History of the ASHS Working Group on Growth Chambers and Controlled Environments, 1969–96: A Case Study of Involvement

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BACKGROUND

The American Society for Horticultural Sciences Working Group on Growth Chambers and Controlled Environments has been an active working group since its establishment in 1969. Over the past quarter of a century, it has been listed by various names, including the ASHS Special Committee on Growth Chamber Environments and the ASHS Committee on Growth Chamber Environments. For convenience, it will be referred to hereafter as the ASHS Growth Chamber Committee (ASHSGC).

The group was established because of the growing recognition that growth chambers were able to greatly increase the precision in plant research and the understanding of the interacting factors controlling plant growth if used to their full potential. Members had a common concern that there was a lack of guidelines on how to manage plants in growth chambers and how to monitor and control the environment to ensure consistent and comparable results among laboratories (Tibbitts, unpublished; Tibbitts and Langhans, 1993).

Also, many growth chambers were idle because of lack of adequate engineering expertise. In addition to the need for improved procedures for plant researchers, commercial growers, seedsmen, and nurserymen were clamoring for guidance on the commercial use of controlled environments for seedling and nursery production (Bailey et al., 1972). Clearly, the time was ripe for professional societies to provide guidance on the proper operation and use of plant growth chambers.

Inception. The initial meeting of the ASHSGC was a luncheon workshop organized by Theodore Tibbitts at Washington State Univ. in Pullman in Aug. 1969. This workshop brought together about 15 individuals with similar concerns from across the United States and outlined and emphasized the problems in controlled-environment research. The group agreed to meet again in Dec. 1969 at the Univ. of Wisconsin in Madison to outline goals for the committee and to develop a program of action.

Goals. The meeting at Madison set the stage for the direction that the ASHSGC took for nearly 15 years. Ambitious goals were outlined:

1) Develop guidelines for the measurement and reporting of the environment in controlled-environment studies;

2) Develop standardized growth curves for selected horticultural crops [petunia (*Petunia* ×*hybrida* Villm.), chrysanthemum [*Dendranthema* ×*grandiflorum* (Ramat.) Kitamura], ageratum (*Ageratum houstonianum* Mill.), marigold (*Tagetes erecta* L.), snapdragon (*Antirrhinum majus* L.), lettuce (*Lactuca sativa* L.), tomato (*Lycopersicon esculentum* Mill.), snap bean (*Phaseolus vulgaris* L.), corn (*Zea mays* L.), radish (*Raphanus sativus* L.), and pea (*Pisum sativum* L.)];

3) Develop and publish a *Procedures Manual for Growth Chamber Users*;

4) Develop a newsletter for exchange of information.

Responsibilities assigned. At its next meeting in Nov. 1970 in Miami, an executive committee of eight members with staggered 3-year terms was established to direct the ASHSGC. This initial executive committee consisted of Theodore W. Tibbitts (Chair) (Univ. of Wisconsin), Donald T. Krizek [U.S. Dept. of Agriculture (USDA)], Robert W. Langhans (Cornell Univ.), Wade L. Berry (Univ. of California, Los Angeles), James C. O'Leary (Univ. of Arizona), John W. Mastalerz (Pennsylvania State Univ.), Andrew T. Leiser (Univ. of California, Davis), and Robert J. Downs (North Carolina State Univ.).

The number of standard plants was reduced to four with responsibilities outlined as follows:

Lettuce ('Grand Rapids'), W. Berry; petunia ('Pink Cascade'), D. Krizek; marigold ('First Lady'), R. Langhans; and tomato ('Fireball'), T. Tibbitts.

D. Krizek agreed to obtain the seed supply and distribute seed lots to cooperators upon request. Seed was provided by various companies, and the seed was packaged and stored in cold-storage rooms at Beltsville, Md. Based on preliminary experiments run by D. Krizek, we used a commercially available peat–vermiculite mix. T. Tibbitts developed baseline cultural procedures (ASHS, 1976a, 1976b). W. Berry ran analyses of plant tissue. Alan Hammer (Purdue Univ.) assumed responsibility for statistical analysis of the data (Hammer, 1978).

