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Assessment of Plant Diseases in Hydroponic Culture

Hydroponics, the growing of plants without soil, has been used in commercial production at least since the mid-1930s. Western Europe is the center of hydroponic production, yet even in the midwestern United States, the size and productivity of a hydroponic facility can be surprisingly large. For example, Archer Daniels Midland's 4 ha (10 acres) of greenhouses in Decatur, Illinois, produce 250,000 heads of lettuce (*Lactuca sativa* L.) per week during the summer. The value of a hydroponically grown crop is likewise surprising: PhytoFarms of America, in DeKalb, Illinois, annually produces vegetables with a retail value of over $5 million from less than 1 ha (2 acres). Despite these figures, the total area involved in the United States is less than 150 ha (370 acres), far less than projected during the early 1980s. The profitability of hydroponic facilities is also less than projected.

Crops grown hydroponically, including spinach (*Spinacia oleracea* L.), lettuce, and herbs, must have a high cash value per unit because of the high operating cost for equipment, energy, and a year-round labor force. Leafy crops that may require as few as 28 days to grow from seed to harvest have a distinct advantage over crops such as tomatoes (*Lycopersicon esculentum* Mill.) and cucumbers (*Cucumis sativus* L.) that must be grown long enough for the fruit to develop—up to 3 months. Although all hydroponic crops can be harvested year-round, their value fluctuates with the supply of seasonal, field-grown crops.

In addition to speed of crop growth, advocates of hydroponics claim several advantages over conventional growth in soil (3). First, in place of soil, chemically inert rooting media such as sand and rock wool provide mechanical support for plants. These media tend to vary less from batch to batch than does soil and provide more consistent rooting conditions for the crop. Furthermore, even these media can be eliminated if some other form of mechanical support, such as floating plastic pallets or metal troughs (Fig. 1), are provided. Second, since nutrients are supplied exclusively in solution by the watering system and not by the rooting medium, the grower has more control over fertility and pH. Third, the elimination of soil theoretically precludes diseases caused by soilborne pathogens.

Hydroponic Technology and Plant Health

Effective management of both infectious and noninfectious, or "abiotic," diseases in hydroponic production requires an understanding of the technology used. The technology ranges from standard hydroponic greenhouses to plant factories such as PhytoFarms, which are actually large growth chambers with totally artificial light and closely regulated environments (Fig. 2). As technology increases, so does the number of environmental parameters, the precise control of which decreases variation in plant growth. For optimal production, crop growth must be uniform to allow efficient, sometimes daily, harvests. But as with any monoculture, increased uniformity may also increase the potential for rapid development of a catastrophic disease.

The ability to rapidly grow vigorous crops, especially in the presence of low populations of a pathogen, is central to plant disease management in hydroponic

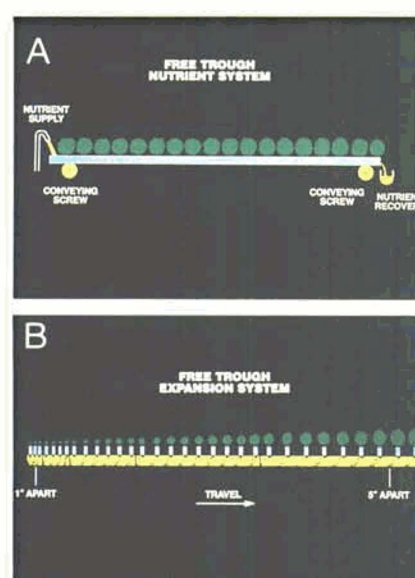

Fig. 1. PhytoFarms grows crops in troughs that are moved down a conveyor by two expanding screws. (A) Nutrient solution flows across a metal bar into a gutter, which returns the solution to the storage tank. (B) As the plants grow, the screw threads expand to increase the space allotted to each plant.

culture. Nutrition, temperature, and light are the physical factors most closely monitored to provide optimal growing conditions and minimal stress for the crop. All three are rather easily and continuously measured, and the corresponding data are often stored in computers for later analysis. In contrast, monitoring of populations of pathogens is considered difficult and therefore done haphazardly or not at all.

The nutrient solution is usually a modified Hoagland's solution and is the most closely monitored environmental factor in hydroponic facilities. The exact composition of the solution is often a closely guarded secret. Once a grower decides on a recipe, critical parameters such as pH and electroconductivity are monitored continuously and the concentrations of macronutrients and micronutrients are measured regularly (at least weekly), using such sophisticated equipment as atomic absorption spectrophotometers.

