The Society for engineering in agricultural, food, and biological systems

An ASAE Meeting Presentation

Paper Number: 054137

QUALITY ASSURANCE FOR ENVIRONMENT OF PLANT GROWTH FACILITIES

J. C. Sager, Senior Biological Engineer and Bioregenerative Research Manager
NASA, Mail Code YA-E4-B, Kennedy Space Center, FL 32899

J. H. Norikane, Assistant Professor
University of Kentucky, Biosystems and Ag. Eng. Dept., 128 C.E. Barnhart Building, Lexington, KY 40546-0276

A. J. Both, Assistant Extension Specialist
Bioresource Engineering, Department of Plant Science, Rutgers the State University of New Jersey, 20 Ag Extension Way, New Brunswick, NJ 08901-8500

T. W. Tibbitts, Emeritus Professor
Horticulture Department, 1875 Linden Dr., University of Wisconsin, Madison, WI 53706

Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005

Abstract. *Quality assurance (QA) processes are necessary to ensure that the environment of controlled environment facilities is known, is accurately measured, and the resulting data is valid. These QA procedures for plant growth facilities are based on the published ASAE Engineering Practice ANSI/ASAE EP411.4, "Guidelines for measuring and reporting environmental parameters for plant experiments in growth chambers". The ISO9001:2000 Quality Assurance System procedures apply to the environmental parameters contained in EP 411.4, the calibration of the sensors and instruments, the characteristics of the acquisition and control systems, and the records necessary to validate the resulting data. Specific quality assurance procedures for parameters of the aerial environment of plant growth facilities are provided. Further development of procedures and guidelines to standardize and* *assure the quality of the environmental measurement of plant growth facilities is required. The comments or suggested revisions of the procedures proposed are solicited from the community of engineers and scientists involved in design, operation and use of plant growth facilities.*

Keywords. controlled environment, International Standards Organization, plant growth, quality assurance, standards

Introduction

The principal factor representing the performance of an organization is the quality of its products and services. The goal of a quality assurance (QA) program is the delivery of safe, reliable products and services that meet or exceed the customer's requirements, needs, and expectations (United States Department of Energy, 1999). In plant growth facilities (e.g., greenhouses, growth chambers, germination rooms) these products and services include the design, operation, and use of these facilities with respect to the enclosure; elements of the aerial and root environment; the control and data acquisition system; and validation of the resulting data. Plant growth facilities are being utilized to an increasing extent for research and for food production in controlled environment agriculture (CEA). The expectations of the scientific and production communities using plant growth facilities include increased quality control, maintainability and reliability, and data validation. These expectations, coupled with the recently increased focused on bio-security (as it relates to genetic research and the threat of bio-terrrorism) and tracking of commodities from the production site to the consumer, have expanded the requirements for a rigorous quality assurance program in plant growth facilities. In the context of this paper, we will specifically focus on quality assurance for plant production facilities in growth chambers.

Safety Emphasis

The current societal emphasis on the security of our food supply, as well as control and validation of the data leading to application of research and development of that supply stemming from plant growth facilities, requires the application of quality assurance procedures to maintain the public trust. Closely linked to these procedures are the economics of plant experiments and production of plants in growth facilities, requiring that the procedures used for collecting environmental measurements and validating the data be established to maintain the quality of the biological materials, as well as the quality of the informational products.

Chronology

A paper with the same title was previously presented at the ASAE 1987 Summer Meeting in Baltimore, MD (Tibbitts and Sager, 1987). The processes and procedures inherent in a QA program were not generally applied to plant growth facilities at that time, and only marginal progress in adopting a quality assurance has been made since then. Processes and procedures have been applied in engineering design and development for centuries. It has only been during the past century that research and development activities have been utilizing quality control procedures, with the most important applications for safety applied to the manufacturing, nuclear and aerospace industries. The International Organization for Standardization (ISO) was established in 1947 and currently is an association of approximately 149 national standards bodies, each representing their own country. The American National Standards Institute (ANSI) is the ISO representative body for the United States. The American Society of Agricultural Engineers (ASAE) is an organizational member of ANSI and has aligned the Power and Machinery standards (PM-23 US TAG ISO/TC23) with ANSI and ISO standards. Other ASAE divisions and areas are not currently aligned with ANSI/ISO, but many ASAE standards and engineering practices carry ANSI designations, e.g., ANSI/ASAE EP411.4, "Guidelines for measuring and reporting environmental parameters for plant experiments in growth chambers" (ASAE Standards, 2002). These guidelines were further developed by the Structures and Environment Committee (SE303) of the ASAE and have been revised several times and published by the ASAE as ANSI/ASAE EP411.4 (e.g., ASAE Standards, 2002). A draft of quality assurance procedures for accuracy in environmental monitoring was developed in parallel with these measuring and reporting guidelines (NCR-101, 1984).

