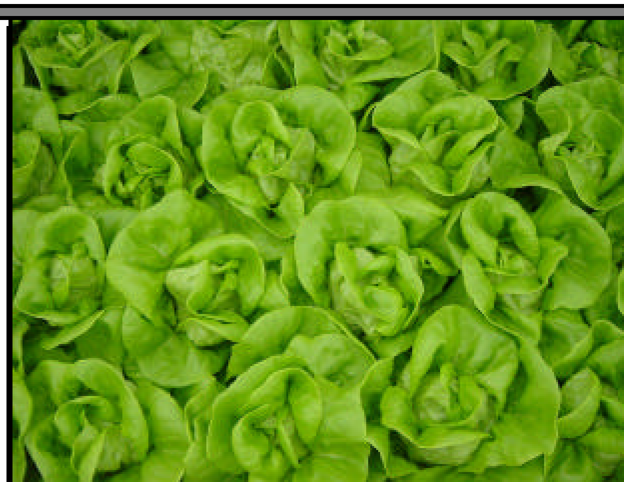
Horticultural Engineering

Volume 18 No. 5, October 2003

Website: http://aesop.rutgers.edu/~horteng

In this Issue:



Hydroponic lettuce ready for harvest.

HYDROPONIC LETTUCE RESEARCH AT CORNELL UNIVERSITY

Introduction

Throughout the year, I receive several questions from people interested in hydroponic crop production. It seems, hydroponic crop production appeals to many people ranging from commercial greenhouse growers to hobby growers. During my previous job at Cornell University, I was fortunate to be part of a research team investigating the hydroponic production of several greenhouse crops. This article describes some of the research findings resulting from lettuce research. For more detail, please visit the following web site: *http://www.cornellcea.com*.

Cornell University's Controlled Environment Agriculture (CEA) Program has been involved in greenhouse hydroponic (butterhead) lettuce production research since 1991. One of the main goals of the research has been to develop a production system for fresh, high-quality, pesticide-free hydroponic lettuce that is produced close to the final retail market. This proximity to final market increases product freshness and reduces the transportation costs involved with shipping produce over large distances. Year-round and rapid production is made possible with accurate greenhouse climate control, including the integration of supplemental lighting, shading, and CO_2 enrichment. Especially during the darker winter months, supplemental lighting is needed to sustain sufficiently rapid plant growth required for profitable production. One of the challenges of the location (Ithaca, NY) was to deal with the significant fluctuation in daily light integrals from day-to-day and from season-to-season. Without consistent daily light integrals, consistent year-round production (i.e., completing every crop cycle in the same amount of time independent of the outside weather conditions) will be difficult to realize.

To integrate and demonstrate the research results, a 96 by 84 ft demonstration greenhouse was built and equipped with the deep flow hydroponic production system. At full capacity, the facility can produce around 945 heads of butterhead lettuce each day, seven days per week. Depending on variety, it takes 34-36 days from seed to produce a target minimum fresh shoot mass (FM) of approximately 5 ounces (150 g). The dry matter (DM) content ranges between 4 and 5% at final harvest. Therefore, 150 g of fresh mass equals approximately 7 g of dry mass.

Description of the Developed Lettuce Production System

During the research trials, butterhead lettuce (*Lactuca sativa*) was germinated in plug trays filled with a peat-vermiculite mixture (1:1, by volume). Trials with different types of media showed that using the peat-vermiculite mixture resulted in better seedling growth and development. However, for commercial lettuce production, the use of rockwool proved more practical. After seeding, the seeds were germinated and grown in an environment controlled growth room for 11 days. The temperature in the growth room was maintained at a constant 75°F with a light intensity of approximately 200 μmol/(m^2s). For two days, the seedlings were covered with a transparent plastic cover to raise the humidity level in the airspace surrounding the germinating seeds. In order to increase seedling production, CO_2 enrichment can be applied during the growth room phase. A visual selection of the seedlings was performed at six days after seeding. At least 80% of the seedlings were normally found to be uniform enough (judged by the size of the first true leaf) to be used for final production.

