Evaluation of Bibb (Butterhead) Lettuce for Hydroponic Production in Saskatchewan Greenhouses

Prepared by:
Doug Waterer and Steffen Bertelsen
Department of Plant Sciences
University of Saskatchewan

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Abstract

Lettuce has excellent potential as a greenhouse crop in Saskatchewan. Lettuce is in demand year round and it grows well under low light levels and cool temperatures – making lettuce well suited for production during winter months. Profitable greenhouse production depends on growers using production practices which maximize productivity and quality while minimizing costs. Selection of well-adapted cultivars is a cost effective means of enhancing productivity and quality. This project sought to evaluate cultivars of lettuce suited to hydroponic production. Performance factors evaluated included speed of development, tolerance of biotic (disease and insects) and abiotic stresses (heat, cold, low light and nutrient imbalances), as well as head size, appearance, texture and flavor. A total of 53 cultivars of Bibb type (aka. Butterhead, Buttercrunch) lettuce were demonstrated over 25 production cycles which ran from January 2012 through June 2014. The lettuce plants were grown for 4 weeks in rockwool or Jiffy pots prior to being moved into the NFT-type hydroponic production system. Through progressive production cycles growing methods were modified in an effort to enhance productivity and quality. After testing many fertility regimes – excellent crop growth and quality could be achieved using a simple fertilizer program based on using a readily available complete fertilizer product (7-11-27+micros) supplemented with calcium nitrate and ammonium sulfate. The lettuce crops reached marketable size within 3-4 weeks of transplanting into the hydroponic system. The rate of crop growth varied with the amount of light available to the crop. Supplementing natural light with artificial light (125 umol/m2 for 16 h/day from a HPS system) enhanced crop growth and quality during the winter months. Cultivars that produced looser heads tended to be higher yielding and had fewer problems with tipburn than the semi-head types. Of the loose head types - Red Sails (Johnny’s Seed), Two Star (Stokes) and Simpsons Elite (Stokes) consistently produced large attractive heads with good flavor and minimal tipburn. Optima (Osborne Seeds), Adriana (Johnny’s), Natalia (Paramount) and Santoro (Rijk Zwaan) were the best semi-head types – combining good yields and appearance with only moderate grade out to tipburn.

Project Background

Lettuce has excellent potential as a greenhouse crop in Saskatchewan. Fresh lettuce is in demand year-round and consumers are prepared to pay a price premium for locally grown high-quality product. Unlike other greenhouse crops such as cucumbers and tomato, lettuce grows fairly well under low light levels and cool temperatures - which makes lettuce better suited for production during winter months.

Profitable production of any greenhouse crop depends on the growers using production practices which maximize productivity and quality while minimizing costs. Selection of well-adapted crop cultivars represents one of the most cost effective means of enhancing productivity and quality.

This ADOPT funded project was designed to help the greenhouse growers of Saskatchewan choose cultivars of bibb type (aka buttercrunch) lettuce that are best suited to local production practices, growing conditions and market specifications.
Factors which determine which cultivar is "best" include speed of development, tolerance of biotic (disease and insects) and abiotic stresses (heat, cold, low light conditions), as well as head size, appearance, texture and flavor.

Materials and Methods

Plant Materials
Bibb type lettuce is well suited to greenhouse production in Saskatchewan. It grows rapidly, even in situations of relatively low light and temperatures – which makes it well suited for production during the winter off-season. Bibb lettuce is also more tolerant of high temperatures than Romaine or standard head types of lettuce. Bibb lettuce cultivars specifically suited to warm weather production have been developed – with resistance to tipburn considered as a key characteristic of heat tolerant lettuce lines. Bibb-type lettuce is also regarded as a “premium” or “gourmet” crop and therefore commands a price premium relative to other types of lettuce. Bibb lettuce that is used in the premium “Living Lettuce” type products

This project made an effort to test as many bibb lettuce cultivars as possible, using seed obtained from suppliers across the world. Price or accessibility of the seed were not considered when evaluating the relative merits of each cultivar.

In all of the trials the seedlings were started off in standard plug trays and then moved to the hydroponic production system once they had 4-6 true leaves (ca. 4 weeks after seeding).

