alter the gas mixture. Plants cannot be grown on earth under zero or even reduced gravity but a klinostst can be utilized to, in some cases, neutralize its effect. With information obtained in this way, experiments could be designed to be done on a spaceship. A great deal is known about photoperiod and thermoperiod, but their effect under space conditions is unknown. Pollination is normally accomplished through insects or wind, neither of which would be present under spece conditions, and therefore, fruit set might be very low.

Proposed Principal Investigator:

Robert D. Powell
Professor, Plant Physiology
Department of Plant Sciences

Facilities Avai˘ ıe:

Three environmental control chambers each 10 x 10 with an eight foot ceiling.

Greenhouse facilities 20 x 45 feet.

Technical Approach:

Light and temperature studies can be carried out in the environmental control chamber. The facilities would have to be modified to obtain very high light intensities, but temperature and humidity can be well controlled under the present conditions. A klinostat can be used to balance the gravitational effect of a plant in a horizontal position. It is also possible to place seedlings in a centrifical field and measure its effect from zero to several times the gravititational force. A combination of these types of studies would give a basis to design experiments to be conducted in space with zero gravity. The problem of fertilization of the ovule can be studied in growth chambers and other types of enclosures.

Problem

* Plants must produce oxygen continuously

Research Questions

* Which plants will grow and yield well in continuous artificial light?

* In plants that require a change in daylength to flower and set seed, can spectral changes be substituted for daylength changes?

Proposed Principal Investigator

Keith J. McCree
Associate Professor, Environmental Agronomy
Soil & Crop Sciences Department

Facilities available

Controlled environment laboratory (1000 square feet)
(Room 120, Soil & Crop Sciences)
Contains: 5 semiclosed test chambers for plant response studies

Environmental controls:
(1) artificial light up to full sunlight levels (500 W/m^2 PAR)
(2) air temperature 5 - 50°C
(3) dewpoint temperature 2 - 30°C (H_2O concentration control)
(4) CO_2 concentration 0.03 to 1%

Chamber sizes:
0.05 m^2 by 0.5mhigh (1)
0.1 m^2 by 1 m high (2)
2 m^2 by 1 m high (2)

Crop physiology research projects:
(1) spectral quantum yield of photosynthesis ;
(2) relation of photosynthesis, respiration and transpiration to biomass accumulation rate.

NASA Project

The Relation of Photosynthesis and Photosynthate Partitioning to Crop Productivity in Closed Ecology Life Support Systems

C. R. Benedict

Department of Plant Sciences, Texas A&M University

Experiments establishing the optimal conditions of light, O_2 and CO_2 levels for photosynthesis is important for establishing the growth of crop plants in closed ecology life support systems. Inherent in this work is that optimal environmental conditions for photosynthesis is directly related to yield.

Many studies have been unable to correlate photosynthetic rate with crop yield Curtis (1969), Duncan and Hesketh (1968). Evans (1975) reports a number of species of crop plants where photosynthesis is not related to crop yield. He also feels that counter productive associations with high photosynthetic rate are operable in many of these cases and that extensive nitrogen mobilization from leaves of high yielding crops occur thus lowering the photosynthetic rate. Other factors which should be considered in photosynthetic measurements and its relation to crop yield are: the storage capacity of the sinks, the feed-back of the sink on the photosynthetic rates, the mobilization of storage carbohydrates from the roots and stems during sink demand, the partitioning of photosynthates between vegetative and fruit parts, correlation of photosynthesis to yield throughout the development of the plant (to account for ontogenetic shifts, feed-back of sink on photosynthesis and protein mobilization in leaves due to heavy sink load). After considerations and measurements of the above we are in a position to correlate environmental conditions, photosynthetic rate and yield, and to understand the effect of increasing rates to crop yield.

In this study, we propose to measure photosynthesis of crop leaves throughout the growing period. A leaf chamber and $^{14}CO_2$ fixation will be used to measure CO_2 fixation in mg CO_2 fixed/dm^2·hr. The photosynthetic rates will be measured under known conditions of leaf $^{\Psi}H_2O$, light intensity and CO_2 concentration. Leaf temperature and stomatal resistance readings will also be determined at the time of CO_2 fixations. The levels of enzymes ribulose-1,5-di P carboxylase, glycolate oxidase, malic dehydrogenase which may be indicators of photosynthesis, photorespiration and dark respiration will also be measured throughout the growth of the cotton. Other measurements of nitrogen storage and mobilization from the leaves as well as starch storage and mobilization from the stems of the crop plants will be measured. These parameters will be correlated to biological yield and harvest index of the cotton stands. The stage of flowering and duration of sink storage both for cotton boll wall as well as for seed and lint growth will be measured.

This data will prove useful in determining the optimal environmental levels of light, O_2 and CO_2 for photosynthesis and to crop yield in a closed ecology life support system. This study will form a firm foundation to understanding the factors which limit yield of a variety of crop plants and form an understanding for the selection of crop plants for growth in life support systems.

3. <u>Preliminary Research Topics</u>:

The study team concluded that an ideal way to approach the plant research needs for a CELSS would be to have a major program conducted by a multiple disciplinary team with experience is both agricultural and basic scientific problems. Questions beyond staff and facilities of the sponsoring organization could be placed on subcontracts to other centers. Nevertheless, there are certain questions that could be attacked in an isolated manner and which would not require extensive coordination by a total group program. These problems, in many cases, would be ideally solved before a major program, with central direction, is organized.

The specific problems are outlined below. We list potential investigators and sample budgets which serve as a guide in this research topics - research plan portion of the report.

List of Proposals, Personnel and Budget Estimates

a. Dr. R. H. Smith. Rapid Clonal Propagation of Plant Life Support Material for Space Travel. This approach will involve tissue culture to hasten propagation of plants; it is an approach which will likely be overlooked by the Ames program because it is unconventional in current agriculture.

b. Drs. C. R. Benedict and R. J. Newton. The Relation of Photosynthesis and Photosynthate Partitioning to Crop Productivity in Closed Ecology Life Support Systems. This study will utilize our most sophisticated growth chamber to optimize conditions for photosynthesis and the biochemical components of that process including a desirable partitioning of the photosynthate into yield and other plant parts.

c. Dr. A. S. Garay. Selection of Gravity-Non-Selective Edible Plants for Manned Space-Flight. This project will study a tomato mutant that doesn't respond to gravity and will seek similar mutants for other crops.

d. Drs. M. P. Grisham and R. E. Pettit, Research Scientist Ruth A. Taber. Management of Ecological Relationships between Plants and Microorganisms to Maintain Pathogen-Free Plant Systems in Space. This team of three plant pathologists will work on procedures to maintain pathogen-free plants, means to detect phytopathogens within a CELSS and determine whether certain beneficial microorganisms should be purposefully added to the CELSS to insure ecological stability in the crops.

e. Dr. P. W. Morgan. Zero Gravity, Geotropism, and the Growth of Plants in Space. Recent understanding of ethylene's involvement in geotropism and the sensitivity of various species to ethylene may allow development of crop systems for CELSS.

f. Other worker on rooting media systems and screening and breeding programs within specific species (i.e., efforts to identify and breed the best tomato, etc.) for a CELSS is still possible by the A&M group, possibly at a later starting date.

Rapid Clonal Propagation of Plant Life Support Material for Space Travel

Objective:

1. Development of procedures for rapid, clonal propagation of plants selected for NASA Closed Life Support System.

Approaches:

Tremendous advances in the propagation of plants of horticultural importance (1) as well as a limited number of crop plants such as varieties of *Brassica*, garlic, strawberries and sugar cane (2) on a practical economic basis have been achieved. However, none of the major crop plants such as the legumes or cereals can be propagated through tissue culture. Presumably these plants would be the basis of a life support system in space, and their rapid propagation by *in vitro* methods would be essential, as well as assuring disease free plant material.