Eleven days after seeding, the seedlings were manually transplanted into the greenhouse production system, either into a NFT system or deep flow hydroponics. In the NFT system, the plants were grown in shallow troughs and somewhat supported by the trough covers. In the deep flow hydroponics system (approximately 12 inches deep), the plants were grown in holes cut through floating polystyrene boards that provided some support. The advantages of the deep flow hydroponics system included the buffer capacity of the nutrient solution (for water, nutrients, and heat) and the ease with which plant material could be transported. However, the deep flow hydroponic production system required a gas delivery system to maintain an adequate dissolved oxygen concentration in the nutrient solution.

The greenhouse temperature was maintained at 75°F between 8:00 am and 6:00 pm, and at 65°F thereafter. The length of the photoperiod depended on the amount of sunlight received earlier during the day and the daily target light integral required to meet the final harvest date. Supplemental lighting was provided at an intensity of approximately 200 μmol/(m^2s) from high-pressure sodium lamps. CO_2 enrichment was applied by releasing pure CO_2 gas above the plants. CO_2 enrichment was usually halted whenever more than a minimum amount of ventilation was required to maintain the temperature and/or humidity set points, or when no light (either sunlight or supplemental light) was available for photosynthesis.

During the research trials, the initial plant spacing during greenhouse production was approximately 7.4 pl/ft^2 for the first 10 days after transplanting, followed by approximately 3.3 pl/ft^2 for the remaining two weeks. Thirty-five days after seeding, the plants reached a target shoot fresh mass of approximately 5 ounces (150 g) when a daily light integral of 17 mol/(m^2d) was maintained at an ambient CO_2 concentration (350-400 μmol/mol).

The mineral composition of the nutrient solution used closely resembled a so-called half-strength Hoagland solution (approximately 120 ppm N). The pH and electrical conductivity (EC) of the nutrient solution was maintained between 5.6 and 6.0 (pH), and 1.15 and 1.25 mS/cm (EC), respectively. Reversed osmosis (RO) water was used as the water source during the research trials. In the demonstration greenhouse, municipal water was used and an EC of approximately 1.65 mS/cm was maintained.

Highlighted Research Results

1. Crop production

The effects of supplemental lighting and the application of a daily light integral for consistent greenhouse hydroponic lettuce production are shown in Figure 1.

It was shown that a daily light integral of no more than 17 mol/(m^2d) was required to guarantee sufficiently rapid production without causing tipburn damage to lettuce plants.

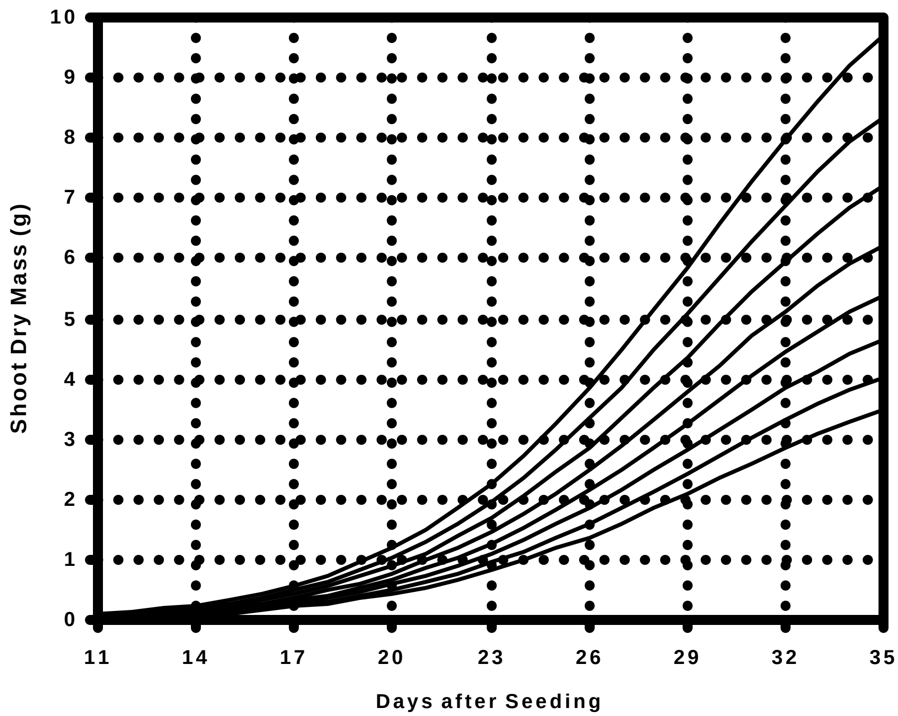


Figure 1. Fitted growth curves for butterhead lettuce (cultivar Ostinata) based on the daily integrated light level maintained during the production cycle (35 days). The curves represent lettuce growth for daily light integrals of 8, 10, 12, 14, 16, 18, 20, and 22 mol/(m^2d) (from bottom to top).

