

THE ROLE OF PLANT DISEASE IN THE DEVELOPMENT OF CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEMS.

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INTRODUCTION

Controlled Ecological Life Support Systems (CELSS) for human habitation are proposed for long duration exploration of extraterrestrial habitats. The prime candidates for the photoautotrophic components of CELSS are edible higher plants. These plants would provide food and oxygen and perform other functions needed for human life. A primary concern in the design and operation of a CELSS based on higher plants is maintaining plant health. Without continuous growth of healthy plants a CELSS would not function properly. Although many aspects of plant growth have been addressed by scientists in the CELSS program, a subject that has received minor consideration is plant disease. Plant disease can be defined as any disturbance of a plant that interferes with its normal structure, function or economic value (2).

IMPORTANCE OF PLANT DISEASE

Higher plants are the most important sources of human food, but their production requires a constant and intensive effort to control diseases, both in the field and in semi-controlled

environments such as in greenhouses (2). Crop loss due to disease is substantial (5). The U.S.D.A. estimated that \$3.7 billion were lost to crop diseases in the United States in 1965 (1). However, the annual overall impact of disease is much greater since an incalculable cost is involved in controlling disease to prevent preharvest and postharvest crop loss. Just one plant disease can have a major impact on crop production. The 1970-71 epidemic of southern corn leaf blight in the United States caused an estimated \$1 billion loss (22). The role of plant disease in the production of healthy plants can not be overemphasized.

There are over a thousand microorganisms that cause plant diseases (2). They represent diverse biological groups such as viroids, viruses, mycoplasmas, spiroplasmas, bacteria, fungi and nematodes. Because of this diversity, there are a wide variety of ways in which pathogens survive, reproduce, disseminate, and infect plants and cause disease. Many pathogens also are highly variable genetically. These factors are some of the reasons why plant diseases are common, destructive and difficult to control (2). Furthermore the genetic uniformity in our important food and fiber crops has contributed greatly to plant disease epidemics (14).

WILL PLANT DISEASE OCCUR IN CELSS.

The important question concerning plant health in CELSS is: will plant diseases be a problem? There is good evidence to suggest that they will indeed occur. At the present time it appears that quarantine is considered the principal means of preventing the introduction of plant pathogens into CELSS. Quarantine programs, however, are not always completely successful (18). The introduction of coffee rust into Central America and downey mildew of maize and sorghum into the United States are just two examples of important diseases not controlled through quarantine.

Because of the diversity of plant pathogenic microorganisms, for example, in size, and the numerous means of dissemination, controlling their movement is notoriously difficult. Consider the numerous organisms that are seed borne either within or on seed (true seed or vegetative cuttings) (15). These organisms can be difficult to detect and are often the primary inoculum for disease (2). Potato production, for example, requires a constant indexing of seed tubers for presence of viruses (8). Plant pathogens also have a wide variety of survival mechanisms (2). Many can tolerate extremes of temperature and moisture and survive for many years in the absence of a host. Some are latent in their host and cause disease only under specific conditions. Many fungi pro-

duce airborne propagules, often in abundance, which are readily disseminated and can easily contaminate equipment and humans. There are also numerous pathogens that are disseminated and introduced into plants by insect vectors such as aphids and mites.

A variety of fungi and bacteria have been detected aboard spacecraft, either on the hardware or the human passengers. In the Apollo 16 and Skylab spacecrafts, 16 fungal genera that contain plant pathogens were detected (4,7). Some of these genera such as Fusarium, Helminthosporium, Alternaria, Phoma and Cephalosporium contain very destructive plant pathogens (2). The potential for introducing specific plant pathogens into CELSS was demonstrated in a Skylab simulation test where 8 species of plant pathogenic fungi were detected on the human participants (6). Human carried bacteria which cause disease on both plants and animals also may be introduced into CELSS (13).

Fungi, bacteria and viruses survive direct exposure to the space environment even for months if shielded from direct solar radiation (9,11,20,21,23). Tobacco mosaic virus and Bacillus subtilis are examples of two plant pathogens which remained viable after exposure to the space environment (9,21). Indeed, the space environment of deep cold and vacuum

are used by plant pathologists in the lyophilization process to preserve plant pathogens. This indicates that contamination of spacecraft and cargo outside of the life support system could introduce plant pathogens into a space station utilizing a CELSS. In view of the preceding evidence, the concept that quarantine procedures could completely exclude plant pathogens from CELSS is unrealistic.