Plants that are to be screened for space life support systems need *in vitro* methods of propagation developed. Three routes of rapid propagation are axillary bud development, adventitious bud formation and asexual embryogenesis. Axillary bud development *in vitro* would be the preferred route as it would virtually assure genetic uniformity; whereas, adventitious bud formation and asexual embryogenesis although having the potential for greater numbers of plant formation, would not assure genetic uniformity.

The major emphasis would be to investigate axillary bud development *in vitro* on potential plant species to be utilized in a space life support system. Adventitious bud formation and asexual embryogenesis would also be investigated for stability of genotype.

Literature Cited

1. Murashige, T. 1974. Plant progagation through tissue cultures. Ann. Rev. Plant Physiol. 25:135-66.

2. Vasil, I. 1978. Plant tissue culture and crop improvement - Fact and fancy. Newsletter Internat. Assoc. Pl. Tissue Culture. 26:2-10.

Investigator:

Dr. Roberta H. Smith
Department of Plant Sciences
Texas A&M University

Budget:

	Year 1	2	3
Technician	$12,000	$13,000	$14,000
Laminar air flow hood	1,500		
Dissecting Microscope	5,000		
Glassware, chemicals	4,000	4,000	4,000

Manpower 3 years

$62,500 Total Budget 3 years.

NASA Project

The Relation of Photosynthesis and Photosynthate Partitioning to Crop Productivity in Closed Ecology Life Support Systems

C. R. Benedict and R. J. Newton

Department of Plant Sciences, Texas A&M University

The Problem

Experiments establishing the optimal conditions of light, O_2 and CO_2 levels for photosynthesis are important for establishing the growth of crop plants in closed ecology life support systems. Inherent in this work is that optimal environmental conditions for photosynthesis are directly related to yield.

Many studies have been unable to correlate photosynthetic rate with crop yield Curtis (1969), Duncan and Hesketh (1968). Evans (1965) reports a number of species of crop plants where photosynthesis is not related to crop yield. He also feels that counter productive associations with high photosynthetic rate are operable in many of these cases and that extensive nitrogen mobilization form leaves of high yielding crops occur thus lowering the photosynthetic rate. Other factors which should be considered in photosynthetic measurements and its relation to crop yield are: the storage capacity of the sinks, the feed-back of the sink on the photosynthetic rates, the mobilization of storage carbohydrates from the roots and stems during sink demand, the partitioning of photosynthates between vegetative and fruit parts, correlation of photosynthesis to yield throughout the development of the plant (to account for ontogenetic shifts, feed-back of sink on photosynthesis and protein mobilization in leaves due to heavy sink load). After considerations and measurements of the above we are in a position to correlate environmental conditions, photosynthetic rate and yield, and to understand the effect of increasing rates to crop yield.

Proposed Research

First, plants will be selected after consultation with plant breeders as to the characteristics desired for the CELSS. Upon determination of the desired plants, the nurseries of these breeders will become the major source of seed for investigation, for the cultural and genetic history of the plant will then be known.

Second, it is proposed to measure photosynthesis of the crop plant throughout the growing period. A leaf chamber and $^{14}CO_2$ fixation will be used to measure CO_2 fixation in mg CO_2 fixed/$dm^2 \cdot hr$. The photosynthetic rates will be measured under known conditions of leaf water potential, light intensity, CO_2 concentration, and O_2 concentration. The plants will be grown in a chamber (See Below) whereby these parameters can be varied in order to optimize yields. The main objective will be to determine what these values should be for a particular crop. Dry weight, starch and nitrogen storage, and mobilization of carbohydrate and nitrogenous compounds from leaves and stems will be measured. Key enzyme (ribulose-1,5 di P carboxylase, glycolate oxidase, malic dehydrogenase, invertase, etc.) levels will be monitored and used as indicators of photosynthesis, photorespiration, dark respiration, unloading, storage product formation, etc. Leaf temperature, stomatal resistance, stage of flowering and sink storage duration will also be determined.

Finally the environmental variables of CO_2 and O_2 levels, temperature and light will be correlated with the internal biochemical and physiological processes as well as the biological yield and harvest index of the crop.

Expected Results

This data will prove useful in determining the optimal environmental levels of light, duration of light, O_2 and CO_2 for photosynthesis and to crop yield in a closed ecology life support system. This study will form a firm foundation to understanding the factors which limit yield of a variety of crop plants and form an understanding for the selection of crop plants for growth in life support systems.

Experimental Conditions

Plants will be grown in a high light environmental chamber (40 ft^2) specifically designed by C. H. M. van Bavel (Soil and Crop Sciences Dept.), whereby PAR, CO_2, windspeed, photoperiod, and O_2 can be monitored. Plants will be grown in containers and soil in a manner dictated by the CELSS.

Budget

Equipment	
Infra-red CO_2 Analyzer	$5400
Oxygen Analyzer	$700
Strip Chart Recorder	$800
Soil Thermocouple Psychometer	$800
Pressure Chamber for measuring leaf water potential	$600
CO_2 Application System	$1000
Growth Chamber Cost (Includes maintenance & operation @ 200/mo X 12 mo X 3 yr)	$7200
Supplies $4000/yr X 3 yr	$12,000
Personnel:	
Tech. II @ $12,000/yr X 3 yr	$36,000
Tech. Assistant @ $8,000/yr X 3 yr	$24,000
Indirect Costs 52% of Salaries @ $10,400/yr X 3 yr =	$30,200
Fringe Benefits 13.5% of Salaries @ $2,700/yr X 3 yr =	$8100
Total (3 yrs)	$126,800

March 5, 1979

Research Proposal for JSPC:NASA

By A. S. Garay, Professor & Principal Investigator

Area: Life Support System for CLSS: Food Growth and Production

Title: Selection of Gravity-non-sensitive Edible Plants for Manned Spaceflight

Objective & Approach: We are in possession of a tomato mutant which does not react to gravity, with respect to growth and/or fruitation. Presumably, this plant grows the same way on Earth, as it would in the zero gravity field of a spaceship. Thus, the unpredictable effects of zero gravity conditions upon these plants could be circumvented, since fruit production does not depend upon the presence of a gravitational field. On the other hand, the astronauts could learn to handle the plants on Earth.

We would like to select for other gravity-non-sensitive mutants of lettuce, carrots, etc., and check these mutants for the following qualities: 1) productivity, 2) nutritional quality, 3) disease resistance, and 4) endurance in closed systems.

If necessary, zero-gravity mutants should be improved by a special breeding program to further accentuate the above qualities.

Finally, all plant candidates for space flight should be checked first on klinostats, for their complex developmental process. In a second stage of experiments, observations must be made in biosatellites.

Background: Effect of reduced or zero-gravity field on growth and development of plants. The overwhelming majority of our knowledge about how gravity effects plant growth and development comes from experiments in which the normal orientation of plants, with respect to gravity, is disturbed. It has been suggested as early as 1914, that the curvature responses to gravity might be due to an unequal distribution of the apically produced growth regulating substances. Since that time, many experiments proved that gravity effects the production, translocation, and accumulation of different plant growth regulators - both the promoters and inhibitors. It has been observed that the changes are not only quantitative. New types of growth inhibitors can be produced due to gravitational disturbances. In accordance to that, almost all experiments prove that the inclination of stem from its normal vertical position to a horizontal position causes growth inhibition, and differential growth of buds on the upper and lower side. In some cases, even one day in a horizontal position caused 30-35% inhibition of shoot growth. Horizontal position influences flower bud set and differentiation. Larch buds were found to differentiate into male flowers only if they were oriented horizontally or downward. The buds which were pointing upward were exclusively vegetative.