Overhead fans (pointing downwards) were used to improve the greenhouse air movement, which stimulated plant transpiration and delayed the onset of tipburn. Tipburn is a physiological disorder caused by calcium deficiency in the rapidly growing tips of developing lettuce leaves. Increased plant transpiration increased the transport of calcium from the roots to the developing lettuce leaves. Tipburn needs to be avoided since its presence will significantly reduce the salability of the crop. Research showed that lettuce plants need to transpire at least 13.5 ounces (400 mL) of water per gram of dry mass accumulated in order to be free of tipburn.

Lettuce growth analyses revealed a linear relationship between the total accumulated light level (since seeding) and the final shoot dry mass (Figure 2). In addition, good correlations were found between leaf area and shoot fresh mass, as well as between shoot fresh and dry mass (Figure 3).

2. CO_2 Enrichment

The usefulness of carbon dioxide enrichment of the greenhouse air for increased lettuce growth, and the interaction between carbon dioxide enrichment and the use of supplemental lighting was also studied. It was shown that the number of hours of supplemental lighting required to reach the daily target light integral could be reduced by increasing the carbon dioxide concentration in the greenhouse (Figure 4).

Used primarily during the winter months, this technique can result in substantial monetary savings to the lettuce grower. For example, instead of providing 17 mol/(m^2d) at ambient CO_2 concentrations to reach a target shoot dry mass of 7 g (approximately equivalent with a shoot fresh mass of 5 ounces or 150 g), 12 mol/(m^2d) can be provided while maintaining a CO_2 concentration of approximately 1,300 µmol/mol (Figure 4).

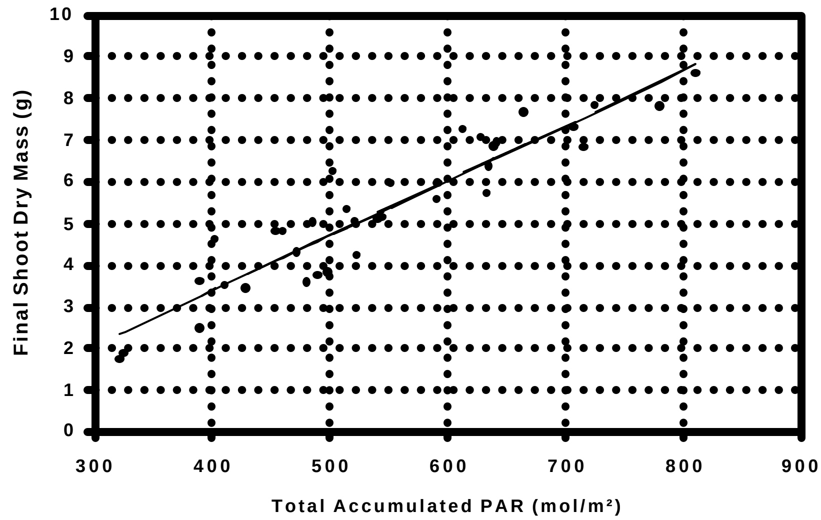


Figure 2. Linear relationship between lettuce (cultivar Ostinata) final shoot dry mass and total accumulated light levels (since seeding).

