PLANT GROWTH IN OUTER SPACE

COMMENTARY BY

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Dr. Johnson has presented a brief but comprehensive discussion on the problems of plant growth in outer space. There are, however, a number of points which I believe require some discussion and clarification. First it is generally agreed among students of photosynthesis that the initial photochemical reaction is the splitting of water with the production of reducing and oxidizing moieties, and that this is not a dark reaction.

Plant reproduction is controlled not only by light-dark cycles, but also by the ratio of carbohydrate and nitrogen, by temperature, by the combination of temperature and photoperiod, and by carbon dioxide concentration in the atmosphere during the light period. A breakdown of the oxygen regenerative system does not <u>necessarily</u> occur upon flowering.

The intensity of solar illumination in the vicinity of the earth is approximately 13,000 foot candles. Dr. Johnson's space ship would have to be about half way between Earth and Venus to be exposed to solar illuminance of 20,000 foot candles. In this case it certainly would be mandatory to reduce the solar intensity. As Dr. Johnson stated this can be done by inserting a concave lens between sun and plant to disperse the light rays thereby reducing intensity. Dispersion of the sun's light will also aid in reducing the infra-red impact on the plants. Conversely, on the Martian side of the Earth, a non-corrective lens could be used, or a convex lens may be required to intensify as the ship travels further from the sun.

We know that earth type photosynthesis has evolved with sunlight as the prime energy source. Plants as we know them on earth, have adapted to sunlight during several millenia. We would expect, therefore, that any artificial illumination, although possibly as good as sunlight, might not be any better. Some plants, for example, soybeans, do not grow as well under any presently available combinations of artificial light as they do when exposed to solar irradiation.

Due to the long decay period of the phosphors with respect to the excitation period there is no appreciable light-dark cycle inherent in fluoresecent lamps. Their emission is essentially continuous. The Department of Agriculture at Beltsville, Maryland, has conducted extensive investigations on fluorescent-incandescent lighting systems, and considerable data is available in the literature on this problem. It is my impression that plant responses to these lighting systems <u>are</u> fairly well known.

Wide temperature fluctuations will certainly have an undesirable effect on plant growth and reproduction whether gradual or not. Not <u>all</u> plants require higher temperature during the photoperiod, and constant temperature is not harmful to <u>all</u> plants. The influence of temperature is affected also by the rate of transpiration, by air movement, and by water content of the rooting medium.

Regarding the problems of weightlessness, there is sufficient evidence in the literature to indicate that geotropism as well as phototropism is important to broadleaf orientation. Our problem is to make the best use of this evidence in planning new experiments to gather data which can be utilized in the application of plants in manned space systems.

Weightlessness presents a severe problem with regard to the control of gases and liquids, or the control of the gas liquid interface. Since neither has weight in zero-G, their separation requires either a centrifugal method or physical separation by using a membrane permeable to gases but not to liquids. I refer you to the gravity-independent photosynthetic gas exchanger which was reported by Dr. Robert Gafford at the Annual Meeting of the Aerospace Medical Association in Los Angeles in April 1959.

Both microscopic and higher forms of plants will play an important part in the future of manned space operations. This is true because the photosynthetic process, which is the exclusive province of living plants, is by far the most efficient method known for converting radiant to chemical energy. It is questionable at this time whether any system other than one using photosynthesis will be as feasible in long-term space operations. It is fairly certain that plants in any form will <u>not</u> be used in operations of short duration, but their use in long-term operations is another matter. It is certainly true that there are many problems to be solved before plant systems will be used in space operations, but I am confidant that we will solve these problems and that eventually our life support systems will be designed quite similar to the closed ecology in which we live here on earth.

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For long-duration missions into space, it has been suggested that green plants be utilized for oxygen production and food. Although artificial environments have been suggested for man on these missions, the environmental parameters for plant growth have received scant attention.

Plants as we know them in their natural habitat have definite requirements for light, temperature, humidity, aeration, and nutrition. Whether these requirements can be met in the completely artificial environment of the space vehicle or station must be established before a working closed ecological system can be developed.

For instance, the light requirement on earth involves light-dark cycles, the length of the light and dark period and the quality and intensity of light.

Photosynthesis is a light-dark reaction. A photochemical reaction in which radiant energy is fixed occurs in the light. In the following dark reaction water is split into oxygen and hydrogen with the hydrogen uniting with carbon dioxide to form essentially carbohydrates. The oxygen formed in the splitting of water is evolved or used in respiration.

The length of the light or dark period largely controls reproduction in many plants. Plants which flower in long light periods are classified as long-day plants while plants that flower in long dark periods are classified as short-day plants. Many plants, however, flower regardless of the length of the light or dark period. These are known as day-neutral plants. The flowering of plants in a closed ecological system would result in a breakdown of the oxygen regenerative system since oxygen production depends upon the plant remaining in a vegetative state.

In addition to the lengths of light or dark periods, the light-dark cycle must be of approximately twenty-four hours duration. If the length of the cycle is considerable below or above the twenty-four hour cycle, the plant will deteriorate.