The data concerning the growth rate of plants rotated on a horizontal klinostat are often contradictory. Several authors observed growth inhibitions; others noted growth stimulation. This discrepancy might be caused by differences in the rates of rotation. Flowers of Gladiolus developing on klinostat display radial symmetry instead of a dorziventral one. It is a strange fact that although a large body of experimental data prove that plant development is regulated by gravity, we can hardly make any predictions concerning the effect of long lasting zero-gravity field. The experiments in biosatellites shows some correspondence to results obtained by klinostats; however, it should be kept in mind that klinostats do not provide a zero-gravity field, but only a continuous symmetric reorientation of field direction. Weightlessness may have special effects, such as the pollen abortion of TRADESCANTIA, increased peroxidase activity in wheat seedlings, faster growth of SALMONELLA, etc. The above have been observed in a two day flight!

It is very reasonable to believe that the unpredictable effect of a zero-gravity field can be neutralized to varying degrees by using gravity non-sensitive cultivars in space flight.

Budget: We think that a two year period of preliminary research would be sufficient to establish whether or not the proposed research should be continued. The anticipated expenses are outlined as follows:

	First Year	Second Year
Salaries		
Graduate Student	$ 5,100	$ 5,100
Technician (half time)	4,700	4,700
Propagation of mutants	300	300
Control of Quality		
Chemicals	1,500	1,500
Glassware	800	800
Klinostats	2,000	
Miscellaneous (pots, greenhouse cost, stationary, etc.)	500	500
Traveling	2,000*	2,000*
TOTAL	$16,900	$14,900

*Although this exceeds normal allotment, this would be necessary in order to visit various plant breeding stations.

Andrew S. Garay

Andrew S. Garay

C-2

PROPOSAL TITLE: MANAGEMENT OF ECOLOGICAL RELATIONSHIPS BETWEEN PLANTS AND MICROORGANISMS TO MAINTAIN PATHOGEN-FREE PLANT SYSTEMS IN SPACE.

INTRODUCTION:

Within limited space maximum plant yield and product quality will be critical. The physical and biological environments under which the plants are grown will need to be controlled within specific parameters. In order to maintain actively growing plants over long periods of time in a closed system (such as a space station) it is tantamount that any known or potential phytopathogens be excluded from the system. It is, however, recognized that plant growth can be significantly improved by the presence of beneficial microorganisms. Interactions between plants and microorganisms must therefore be considered in developing a closed life support system. Procedures must be developed to prevent the introduction of phytopathogens. Also, systems must be designed for monitoring the presence and activity of beneficial microorganisms.

OBJECTIVES:

1. To develop procedures for the production of certified pathogen-free sexual and asexual propagative plant parts to be used in the Closed Life Support System (CLSS).
2. To devise procedures for the detection of phytopathogens associated within host plants, within the growth medium and in the air.
3. To determine if certain ecological combinations of plants and beneficial microorganisms result in reduced plant stress, alterations in pest problems and/or changes in yield and product quality under CLSS conditions.

APPROACHES:

1. Procedures used in current pathogen-free seed certification programs will be tested and modified to meet standards necessary to certify sexual and asexual propagative plant parts as pathogen-free for use in the CLSS.
2. Various isolation techniques - such as selective media and indicator plants - will be tested to determine their effectiveness in detecting phytopathogens within the CLSS.
3. Cultures of microorganisms - including proven beneficial fungi (mycorrhizae), bacteria and nematodes - will be added to the plant growth medium and/or plant parts, and their effects on plant productivity and quality of plant products will be monitored.

PRINCIPAL INVESTIGATORS:

Ruth Ann Taber, Research Scientist

Michael P. Grisham, Assistant Professor

Robert E. Pettit, Associate Professor

PROPOSED BUDGET:

Salaries, Wages, OASI, WC and Fringe Benefits	
Principal Investigator (Ruth Ann Taber, Research Scientist)	-----
Principal Investigator (Michael Grisham, Assistant Professor)	-----
Principal Investigator (Robert E. Pettit, Associate Professor)	-----
Research Associate	$19,295
Research Technician	11,808
Clerical	4,353
Wages - Student assistants	3,560
Supplies and Equipment	10,550
Travel	2,100
Operating Expenses and Services	32,000
Total Direct Costs Per Year	$56,866
Indirect Costs (15% of total)	8,229
Total Requested per Year	63,095
Three year Grant proposed (3 x 63,095)	$189,285

TITLE: Zero Gravity, Geotropism, and the Growth of Plants in Space

INVESTIGATOR: Page W. Morgan, Department of Plant Sciences, Texas A&M University

INTRODUCTION:

Through NASA-sponsored research by C. J. Lyon (Plant Physiology 45:645-646, 1970) and A. H. Brown, et al. (Plant Physiology 58:127-130, 1976) it seems likely that zero-gravity or weightlessness may interfere with normal growth and development through a disruption of auxin transport. Ethylene is known to disrupt auxin transport (Morgan and Gausmann, Plant Physiology 41:45-52, 1966), and ethylene has been proposed to act in normal geotropism (Kang and Burg, Plant Physiology 50:132-135, 1972). Some plants show little change in auxin transport when treated with ethylene (Morgan, et al. in Biochem. and Physiol. Plant Growth Subs. pp. 1255-1273, 1968, Runge Press), and some plants (rice, for example) actually grow better when exposed to ethylene (Imaseki and Pjon, Plant Cell Physiology 11:827-829, 1970). In addition, auxin transport inhibitors, other than ethylene, have shown great ability to prevent the normal expression of root geotropism (Katekar and Geissler, Plant Physiology 60:826-829, 1977). Thus, there appears to be a variety of related physiological processes, unique species characteristics and plant growth regulators that should be brought together in a new investigation with both theoretical and practical objectives.

OBJECTIVES:

1. Conduct an exhaustive literature survey on geotropism, gravity compensation, klinostat investigations, auxin transport and auxin-ethylene interactions. Collect all "old" literature on plant behavior in klinostats.
2. Investigate: (a) the relationship between auxin-transport, ethylene synthesis, geotropism and zero-gravity simulated by klinostat conditions,

(b) the feasibility of circumventing the presumed disturbances of auxin transport and ethylene synthesis under zero-gravity by auxin transport inhibitors and conditions to disrupt ethylene physiology (reduced pressure, increased CO_2 levels, Ag^+, etc.), (c) the behavior of ethylene-resistant crop species and those in which growth is <u>promoted</u> by ethylene as potential optimum candidates for use in a CELSS with zero gravity conditions.

3. Develop techniques, protocol, a research proposal for Space Shuttle experiments in which plants will be grown in orbit and auxin transport, ethylene synthesis, root geotropism and leaf epinasty will be characterized, hopefully by the scientist mainly involved in objectives 1 and 2 above.

Staffing and Financial Estimates

Personnel	Man-years	Costs
P. W. Morgan	¼	
Post doctoral fellow (to be selected)	1	$20,000
Graduate research assistant	½	5,100
Technical Assistant II (Library Research)	1	7,700
Labor (hourly)		2,000
Fringe Benefits		4,698
		$39,498
Equipment/Operations		
Capital Equipment		$ 6,000
Expendables		3,000
Travel		2,000
		$11,000
Overhead		18,096
Total Per Year		$68,594

Proposed Duration - 3 years

C. Technical Expertise and Facilities

1. Vitae of Experts Preparing this report. Publications are listed earlier.

Page W. Morgan

Born: [redacted]

Education:

Ph.D., Plant Physiology, Texas A&M University, 1961
M.S., Range Management, Texas A&M College, 1958
B.S., Range & Forestry, Texas A&M College, 1955

Experience:

Educational

Professor and Section Leader for Plant Physiology, 1974-present
Professor, Texas A&M University, 1969-1974
Associate Professor, Texas A&M University, 1966-1969
Assistant Professor, Texas A&M University, 1961-1966

Governmental

Range Conservationist, Soil Conservation Service, USDA, 1955-1956

Military

U.S. Army, Active Duty, 1956; U.S. Army Reserve 1956-1966.