Quality Assurance Standards

The ISO quality assurance standards are contained in ISO 9000:2000. The ISO 9000:2000 standards provide organizations with an opportunity to increase value to their activities and to continually improve their performance, by focusing on their major processes. There are approximately 25 documents in the ISO 9000:2000 standards collection altogether, with new or revised documents being developed on an ongoing basis. These ISO 9000:2000 standards place great emphasis on bringing quality management systems closer to the processes of organizations, and on continual improvement. As a result, they direct users to the achievement of business results, including the satisfaction of customers and other interested parties. In discussing the applicability of ISO 9000:2000 as an effective management tool for providing discipline to the business, Dill et al. (2003) highlighted the importance of remembering that the ISO standard does not determine how to perform the task. Evaluation of existing problems for correction and root cause analysis using the ISO approach may also serve to identify and address potential problems. If implemented, ISO requirements should be integrated with the existing processes developed for plant growth facilities. The structured internal audit program of ISO provides discipline to assure effective process monitoring. The goal is process improvement, through continuous review, that contributes to improved quality of the design, operation, and use of these facilities, thus resulting in a focusing of the business or organization on the requirements of the customer.

The ISO9001:2000 Quality Assurance System procedures apply to the environmental parameters contained in ANSI/ASAE EP 411.4, the calibration of the sensors and instruments, the characteristics of the data acquisition and control systems, and the records necessary to validate the resulting data. ISO 9001:2000 can be divided into the following categories: planning a business, controlling a process, and maintaining a production system. The ISO 9001:2000 Management Model for each of these categories is presented in Figure 1. The ISO 9001:2000 model functions are management responsibility, resource management, production/service delivery, and management analysis and improvement. These functions can also be applied to plant growth facilities. Each one is critical in the quality of the measurements characterizing the environments inside the facility. The procedure should cover the environmental sensors and acquisition system and should include a procedure to apply the ISO 9001:2000 quality assurance process to outline procedures, to carry out the procedures, and to document what was done.

In the context of applying the ISO 9000:2000 Model to the environment of plant growth facilities, the categories can be defined as a project plan, the operation of the facility to provide a specified environment, and the procedures required to maintain the facility. The project or experimental plan, describes the research including individual experiments. The plan includes a project description and summary, identification of principal and other investigators, and the proposed time schedule. In addition the plan includes a summary of resources required, e.g., chamber and laboratory characteristics and space, the desired environmental conditions for the experiments, data required and type of data report required, and hazard analysis and safety documentation required by the local administration (Starr, 2004). The Environmental Protection Agency (EPA) has developed an extremely detailed project plan development guide in

Guidance for Quality Assurance Project Plans, EPA QA/G-5 (United States Environmental Protection Agency. 2002). The guidance contained in EPA QA/G-5 emphasizes the implementation of data collection and documenting the sampling procedures. The procedures in EPA QA/G-5 follow the ISO 9001:2000 processes and define two distinct levels; data quality objectives and criteria for data measurement. The Data Quality Objectives (DQO) specify the systematic planning process used to design the study. The criteria for data measurement performance and acceptance criteria are established as part of the study design.