At the Miami meeting, the group realized that the projects outlined would require many hours of discussion to obtain agreement on the best alternatives to follow. It became clear that two meetings a year would be required to make progress. However, because of funding difficulties, a USDA/Cooperative State Research Service regional growth chamber committee was organized to obtain funding for one of the two meetings each year.

Linkage to the NCR-101 Committee on Growth Chamber Use. Since two members from the same region were required to submit a proposal for establishing a regional USDA committee, A. Hammer and T. Tibbitts volunteered to serve as spokespersons for the group and contacted their respective experiment station directors within the North Central Region (NCR). The new committee became a reality in 1972, as the North Central Regional (NCR-101) Committee on Growth Chamber Use. The name of the committee was subsequently changed to the NCR-101 Committee on Controlled Environment Technology and Use. The organization of this committee broadened the support for addressing controlled-environment concerns by involving agronomists, agricultural engineers, and plant pathologists.

The group early decided that the contribution of the NCR-101 Committee should be extended to as many plant science groups as possible, so representatives were assigned to interact with other plant science societies. Thus, D. Krizek and T. Tibbitts worked with the SE-303 Environment of Plant Structures Committee of the American Society of Agricultural Engineers (ASAE), R. Langhans was liaison with the International Society for Horticultural Sciences (ISHS) Commission on Horticultural Engineering, and D. Krizek contacted the Council of Biology Editors (CBE) regarding publication of standardized reporting procedures in the *CBE Style Manual.*

Publication of a growth chamber manual

A major effort by the committee was the publication of a growth chamber procedures manual, which was initiated by A. Leiser, but R. Langhans did the major work of collecting the information and editing the manual. The manual was published in 1978 by Cornell Univ. Press as: *A Growth Chamber Manual: Environmental Control for Plants* (Langhans, 1978). Over the years, nearly 2000 copies of this manual have been distributed.

Soon after the book was published, mem-

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bers of the ASHSGC recognized that information on controlled environments was increasing rapidly and that there was a need to update the manual. Efforts to revise and expand the handbook were discussed repeatedly in the following years, but it was not until 1989, however, that a revision was initiated, again by R. Langhans, with the help of T. Tibbitts. The handbook was finally completed in 1995 and published in 1996 (Langhans and Tibbitts, 1996).

Development of standardized measurement and reporting guidelines

Immediately following the 1969 meeting in Madison, T. Tibbitts and D. Krizek developed a rough draft of guidelines for standardizing measurement and reporting of the environment and distributed these to growth chamber users, manufacturers, and other interested individuals for comments. These were discussed at an ASHS Workshop on Environmental Standardization that the group sponsored at the annual meeting in 1970 in Miami, and plans were laid for publishing these guidelines to obtain response from other plant scientists. This text was published initially in 1970 (Krizek, 1970), finalized in 1972 (ASHSGC, 1972), and revised in 1977 (ASHSGC, 1977) and again in 1982 (Krizek, 1982).

At the same time, individual members of the group assumed responsibility for submission of the ASHS Guidelines to other professional societies; during this period they were published in many publications and newsletters (see, e.g., Krizek, 1982; Krizek and McFarlane, 1983; Langhans and Tibbitts, 1981; McFarlane, 1981; Spomer, 1981a, 1981b).

The universal acceptance of these guidelines was promoted through an International Controlled Environments Working Conference organized by T. Tibbitts and held at Madison in Mar. 1979 (Krizek, 1979a, 1979b, 1979c, 1979d). This conference brought scientists and industry researchers together to discuss the development of effective guidelines for plant research. The proceedings of this conference were published by Academic Press (Tibbitts and Kozlowski, 1979).

The international acceptance of these guidelines has been helped significantly by the efforts of members of ASAE in having them published as *ASAE Engineering Practice EP 411.2* in their handbook of standards (ASAE, 1992). This effort was initiated by Bruce Curry (Ohio Agricultural Research and Development Center, Wooster) but carried through by John Sager [National Aeronautics and Space Administration (NASA) Kennedy Space Center] and published first in 1982, with two subsequent revisions, the latest in 1992 (ASAE, 1992). The responsibility for updating these guidelines is being continued by the committee to the present by D. Krizek and supported by J. Sager and T. Tibbitts (Krizek and Sager, 1996; Sager et al., 1996). The guidelines have also been included in *Units, Symbols, and Terminology for Plant Physiology* (Salisbury, 1996).