Duties of Present Position:

Coordination of teaching and research programs in plant physiology in Department of Plant Sciences, Texas A&M University and assist department head with subject matter coordination of plant physiology research in Texas Agricultural Experiment Station. Teaching, directing graduate student research and directing research programs. Research now centers on the hormone physiology of the sorghum plant controlling flower initiation (photoperiodism), height, apical dominance (tillering) and root development and the hormone physiology of the cotton plant controlling fruit shed/fruit retention, leaf shed and seed germination..

Research Qualifications:

Seventeen years experience in plant hormone research including discovery of three major auxin-ethylene interactions and contributions to the understanding of leaf abscission, fruit dehiscence, fruit shed, seed germination, and herbicide action. Experience in ethylene research includes the production of ethylene by plant tissue, air pollution effects of ethylene and physiological roles of ethylene as a plant hormone.

Research Qualifications: continued

Studies on auxin transport have centered around its correlative role and modification by ethylene and stress. Research on photoperiodism has involved a genetic and physiological approach including analysis of hormone levels in genotypes with different gene combinations regulating night length requirements for floral initiation.

Chauncey R. Benedict

Age: 48 Citizenship: U.S.

Birthplace: Lake Placid, NY

Number of Children: Two

Professor, Plant Sciences

S.S. No. [redacted]

Marital Status: Married

Professional Interest:

Plant Biochemistry
Photosynthesis
Carbon Metabolism
Enzymes

Education:

Ph.D., Plant Biochemistry, Purdue University, 1960. Research Advisor, Professor Harry Beevers. Grade Index on 6.0 Basis = 5.8
M.S., Plant Physiology, Cornell University, 1956. Research Advisor, Professors R. D. Sweet and Edwin B. Oyer
B.S., Botany, Cornell University, 1954

Experience:

<u>Educational</u>

Professor, Plant Sciences (tenured), Texas A&M University, 1969-Present
USDA Senior Plant Physiologist, Texas A&M University, 1966-1969
Visiting Professor, Dr. John Porter's Lipid Laboratory, University of Wisconsin, Summer 1964
Assistant Professor Biochemistry (tenured), Wayne State University, 1962-1966
Postdoctoral-Assistant Professor, Dartmouth Medical College, 1961-1962
Postdoctoral, Brookhaven National Laboratories, 1960-1961

<u>Military</u>

USAR, Retired Capt., 8 years

Society Memberships:

American Society Biological Chemists
American Society Plant Physiologists
Crop Science Society of America
Gamma Sigma Delta
Sigma XI
Phi Kappa Phi

Honors and Awards:

Faculty Research Award, Wayne State University (1964-1965)
NIH Research Grants, $75,428
NSF Research Grants, $51,765
Cotton Incorporated Grants (1969-1976), $150,000
USDA Grant (1974-1975), $25,000
Center of Energy and Mineral Resources Grant (1975-1978), $36,000
Robert A. Welch Foundation Research Grants (1972-1978), $81,000

Committee Memberships:

National Research Council, Subcommittee Biological Chemists, 1964-1974
Member Cotton Task Force Review Committee
Member Southern Region Task Force on Energy in Agriculture
Chairman Southern Section American Society of Plant Physiologists
Associate Editor Crop Science Editorial Board
Technical Editor Crop Science Editorial Board

Duties of Present Position:

Teaching, directing graduate student research, and directing research programs. Research now centers on photosynthetic carbon metabolism and plant productivity.

Research Qualifications:

Eighteen years of experience in plant metabolism. I have a continuing interest in autotrophy in plants which centers around CO_2 fixation, carbon metabolism, the biochemistry and enzymology of the fractionation of stable carbon isotopes, and the partitioning of photosynthate in crop plants. This research has contributed information on:

1. The role of acetyl-CoA regulation of pyruvate carboxylase.

2. The active species of "CO_2" utilized in carboxylation reactions.

3. The photoautrophy of photosynthetic bacteria.

4. The enzymatic fractionation of stable carbon isotopes in C_3 and C_4 plants.

5. The kinetics of photosynthate utilization during seed filling in crop plants.

Keith J. McCree

Associate Professor, Environmental Agronomy,
Soil and Crop Sciences Department,
Texas A&M University,
College Station, Texas 77843

Born: [redacted]

Birthplace: [redacted]

Citizenship: New Zealand (immigrant visa)

Married with two children

Education:

Ph.D., 1958, Technical Optics, Imperial College, University of London
M.S., 1949, Physics, University of New Zealand
B.S., 1946, Physics, University of New Zealand

Professional Societies:

American Society of Plant Physiologists
American Society of Agronomy
Crop Science Society of America

Professional Interests:

Crop Physiology (photosynthesis, water relations)
Crop Ecology
Agricultural Meteorology (photosynthetically active radiation)

Julian Creighton Miller, Jr.

Business

Department of Horticultural Sciences
Texas A&M University
College Station, Texas 77843
(713) 845-3828 or 845-5341

Home

[redacted]

Born: [redacted]

Birthplace: [redacted]

Social Security No.: [redacted]

Education:

B.S., Arts and Sciences, Louisiana State University, 1965
M.S., Horticulture, Louisiana State University, 1967
Ph.D., Horticulture (plant breeding-genetics), Michigan State University, 1972

Academic Experience:

Associate Professor, Texas A&M University, 1977-
Assistant Professor, Texas A&M University, 1975-77
Assistant Professor, TAES, Lubbock, 1972-75
Research Assistant, Michigan State University, 1968-72
Research Assistant, University of Wisconsin, 1967-68
Research Assistant, Louisiana State University, 1966-67

Research Field:

Breeding-genetics of vegetable crops; growth and development physiology

Professional Societies and Activities:

West Texas Vegetable Growers and Shippers Council
West Texas Greenhouse Vegetable Council
Texas State Horticultural Society
Texas Vegetable Association
American Society for Horticultural Science, Southern Region
(Membership Committee, 1974, Chairman, 1975; Ware Teaching Award Selection Committee, 1977; Vegetable Crops Section, Chairman, 1978-)
American Society for Horticultural Science
(Vegetable Breeding and Varieties Committee, 1976- ; Seed Crop Working Group, 1978- ; Vegetable Breeding Working Group, 1978-)
International Society for Horticultural Science
Crop Science Society of America
Texas Chapter American Society of Agronomy
American Society of Agronomy
Weed Science Society of America
The American Genetic Association

Professional Societies and Activities - continued

American Institute of Biological Sciences
The Potato Association of American
(Breeding and Genetics Committee, 1974-79; Pathology Section, 1975- ;
Marketing Committee, 1976-78; Breeding and Genetics Section, 1978-)
American Association for the Advancement of Science

Honor Societies:

Alpha Zeta
Sigma Xi
Phi Sigma

Research Activities:

Initiated potato variety development program for Texas, 1973
Assumed leadership of vegetable legume breeding program, 1975

Major Grants:

A.I.D. (C.S.R.S.). Grant no. G-6306. Maximization of Symbiotic Nitrogen Fixation Utilizing Cowpea Genotypes and Specific _Rhizobium_ Strains. 1977-79. $45,000.00

Personal Information:

Military service, U.S.C.G.R., 1964-70
Married August 14, 1965
Wife: Jeannie; B.A. Spanish, MLS
Children: Julian Creighton III, May 14, 1970
Jennifer Christine, May 31, 1973

Andrew S. Garay

Born: [redacted] Refugee from Hungary in 1975, Recently U.S. immigrant status.

Education:

Ph. D., Eotvos University, Budapest, Hungary, 1952.
M.D., Eotvos University, Budapest, Hungary, 1949.

Experience:

Research
Postdoctorate fellow at University of British Columbia, Vancouver, Canada, 1964-65.
Visiting research fellow: Laboratoire d'Optique Physique, Paris, France, 1969.
Visiting professor: Plant Virus Research Institute, Chiba, Japan and Japanese Spectroscopic Company, Tokyo, Japan, 1972.