Nutrient systems may be recirculating or nonrecirculating (Fig. 3). The solution in a recirculating system may require adjustment in nutrients or pH as it returns from the growing area back to the storage tank. Proper sampling of the nutrient solution is needed if data on the solution in the tank are to accurately reflect the conditions the crop experiences. For example, rapidly growing plants may quickly deplete the dissolved oxygen in the nutrient solution immediately around their roots. Because the pumping of solution back to the storage tank may also reaerate it, measuring the level of oxygen in the tank may not accurately indicate the level at the roots. In one case, the solution in the tank contained 7 ppm of oxygen, while the solution after flowing through a 2-m wide tray of plants contained only 3 ppm (J. Gerber and K. Wallick, *personal communication*). In addition, each plant in a recirculating system is a "near neighbor" of every other plant because a pathogen shed from one plant will enter the storage tank and be quickly spread to all plants served by that tank. In a nonrecirculating system, the storage tank cannot be contaminated by nutrient solution returning from the growing area (6), and the plants are thus more isolated and less prone to rapid spread of pathogens.

The precise control of temperature can be aided by using the nutrient solution to heat or to cool the crop; by controlling water temperature, air temperature can also be controlled. Heat stress on summer crops of lettuce grown hydroponically in a greenhouse can be reduced by maintaining the nutrient solution temperature at 22 C (72 F) during the day and as low as 7 C (45 F) at night. Decreasing the temperature of the solution has the added benefit of increasing the solubility of O_2 in the solution.

Crop temperature fluctuates with intensity of sunlight in hydroponic greenhouses. More precise control of temperature is possible when plants are grown exclusively under artificial lights. Crops grown under high-pressure sodium lights, however, may be excessively heated by the infrared radiation emitted by the lights. Growers may place a Plexiglas jacket around their lights through which water is circulated to absorb the infrared light. This allows the lights to be placed closer to the crop to provide high light intensity without excessive heating. During the cool seasons, the heat trapped by the circulating water is used to warm the nutrient solution; in the summer, the