Another important point to consider is the vulnerability of CELSS to plant disease. If plant growth systems such as aeroponics, misting, thin films, etc., lack a natural microbiological community, there will be no natural competition to prevent establishment and spread of pathogens. This can result in rapid and destructive disease development. This phenomenon is well known in plant pathology (3,10). The recolonization of steam sterilized greenhouse beds by Fusarium oxysporum and the development of tomato wilt is a good example of serious disease resulting from the lack of a biological buffer (16).

The plant growth systems proposed for CELSS (12) also may be vulnerable to disease induced by non-infectious microorganisms (exopathogens). These microorganisms could adversely affect plant growth through competition for rooting substrate and/or liberation of toxins that inhibit normal plant growth (26).

These diseases could be severe in a system lacking a normal rhizosphere flora.

Eight higher plant species have been recommended for prime consideration in CELSS: wheat, rice, potato, sweet potato, soybean, peanut, lettuce, and sugarbeet (25). Of those, wheat, potato and soybean were recommended for intensive research to obtain baseline information for evaluating the use of plants in CELSS (25). All of these crops however are susceptible to a wide variety of plant pathogenic microorganisms (8,17,24). For example, at least 200 diseases have been described on wheat but about 50 are routinely important economically (24).

EFFECTS OF PLANT DISEASES

There are four important effects that plant disease could have in CELSS. These are: (a) complete destruction of plants, (b) reduction in efficiency of plant growth, (c) destruction of the useful parts of plants and (d) creating sanitation and environmental contamination problems.

Damping off and root diseases (i.e. soil borne diseases) are those most likely to result in complete destruction of plants. The plant growth systems proposed for CELSS would be highly vulnerable to those diseases since many root pathogens require

high water potential for activity (2) and normal rhizosphere flora would be absent. Also, water delivery systems to roots could become contaminated and act as a means for rapid dissemination of pathogens.

The efficiency of plant growth could be affected by numerous pathogens which attack only certain tissues such as feeder roots, leaves or stems. Powdery mildew is an example of a disease where the pathogen usually does not kill the plant, but can severely reduce growth (19). Powdery mildews are often a serious problem in semi-controlled environments such as greenhouses.

Infection of edible or usable parts of higher plants by pathogens can destroy, reduce the quality or adversely affect processing or storage of the plant product. The cereal smuts, for example, completely replace the grain with smut spores. The production of mycotoxins in fruits, vegetables and seeds is an example of a reduction in quality and a health hazard. Aspergillus flavus one of the fungi found aboard spacecraft, (4) is a principal producer of a mycotoxin found in infected cereals and legume seeds (2).

Plant diseases would also necessitate the implementation of sanitation procedures, requiring time and energy, to destroy