Eudcational Experiences:

Professor of Biophysics and Biochemistry, Texas A&M University, 1976-present.
Senior Research Scientist, Texas A&M University, 1975-76.
Professor and Head of the Institute of Biophysics, Szeged, Hungary, 1970-75.
Professor of Plant Physiology, J. A. University, Szeged, Hungary, 1968-70.
Head of the Plant Physiology Laboratory in Fertod, Hungary, 1956-68.
Associate Professor and Research fellow in Agricultural Experiment Station, Budapest, Hungary, 1953-56.
Assistant Professor, Eotvos University, Budapest, Hungary, 1952-53.

Duties of Present Position:

In charge of introducing Biophysics teaching at Texas A&M University, and directing graduate student research in N_2-fixation.

Research Qualifications:

Twenty-five years experience in plant physiology research. Between 1953-68 I was mostly interested in the biochemical basis of plant growth regulation, especially by the auxinoxidase enzyme. In 1968 my work was shifted towards physical aspects of the basic metabolism. Recently my research is centered on the mechanism of N_2-fixation and on the origin and role of optical isomery in life. I am the editor of Radiation and Environmental Biophysics.

Publications:

62 papers in edited journals and two books in Hungarian.

Robert E. Pettit

Associate Professor
Department of Plant Sciences
Texas A&M University
College Station, Texas 77843

Born: [redacted]

Birthplace: [redacted]

Citizenship: American (United States)

Married with 4 children

Education:

Ph.D., 1966, Plant Pathology, University of Missouri
M.S., 1955, Plant Physiology, University of Missouri
B.S., 1955, Science and Mathematics, University of Missouri
Electronic Technician, 1956, Dynamic Electronics, Long Island, N.Y.
Fixed Station Radio Repair, 1948, U.S. Army Signal Corps

Professional Societies:

American Phytopathological Society
American Peanut Research and Educational Association
Sigma Xi
Gamma Sigma Delta
American Institute of Biological Sciences

Professional Interests:

Ecology of Soil Microorganisms
Plant Pathology
Host-Parasite Relationships
Plant Nutrition in Relation to Disease Development
Mycorrhizae Fungi and Their Relationship to Plant Development

Ronald James Newton

Assistant Professor
Department of Plant Sciences
and
Research Plant Physiologist
Texas Agricultural Experiment Station
Texas A&M University
College Station, Texas 77843

Born: [redacted]

Education:

Mead Consolidated High School, Mead, Colorado; 1957
University of Northern Colorado; Greeley, Colorado; B.A. 1961
University of Utah, Salt Lake City, Utah; M.S. 1965
Texas A&M University, College Station, Texas; Ph.D 1972

Honors:

High School - Salutatorian, 1957
Colorado Joint-Honor Academic Scholarship Award, 1957

Undergraduate - Fraternity Council Scholarship Award, 1958
BlueKey National Honorary for Men, 1959
Who's Who in American Colleges and Universities, 1961

Graduate - Society of Sigma Xi Research Grant, 1961

Experience:

Science Teacher, 1961-1965. Taught general science and biology in junior high and senior high schools.
Graduate Student, 1964-1965. University of Utah, Thesis Topic: Mathematical treatment of biological concepts.
Instructor of Botany, 1966-1968. Biology Department, Texas A&M University.
Graduate Student, 1968-1972. Biology Department, Texas A&M University.
Presidential Research Intern, Southern Weed Science Research Laboratory, USDA, Stoneville, Mississippi, 1973-1973.
Assistant Professor, Department of Biology, Texas A&M University, 1972-1974.
Assistant Professor, Department of Plant Sciences, College of Agriculture and Texas Agricultural Experiment Station. 1974-present. Teach introductory plant physiology and conduct research with aquatic weeds and crop plants.

Professional Organizations:

Phi Sigma National Biological Honor Society, Beta Rho Chapter
American Society of Plant Physiologists
Society of Sigma Xi
Southern Section of the American Society of Plant Physiologists
Botanical Society of America
Aquatic Plant Management Society
Lake Conroe, Inc.
Japanese Society of Plant Physiology

Ruth Ann Taber

Research Scientist
Department of Plant Sciences
Texas A&M University
College Station, Texas 77843

Born: [redacted]

Birthplace: [redacted]

Citizenship: American (United States)

Married with 3 children

Education:

- B.S., Bacteriology-Botany, West Virginia University, 1949
- Mycology, University of Iowa
- M.S., Plant Pathology, University of Saskatchewan, Canada, 1964
- Plant Pathology - Mycology, Texas A&M University
- EPA Certification for pesticide usage

Professional Societies:

- Mycological Society of America
- Canadian Phytopathology Society
- British Mycological Society
- American Phytopathological Society
- Southern Branch, APS
- Texas Branch ASM
- American Peanut and Research Association
- Pecan Growers Association
- Texas Mycological Society
- Texas Association of Plant Pathologists and Nematologists

Professional Interests:

- Fungal taxonomy
- Fungal diseases of crop plants
- Mycotoxins
- Soil microbiology

Roberta Hawkins Smith

Assistant Professor
Department of Plant Sciences
and
Research Plant Physiologists
Texas Agricultural Experiment Station
Texas A&M University
College Station, TX 77843

Born: [redacted]

Education:

Ramstein High School, Germany and Poly High School, Riverside California: 1963
B.S., Microbiology, University of California, Riverside: 1967
M.S., Plant Sciences, University of California, Riverside: 1968
Ph.D., Plant Physiology, University of California, Riverside: 1970

Honors:

High School - California Scholarship Federation, 1963
Graduate - Charles Teague University Fellowship Society of Sigma Xi
Professional - Research Council "Post Doctoral Stipened Program" Funds Texas A&M Alternate National Correspondent, International Tissue Culture Association 1979-1983 Member of Philip White Memorial Committee, Tissue Culture Association.

Experience:

Research Assistant - 1968-1970, University of California, Riverside. Dissertation research on _in vitro_ development of the isolated shoot apical meristem of angiosperms. Dr. Toshio Murashige was chairman.

Research Associate - 1971-1972, Texas A&M University. Research using ^{14}C-photosynthate and its incorporation into developing cotton bolls was conducted.

Post Doctoral - 1972-1973, Texas A&M University. Enzymes in germinating cotton seeds were examined.

Assistant Professor of Biology - 1973-1974, Sam Houston State University. Taught introductory plant biology, plant physiology, medical microbiology. Duties consisted of lecturing any two of the above classes, each twice a week and teaching the laboratory sections which each met once a week.

Assistant Professor - 1975-present, Department of Plant Sciences, College of Agriculture and Texas Agricultural Experiment Station. Teach introductory plant physiology, an undergraduate and graduate plant tissue culture courses; developed a graduate program using plant tissue culture; have an active research program in plant tissue culture for the improvement of crop plants, and actively participate in professional societies.

Michael Paul Grisham

Assistant Professor, Plant Pathology
Department of Plant Sciences
Texas A&M University
College Station, Texas 77843

Education:

Ph.D., March 1979, Plant Pathology, University of Minnesota
M.S., 1972, Plant Pathology, University of Arkansas
B.S., 1970, Biology, Ouachita Baptist University

Research Interest:

Genetics of plant pathogens, soil-borne plant pathogens.

Professional Societies:

American Phytopathological Society
Society of Nematologists
Gamma Sigma Delta

J D. Martyn, Jr.

Assistant Professor
Department of Plant Sciences
Texas A&M University
College Station, Texas 77843

Education:

Ph.D., University of Florida, 1977. Plant Pathology
M.S., Florida Atlantic University, 1971. Microbiology
B.S., Florida Atlantic University, 1969. Microbiology

Research Interests:

Physiology of Disease; biological control

Professional Societies:

American Phytopathological Society
Southern Division, American Phytopathological Society
Texas Academy of Sciences
American Association for the Advancement of Science
Sigma Xi
Phi Kappa Phi
Gamma Sigma Delta

Professional Honors:

Recipient of the "Award of Excellence for Graduate Research - Ph.D." Institute of Food and Agricultural Sciences, University of Florida, Gainesville, May, 1978.