The quality of the illumination is also important. Action spectra for plant responses show peaks in the blue for photosynthesis, phototropism, flowering and dwarfism; in the red for photosynthesis, dormancy, flowering and coloration; in the far-red for cell division and elongation, prevention of flowering, and a general reversal of red reactions. Ultraviolet below 3000 Angstroms is usually lethal but above 3000 A° certain compounds, such as some of the vitamins, are increased. The infra-red partially regulates the water economy of the plant as water strongly absorbs in certain of the infra-red bands.

The optimum light intensity for plant growth varies. The algae require approximately 500-1000 foot candles, shade plants 2-3000 foot candles, full-sunlight plants 4-5000 foot candles, and alpine 6-7000 foot candles. The full 10,000 foot candles found in clear days is adverse to plant growth.

At present, in space vehicles, two types of plant illumination appear feasible. The first one utilizes solar radiation with the lethal portion of the ultra-violet and infra-red filtered out. In addition, a lens is inserted into the system to reduce the light intensity from approximately 20,000 foot candles to that desirable for the particular plant. The response of plants to filtered solar radiation will be similar to the plant responses as we now know them.

A fluorescent-incandescent system deriving power from an internal source is the second type of light illumination. This system is highly promising as the emission spectrum of the lamps may be controlled to a greater extent than that of the sun, thus furnishing a spectrum closely approximating the optimum spectrum for plant growth. Intensity and the length of the light period may be easily controlled. The presence of light-dark cycles inherent in fluorescent lamps seems to satisfy the plant requirement for this cycle.

However, fluorescent-incandescent systems have not been extensively investigated. Many problems encountered in their use remain to be solved. Not only are the responses of plants to this system largely unknown but the ratio of power input to light output is not favorable at present.

Abrupt changes in temperature are adverse for plant growth. However, plants can tolerate rather wide fluctuations in temperature when the change is gradual. More important is that plants require a higher temperature during the period of illumination than during the dark period. Constant temperature is adverse, if not lethal, over a long period of time.

Two strains of algae are presently under consideration: a moderate temperature strain having an optimum at 25° Centigrade and a high temperature strain having optimum growth at 39° C. It is not known if these two strains require an alteration of temperature for best growth.

The broadleaf plants presently being considered for closed ecological systems are horticulturally classified as cool season crops and require a temperature regime of approximately 65° Fahrenheit during the dark period and 75° F during the light period. These are the leafy varieties, such as cabbage, lettuce, turnip, spinach, and carrots, which have large leaf areas for efficient photosynthesis and are highly edible.

Temperature regimes for algae and broadleaf plant growth in space vehicles or stations will be relatively easy to establish under simulated space environments in the laboratory.

A high relative humidity of approximately 85-90 per cent during the dark period and a lower humidity of approximately 60-65 per cent is considered optimal for broadleaf plant growth in space vehicles.

Gaseous exchange in broadleaf plants is primarily concerned with the composition of the plant atmosphere and the rate of flow of the various gases across the leaf surface.

For practical purposes an optimum atmospheric composition is approximately twenty per cent oxygen, one per cent carbon dioxide, and seventy-nine per cent inert gas. Proposed atmospheric composition for space environments is forty per cent oxygen, less than one per cent carbon dioxide, and fifty-nine per cent inert gas at one-half atmosphere. The effect of this composition and reduced atmospheric pressure on plant growth is not known at this time.

The atmosphere must be relatively free of toxic volatile elements derived from materials within the space vehicle or station. Plants also produce carbon monoxide, ethylene and various aromatic esters which, if accumulated in the plant atmosphere, are toxic.

The rate of flow of carbon dioxide across the leaf surface of a plant in the closed ecological system must be established since the data on hand pertains to the earth's atmosphere which contains about one-thirtieth of the proposed level of carbon dioxide in the space vehicle or station.

The closed ecological system presents several rather complex nutritional problems. The human and plant requirements for essential inorganic ions are quite similar with the exception of sodium and chlorine. The human requirement for sodium is approximately thirty per cent of the total weight of the required ions and for chlorine approximately fifty per cent. In plant nutrition these two ions are considered trace elements and are toxic in high amounts. Some provision must be made to remove the excess sodium and chlorine from the waste disposal system which can then be incorporated into the human diet in the form of table salt.

A second problem occurs in that certain of the components of human waste cannot be utilized by plants. These are the bile pigments and certain aromatic compounds. Provisions must be made to chemically alter these compounds into forms usable by plants.

The effect of ionizing and X-radiation on plants has been extensively studied. If shielding for the crews is thorough, radiation is not expected to be a problem.

Acceleration, vibration and system noise are not expected to be a difficult problem with the algae since they are highly resistant to these stresses. The broadleaf system is more susceptible and may not be operational until the period of stress is over.

Weightlessness or near weightlessness will not pose any problem to broadleaf systems since orientation is primarily phototropic and chemotropic. The algae, growing in a liquid medium, are not subject to weightlessness problems except that aeration of the culture and recovery of the oxygen produced may be a problem.

In conclusion, it should be noted that the requirements for optimum plant growth on the earth are extremely complex. Before plants can be incorporated into a working closed ecological system, a considerable amount of research must be done in order to define the parameters for optimum plant growth in the exotic environment provided by a space vehicle or environment.