REPORTING AND MONITORING FOR USER RECORDS

T. W. Tibbitts, Horticulture Department, University of Wisconsin, Madison, WI 53705

Monitoring and recording of environmental conditions is significant in insuring that individual research studies can be accurately duplicated and/or compared to research studies undertaken by other researchers. Detailed monitoring becomes of particular importance when two studies differ greatly, yet it appears that they were conducted in a similar manner.

This report is directed toward indicating what environmental parameters should be monitored and explaining where and when each should be monitored and what is most significant to report. The emphasis will be on the minimum effort that needs to be expended in order that one can come close to duplicating plant growth in duplicate studies. Additional monitoring would be desirable but there are always time and labor constraints in taking the measurements and in summarizing the data. Also, the constraints by journal reviewers and editors to keep reports brief greatly limit the extent of information that can be provided to other researchers.

A summary of the guidelines as published by the USDA North Central Regional (NCR-101) Committee on Controlled Environment Technology and Use is provided in Table 1 and should be used as reference for this report.

Radiation:

Where: The radiation should be monitored at the top of the containers at the start of any research study and at the top of the plant canopy during a study. Measurements should be taken at several positions across the chamber in a regular pattern or grid that accurately represents all of the area being used for plant growth. It would be desirable to monitor between the plants or within the plant canopy, but no procedures have been identified to standardize these measurements.

When: It should be monitored at the start and finish of each study and every 2 weeks in extended studies. Monitoring should be delayed for at least 30 minutes after any light intensity change because of variations in intensity as lamps warm.

What: The average of the different measurement times with ± the variation over the containers.

Air temperature:

Where: The temperature should be monitored at the top of the containers at the start of any research study and at the top of the plant canopy during a study. Measurements should be taken at several positions across the chamber to determine variations in temperature across the area being used for plant growth. This variation will result principally from variations in the air flow patterns within the chamber.

When: Measurements should be made at least once each light and dark period but it would be better to have continuous measurements with averaging every few seconds or minutes. If records are taken only once each light and dark period, they should be delayed at least one hour after each light and dark change.

What**:** The average of both the light and dark periods should be reported with ± the range of temperatures over the growing area if this deviates more than 0.1 C. It would be desirable to report any high or low temperature deviations that cause damage to the plants, however smaller deviations resulting from power disruptions and people entering the chamber do not need to be reported for they will be represented in the daily average provided continuous measurements are being averaged.

Atmospheric moisture (humidity):

Where: The humidity should be monitored at the top of the plant canopy in one location. The humidity is quite uniform across the chamber with the good air movement present in controlled growth facilities.

When: Measurements should be made at least once each light and dark period. If the chamber does not have proportional cooling, several successive measurements should be taken to obtain a value that represents the average over a heating and cooling cycle. If plant watering produces accumulation of moisture on the floor of the chamber for a brief period, measurements should not be taken while the floor is wet.

What: The average of the light and dark periods should be reported.

Carbon dioxide:

This parameter is often not measured because of the difficulty in maintaining accurate calibrated analyzers continuously for the period of a study. Yet carbon dioxide can be a significant variable among studies conducted at different times or in different locations because of the variations in ambient carbon dioxide resulting from inversions and automobile traffic in the surrounding areas. Also the amount of human activity within and around chambers is a significant factor in variable carbon dioxide levels for plant growth. The fact that most phytotrons and other large facilities can maintain calibrated analyzers for all research studies is a distinct advantage for the conduct of critical research investigations.

Where: The carbon dioxide can be monitored anywhere within the plant enclosure for the location is not important if there is reasonable air movement through the chamber.

When: This should be monitored at least hourly but continuous measurements are desirable.

What: The average carbon dioxide level for the light periods should be reported. The average for the dark period has not been shown to have a significant effect upon growth and should be discarded or reported separately from the light period level.

Air velocity:

This measurement is rarely undertaken or reported. However it does influence the amount of transpiration and hence alters the leaf temperature and water use by the plants. It can be a significant variable between similar research studies conducted in different size or type of chambers.