Development of quality assurance recommendations

In ensuing years, other guidelines and recommendations were prepared by the committee. Quality assurance recommendations were developed by J. Sager and T. Tibbitts (McFarlane, 1978b; Tibbitts, 1990; Tibbitts and Sager, unpublished) to outline types of sensors to use, accuracy in sensors desired, frequency of measurement, and procedures for calibration of sensors. These were published in *ASAE Engineering Practice EP 411.2* and in *Biotronics* as a draft in 1984 (NCR, 1984) and in final version in 1986 (NCR, 1986).

Development of a list of recommended instruments

The committee also extended the recommendations on instruments that could be used effectively in growth chambers by developing a list of types of instruments, along with a list of committee members willing to answer questions on instrument use. This list was made available to ASHS headquarters for distribution to interested persons.

Information exchange

Throughout its history, the ASHS Working Group has directed significant effort toward the dissemination of information on improving the quality of growth chamber research through organization of regular workshops and frequent symposia at the annual ASHS meetings (Hammer and Langhans, 1978; Kramer, 1978; Langhans and Hammer, 1978; Ormrod and Krizek, 1978; Scott, 1978; Tibbitts, 1978, 1988; Tibbitts et al., 1977), through annual reports of committee activities in *HortScience* (Krizek, 1975c, 1976, 1978; Langhans, 1972, 1974; Langhans and Krizek, 1974; McFarlane, 1978a; Tibbitts, 1971a, 1971b), and brief reports published in *HortScience* (Hammer, 1975; Wheeler et al., 1985).

Members of the committee have also worked to disseminate information worldwide through the development of sessions and workshops at International Horticultural Congresses held in Warsaw, Poland (1974) (Hammer and Langhans, 1975; Krizek, 1975a, 1975b; Krizek et al., 1975; Tibbitts, 1975); Sydney, Australia (1978) (Berry et al., 1979; Hammer, 1979; Langhans and Poole, 1979; Ormrod and Krizek, 1979; Tibbitts and Hodgson, 1979); and Florence, Italy (1992), and through news notes in *Phytotronics Newsletter,* published in France until 1979, and in *Biotronics*, published in Japan since 1983.

Development of standardized cultural procedures

A major effort and interest of the committee was in the development of standardized baseline growth curves of plants grown over 4 weeks (ASHSGC, unpublished). This effort was undertaken for two reasons: 1) to help scientists know if plants in their chambers were growing normally and 2) to allow the committee to obtain agreement on growing and measurement procedures that could be recommended for general research use in controlled-environment chambers. There were large differences in opinion within the committee on growing media, watering procedures, nutrients to provide, where to take environmental measurements, importance of CO_2 and humidity, need for ramping of light and temperature changes, etc.

Once the committee began working on trying to get agreement on standardized baseline procedures, it was obvious that the number of species tested had to be reduced. By July 1971 it was agreed to concentrate on lettuce and marigold.

Development of a standardized instrument package

The development of standardized baseline growth curves required similar environmental measurements at the separate cooperating research laboratories. Thus, a proposal was developed by T. Tibbitts as principal investigator (with committee members as co-principal investigators) and submitted to the National Science Foundation (NSF) as a committee project to purchase a package of instruments that would be calibrated and distributed to the cooperating laboratories to be used in conjunction with baseline growth studies on selected horticultural crops. Initial funding of $10,000 for 2 years was received in 1972 (ASHSGC, 1973) and made possible the purchase of instruments for measuring and recording light, temperature, humidity, and air movement, and provided tanks for standard CO_2 concentration that were forwarded for use at each laboratory. Distributed with the standard instrument package were standardized procedures on where and how to make measurements to ensure consistency among laboratories. NSF funding for these baseline growth studies was renewed in 1974 for 2 years at $29,500 (ASHSGC, 1974) and in 1976 for 2 more years at $41,500 (ASHSGC, 1976).