Seedling Production
The germination procedures generally followed the recommendation provided by Resh (http://www.howardresh.com/Hydroponic-Lettuce-Production1.html). For Demonstration Trials #1-14 the lettuce was seeded into rockwool cubes (2.5 cm * 2.5 cm * 3.0 cm deep) which had been previously soaked in water adjusted to pH 5.5. Demonstration projects #15 and #16 showed that the seedling had a higher germination % and grew more quickly in Peat Pellets (Jiffy Products Ltd) than in rockwool cubes. As the peat pellets were lower cost and more readily available than the rockwool, peat pellets were used to produce seedlings in all subsequent trials. The seeds were germinated at 23/18 day/night temperature. To ensure that the seeds did not dry out during germination, a moistened piece of paper towel was laid on top of the germinating seeds and the germination tray was covered with a plastic, transparent lid which had perforations to prevent overheating. Some cultivars were supplied as pelleted seed – which did not germinate well under these conditions. Pelleted seed may perform better if placed in an intermittent mist type germination system or a soil medium (G. Sweetman – pers. comm., 2012). Once germination was well underway, the paper towel and tray lids were removed. The seedlings were watered from days 1-7 with pH-adjusted water (pH 5.5). From day 7 onward the seedlings were watered every 2-3 days with 20-20-20 plus micronutrients (Plant Products) at 100 ppm N. The seedlings were thinned to one per cell once they reached the 2 true leaf stage. At 4 weeks after seeding the seedlings were about 10 cm tall and had 6 true leaves – at which point they were considered to be ready for transplanting into the production system (Fig. 1).
Fig. 1. Four week old seedlings of bibb lettuce growing in rockwool cubes. Plants were ready to be moved into the hydroponic production system. Notice the variability in the stand % and plant size amongst the various cultivars being tested.

Hydroponic production systems were used in this project, as hydroponic production;
   a) Represents the most effective use of growing space and nutrients in a greenhouse environment
   b) Is well suited to the production of greenhouse lettuce
   c) Can be used to generate high value “novelty” products such as root-on “Living Lettuce”

NFT Hydroponic System Design
The Nutrient Film Technique (NFT) of hydroponic production was utilized in this project. The design of the NFT system was based on pictures and ideas gathered from various print and online sources, as well as conversation with growers. Using locally available, affordable materials that could be assembled with a minimum of tools, skill or effort were considered priorities when designing the system and selecting the materials used.

Each NFT system consisted of 4 production troughs and a plastic capture tank (212L). The production troughs were sections of rectangular PVC eavestroughing - 3.6 m long, 6.35 cm wide and 6.35 cm deep (Fig. 2). Trough lengths were kept relatively short to minimize nutrient and oxygen gradients along the trough. While short troughs are recommended, trough lengths of 12-15 m are common in industry, and lengths of 40 m have been used successfully. Ideally the troughs would have been white to increase
Fig. 2. NFT Hydroponic System. A thin film of nutrient solution runs over the root system as the nutrient solution flows down the slightly sloped production trough. At the end of the trough the nutrient solution is captured and returned to holding tank where it is aerated prior to being pumped back to the top of the trough.

reflectance and therefore keep the root systems and nutrient solution cool. As only brown trough was available we wrapped each trough in aluminum foil to increase its reflectance. A hole-saw was used to cut circular holes (5cm diam) into the upper surface of each trough. The holes were spaced 20cm from each other. The holes were large enough to allow the lettuce transplants in their plugs to be dropped easily to the bottom of the trough. Unless otherwise specified, the seedlings were placed in the bottom of the trough – with the leaves arranged so that they protruded through the hole cut in the top of the trough. The troughs were spaced 20 cm apart – providing each plant with 20’20 or 400 cm2 of growing space. This spacing allowed each plant enough space to reach its full size, without wasting space. A total of 8 troughs were used, with each trough holding 14 plants for a total of 112 plants per production run. The 8 troughs were divided into two groups of 4 to allow for comparison of different management practices. Each group of 4 troughs operated with its own supply pump and nutrient solution reservoir.