Where: Air velocity should be monitored at the top of the containers or plants. Measurements should be taken at several positions across the chamber that represents the area being used for plant growth.

When: Air velocity should be monitored at the start of each study. It is difficult to establish any consistent procedure for measurement when plants enlarge and cause uneven air patterns through a chamber.

What: The average air movement ± the maximum and minimum readings over the containers. Because of the variable air currents in chambers, a series of 10 or more successive readings should be taken at each location and averaged for each measurement. The purchase of an instrument that averages a series of successive readings is extremely useful for these measurements..

Watering:

This parameter for pot culture investigations is generally not adequately reported in research publications. There are not good measurement devices to monitor the water added to each container and the variations in plant growth and airflow over the containers make it essentially impossible to insure uniformity in soil moisture among separate plants. As a consequence the North American growth chamber group worked to find an artificial media that would permit watering to excess at frequent intervals in order to minimize plant-to-plant and experiment-to-experiment variability in plant watering.

When: Watering should be at frequent enough intervals to minimize water stress on the plants.

What: The frequency and amount of solution added at each watering should be indicated.

pH:

This parameter also is generally poorly reported. The pH of liquid culture studies is sometimes carefully reported but the pH of solid substrate studies is rarely reported. Although the pH changes dramatically in solid culture media over time there is not good knowledge on how significant this factor is to plant growth over the course of a study. It is difficult to maintain and accurately report the pH in solution cultures unless all containers and troughs are connected together and an automatic controller utilized to continuously adjust the pH.

Where: The ph of solid media studies should be determined from an extract of a small sample of the media using a standardized soil analysis procedure. With solution culture, a pH probe is inserted into the liquid.

When: The monitoring of solid media should be undertaken at the start and end of a study. In solution cultures, it should be taken at least daily and the solution pH adjusted back to the set level.

What: The average pH ± the range over the study.

General comments:

There are several parameters and many aspects of research studies that are not reported for several reasons. Factors as nutrient availability and oxygen levels in the media during the course of a study are too variable to be effectively monitored. Various atmospheric contaminants, as ethylene, ozone, etc are very difficult to monitor and have uncertain effects on each separate experiment. Also lighting, temperature, and air movement within a canopy is too variable to monitor. As a consequence, it is impossible to effectively duplicate growth rates in different laboratories and even in successive research studies in the same laboratory and variable growth results must be expected. As shown by the ASHS Growth Chamber Group (*J. Amer. Soc. Hort. Sci.* 103(5):649-654) [1978], the vegetative growth rates of studies carefully undertaken under the 'same' conditions with the same seed lot and media varies within a ± range of 30 %. Thus it is not surprising that if careful attention is not given to environmental control, differences in growth between two 'similar' studies may be much greater than this.

The parameters emphasized in this discussion are recommended for most research studies. There are additional needs for specific studies that are investigating particular parameters as with nutritional studies, light spectrum investigations, media temperature studies, etc. Reporting and monitoring needs may change in the future as the significance of additional factors are documented to have major controlling effects on plant growth.

Table 1. Summary of Guidelines for Measuring and Reporting Environmental Parameters for Plant Experiments in Growth Chambers