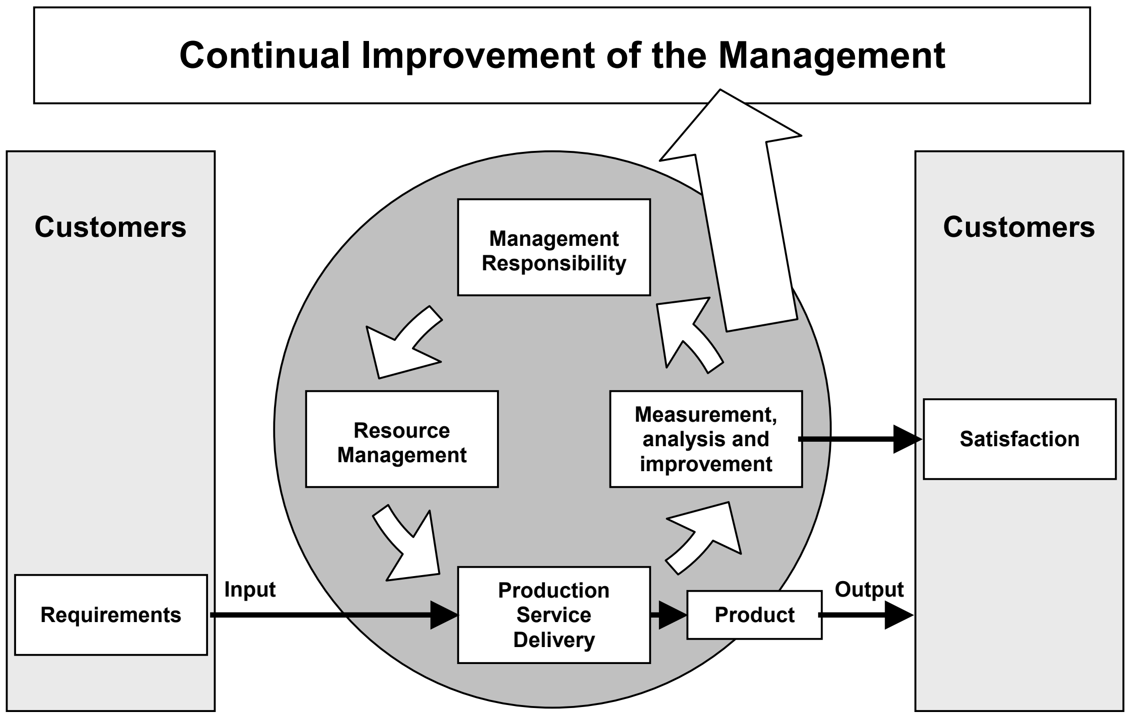

Figure 1. The ISO 9001:2000 Model (Dill et al., 2003)

Application of Quality Assurance Standards

The operation of the facility and the procedures to maintain the facility are separate components of the ISO Model, but both must address the critical chamber sub-systems -- structure, sensing of the aerial and root environment, and data acquisition. The structure includes the fixed structural components; e.g., walls, doors, ceiling, and floor; the operating components; e.g., fans, heat exchangers, refrigeration compressors, valves, lighting systems, and pumps; and experiment or production components, e.g., benches, tables, walk-ways, and containers. The sensing component includes sensors for the parameters as listed in ANSI/ASAE EP 411.4 and, in addition, parameters of importance for that specific experiment or operation. These parameters for the aerial environment include radiation, temperature, carbon dioxide concentration, atmospheric moisture, air movement, and selected others. In addition to the sensors, the sensing component includes the interface or transducer for each sensor and the transfer to the data acquisition system and the system controller. In practice the three components are interdependent and it is important to apply the ISO 9000:2000 Model to each component of the system to adequately define the application of these operational components.

An example of facility maintenance protocol was developed by Romer et al. at the McGill University Phytotron (Romer et al., 2000) and includes all three major components for their facility; the fixed structural components, the operating components, and the experimental or production components. Maintenance is usually performed between experiments or periodically during experiments of long duration.

Quality Assurance in Plant Growth Facilities

Quality assurance procedures have been developed for engineers and others involved in the design, construction, and operation of controlled environment facilities. They are intended to indicate both minimum measurements for the operation of facilities, and also realistic maximum calibration needs to assure measurement quality and to keep costs within reasonable limits. These procedures emphasize the importance of measurement quality that is lacking in many controlled environment facilities today, specifically:

1. Using separate sensors for data acquisition and control of environmental conditions.

2. Regular and accurate calibration of environmental sensors.

3. Monitoring of events to ensure reliability during the periods of operation (i.e., the operation of lamps for photoperiod control or valve operations that add CO_2 to maintain a set concentration).