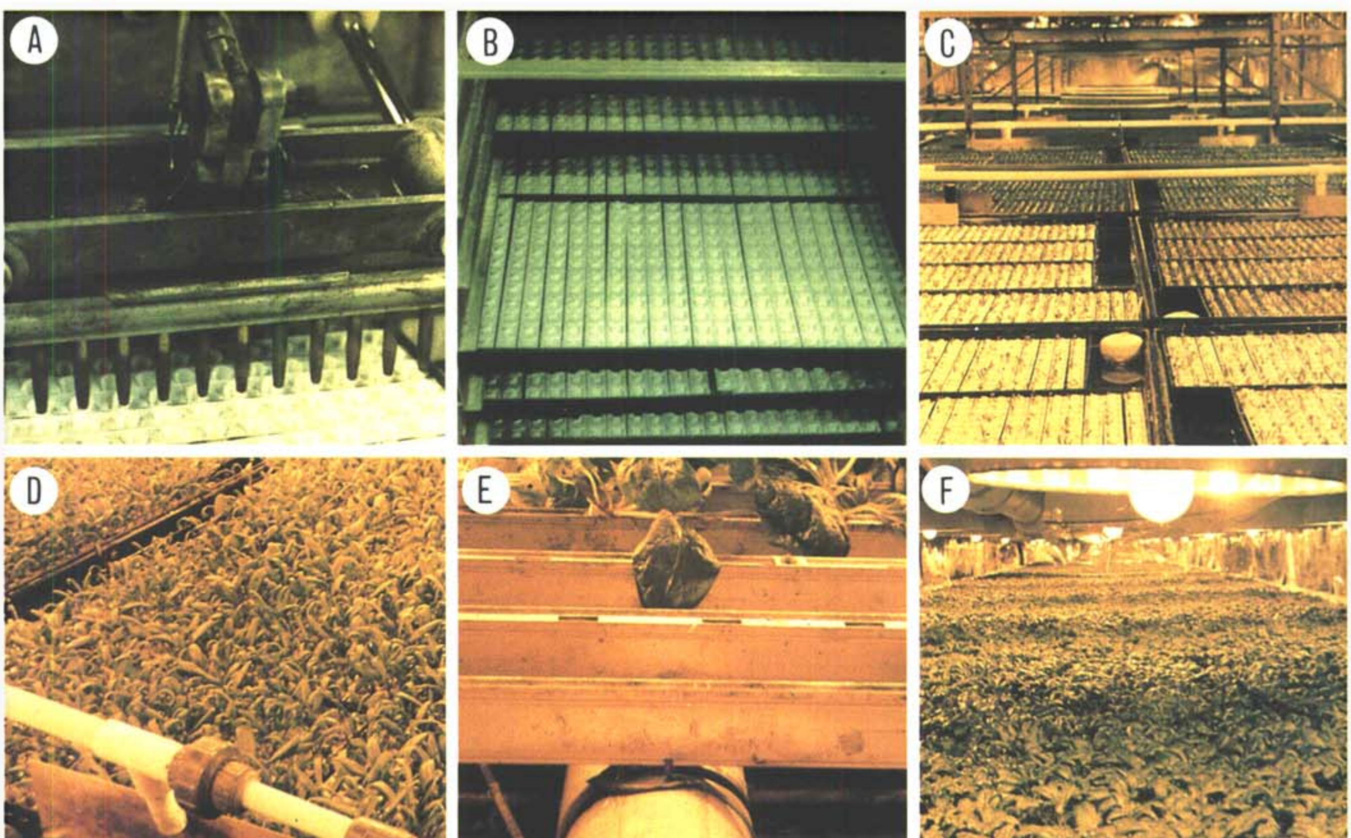

Fig. 2. Six stages of production using hydroponic conveyer technology: (A) Mechanical sowing of seeds into plastic strips containing a foam collar. (B) Germination in the dark on racks in chambers with controlled humidity and temperature. (C) Seedlings floating in pallets in the nursery. (D) Older seedlings in the nursery ready for transfer to the conveyor; note aeration caused by water stream. (E) Close-up of racks showing holes for plants; note thread on supporting screw. (F) Conveyor with high-pressure sodium lights and aluminum drapes; seedlings are at the far end and plants ready for harvest are in the foreground.

heated water is transferred outdoors to cooling towers and recirculated.

The intensity, photoperiod, and spectrum of artificial light may need to be adjusted for each crop. For example, a pronounced interveinal chlorosis of basil (*Ocimum basilicum* L.) observed at two different hydroponic facilities correlated with the use of high-pressure sodium lamps (Fig. 4). Spinach and lettuce grown under the same conditions did not become chlorotic. Furthermore, basil grown in a greenhouse or under fluorescent light did not become chlorotic. Attempts to transmit this disease to unaffected plants, thus implicating an infectious agent, have been unsuccessful. Apparently, light is at least one factor involved in the basil chlorosis.

Growers commonly inject CO_2 into the air inside their facilities (to a target concentration of 1,000 ppm) to increase plant growth. Whereas elevated CO_2 apparently benefits lettuce and spinach, it may actually reduce growth of cucumbers. Since conditions optimal for one crop species may be detrimental to another, the ability to maintain different environmental conditions within one facility (or greenhouse section) may enhance the chances of producing more than one crop simultaneously.

Infectious Diseases and Their Control

For a technique originally touted as an end to root rots, hydroponics provides growers with a considerable challenge in disease control (2). The number of infectious root diseases observed in a crop grown in hydroponic culture appears to be less than when that crop is grown in the field. The severity of a disease, however, is often intensified by the favorable temperature and water conditions and by the close monoculture of succulent plants. Once a pathogen is established, growers have few options. Considerable effort is required to determine the actual effectiveness of sophisticated sanitation procedures, such as disinfesting growing trays and flushing nutrient solution systems. A noncirculating system may be appropriate for tomato and cucumber growers (6) but is apparently unsuited for profitable production of leafy vegetables because of the added cost of wasting nutrients. Continuous production is a further burden—there is no off-season to help reduce the populations of pathogens.

Chemical control is limited by the lack of registered products. Pesticide manufacturers are reluctant to pursue registrations for hydroponic use because potential sales are small and the risk of liability is high. Similarly, disease-resistant cultivars specifically developed for hydroponic growth are not available; seed companies have little incentive to produce such cultivars because the potential market is small. Because hydroponic facilities are highly mechanized, crops must be selected for synchronous and high germination, rapid and uniform growth, cosmetic quality, and pleasant taste. Cultivars without these features are of little use to a grower who must harvest a crop on time every day.