Of equal importance to this baseline growth effort was obtaining and using a single large lot of growing medium (peat–vermiculite), obtaining a single lot of seed stored at one location, grading the seed for uniformity of size, providing each cooperator with the same kind of container (12.7-cm-diameter, 1-L, white plastic pots), and standardizing the nutrient procedures by using the same nutrient solution (modified Hoagland) and an automatic watering system to ensure that all plants were fertilized at the same rate and frequency.

When there was agreement on the growing procedures with a solid medium in Aug. 1972, the members all agreed to undertake four or more uniformity studies in their individual growth chambers and forward the data to A. Hammer for statistical analysis and to summarize and prepare a manuscript for publication. All individuals cooperated using lettuce, but only data from the four members who completed the requisite number of studies were included in the final manuscript (Hammer et al., 1978). This study documented rather conclusively the difficulty in obtaining precise repeatability in growth studies. Also, it revealed that the variation in growth among studies was as large within the same laboratory as it was among separate laboratories.

A companion study was conducted on elemental analysis of lettuce grown under baseline conditions in five separate controlled-environment facilities (Berry et al., 1981). This study documented the components of variation contributed by analytical method for individual elements, plant to plant variation, variation within a single laboratory, and variation among different laboratories.

After the baseline growth studies with lettuce were completed, similar studies were initiated with marigold, and by the end of 1979, six committee members had completed four uniformity studies with marigold that were summarized and published (Ormrod et al., 1980).

These growth studies with lettuce and marigold revealed subtle differences in the composition of the peat-lite mixes from one lot to the next that made it difficult to totally standardize cultural procedures. W. Berry convinced the group that repeatability in growth required liquid culture, thus, followed a major effort toward development of a liquid culture system. Funds from the second NSF grant were used to purchase readily available pumps, containers, and other equipment for the liquid culture studies that were distributed to committee members. The maintenance and time requirements for these liquid culture studies, however, proved too much for committee members, and insufficient data were collected to publish standardized growth data, although a research bulletin was prepared detailing the growing system (Tibbitts et al., 1978).

During the conduct of these baseline growth studies, committee members quickly recognized the very difficult task of defining and conducting repeatable growth studies. Small variations in any one environmental factor were found to have a large impact on the growth and yield of the plants. Thus, studies with additional species were abandoned when it was realized that standard growth curves might be less useful than committee members believed initially.

Instrument calibration

However, the value and usefulness of instruments that could be distributed to each laboratory to ensure similar measurements has continued to be recognized and promoted, particularly for radiation measurements—a project that has been continued to the present. The instruments are maintained by T. Tibbitts at the Univ. of Wisconsin and supported by a service charge (now $300) for each use at a location. Upon receipt of the instrument package, each ASHSGC member is encouraged to contact other growth chamber users at his or her location and encourage them to bring in their quantum sensor(s) or other radiation measuring instruments for cross comparison. Before and after each use, the radiation measuring instruments are audited with calibration systems maintained at the Univ. of Wisconsin, and users are notified if any significant deviations have occurred in any instrument during the period it was distributed.

In the late 1970s to early 1980s, efforts were undertaken to have the National Bureau of Standards (NBS) [currently the National Institute of Standards and Technology (NIST)] calibrate some of the radiation sensors. Donald McSparron (NBS), T. Tibbitts, and D. Krizek conducted a cooperative study to examine the response of two LI-COR (Lincoln, Neb.) photon flux sensors for measuring photosynthetic photon flux under various spectral sources (Tibbitts et al., 1986). Because of increasing demands for calibration services at NBS, users were encouraged to seek secondary calibration laboratories. Currently, most members of the committee routinely send their radiation measuring instruments back to the respective manufacturer for recalibration at 1- to 2-year intervals.