These quality assurance procedures are focused on the sensors for control, acquisition, and calibration. It is recommended that separate systems be utilized for control and acquisition of each of the environmental parameters. If control and acquisition are undertaken with the same system, a separate redundant acquisition system should be maintained to indicate sensor drift or failure of the control and acquisition system. The calibration sensors should not be operated and recorded through the same electronic circuits or acquisition system that operates the control or acquisition system sensors. All calibration records should be retained on a permanent basis to ensure the validity of the measurements.

Data measurement and acquisition are the keystones of these systems. It is here that standardization can result in the greatest benefit to quality assurance in plant growth facilities. The following tables (Tables 1-5) outline the measurement requirements for the aerial parameters commonly measured in plant growth facilities. These parameters include radiation, temperature, atmospheric moisture, carbon dioxide concentration, and air movement. Definitions for terminology used are found following Table 5.

Table 1. Radiation

	Control	Acquisition	Calibration	
			On-Line Reference	Primary Calibrator
Sensor				
Type	Cosine corrected PAR sensor	Cosine corrected PAR sensor	Cosine corrected PAR sensor	Cosine corrected photon meter for λ = 400-700 nm
Accuracy	<±10% of reading	<±10% of reading	<±5% of reading	<±5% of reading
Precision	<±1% of reading	<±1% of reading	<±1% of reading	<±1% of reading
Response Time	<30 sec	<30 sec	<30 sec	<30 sec
Sampling location	Anywhere in room above plant height	Anywhere in room above plant height	Center of room above maximum height of plants	In room under lamps used in experiments
Monitoring frequency	Start and end of photo-period	Middle of each photoperiod	Every two weeks	Every six months
Data to file	Daily reading and off times	Daily reading	Original and corrected reading	Deviation of calibrator from standard
Alarms				
Range	>±10% of set point	>±10% of set point	NA	NA
Time Delay	10 min	10 min	NA	NA
Calibration				
Instrument or standard	On-line reference	On-line reference	Primary calibrator	Instrument traceable to National Bureau of Standards
Location	In growth chamber	In growth chamber	In growth chamber	In growth chamber
Frequency	Every six months	Every six months	Every six months	Every 24 months
Check points	Anywhere in room	Five levels over range attainable	Five levels over range attainable	Five levels over range attainable

NA - Not applicable or not available

Table 2. Temperature

	Control	Acquisition	Calibration	
			On-Line Reference	**Primary Calibrator**
Sensor				
Type	Aspirated and shielded sensor	Aspirated and shielded sensor	Aspirated and shielded sensor	Thermometer traceable to or calibrated by the NIST
Accuracy	<±0.5°C of reading	<±0.5°C of reading	<±0.2°C of reading	<±0.05°C of reading
Precision	<±0.1°C of reading	<±0.1°C of reading	<±0.1°C of reading	<±0.02°C of reading
Response Time	<1 min	<1 min	<30 sec	<1 min
Sampling location	In air	Plant height at center of room	Plant height at center of room	Constant temperature bath
Monitoring frequency	<3 min	≤30 min	Every two weeks	Every six months
Data to file	30 min average	30 min average	Original and corrected reading	Deviation of calibrator from standard
Alarms				
Range	>±5°C of set point	>±5°C of set point	NA	NA
Time Delay	15 min	15 min	NA	NA
Calibration				
Instrument or standard	On-line reference	On-line reference	Primary calibrator	Mercury thermometer, platinum thermistor traceable to NIST
Location	In growth chamber	In growth chamber	In temperature control bath	NIST
Frequency	Every six months	Every six months	Every six months	Annually
Check points	Three temperatures over range attainable	Three temperatures over range attainable	10, 20, and 30°C	10, 20, and 30°C