A specific example of hydroponic disease management is the control of *Pythium* spp. on leafy crops (Fig. 5). The production of spinach, the most profitable crop for midwestern hydroponic growers, is currently limited by *P. aphanidermatum* (Edson) Fitzp. and *P. dissotocum* Drechs. In at least one case, these fungi forced growers to abandon production of spinach in favor of less susceptible—and less profitable—crops

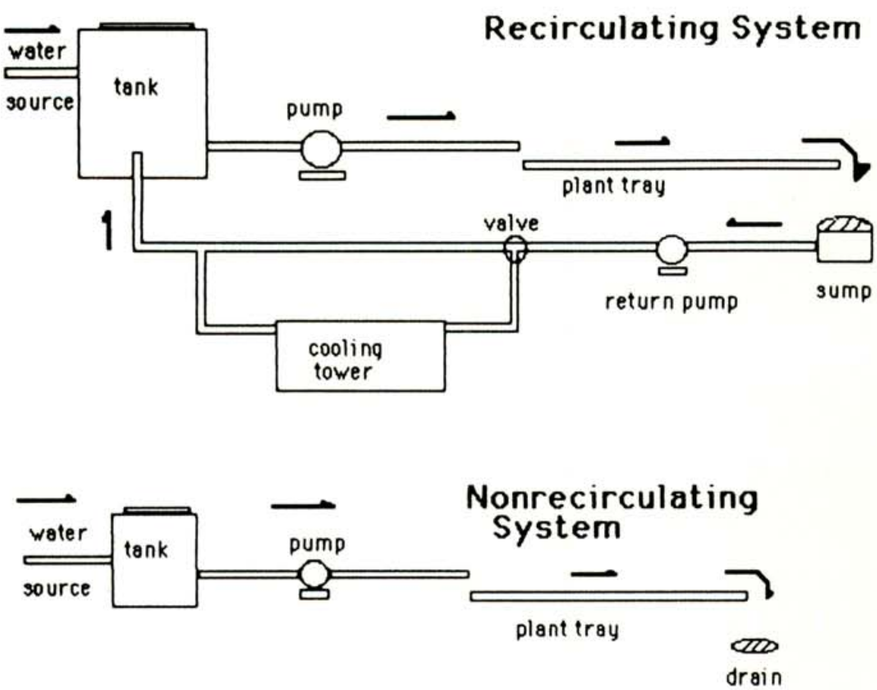

Fig. 3. Recirculating system vs. nonrecirculating system. Arrows indicate direction of flow of nutrient solution.

Fig. 4. Chlorosis of basil grown hydroponically under high-pressure sodium lights.

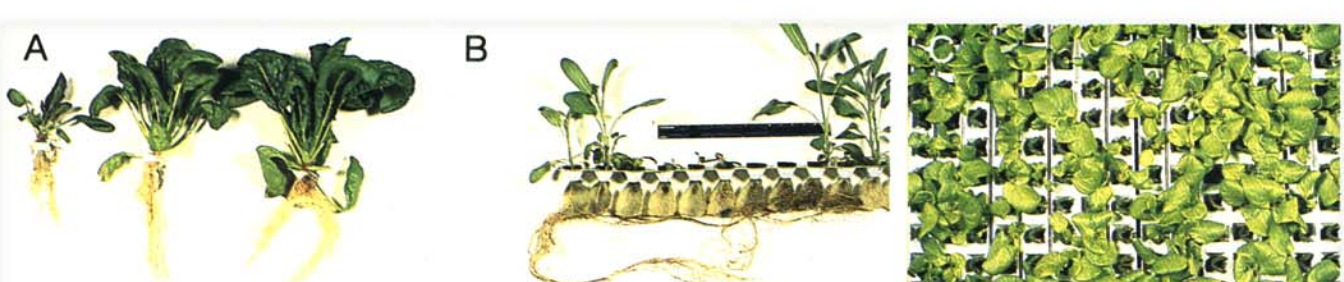

Fig. 5. Conditions on leafy crops attributed to infection by *Pythium* spp.: (A) Reduced growth of spinach; note brown discoloration of roots, especially prominent on the most stunted plant. (B) Damping-off of sorrel. (C) Damping-off of lettuce.

