A Review of Plastic Greenhouses: The Problems, Progress, and Possibilities

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Over two centuries ago Jonathan Swift wrote "necessity is the mother of invention." Because the late Professor Emery Myers Emmert could not afford an expensive glass greenhouse, he invented the plastic greenhouse in 1948. It was covered with 4′ x 4′ wooden frames with supporting form wire (spaced every 6 inches) on which cellophane film was attached. These frames were nailed on the rafters of narrow wooden structures and lapped similarly to greenhouse glass. Remarkable as it now seems, he grew commercial crops of lettuce, tomatoes, and bedding plants in these houses for several years before the era of polyethylene.

When sheet polyethylene became available, Dr. Emmert was quick to see its potential for covering his greenhouses. Encouraged by the success of initial crops in these houses, he constructed a private range of over a half acre (see photo on cover). Fruition of the concept came about by his combining an idea, persistence, and unusual skill in plant culture.

Extensive commercial adoption of plastic greenhouses was retarded because of a lack of knowledgeable growers. Glass greenhouse growers who possessed the skills in plant forcing were often unwilling to accept plastic greenhouses because of difficulties encountered during their early developmental stages. Thus, the first group of growers with the best chance to succeed did not accept the challenge.

Bedding plant growers adopted plastics readily. This represents an important use of plastic greenhouses throughout the United States, especially in the northeast and north-central regions. The main responsibility for proving plastic greenhouses, however, fell to the novice. Normally, the size of the trial greenhouse of these growers was limited to a few thousand square feet. The combination of limited capital investment, poor environmental control, and insufficent skill in the art of plant forcing and a general unwillingness to persevere led to a relatively high proportion of marginal successes or failures.

The first plastic greenhouse built on the Kentucky Agricultural Experiment Station in the winter of 1953-54 is still functional (Figure 1). The early concepts used in building plastic greenhouses emphasized economy of construction and normally used designs and principles utilized in glass greenhouses. However, essential compromises were made and significant changes from glass types occurred. These changes may be divided into the following three categories listed in order of their initial importance: structural design, environment control, and disease control.*

Structural Design

Much developmental research has been done in the design and testing of wooden structures for supporting the film. Generally, the traditional designs developed for glass greenhouses but made with construction grade lumber have been most readily acceptable. The "A" frame (8, 11), truss (14), ridge and furrow (18, 23), rigid frame (17, 21, 25), and the Gothic designs (14) are all good examples. Structures deviating from the traditional, such as the air-supported structures (22, 28), the flat-roof design (3), and the multibarrel and hyperbolic paraboloids (1), have not received general acceptance.

Enironmental Control

While there has been a great deal of developmental research on structures, very little systematic research has been done on the design of systems for environmental control. Greenhouse environment control systems should have three basic components, i.e., heating, ventilation, and circulation. Temperature control (heating and ventilation) is accepted as vital (15, 20, 24, 26).

Circulation, traditionally provided by convection currents established from heating pipes in glass greenhouses, was often overlooked in the early plastic greenhouse and heat stratification occurred. The air surrounding the plants

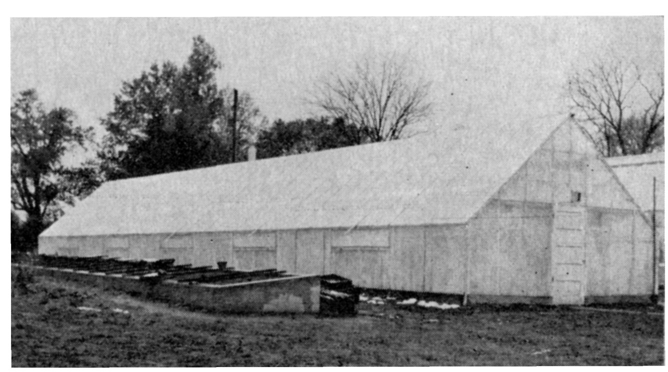

Fig. 1: A 1954 photograph showing the first plastic greenhouse built on Kentucky Agricultural Experiment Station. Note the vent hole above the door, found necessary to replace the oxygen consumed in the combustion of heating fuel. Manually operated side ventilators were the only form of ventilation. Similar ventilators positioned at the ridge were added soon after.