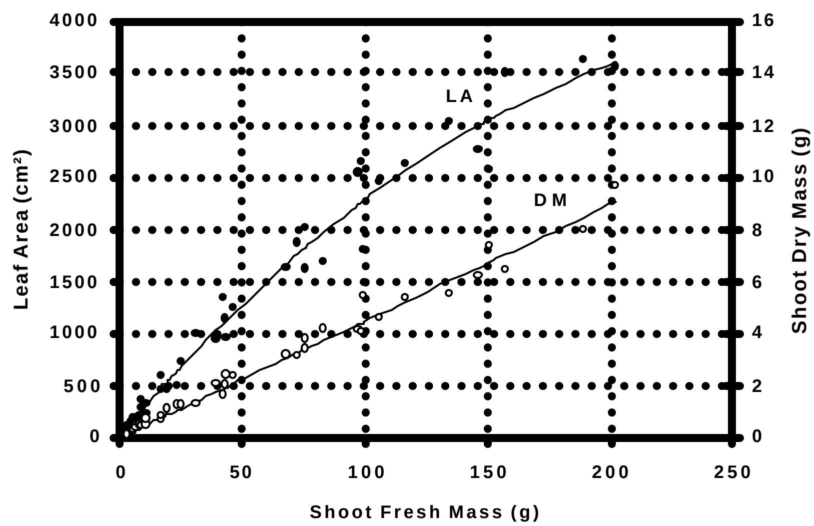


Figure 3. Correlations between lettuce (cultivar Ostinata) leaf area and shoot dry mass, and between shoot dry and fresh mass.

3. Deep Flow Hydroponics

- Dissolved Oxygen (DO) Concentration

A study into the effects of different dissolved oxygen concentrations in the nutrient solution on lettuce growth in deep flow hydroponics showed that a dissolved oxygen concentrations of at least 4 mg/L is recommended for optimum lettuce growth and development. Severe plant stress was observed at DO concentrations below 2 mg/L

- Nutrient Solution Temperature

Research also investigated the shoot and root temperature effects on lettuce growth in deep flow hydroponics. It was found possible to produce a quality lettuce crop even when grown at continuously elevated greenhouse aerial temperatures (above 75°F during the light period) but only if the root zone temperature (nutrient solution) was kept below 68°F. This result showed that successful lettuce production is possible in warmer climates when the temperature of the root zone environment is maintained at appropriate levels.

- Root and Shoot Growth

Figure 5 shows typical root and shoot growth for lettuce plants grown in a floating hydropon-

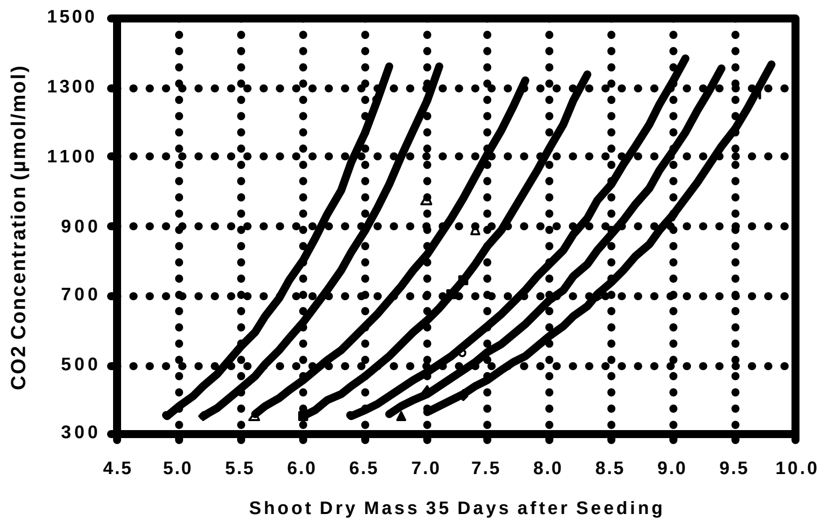


Figure 4. Lettuce (cultivar Vivaldi) shoot dry mass production at 35 days after seeding versus average aerial CO_2 concentration (µmol/mol) during the light period. The curved lines indicate the required daily integrated light level, from 11 through 17 mol/(m^2d) in steps of 1 mol/(m^2d) from left to right.