(1). The continuing production of lettuce rather than spinach is probably an indication that a grower has tried unsuccessfully to produce spinach. In soil culture, *Pythium* spp. are usually considered pathogens of younger plants. But as Rowe (6) notes, *Pythium* spp. have become a serious problem in mature plants grown hydroponically; the high humidity and succulent plants allow infection of aerial stems as well as roots. Such aerial infection is a greater threat to plants that must be grown for 2–3 months to produce a crop, e.g., cucumbers, than to shorter-term leafy crops.

The epidemiology of *Pythium* spp. on hydroponic lettuce and spinach has been studied by Stanghellini and colleagues. When the temperature of the nutrient solution was less than 23 C (73 F), *P. dissotocum* was the dominant pathogen; at warmer temperatures, *P. aphanidermatum* dominated (1). These observations were confirmed and expanded in laboratory tests (4). Moreover, if both fungi were present, the optimal temperature of the nutrient solution for lettuce production was 21 C (69 F)—intermediate to the optimal temperatures of the two fungi. But even at 21 C, shoot weight of plants grown in the presence of both fungi reached only 30% of that of plants grown in their absence.

Recently, Stanghellini and Kronland (7) found that *P. dissotocum* caused yield losses in lettuce of up to 50% even in the absence of root rot symptoms. The implications to growers are rather stunning. Even when they produce an apparently healthy crop, with rotfree, white roots, growers may be losing half their yield potential to a pathogen they cannot see—a pathogen not easily identified and quantified except by mycologists.

Managing *Pythium* diseases depends on selecting the crop, controlling the temperature, and encouraging rapid growth. Currently, only facilities that use artificial lights can control temperature with sufficient precision to grow spinach year-round in the presence of *Pythium* spp. Exclusion of inoculum has proved impractical, and sanitation to reduce inoculum load appears futile once the fungi have been established in a recirculating hydroponic facility. Irradiation of the nutrient solution with ultraviolet light gave remarkable control of *Pythium* spp. in a small, experimental system (8), but its effectiveness on a commercial scale is not yet known. Metalaxyl, a fungistatic chemical, controls root rot in experimental tanks but is not registered for commercial use. Furthermore, strains of *Pythium* resistant to metalaxyl have already been discovered (4).

Several pathogens in addition to *Pythium* spp. have been detected in hydroponic crops. For example, Jenkins and Averre (5) reported *Colletotrichum coccodes* (Wallr.) Hughes from roots of tomato; *Pseudomonas solanacearum* (Smith) Smith, *Fusarium oxysporum* Schlecht., and *Erwinia* spp. from stems of tomato; and *Pythium aphanidermatum, P. myriotylum* Drechs., *P. debaryanum* Hesse, and *P. ultimum* Trow from roots of tomato, cucumber, and lettuce. *Erwinia carotovora* (Jones) Bergey et al has been isolated from stems of basil and spinach (A. Kelman, *personal communication*; K. Gannon, *unpublished*). In the United Kingdom, hydroponic cucumbers have been infected by melon necrotic spot virus, which is vectored by the fungus *Olpidium radicale*. The disease was managed by adding a surfactant (Agral) to the nutrient solutions to reduce the number of fungal zoospores (9). Lettuce big vein disease, which is also spread by fungal zoospores, has been observed in lettuce crops, although only rarely in the Midwest.

What Is Needed in Hydroponics Research and Development

Because of the number of diseases that affect hydroponic crops, growers have identified several areas for possible research and development by plant pathologists:

1. Cultivars adapted to the special hydroponic environment are needed, regardless if their development proves unprofitable to commercial seed companies. Universities and state experiment stations are the only other possible sources of such specially selected cultivars.
2. Establishing the effects of latent infections on crop yield would help growers obtain more of their crop's potential yield.
3. Hydroponics research may have a far-reaching twist: NASA is working to develop hydroponics as a self-contained means to produce vegetables in space stations in orbit.
4. The most pressing need today is for methods to detect and quantify waterborne pathogens so that biotic stresses can be monitored with the same precision that abiotic stresses are monitored.
5. Reliable quantitative assays of pathogens will allow the evaluation of more sophisticated methods of disease control, including techniques to eliminate pathogens from the nutrient solution and to cure infected plants. As one grower, an engineer by training, put it, "Right now our only assay for pathogens is a bioassay—and that bioassay is our crop." Obviously, growers could use a less expensive assay.

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