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* The necessity of suitable glazing plastic films has been omitted because the success of the entire concept was predicated upon the availability of at least one suitable plastic film

was relatively cold and saturated with water vapor (4, 15). Vapor condensing on the interior film surface accumulated and fell on plants. Such conditions favored high infection and spread of plant diseases such as leaf mold (*Cladosporium fulvum*) and rot (*Botrytis cinerea*) with alarming frequency and severity.

Once air circulation was accepted as a necessary part of environment control systems, stratification of heat and humidity was lessened and incidence and severity of plant diseases were minimized (4). Thus, environment control was shown to be interrelated to disease control.

Plastic greenhouses are generally heated with relatively small, inexpensive hot air furnaces. Air circulation systems are used in conjunction with them to distribute the heat (4, 13, 15). Uniform greenhouse environments for plant culture depend upon a suitable association of these two systems.

Early designs for ventilation systems used manually operated ridge and side ventilators (Figure 1). These have proven unsatisfactory. Presently, most greenhouses use fans which either exhaust warm air from, or introduce cool, outside air into the house. In both methods care must be taken to mix the cold ventilating air with the warmer inside air before distributing it uniformly at plant height. The first automatic environment control system integrating the three components was developed and tested at the Kentucky Agricultural Experiment Station in 1960 (5, 6). Evaporative cooling is often used in conjunction with fan ventilation during the warm parts of the growing season (10).

Disease Control

The problems of disease control in plastic greenhouses fall into two categories; those diseases affecting the aerial plant parts, and those which are soil-borne (including nematodes).

Many of the problems of disease control during the early years of plastic greenhouses were with aerial diseases. These are now minimized with the incorporation of air circulation as an essential part of all environment control systems. As the external air temperature decreases, moisture condenses on the cold inner plastic surfaces. This condensation causes a reduction of humidity in the layer of air proximal to the film. Air currents from constant circulation mix the "dry" air at the film surface with the ambient greenhouse air. This results in a measurable drying of the greenhouse atmosphere (7). Air circulation not only reduces stratification but makes it possible to utilize natural dehumidification when condensation occurs during cold weather.

Generally, commercially acceptable disease control occurs with adequate air circulation and humidity control. However, use of fungicides and suitable resistant varieties are also important.

Soil-borne disease are effectively controlled in glass greenhouses by steam sterilization. Small ranges and emphasis on economy of construction precluded the use of boilers for heating in most plastic greenhouses. Accordingly, alternative methods for controlling soil-borne diseases had to be devised. Presently, the most satisfactory system for plastic greenhouses includes the combined use of greenhouse sanitation techniques, resistant varieties, and regular soil fumigation. The most commonly used fumigant in many areas is methyl bromide. However, soil-borne diseases continue to be a potential threat to growers.

The outlook for reliable control of soil-borne diseases is promising. There are some new soil fumigants in advanced