Recipient of the "Graduate Student Research Award", Southern Division of the American Phytopathological Society, Atlanta, Georgia, February, 1977.

Lloyd R. Hossner

Professor
Soil and Crop Sciences Department
Texas A&M University

Age: 41 Citizenship: U.S.

Birthplace: Ashton, Idaho

S. S. No.: [redacted]

Marital Status: Married

Pre-University Background: Farm

Security Clearance: DoD Secret

Number of Children: Three

Professional Interests:

Soil Chemistry
Analytical Chemistry
Inorganic Chemistry
Plant Nutrition and Metabolism
Geology and Geography

Education:

Ph.D., Soil Chemistry, Michigan State University, 1965
M.S., Soil Chemistry, Utah State University, 1961
B.S., Agronomy, Utah State University, 1958

Experience:

Educational

Professor, Soil Chemistry, Texas A&M University, 1977-present
Associate Professor, Soil Chemistry, Texas A&M University, 1970-1977
Assistant Professor, Soil Chemistry, Texas A&M University, 1968-1970
Research Assistant, Michigan State University, 1962-1965
Instructor and Assistant, Soils, Montana State University, 1961-1962
Research Assistant, Utah State University, 1959-1961

Industrial

Research Soil Chemist, International Minerals & Chemical Corp., 1965-1968

Military

Commissioned ROTC Officer, 1958; Served as 2nd Lt., U.S. Infantry, Discharged as 1st Lt., 1964 (Honorable)

Society Memberships:

American Association for the Advancement of Science
American Society of Agronomy
Soil Science Society of America
International Soil Science Society
Sigma Xi
Texas Chapter American Society of Agronomy

Honors, Awards and Listings:

American Men of Science
Outstanding Research Award, Michigan State Chapter Sigma Xi, 1965
Who's Who in the South and Southwest
Who's Who in Interagency Energy Programs

Richard W. Weaver

Associate Professor
Soil and Crop Sciences Department

Age: 33 Citizenship: U.S.

S. S. No.: [redacted]

Birthplace: Twin Falls, Idaho

Marital Status: Married, 2 children

Pre-University Background: Farm

Education:

B.S., Utah State University, 1966 - Soil Science
Ph.D., Iowa State University, 1970 - Soil Microbiology and Immunobiology

Experience:

Associate Professor and tenure, Texas A&M University, September 1, 1976 to present
Assistant Professor, Texas A&M University, June 1, 1970
Research Associate, Iowa State University, June 1, 1967
Research Assistant, Iowa State University, June 1, 1966

Professional Societies:

American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
American Society for Microbiology

Subscriptions:

Crop Science
Soil Science Society of America Proceedings
Agronomy Journal
Journal of Environmental Quality
Applied and Environmental Microbiology
Bacteriological Reviews

Honors Societies:

The Fraternity of Alpha Zeta
Gamma Sigma Delta
The Society of Sigma Xi

Consultant Activities:

(1) Consultant to the University of Illinois INTSOY project on inoculant production in Thailand. I spent time in Thailand and other Southeastern Asian countries. (2) Consultant to the University of Hawaii NIFTAL program. I supervised a workshop designed to instruct scientists, from developing countries, techniques used in nitrogen fixation research.

Current Projects:

(1) Hatch 3121: Enhancing biological dinitrogen fixation in soybeans and other legumes. (2) Development of a nitrogen fixing system for selected grasses and non-leguminous crops. Funded by the Sid W. Richardson Foundation at a level of $100,000 for 3 years beginning in 1977.

Pending Project:

Stability of Effectiveness in Cowpea Rhizobia. Submitted to the Cooperative State Research Service for funding at a level of $75,000 for 3 years.

David Alan Zuberer

Assistant Professor
Soil and Crop Sciences Department

Born: [redacted]

Citizenship: U.S.A.

Date of Appointment: June 7, 1978

Education:

A.B., Biology, 1969, West Virginia University
M.S., Microbiology, 1971, Department of Plant Pathology and Bacteriology - West Virginia University
Ph.D., Biology (Emphasis in microbial) under Professor Warren S. Silver, 1976, University of South Florida

Professional Employment:

Research Scientist

September 1976 to May 1978
University of Florida, Department of Microbiology and Cell Science.
Research on the microbial ecology of associative nitrogen fixation in grasses.

Assistant Professor and Soil Microbiology, Texas A&M University, June 1978 to present.

Robert D. Powell

Professor, Plant Physiology
Department of Plant Sciences
Texas A&M University - Texas Agricultural Experiment Station
College Station, Texas 77843

Born: [redacted]

Education:

Ph.D., Iowa State University, Plant Physiology, 1950
B.S., University of Minnesota, Biochemistry, 1943

Professional Societies:

American Society of Plant Physiologists
Texas Academy of Science

Honors:

Sigma Xi
Phi Kappa Phi
Pi Sigma
Gamma Sigma Delta
Fellow Texas Academy of Science

Robert S. Halliwell

Professor

Born: [redacted]

Birthplace: [redacted]

Sex: Male

Citizenship: U.S.A.

Marital Status: Married, 3 children

Home Address: [redacted]

Business Address: Department of Plant Sciences
Texas A&M University
Phone - 713/845-7311

Military: Army, 1950-1952

Education:

B.S., University of Wyoming, Pre-vet, General Agric. 1956
M.S., University of Wyoming, Plant Pathology, Biochemistry, 1959
Ph.D., Oregon State University, Plant Pathology, Physiology, Biochemistry, 1962
Post Doctorate, University of Maryland, Plant Virology, 1963

John D. Goeschl

Research Scientist
Department of Plant Sciences

Date of Appointment: February 1975

Education:

B.A., Biology, Los Angeles State College, 1959
Ph.D., Plant Physiology, University of California, Davis, 1967

Professional Experience:

1957-1959 Research Technician, Los Angeles County Air Pollution Control District. (work done primarily in the Phytotron at California Institute of Technology)

1959-1967 Research Technician, Department of Vegetable Crops, University of California, Davis

1968-1974 Assistant Professor, Department of Biology, Texas A&M University

1975-present Research Scientist, Joint appointment with: Texas Agricultural Experiment Station, Department of Plant Sciences; and Biosystems Research Division, Department of Industrial Engineering.

Present Position, Description of Duties:

My joint appointment with the Texas Agricultural Experiment Station and the Biosystems Research Division, Department of Industrial Engineering involves an interdisciplinary effort to develop biophysical-mathematical models of physiological processes in plants. These models represent photosynthesis, phloem transport, carbohydrate assimilation in metabolic sinks. They are combined to predict the productivity of plants in agricultural and natural ecosystems as for example in integrated pest management such as the Texas "BUGNET" program and the Southern Pine Bark Beetle program.

A major responsibility is to help coordinate the interaction between the mathematical modelling group (Biosystems Division) and the experimental cooperators in TAES, including Dr. Ronald J. Newton, Dr. Kirk W. Brown, Dr. Robert D. Powell, Dr. Robert Coulson and others. A significant effort at present is the development of a new continuous $^{11}CO_2$ tracer technique in order to understand the physiological limits on photosynthetic productivity and carbohydrate allocation in crop plants.