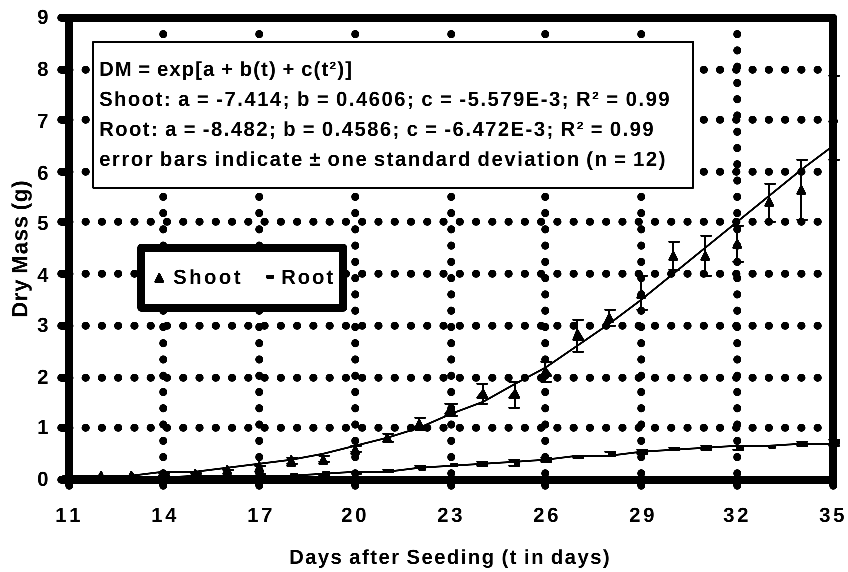


Figure 5. Root and shoot growth of lettuce plants (cultivar Vivaldi) grown in a floating hydroponics system under a daily integrated light level of 16 mol/(m^2d).

ics system under a daily integrated light level of 16 mol/(m^2d).

4. Controlling the Greenhouse Light Environment

A control algorithm was developed capable of providing a fixed daily light integral independent of the amount of outside solar radiation received. The control algorithm directs, in hourly increments, the operation of the lighting and shading system. The algorithm allows for maximum use of solar radiation, while preventing the daily light integral from overshooting its target. In addition, the algorithm operates the supplemental lighting systems as much as possible during off-peak hours in order to reduce electricity costs. A US Patent (Patent No. 5,818,734) was granted for this control algorithm.

Figure 6. Outside view of the 8,064 ft^2 hydroponic lettuce demonstration greenhouse in Ithaca, NY, USA. This facility produces 945 heads of lettuce every day of the year using the floating hydroponics system. The total production cycle is 35 days; 11 days in an environment controlled growth room and 24 days in the greenhouse. At approximately 5 ounces per head (fresh mass), this greenhouse facility has the potential to produce just over 108,000 lb of edible biomass annually (17.2 lb/ft^2 of growing area per year).

Figure 7. Inside view of the hydroponic lettuce demonstration greenhouse. The lettuce plants are supported by floating polystyrene boards in which holes are drilled at the desired plant spacing. In order to increase space utilization, the plants are respaced once (10 days after transplant). Every day, 945 plants are harvested and 945 seedlings are added. Accurate control of the supplemental lighting and shading systems results in a consistent daily light integral of 17 mol/(m^2d).

5. Demonstration Greenhouse

An 8,064 ft^2 glass-clad gutter-connected greenhouse was constructed near Cornell University in Ithaca, NY, USA. Glass was used in the roof and sidewalls for optimum light transmission (Figure 6). The greenhouse is mechanically ventilated and equipped with an evaporative pad cooling system.

A shade curtain can be deployed to reduce solar radiation on the crop. A supplemental lighting system consisting of 600-watt high-pressure sodium lamps is providing a uniform light intensity of approximately 180 µmol/(m^2s) at canopy level. Vertical airflow fans were installed to increase air movement over the crop. A CO_2 enrichment system was installed to enrich the greenhouse air. At full capacity, the facility produces approximately 945 heads of butterhead lettuce each day, seven days per week (Figure 7).

6. Recent Modifications

In addition to butterhead lettuce, romaine (cos) lettuce is successfully being grown in the demonstration greenhouse (Figure 8). Plant spacing has been adjusted, resulting in a final plant spacing of 3.5 plants/ft^2 and a daily production of 1,260 lettuce heads. This modification increases the potential annual biomass production to 22.9 lb/ft^2 of growing area per year.

Figure 8. Romaine lettuce grown in the Cornell University demonstration greenhouse.

Crop Insurance
For more information and eligibility requirements for the 2004 crop insurance program, please contact one or all of the following:

1. Private crop insurance agents
2. Garden State Crop Insurance Education Initiative: *http://salem.rutgers.edu/cropinsurance/index.html* (RCE of Salem County, Kim Linonis: 856-769-0090)
3. USDA Risk Management Agency: *http://www.rma.usda.gov/*

Workshops for the Adjusted Gross Revenue-Lite (AGR-Lite) program are scheduled for:
- November 19, Hunterdon Extension Office
- December 17, Centerton Research Center
- December 18, NJ-EcoComplex.