NA - Not applicable or not available

Table 3. Atmospheric Moisture

	Control	Acquisition	Calibration	
			On-Line Reference	Primary Calibrator
Sensor				
Type	Aspirated and shielded sensor	Aspirated and shielded sensor	Psychrometer, dew point or infrared sensor	Constant humidity chamber
Accuracy	<±5% of reading	<±5% of reading	<±2% of reading	<±2% of reading
Precision	<±2% of reading	<±2% of reading	<±2% of reading	<±2% of reading
Response Time	<2 min	<2 min	<2 min	<15 min
Sampling location	In air stream	In air stream	Near plants	Convenient location
Monitoring frequency	<3 min	≤30 min	Every two weeks	Every six months
Data to file	30 min average	30 min average	Original and corrected reading	Deviation of calibrator from standard
Alarms				
Range	>±5% of set point	>±5% of set point	NA	NA
Time Delay	15 min	15 min	NA	NA
Calibration				
Instrument or standard	On-line reference	On-line reference	Primary calibrator	Instrument traceable to NIST
Location	In growth chamber	In growth chamber	Convenient location	NA
Frequency	Every six months	Every six months	Annually	NA
Check points	30, 60 and 90% RH	30, 60, and 90% RH	30, 60, and 90% RH	NA

NA - Not applicable or not available

Table 4. Carbon Dioxide Concentration

	Control	Acquisition	Calibration	
			On-Line Reference	Primary Calibrator
Sensor				
Type	Infrared analyzer	Infrared analyzer	Span concentration of CO_2 in air or N_2	Certified span concentration of CO_2 in air or N_2
Accuracy	<±5% of reading	<±5% of reading	<±2% of reading	<±1% of reading
Precision	<±1% of reading	<±1% of reading	<±1% of reading	<±1% of reading
Response Time	<2 min	<2 min	<2 min	<15 min
Sampling location	In air stream	In air stream	NA	NA
Monitoring frequency	≤30 min	≤30 min	Every two weeks	Every six months
Data to file	30 min average	30 min average	Original and corrected concentration	Original and corrected concentration
Alarms				
Range	>±10% of set point	>±10% of set point	NA	NA
Time Delay	5 min	5 min	NA	NA
Calibration				
Instrument or standard	On-line reference	On-line reference	Primary calibrator	Certified span concentration of CO_2 in air or of N_2
Location	In growth chamber	In growth chamber	Convenient location	Convenient location
Frequency	Every six months	Every six months	Annually	NA
Check points	Three concentrations over measurement range	Three concentrations over measurement range	Three concentrations over measurement range	NA

NA - Not applicable or not available

Table 5. Air Movement

	Control	Acquisition *	Calibration	
			On-Line Reference	Primary Calibrator
Sensor				
Type	NA	NA	Directional hot wire anemometer	Certified air velocity from NIST
Accuracy	NA	NA	<±5% of reading	NA
Precision	NA	NA	<±3% of reading	NA
Response Time	NA	NA	<3 sec	NA
Sampling location	NA	NA	Above plant level	NA
Monitoring frequency	NA	NA	Start and end of experiment	NA
Data to file	NA	NA	Velocity at start and end of experiment	NA
Alarms				
Range	NA	NA	NA	NA
Time Delay	NA	NA	NA	NA
Calibration				
Instrument or standard	NA	NA	Calibrated wind tunnel	Calibrated wind tunnel
Location	NA	NA	Convenient location	Convenient location
Frequency	NA	NA	Annually	NA
Check points	NA	NA	Three velocities spanning the range of velocities in chamber	NA

* - Active monitoring and data acquisition may be required for plant tissue vessels.

NA - Not applicable or not available

DEFINITIONS

Definition of Instrument Categories:

Control - The instruments used for control of a parameter.

Acquisition - The instrument used for recording of the values of a parameter.

On-line Reference - The instrument used to regularly calibrate the control and acquisition sensors.

Primary Calibrator - The instrument or standard with direct traceability to NIST standards that is utilized to calibrate the on-line reference calibrators.

Definition of terms used in the tabular recommendations:

Type - The type of sensor/instrument used for measurement.

Accuracy - The extent to which the readings of a parameter measurement approach the true value of the measured quantity.

Precision - The ability of the instrument to reproduce measurements of the measured quantities.