Evaluation of long-wave radiation effects in growth chambers

In the course of the baseline growth studies, it was discovered that small differences in the amount of infrared radiation (IR) provided by varying the wattage of incandescent lamps had a significant effect on vegetative growth of lettuce and marigold and on their nutrient composition. Since the pots were spaced far apart, the possible confounding effects of crowding were avoided. Separate papers describing IR effects on growth and elemental concentration were published (Krizek and Berry, 1981; Krizek and Ormrod, 1980). Efforts to obtain NSF funding for a concerted committee study of the effects of spectral quality effects on plant growth under growth-chamber conditions proved unsuccessful, and no further attempts were made to secure outside funding.

The committee has taken an active role in characterizing the large differences in thermal radiation (particularly 3- to 50-µm wavelengths) in various growth chambers and in documenting the significantly higher levels in certain chambers than present outdoors under solar radiation (Tibbitts et al., 1976). The assistance of Henry Kostkowski at NBS in providing a Kendall radiometer as a calibration device and of Leo Fritschen (Univ. of Washington, Seattle) in providing a Fritschen net radiometer was invaluable in this effort.

Considerable emphasis has been placed on evaluating diverse types of long-wave monitoring devices that would be effective in characterizing this radiation. The sensors were made available to committee members through distribution of the instrument package. Initially, this included a Fritschen net radiometer. In the early 1990s, the committee purchased an Eppley pyranometer and an Eppley pyrgeometer to measure radiation in the region of 0.29 to 3 µm and 3 to 50 µm, respectively. Several committee members compared the spectral properties of various radiation sources using these sensors. Radiation sources examined included incandescent (INC), cool-white fluorescent (CWF), metal halide (MH), high-pressure sodium (HPS), and low-pressure sodium (LPS) lamps. Insufficient data for any single radiation source and large differences in growth chamber design with regard to type and placement of the glass or plastic barrier separating the light bank and the plant growing area, cooling of the lamps in the light bank, and other design features among laboratories precluded the committee from publishing these data.

Concern over long-wave radiation and other spectral requirements of plants led to the organization by T. Tibbitts of a second International Controlled Environments Workshop at Madison, Wis., in Mar. 1994, with emphasis on lighting. Support was provided by NSF, NASA, the Dept. of Energy, growth chamber manufacturers, and lighting organizations. The proceedings were published by NASA (Tibbitts, 1995).

Cooperation with industry

The committee has encouraged participation by industry groups, with growth-chamber manufacturers and lamp manufacturers being regular attendees at the meetings. The committee has also played an active role in promoting the development of improved instrumentation for monitoring the environment and in the evaluation of new instrumentation that becomes available.

Early in the baseline growth studies, it became clear that variation in the amount of incandescent lighting among growth chambers was responsible for large differences in the far-red component of the spectrum among laboratories, but no broad-band sensors were available to monitor this variation. Thanks to the cooperation of industry, the committee was able to persuade LI-COR to manufacture a far-red sensor for inclusion in the instrument package that could be distributed to members.

Many members also recognized the need to carefully monitor the spectrum of radiation in their separate chambers, and the committee was able to obtain a spectroradiometer on loan from LI-COR that was available to members, along with the instrument package, for 2 years.

In the late 1980s, Skye Instruments (Liandrindod Wells, Powys, England) produced a model SKP-210 sensor to monitor photosynthetically active radiation (PAR) in terms of yield photosynthetic flux (YPF). This instrument weights photons in the range from 360 to 760 nm according to plant photosynthetic response as opposed to the LI-COR quantum sensor, which weights all photons from 400 to 700 nm equally. Four members of the committee purchased the Skye YPF sensors and evaluated them under seven radiation sources [solar, INC, CWF, MH, HPS, LPS, and red light emitting diodes (LEDs)] during the ASHS meeting at Utah State Univ. in 1991.