These workshop are scheduled from 7-9 pm. The deadline for purchasing AGR-Lite policies is January 31, 2004.

Agricultural Management Practices
Representatives from the NJ State Agricultural Development Committee (SADC) have asked Cook College to help develop agricultural management practices (AMPs) for permanent greenhouses. Several members of Rutgers Cooperative Extension that work with the greenhouse industry have been working on a draft document that will be submitted to the SADC for review and comment. Below follows the draft introduction for the AMPs.

Introduction
The production of plants for sale as edible or ornamental crops, is by definition a classical agricultural enterprise. The production of crops in permanent greenhouses in New Jersey adheres to this classical agricultural objective while utilizing protective structures and the most modern crop management technologies.

The production of crops in this manner is a significant agricultural industry comprised of over 300 commercial producers. New Jersey is among the top ten producers of floriculture crops in the United States. Overall a wide variety of ornamental and food crops are produced in a wide array of different greenhouse structures and environments. This diversity of crops and greenhouse environments necessarily leads to a diversity of infrastructural requirements and management practices. This agricultural management practice is an attempt by the authors to compile what are considered generally accepted management practices for this very diverse industry.

The management practice guidelines described herein are intended to pertain to greenhouses that would be considered "permanent" under the guidelines set forth in, N.J.A.C. 5:23-3.14 "Fact Sheet For Temporary Greenhouses". Furthermore, it is our belief that these guidelines are most applicable to greenhouse producers whose annual revenues are in excess of $10,000. This economic threshold is the minimum necessary to be included in the USDA Floriculture Crops Summary, which is published annually in conjunction with the National Agricultural Statistics Service.

These guidelines do not establish any legal requirements but rather are intended to provide a framework for considering any environmental or aesthetic concerns that might be raised with respect to the production of crops in permanent greenhouses. These guidelines are intended to assist producers in maintaining or improving a safe environmentally and aesthetically responsible greenhouse that, is both efficient and economically viable. These guidelines suggest methodologies for sound horticultural practices for production and handling of crops in a greenhouse production system.

These guidelines present suggested methodologies and management practices for insect and disease management, weed management, water and nutrient management, greenhouse structures and environmental management, sanitation, vehicle access, impervious coverage, storm water control, commercial vehicle access, lighting, hours of operation and ingress and egress.

Please feel free to provide feedback or comments to the address listed on the final page of this newsletter.

RUTGERS COOPERATIVE EXTENSION
COOK COLLEGE
RUTGERS, THE STATE UNIVERSITY
NEW BRUNSWICK, NJ 08901

Greenhouse poinsettia production.

HORTICULTURAL ENGINEERING

Dr. A.J. Both
Assistant Extension Specialist
Director of CCEA
Bioresource Engineering
Rutgers, The State University of NJ
George H. Cook College
20 Ag Extension Way
New Brunswick, NJ 08901-8500
Your comments, questions, and suggestions are always welcomed.
Phone (732) 932-9534
email: both@aesop.rutgers.edu
Web: http://aesop.rutgers.edu/~horteng

Horticultural Engineering Web Site

This issue of Horticultural Engineering, like previous ones, is available on the internet at:

http://aesop.rutgers.edu/~horteng

If you provide us with your e-mail address, we will send an e-mail announcing each Horticultural Engineering Newsletter as it is posted on our web site. Thanks to those of you who have elected to receive this newsletter via the Web. We appreciate your help in reducing the duplicating, postage, and handling costs.

Upcoming Meetings, Shows, etc.

HortiFair (NTV)
Amsterdam, the Netherlands
November 5-8, 2003
http://www.hortifair.nl

!! Important Dates !!
January 8 – 9, 2004
Greenhouse Engineering Short Course
at Rutgers University

This 2-day course features timely topics for greenhouse operators and those interested in learning more about greenhouse engineering or perhaps thinking about getting started in the greenhouse business. Registration information is available from the Office of Continuing Professional Education at Cook College, Phone: (732) 932-9271, or on the web: *http://cook.rutgers.edu/~ocpe*

It is not too early to plan to attend this program! Topics include heating, ventilation, supplemental lighting, environment control, insect screening, open-roof greenhouses, simple greenhouses (high-tunnels), planning, crop production, and more.