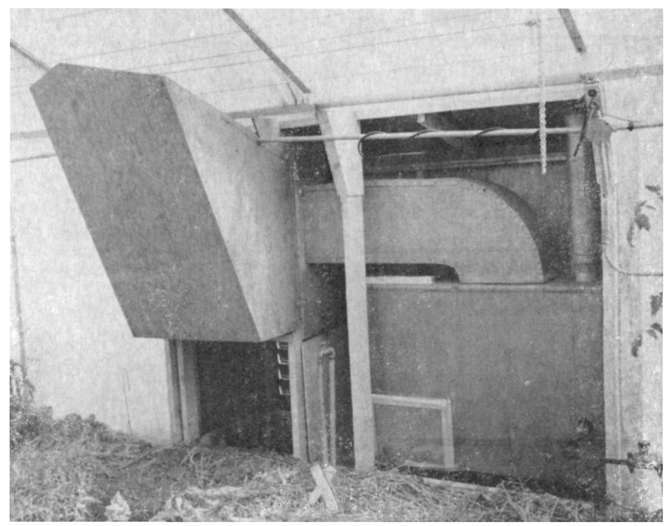

Fig. 3: A view of the greenhouse automatic environment control system (5). A single fan located behind plywood nozzle circulates the air continuously, ventilates the structure, and distributes hot air from the standard hot air furnace at right.

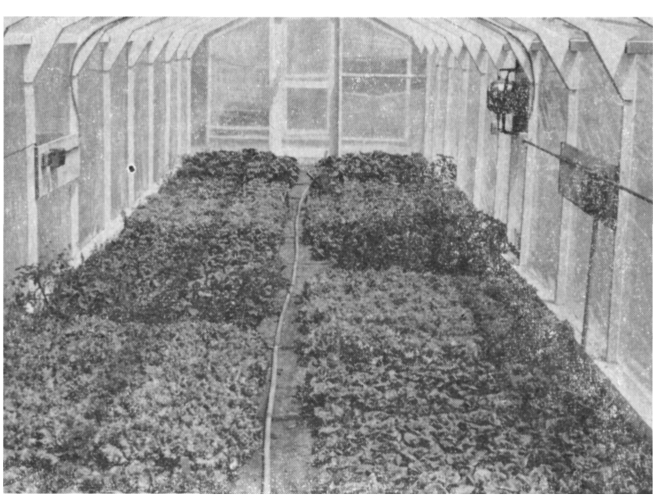

Fig. 2: A minimum cost, 10′ wide, rigid-frame structure developed at the Kentucky Agricultural Experiment Station. Note the exhaust type ventilation fan on the right, and control panel at left.

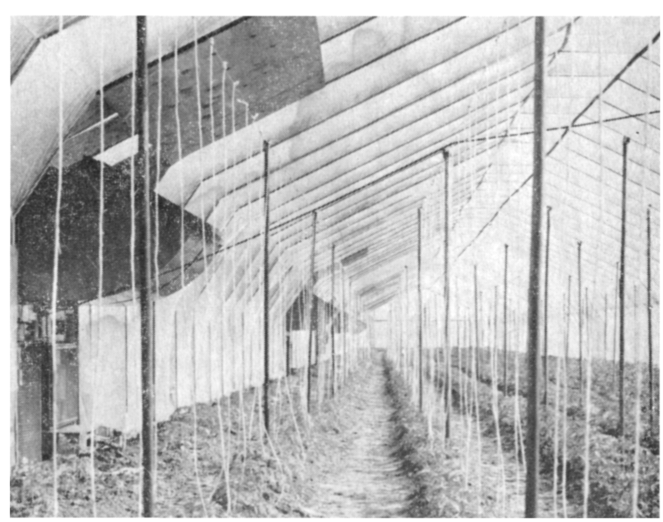

Fig. 4: An interior view of an early tomato crop cultured in rigid frame greenhouse covered with two layers of polyethylene. Note the air distributing nozzle of the environment control system at left.

stages of testing, and there will be further technological advances in the development of others. Recent results using limited volumes of sterile growth media (19, 27) suggest that such techniques may replace the need for sterilizing massive quantities of soil. Annual media replacement or sterilizing small volumes of soil with steam, similar to bench sterilization, would be feasible.

At the present time the plastic greenhouse has "matured" considerably and is enjoying ever-increasing acceptance. According to a recent survey in which 40 states reported, plastic greenhouses have increased from 123 acres in 1960 to 437 in 1965 (2). The growth pattern has developed sufficiently to permit generalization. The regions in the United States exhibiting the strongest growth in using plastic greenhouses appear to be the south, southwest, and the arid west. Each of these areas is characterized by a small initial glass greenhouse industry and a relatively mild winter climate. While development has generally centered in regions of mild climates, the use of plastic greenhouses in colder regions is feasible and economical (24, 26). According to the developmental pattern it is reasonable to expect plastic greenhouses to become popular in those regions lying north of glass greenhouse concentrations.