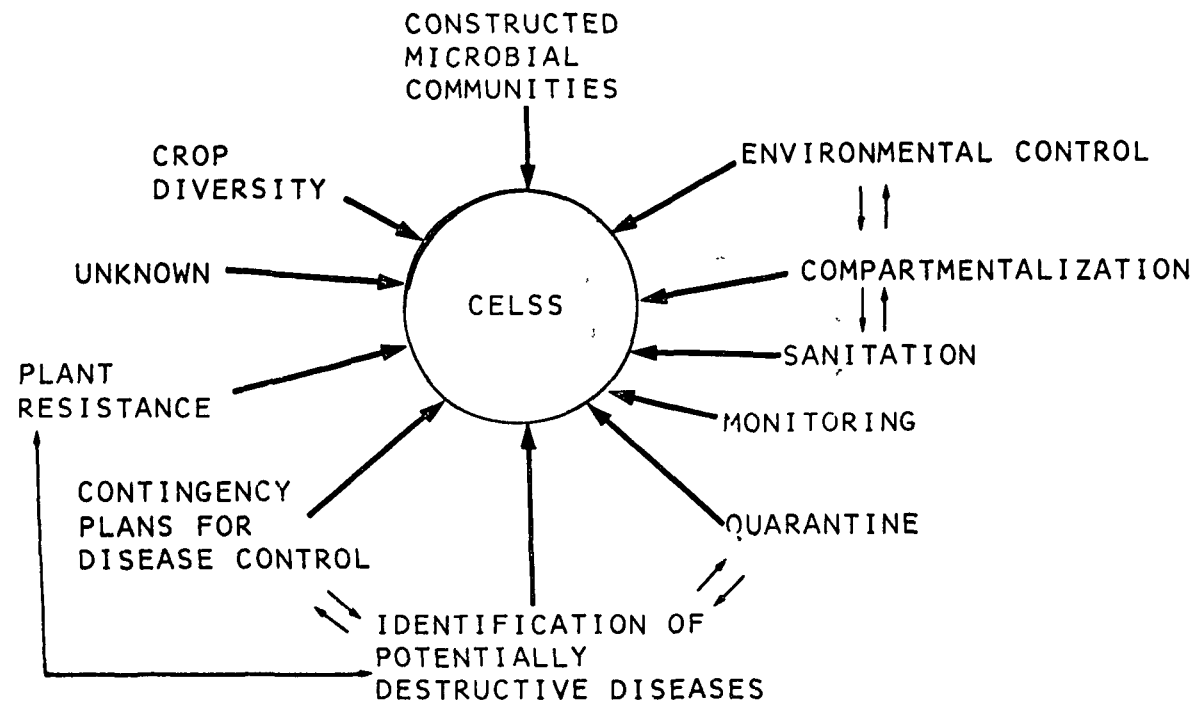


FIG. 1. SCHEMATIC DIAGRAM OF AN INTEGRATED PLANT DISEASE CONTROL PROGRAM.

disease inoculum (2). The greater the complexity of a growth system the more difficult the procedure to successfully eliminate inoculum. Plant debris, the physical parts of the rooting area, the rooting medium and the water delivery system would all need sterilization.

There is a potential problem of environmental contamination associated with some diseases. Plant pathogenic fungi can produce large quantities of spores on plants and these spores are liberated into the air and might be a health hazard in a closed system. Also, the control of certain diseases can be achieved with chemicals. However, air and water contamination could occur as a consequence of chemical applications. In CELSS, chemical control may be undesirable.

PLANT DISEASE CONTROL IN CELSS

Plant diseases in CELSS can be prevented or their damage minimized with an integrated disease control program. The important components (and their interactions) of such a program are diagrammed in Figure 1. They are as follows:

1. Quarantine. An important step to prevent introduction of pathogens. NASA should establish a policy that only pathogen free plants (seed and vegetative stock) are introduced into CELSS. The policy should be implemented prior to the development of an operational CELSS for a permanent

space station.

2. Identification of diseases most likely to occur in CELSS. Such information can be gained from current knowledge on plant disease, microbial contamination of spacecraft and astronauts, and from land based CELSS experiments. This information is fundamental to all aspects of integrated disease control.
3. Plant resistance. Host resistance should be utilized for those diseases which are potentially most destructive in the CELSS environment.
4. Crop diversity. When feasible, diverse crops should be utilized to minimize the impact of damage from plant disease.
5. Constructed microbial communities. The utilization of constructed beneficial rhizosphere and phylloplane microbial communities would act as a buffer against increases in pathogen populations and reduce infections. This would be true biological control. Such microbial communities might also prevent problems with exopathogens and could directly benefit plant growth (for example, through mycorrhiza). Maguire (13) has addressed this concept in a NASA contracted report.
6. Environmental control. Controlling environmental factors such as temperature and humidity are important methods of preventing or minimizing disease development.

7. Compartmentalization. Dissemination of pathogens and loss from disease can be minimized by compartmentalization of plant growth systems. This should include water delivery systems, plant handling equipment and processing areas. This would greatly facilitate sanitation procedures.
8. Sanitation. The destruction or removal of inoculum is often essential to prevent further disease occurrence. Since plant growth systems will most likely be in constant use, sanitation will be an extremely important disease control procedure. Plant growth systems should be designed for fast and efficient sanitation (i.e. sterilization or pasteurization). In semi-controlled environments such as greenhouses, sanitation is widely practiced for disease control.
9. Monitoring. Disease monitoring is necessary to implement specific disease controls, prevent spread of pathogens and provide information upon which future disease control decisions are based. Due to the greater value of plants in CELSS, disease monitoring will be more important than in earth agriculture. Sophisticated disease monitoring systems such as measuring reflected radiation in specific infrared wavelengths could be utilized in CELSS.
10. Contingency plans to control epidemics. Control procedures should be formulated for plant disease epidemics

that might occur in the CELSS environment. For example, powdery mildew may be a potential threat in controlled environments. Although powdery mildew can be controlled with sulfur dust, such a control may not be practical in CELSS. What specifically would be the control to prevent a powdery mildew epidemic?

CONCLUSION

Plant diseases could be important factors affecting growth of higher plants in CELSS. Disease control, therefore, will be needed to maintain healthy plants. The most important controls should be aimed at a) preventing the introduction, reproduction and spread of pathogens and b) preventing plant infection. An integrated disease control program will maximize that approach. In the design and operation of CELSS, plant disease should be considered an important aspect of plant growth.

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