Parameter	Units [a]	Measurements		
		Where to take	**When to take**	**What to report**
Radiation				
Photosynthetic photon flux, (PPF) (400 - 700 nm)	$\mu mol \cdot m^{-2} \cdot s^{-1}$	At top of plant canopy. Obtain maximum and minimum over plant growing area.	Minimum measurement: at start and finish of each study and biweekly if studies extend beyond 14 days.	Average (± range) over containers. Source of radiation and instrument/sensor.
Photon flux (nm waveband)	$\mu mol \cdot m^{-2} \cdot s^{-1}$	At top of plant canopy. Obtain maximum and minimum over plant growing area.	Minimum measurements: at start and finish of each study and biweekly if studies extend beyond 14 days.	Average (± range over containers. Source of radiation and instrument/sensor.
Energy flux (Irradiance)[b], (nm waveband)	$W \cdot m^{-2}$			
Spectral photon flux in ≤2 nm bandwidths	$\mu mol \cdot m^{-2} \cdot s^{1} \cdot nm^{-1}$	At top of plant canopy in center of growing area.	Minimum measurement: at start and end of each study.	Spectral distribution of radiation at start of study. Source of radiation and instrument/sensor.
Spectral energy flux (Spectral irradiance) in ≤2 nm bandwidths.	$W \cdot m^{-2} \cdot nm^{-1}$			
Temperature				
Air	°C	At top of plant canopy. Obtain maximum and minimum over plant growing area.	Minimum measurement: measure once daily during each light and dark period at least 1 h after light change. Desirable: continuous measurement.	Average of once daily readings (or hourly average values) for the light and dark periods of the study with ± range of variation over the growing area.
Soil and liquid	°C	In center of container. Obtain maximum and minimum over plant growing area.	Minimum: measure at the middle of the light and dark periods at the start of the study. Desirable: continuous measurement.	Light and dark period readings at the start of the study.
Atmospheric moisture				
Relative humidity (RH)	% RH	At top of plant canopy in center of growing area.	Minimum: once during each light and dark period at least 1 h after light changes. Desirable: continuous measurement.	Average of daily readings for both light and dark periods.
or				
Dew point temperature	°C			
or				
Vapor deficit, (VPD)	kPa			
or				
Water vapor density	$g \cdot m^{-3}$			
or				
Humidity ratio	$kg \cdot kg\ dry\ air^{-1}$			
Air velocity	$M \cdot s^{-1}$	At top of plant canopy. Obtain maximum and minimum readings over growing area.	At start of studies. Take 10 successive readings at each location and average.	Average reading and range over containers at start of the study.
Carbon dioxide				
Mole fraction	$\mu mol \cdot mol^{-1}$	At top of plant canopy.	Minimum: hourly measurements. Desirable: continuous measurement.	Average and range of concentrations.
or				
Partial pressure	Pa			
or				
Concentration	$mol \cdot m^{-3}$			

Table 1 (continued). Summary of Guidelines for Measuring and Reporting Environmental Parameters for Plant Experiments in Growth Chambers

Parameter	Units [a]	Measurements		
		Where to take	**When to take**	**What to report**
Watering	liter (L)		At times of water additions.	Frequency of watering, source and amount of water added and/or range in soil moisture content between waterings.
Substrate			At beginning of studies.	Type of soil and amendments. Components of soilless substrate. Container dimensions.
Nutrition **Solid media** **Liquid culture**	$mol \cdot m^{-3}$ or $mol \cdot kg^{-1}$ $mol \cdot L^{-1}$		At times of nutrient additions	Nutrients added to soil media. Concentration of nutrients in liquid additions and solution culture. Amount and frequency of solution addition and renewal.
pH	pH units	Extract from media or in solution of liquid culture.	Start and end of studies in solid media. Daily in liquid culture. Before each pH adjustment.	Average and range during studies.
Electrical conductivity	$mS \cdot m^{-1}$ (milliSiemens per meter)[d]	Extract from media or in solution of liquid.	Start and end of studies in solid media. Daily in liquid culture.	Average and range during studies.
Dissolved oxygen	$mg \cdot L^{-1}$	In center of liquid containers	Daily. Desirable: continuous measurements in container with largest plant(s).	Average of daily or hourly readings with ± range of variation over the growing period.

[a] Report in other subdivisions of indicated units if more convenient.

[b] The energy flux (irradiance) is also commonly reported in $J \cdot m^{-2} \cdot s^{-1}$ (equals $W \cdot m^{-2}$).

[c] Referred to as photosynthetically active radiation (*PAR*) for general usage and described as photosynthetic photon flux density (PPFD) by many journals, professional societies and manufacturers of quantum sensors.

[d] $mS \cdot m^{-1} = 10\ \mu mho \cdot cm^{-1}$.