A similar pattern has occurred in Europe, i.e., regions of high glass greenhouse concentrations (Ireland, England, Holland, Denmark) have not yet considered adopting the plastic greenhouse, but regions to the south (France, Italy, and Spain) and north (Scandinavia) have displayed considerable scientific and/or commercial interest.

Rising affluence, discriminating consumers, and an increasing demand for salad vegetables, bedding plants, and flowers hold promise for a very bright future for the continued expansion of plastic greenhouses. The economy of initial investment and the impetus given by research scientists suggest that most new greenhouse construction will be plastic. Additionally, glass growers are beginning to accept certain types of plastics, especially the longer lasting rigid types.

It now appears that protected plant growing will take two forms. First, fully automated environment control systems coupled with cultural advances will optimize all cultural, engineering, and managerial aspects for the economical production of high yielding, high quality crops. Many phases are in a relatively high state of development at the present time.

The increased emphasis on the use of "synthetic" soils (16), combined automatic irrigation and fertilizing of plants (16, 19, 27), new knowledge on environmental requirements of plants and automatic systems to achieve them, suggest strongly that the art of plant forcing will evolve into a science. Yields and produce quality will increase. Management decisions and labor inputs will be minimal.

The second will be composed of specialized systems which will vary in form and function. However, all will have provision for adequate crop production under adverse conditions and will emphasize ease and economy of construction. They will normally develop where mild climatic limitations lead to special price advantages for specific crops. Owing to the diversity of special uses, research on each application is normally restricted to the regions where opportunities exist, and the growth pattern of individual systems may be slow and erratic.

One example of the special uses type is the minimum cost structure featuring narrow rigid frame, independent, single control heating system and automatic extractive fan ventilation system shown in Figure 3. Its low height and narrow width make it possible to cover it from the ground with a single wide sheet of polyethylene. Many uses for it are possible, including the extension of the field cropping season in the spring and fall (tomatoes, flowers, etc.), mid-winter production of cool-season crops (stocks, lettuce, etc.), and spring bedding plant production.

The growth of the plastic greenhouse from its conception in 1948 has been slow. However, recent advances in plastic coverings, structures, environment and disease control, and improved forcing varieties have put it in contention as becoming the most important forcing structure of the future. It is offering the first serious competition to glass greenhouses. It has stimulated scientists and growers to consider forms of crop protection never before considered feasible or possible.