Response Time - The time required for the instrument to reach 98 percent of the final measurement value.

Sampling Location - The location in the environmental facility where the sensor should be placed for measurement.

Monitoring Frequency - The minimum sampling rate or maximum period between measurement or calibration of the instruments.

Data to File - The baseline data required for documentation of the parameter being measured.

Alarm - A signal to the operator that the environmental parameter has exceeded a value by a given range in a given time.

Range - The limits of a parameter's values that trigger an alarm.

Time Delay - The length of time a parameter can exceed the range before an alarm is triggered.

Calibration - The comparison of instruments to standards for the purposes of establishing the accuracy of the measured parameter by an instrument.

Instrument - The comparison instrument which has traceability to a standard.

Standard - The ultimate measurement source for establishing accuracy of instruments.

Location - The place where the calibration procedure is performed.

Frequency - The frequency of calibration procedure required for that instrument.

Check Points - The actual values for a parameter which should be calibrated for that instrument.

Conclusion

Quality assurance (QA) processes are necessary to ensure that the environment of controlled environment facilities is known and accurately measured, and the resulting data is valid. The security of the food supply, and control and validation of the data leading to application of research and development of that supply in plant growth facilities, requires the application of quality assurance procedures to maintain the public trust. The ISO9001:2000 Quality Assurance System processes apply to the environmental parameters contained in ASAE Engineering Practice ANSI/ASAE EP411.4. These quality assurance procedures for plant growth facilities provide the basis for the calibration of the sensors and instruments of the acquisition and control systems, and the records necessary to validate the resulting data for the parameters characterizing the plant growth environment. Further development of procedures and guidelines to standardize and assure the quality of the environmental measurement of plant growth facilities is required, e.g., the root environment. The Comments or suggested revisions of the procedures proposed are solicited from the community of engineers and scientists involved in design, operation and use of plant growth facilities.

Acknowledgements

The development of procedures and guidelines to standardize and assure the quality of the environment of growth chambers by members of the American Society for Horticultural Sciences (ASHS) Working Group on Growth Chambers and Controlled Environments, the North Central Region Technical Committee (NCR-101) on Growth Chamber Use and the ASAE Environment of Plant Structures Committee (SE303) is gratefully acknowledged. Continued cooperation between these groups and development of these procedures and guidelines is encouraged.

References

ASAE Standards. 2004. ANSI/ASAE EP411.4, Guidelines for measuring and reporting environmental parameters for plant experiments in growth chambers. St. Joseph, Mich.: ASAE.

Dill, D.E., D. L. Newslow, and D. R. Sasseville (ed. Kevin Janni). 2003. Quality Management Standards for Dairy Excellence. Pp. 036-039 in Fifth International Dairy Housing Proceedings of the 29-31 January 2003 Conference (Fort Worth, Texas USA) Publication Date 29 January 2003. ASAE Publication Number 701P0203, St. Joseph, Mich.: ASAE.

NCR-101. 1984. Quality assurance procedures for accuracy in environmental monitoring -draft proposal. Biotronics 13:43-46.

Newslow, D. L. 2001. The ISO 9000 Quality System: Applications in Food and Technology. John Wiley & Sons, Inc. New York, NY.

Romer, M. J., C. Cooney, and F.S. Scopelleti. 2000. Growth chamber maintenance protocols. In: Phytotronics for Agricultural Research. K. Y. Prabhu and P. Chandra (eds.). National Phytotron Facility Indian Agricultural Facility, Indian Agricultural Research Institute, New Delhi, India (206 pp).

Starr, S. O. 2004. LSSC Ground Research Test Plan. Life Science Services Contract (DYN-1), J.F. Kennedy Space Center, FL 32899.

Tibbitts, T.W. and J.C. Sager. 1987. Quality Assurance for Environment of Plant Growth Facilities. ASAE Paper No. 874021. St. Joseph, Mich.: ASAE.
United States Department of Energy. 1999. DOE Quality Management System Guide (DOE G414.1-2). Washington, DC 20585.
United States Environmental Protection Agency. 2002. Guidance for Quality Assurance Project Plans (QA/G-5). (EPA/240/R-02/009). Washington, DC 20460.