Comparative measurements of YPF and PPF were made with Skye and LI-COR sensors and data compared with YPF and PPF values calculated from measurements made with a LI-COR (model LI-1800) or an Optronics spectroradiometer (model 740A; Optronics, Orlando, Fla.). This work was subsequently published (Barnes et al., 1993). According to spectroradiometric measurements, YPF sensors were significantly less accurate (>9% difference) than PPF sensors under MH, HPS, and LPS lamps. The Skye sensors performed best under broad-spectrum sources, including solar, INC, and CWF lamps, where measured values were <10% lower than spectroradiometric values. Values obtained with the Skye sensors were considerably lower than spectroradiometric values under narrow-band sources or sources having a large fraction of their output at discrete wavelengths, i.e., MH, HPS, LPS lamps, and red LEDs. Both sensor types were inaccurate (>18% error) under red LEDs. This investigation thus raised serious questions as to the accuracy of these special photosynthetic sensors.

Improved characterization of air movement

Accurate measurement of air velocity has been a major concern of the committee since its inception. When using a hot wire anemometer without analog output, committee members took a series of at least 10 measurements at each location in succession and averaged the data (Downs and Krizek, 1996). The recommendation was made to measure the air flow at a minimum of five positions uniformly spaced throughout the plant canopy. In 1991, a unidirectional instrument was purchased and distributed for use with the instrument package.

Cooperation with other American societies

Since its inception, the ASHSGC has maintained active liaison with many committees in other societies. One of the closest linkages has been with the ASAE through its Environment of Plant Structures Committee of the Structures and Environment Division (SE303) [known initially as the Plant and Animal Physiology Advisory Committee (ASAE C-18)] and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Committee on Plant Structures (known initially as ASHRAE TC 1.5 Committee and later as the ASHRAE TC 2 Committee). Members of the ASHSGC have provided input in updating the chapter on "Environmental Control for Animals and Plants" that first appeared in the *ASHRAE Guide and Data Book, Applications* in 1966 (Chapter 31), and was later published in the *ASHRAE Handbook of Fundamentals* in 1967 (Chapter 9) and the *ASHRAE Guide and Data Book, Applications* in 1968 (Chapter 16) (ASHRAE, 1966, 1967, 1968).

The ASHSGC provided input to the fifth edition of the *Council of Biology Editors Style Manual* and to the *American Society of Plant Physiologists Instructions for Contributors* (Krizek, 1983). The committee also worked with the AIBS BioInstrumentation Advisory Committee (BIAC) headed by John Busser and participated in workshops sponsored by BIAC. Recently, several of the members (Krizek and Sager, 1996; Sager et al., 1996) contributed to *Units, Symbols and Terminology for Plant Physiology* (Salisbury, 1996).

International cooperation

International groups that the committee has worked with include the Commission Internationale de L'Eclairage (Commission on Illuminating Engineering) (CIE) (Tibbitts, 1993) and the ISHS Commission for Horticultural Engineering. Efforts within CIE have focused on developing measurement guidelines for plant lighting and have used various forums, including regional and international workshops and symposia. T. Tibbitts and D. Krizek have been the principal ASHS members active within CIE. R. Langhans has served as the main contact with the ISHS Commission for Horticultural Engineering.

The ASHSGC has taken an active role in organizing international conferences and workshops and sponsoring sessions at the International Horticultural Congresses (IHC), which were published in *Acta Horticulture* and in a book edited by Pierre Chouard and N. de Bildering entitled *Phytotronique I.* In 1978, Craig McFarlane chaired a similar session at the IHC in Sydney, Australia. The proceedings of the Australian session were published in *Phytotronics Newsletter*. At the IHC in Florence, Italy, in 1990, several members participated in a Workshop on Lighting in Controlled Environments organized by T. Tibbitts.

EPILOGUE

There is little double that within the annals of professional societies, the ASHSGC is indeed unique. There have probably been few other groups that have been as productive. While it may be presumptuous to pat oneself on the back, there may be merit in providing this documentation in the hope that future committees and working groups of our society may draw encouragement and inspiration to take an equally active role in the activities of our society.

The ASHS Growth Chamber Committee has been fortunate in having a core group of members who have had a singleness of purpose and the right group dynamics to be able to work together for more than a quarter of a century toward a common goal, viz., to improve the quality of controlled-environment research. The committee's younger members exhibit these same qualities and we hope that there will be future generations of scientists who are as willing and enthusiastic to investigate and resolve other issues facing plant scientists.

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