Franklin Fong

Born: [redacted]

Birthplace: [redacted]

Present Address: Business
Department of Plant Sciences
Texas A&M University
College Station, TX 77843
(713) 845-7311

Education:

Ph.D., Biology, University of California, Riverside, October 1970-June 1975
Physiology Department, Columbia University, N.Y., October 1969-June 1970
B.S., Biology, University of California, Davis, February 1965-June 1969

Academic Employment:

Assistant Professor, 1978-present, Department of Plant Sciences, Texas A&M University
Postdoctoral Fellow, 1975-1978, Institute for Photobiology, Brandeis University
Teaching Associate, 1974-1975, Biology Department, University of California, Riverside
Teaching Assistant, 1973-1974, Biology Department, University of California, Riverside
Research Assistant, 1971-1973, Biology Department, University of California, Riverside

Grants and Awards:

National Science Foundation Energy Related Postdoctoral Fellowship July 1975-July 1976. (HES 75-19873) Title: Cytoplasmic regulation of plastid development in *Euglena gracilis*.

National Science Foundation-Experimental Marine Botany Research Program, Summer 1973. Experimental Marine Botany Department, Marine Biological Labs, Woods Hole, MA. Junior Investigator with Dr. Frank Loweus. Research topic: carrageenan biosynthesis in *Chondrus crispus*.

Intercampus Research Opportunity Award, 1974 ($300); University of California, Riverside, to continue studies on fatty acid metabolism at University of California, Davis.

Chancellor's Patent Fund Award, 1972 ($500); University of California, Riverside; to continue studies on phospholipid metabolism.

National Institutes of Health Predoctoral Trainee Fellowship, 1969; Department of Physiology, Columbia University, N.Y.

National Science Foundation Undergraduate Research Program (NSF-GY-4366), Department of Botany, University of California, Davis, to study plastid differentiation in bean leaves. (Dr. T. E. Weier)

JOHN E. LARSEN

Plant Nutrition Specialist--Greenhouse Vegetable Production
Texas A&M University
College Station, Texas 77843

Educational background. B.S.A. in agronomy (soils), Purdue University, 1942; M.S. in soil science, Purdue University, 1946; Ph.D. in horticulture, Purdue University, 1957.

Experience. Agronomist for Stokely Foods, Inc., Indianapolis, Indiana, 1946-50; junior assistant in horticulture at Purdue University, Lafayette, Indiana, 1951-55; farm manager for Grand Prairie Farm, Otterbein, Indiana, 1955-56; horticulturist for J. W. Davis Company, Terre Haute, Indiana, 1957-61; Extension horticulturist-vegetables, Texas A&M University, 1961-75; Extension Plant Nutrition Specialist--Greenhouse Vegetable Production, Texas A&M University, 1975.

Area of specialization. Works in all aspects of commercial and home greenhouse vegetable production and marketing.

Honors received. Distinguished student at Purdue University, 1939-42; graduated with distinction, Purudue University, 1942; Ceres (Honorary Agronomy Society); Sigma Xi.

Additional information. Dr. Larsen is a native of Watseka, Illinois. He is secretary of the Texas Greenhouse Growers Council. As a member of the Texas A&M graduate faculty, he assists with graduate student research programs.

Family information. Dr. Larsen is married to the former Mary Virginia Hencke of Lafayette, Indiana. They have a son, Bruce, and a daughter, Andrea.

Compiled July 1976

GREENHOUSE EXPERIENCE
of
John E. Larsen

As horticulturist for the J. W. Davis Co. from February 1957 to November 1961 (was elected Assistant Secretary of the Corporation by the stockholders in the spring of 1961), some of my responsibilities were to schedule and supervise the seeding, transplanting, production and harvest of 25 acres of Bibb lettuce for continuous harvest of 3,500 baskets per week from October through May of each year. I supervised the seeding, transplanting, production and harvest of approximately 32 acres of greenhouse tomatoes per year and from one-fourth to one acre of cucumbers. One-third acre of the 24 acres tillable under glass was in hydroponic production (soilless culture). I directed the analysis of the nutrient solutions which were brought up to a standard two to three times weekly. I determined the first symptom of boron deficiency on tomato fruit two years previous to its publication by other researchers. J. W. Davis Co. did not allow me to publish my findings.

I set up the disease control programs for the greenhouse vegetables produced and assisted with the insect control program.

I produced a new variety of greenhouse tomatoes. Records of the J. W. Davis Co. showed a gross return of $5,000 more per acre than that of the previous varieties grown.

Any unusual insect, possible disease symptom, and plant abnormalities were brought to my attention for analysis and recommendations for control if needed.

Each successive year since my employment with the Texas Agricultural Extension Service more and more of my office work has been utilized with correspondence, phone calls, individual consultations with growers and potential growers, and preparation of information sheets on greenhouse vegetables. However, my travel time and expense allotment have been utilized primarily for county home garden presentations.

Because of the great interest in greenhouse tomatoes, I perceived the need for a greenhouse tomato production short course of which the first was held in June 1964. The thirteenth was completed July 20, 1976. In December 1964, a state charter for a non-profit educational Texas Greenhouse Vegetable Growers Council was obtained by the greenhouse growers. I have been secretary of this association since its formation.

The Texas Greenhouse Vegetable Growers Council gave Texas A&M University two greenhouses for research on commercial production of greenhouse vegetables. The research and result demonstrations conducted in these houses have been under my direction since their establishment. To date, three graduate students have conducted their research toward an advanced degree in these greenhouses. Numerous graduate and undergraduate students have conducted problems courses under my supervision. The graduate students have presented their research findings at the annual short course. I have presented the results of demonstrations and other research findings at each of the annual meetings.

John E. Larsen
Continued

I have obtained colored slides of the various deficiency symptoms of all the essential elements for greenhouse tomatoes except chlorine and sulfur from result demonstrations conducted in the greenhouses. I plan to submit an Extension publication on nutritional deficiency symptoms of greenhouse tomatoes when the work load permits.

Because of promotion and sales of commercial hydroponic greenhouses to Texas growers with resulting nutritional problems in tomato production, I was forced to work on the nutrition and nutrient solutions for soilless culture growth media in order to assist these growers with their problems.

Result demonstrations on various nutrient solutions in the Texas A&M greenhouses showed that a modification of one devised by Abram Steiner of The Netherlands either out produced or gave superior quality than all others tried. I prepared information sheets on the Steiner and modified Steiner nutrient solutions which have been widely distributed in both Texas and the U.S. As soon as my work load permits, a fact sheet on these nutrient solutions will be prepared and submitted for an Extension publication.

Result demonstrations of the modified Steiner nutrient solution with growers has resulted in the adoption of this solution by many. At my suggestion the Steiner solution has been used and adopted by some producers of flowers, foliage and bedding plants. The cost of the ingredients to make the Steiner solution is considerably less than any of the commercial mixes.

Through working with nutrient solutions in soilless culture, I discovered an apparent nutritional relationship of nitrogen with boron. High nitrogen prevents the translocation to or the utilization of boron in the apical meristem. Maintaining nitrogen in the plant in the lower range of what is considered normal, prevents the development of boron deficiency symptoms, catface fruit, and various other plant abnormalities. Boron foliar sprays help to eliminate these problems providing the nitrogen is not too excessive. No amount of boron added to the the growing media will alleviate the excess nitrogen problem. One demonstration showed boron toxicity symptoms on the lower leaves and deficiency symptoms on the growing point of the same plant.

Demonstrations by this specialist in the Texas A&M greenhouses with modifications of the Steiner nutrient solution irrigated on soil tomatoes, resulted in greater yields than that obtained by standard methods of fertilizing. Result demonstrations with growers also proved better, with several soil growers now using formulations of a nutrient solution tailored for their soil.

A very recent result demonstration by this specialist has shown that automatic irrigation of a nutrient solution is producing excellent home garden vegetables. This specialist has also assisted with automation of irrigating a nutrient solution in backyard greenhouses of which there are now many in the state.

Result demonstrations have been conducted in the A&M greenhouses under my supervision on soilless culture production of greenbeans, cantaloupe, peppers, eggplant, Bibb lettuce, cucumbers and strawberries. To date, cucumbers, Bibb lettuce and possibly strawberries are economic crops other than tomatoes for Texas greenhouse vegetable producers.