Selected References

1. Aldrich, Robert A. and John White. 1964. Thin Shells for Greenhouses. *Fifth National Agricultural Plastics Conference Proceedings*, pp. 1-13.
2. Anonymous. November 1965. An Undercover Report. *Amer. Veg. Agr. Exp. Sta. MP-163.*
3. Bessey, Paul. 1965. Panel on Greenhouse Construction Costs. *Sixth National Agricultural Plastics Conference Proceedings*, pp. 167-170.
4. Cotter, D. J. and R T. Seay. 1961. The effect of Circulating Air in the Environment and Tomato Growth Responses in a Plastic Greenhouse. *Proc. Amer. Soc. Hort. Sci.* 77:643-46.
5. ——— and J. N. Walker. 1962. An Automatic System for Environment Control in Plastic Greenhouses. *Ky. Agr. Exp. Sta. Misc. 275-A.*
6. ——— and ———. 1967. Positive Heating and Ventilation of Plastic Greenhouses with Automatically Controlled Equipment." Symposium on Plant Environments in Glass Houses, Silsoe, England, *Acta Horticulturae.*
7. ——— and ———. 1966. Climate-Humidity Interrelationship in Plastic Greenhouses. *Proc. Amer. Soc. Hort. Sci.*
8. Courter, J. W. and J. O. Curtis. 1963. New Quonset and Rigid Frame Plastic Greenhouse Structures. *Fifth National Agricultural Plastics Conference Proceedings*, pp. 41-48.
9. Courter, J W. 1965 Plastic Greenhouses. *Univ. of Illinois Circular* 905.
10. DeWorth, A. F. and R. C. Jaska. 1958. Greenhouse Cooling. *Texas Agr. Exp Sta. MP-163.*
11. Emmert, E. M. 1955. Low-cost Plastic Greenhouses. *Kentucky Agr. Exp. Sta. Prog. Report 29.*
12. ———. 1960. Construction and Heating of Plastic Greenhouses. *Ky. Agr. Exp. Sta. Progress Report 92.*
13. Massey, P. H., McNeill, Marshall, and R. W. Gray. Research Report on Plastic Greenhouses. *Virginia Polytechnic Institute Agr. Exp. Sta.* (Blackburg, Va.) *Report No. 63..*.
14. ———, ———, and L. B. Wilkins. 1960. Plastic Greenhouses. *Virginia Polytechnic Institute Agr. Ext. Serv. Cir.* 760.
15. Moore, E. L. and T. N. Jones. 1963. Heating Plastic Greenhouses. *Minn. Agr. Exp. Sta. Bull. 666.*
16. Winspear, K. W. and L. G. Morris. 1965. Automation and Control in Glasshouse, *Acta Horticulturae* 2:61-71.
17. Roberts, William J. and David Buchanan. 1964. The New Jersey 26′ and 17′ Slant-leg Rigid Frame Plastic Covered Greenhouse. *Fifth National Agricultural Plastics Conference Proceedings*, pp. 24-31.
18. Roberts, William J. 1966. Plastic Greenhouse Structures for Nursery, Flowering Plants, and Vegetable Production, preesnted at the 59th Annual Meeting of American Society of Agricultural Engineers.
19. Sheldrake, Raymond, Robert Husted, and Robert M. Sayles. 1964. A Production Program for Greenhouse Tomatoes Utilizing a Modified Ring System. *Fifth National Agricultural Plastics Conference Proceedings.*
20. ——— and R. W. Langhans. 1962. Heating Requirements of Plastic Greenhouses. *Proceedings Amer. Soc. Hort. Sci.*, 80-666-669.
21. ——— and Robert M. Sayles. 1963. The Cornell Twenty-One Plastic Greenhouse. *Vegetable Crop Bulletin 3*, Cornell University.
22. Sobek, I. G., *et al.* 1961 Air-supported Plastic Greenhouses. Department of Agricultural Engineering, Washington State University, Pullman, Washington. *Wash. Farm Electrification Committee Progress Report.*
23. Van Dam, John and Norman C. Welch. 1964. Plastic Greenhouse Construction." *University of California Ext. Serv.* (San Bernardino) *AXT-163.*
24. Walker, J. N. 1963. Heating and Ventilating Plastic Greenhouses. *Fourth National Agricultural Plastics Conference Proceedings, pp.* 16-29.
25. Walker, J. N. 1963. Rigid Frame Greenhouse Construction—10 to 40 Feet. *Fourth National Agricultural Plastics Conference Proceedings*, pp. 8-15.
26. ——— and D. J. Cotter. 1966. Influence of Structural Features and Plant Growth on Temperatures in Greenhouse Studies with Particular Emphasis on Plastic Glazed Structures. Symposium on Plant Environments in Glasshouses, Silsoe, England. *Acta Horticulturae.*
27. Wells, D. A. 1966. Capillary Watering of Plants in Pots and in Beds. Symposium on Plant Environments in Glasshouses. *Acta Horticulturae.*
28. Wiebe, John. 1961. Plastic Greenhouses. Ontario Horticultural Experiment Station, Vineland Station, Ontario, Canada. *Publication 40.*