2. Other Recognized Expertise and Specialized Facilities

a. Geotropism, Genetics of geotropic sensitivity, hormones and gravity

Recognized expertise

R. W. Zobel, Cabot Foundation, Harvard University, Petersham, MA*
C. C. Wunder, Department of Zoology, University of Iowa, Iowa City*
B. G. Kang, Yonsei University, Seoul, Korea - (geotropism, ethylene)
Mary H. Goldsmith, Department of Biology, Yale University, New Haven, CT 06520
J. Digby, Department of Biology, University of York, Heslington, England
Jane Shen-Miller, Associate Prog. Director, National Science Foundation, 1800 G Street NW, Washington, D.C.

* Data valid in 1973.

Unique facilities

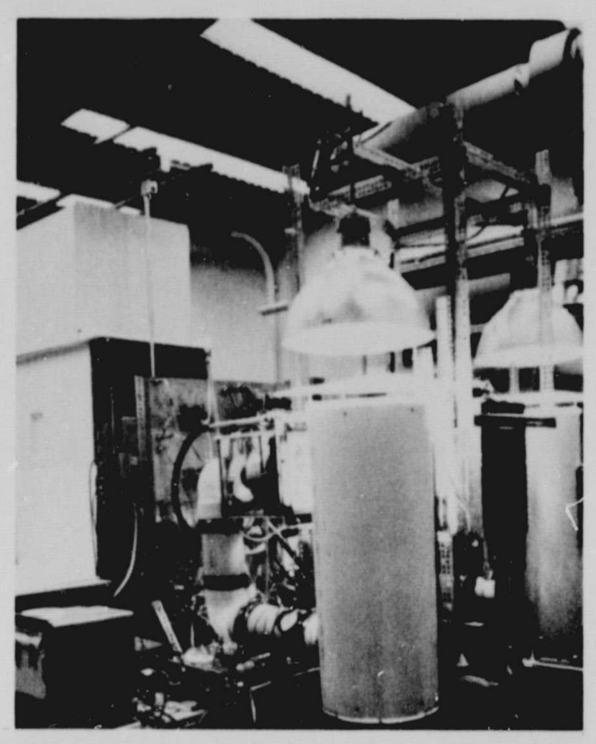
Department of Zoology, University of Iowa, Iowa City
Agronomy National Laboratory, Chicago, IL (geotropism)

b. Environmental components, environmental simulators

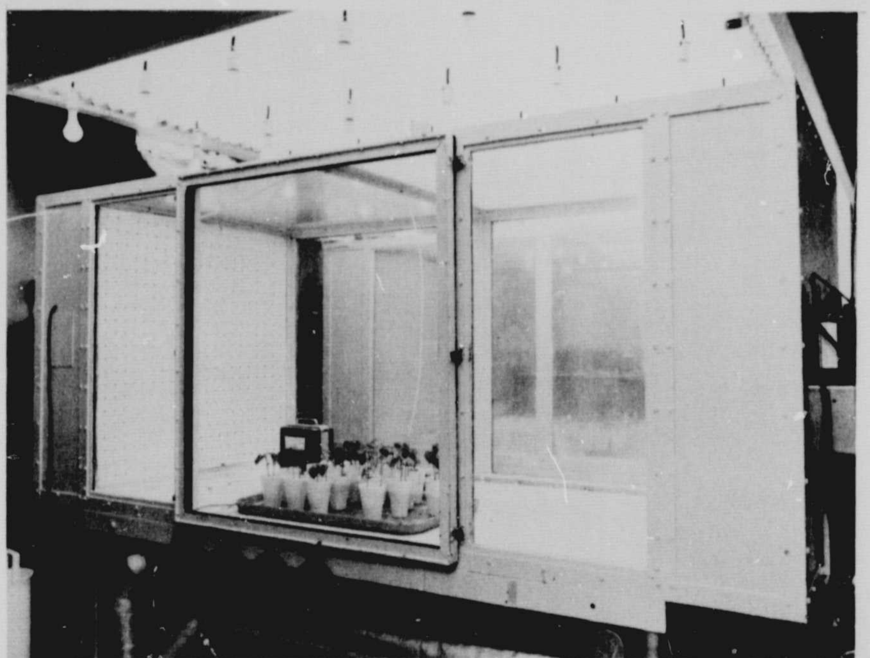
R. J. Down, North Carolina State University, Raleigh, NC,
H. Hellmers, Duke University, Durham, NC,
authors of "Environment and The Experimental Control of Plant Growth. Academic Press. 1975.

The relevant facilities are the North Carolina State and Duke Phytotrons, probably the largest collections of controlled environment chambers and greenhouses at a single location (close proximity) in the United States. Also, the biotron faculty at the University of Wisconsin, Madison should be considered.

3. Photographs of Some Controlled Environment Research Facilities for Plant Growth at Texas A&M University.

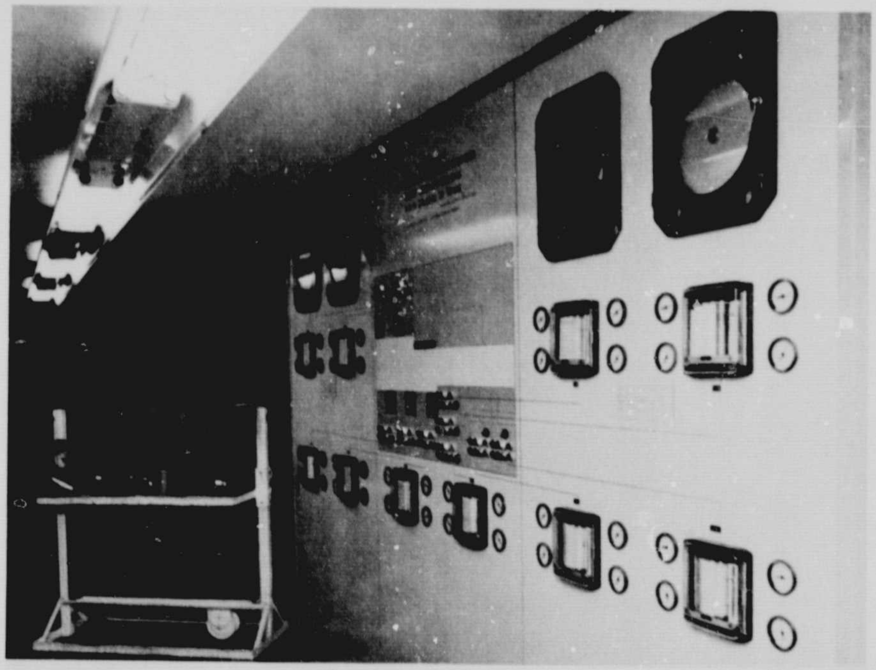


Semi-closed test chambers for plant response studies. Control of: light, temperature, humidity, CO_2 concentration. Measurement of: CO_2 and H_2O exchange rates of whole plants. Location: Controlled environment laboratory, Soil and Crop Sciences Department, Texas A&M University, College Station, TX 77843. Investigator: Dr. Keith McCree



View of a semi-enclosed, controlled environment chamber in the Air Pollution Laboratory, Department of Plant Sciences, Texas A&M University. Three chambers are available which allow fumigation of plants with air pollutants. Investigator: Dr. Franklin Fong.

Typical walk-in controlled environment room in the Plant Sciences Building at Texas A&M University with an experiment in progress. Investigator: Dr. R. D. Powell.



View of central control panel for 7 walk-in controlled environment rooms in the Plant Sciences Building, Texas A&M University. These rooms are assigned to the Departments of Plant Sciences, Horticulture and Range Science. The rooms are 10 ft. x 10 ft. x 8 ft. and provide control for light intensity, light duration, temperature and relative humidity.