Each production trough was placed on a 2% slope so that the nutrient solution ran down the trough and over the root systems. A 2% slope is considered optimal in most NFT systems operating in temperate regions (Lopez-Pozos et al., 2011). At the end of each trough the nutrient solution was gathered back into the capture tank and then pumped back to the top of the channels using a small (7 watt) aquarium pump. The capture tanks were painted black to minimize algal growth and wrapped in aluminum foil to reduce solar heat gain.

The rate of flow of the nutrient solution through channels in NFT systems is important. Insufficient flow volumes result in the depletion of nutrients and oxygen as the nutrient solution runs down each channel. However, excessive high flow rates waste pumping capacity and are thought to interfere with the uptake of certain nutrients. Nutrient solution was pumped through the production troughs at the rate of 1L/min. This flow rate corresponds to flow rates recommended by some sources (Wilson 1978, Morgan, 1999) but is a far higher rate than is recommended by other sources (van Os 1982). The selected nutrient solution delivery rates were achieved by installing pressure compensated button-type emitters (Rainbird mfg. See Fig.3) in the spaghetti tubes that supplied each grow channel. These emitters proved to be an inexpensive and durable way of achieving the desired flow rate - but they were easily plugged by any plant debris or algae in the nutrient solution. Installing a 100 mesh in-line filter just upstream of the emitters solved this plugging problem.
The nutrient solution in the catchment tank was kept aerated by using an aquarium pump hooked to a standard aquarium air stone. Equipment failure prevented us from monitoring the dissolved oxygen levels in the nutrient solution.

**Nutrient Management**

A number of sources were consulted regarding nutrient recommendations for hydroponic lettuce. There was relatively little variation amongst the sources as to the nutrient concentrations recommended. We opted to use the recommendation developed by Dr. Howard Resh as provided in the on-line program - “Hydrobuddy” http://scienceinhydroponics.com/2011/01/the-first-free-hydroponic-nutrient-calculator-program-o.html The Hydrobuddy System takes the grower through a series of steps that help develop a suitable nutrient regime for their hydroponic crop.

Step 1. The grower selects the crop and the desired nutrient regime from the dropdown menu. Hydrobuddy provides three potential nutrient regimes for lettuce.

Step 2. The grower enters the volume of nutrient solution they wish to mix.

Step 3. The grower indicates which fertilizer sources they intend to use. Fertilizer sources can be selected from a drop down menu or can be custom-added. Fertilizers can be single nutrient or nutrient blends – including quite complex blends containing assorted micronutrients. The grower can provide information as to the cost of each fertilizer source selected.

Step 4. Grower provides information on the chemistry of the water source. Quality information for the water source used in this study was obtained from the City of Saskatoon website; https://www.saskatoon.ca/services-residents/power-water/water-wastewater/drinking-water/water-quality-characteristics-2015

Step 5. Hydrobuddy then calculates the amount of the various nutrient sources selected that will provide a nutrient solution that most closely matches the specifications laid out in the selected regime. Hydrobuddy indicates the amount (grams) of each nutrient source required to produce the recommended nutrient concentration in a tank of the volume previously specified by the grower user. Hydrobuddy also indicates the deviation (%) between the nutrient concentrations achieved using the selected nutrient sources relative to the “ideal” regime. Hydrobuddy flags any nutrient where the % deviation from optimal exceeds the % error threshold. The stringency of this “error” threshold can be controlled by the user.

Step 6. Cost calculations. Hydrobuddy calculates the cost of preparing the nutrient solution based on the amount of each nutrient required and the cost/unit information provided by the grower.

The nutrient levels for hydroponic lettuce recommended by Resh are presented in Table 1. As the objective of the project was to develop a simple production system, wherever possible, readily available, low cost commercial fertilizer sources were used as the nutrient sources. While pre-mixed hydroponic solutions are available, they are more costly and do not provide the grower with any flexibility beyond the total concentration of nutrient solution supplied.
An example of the actual nutrient levels that could be achieved when Hydrobuddy is presented with an array of commonly available fertilizers is presented in Table 1. For most nutrients the concentrations achieved using an array of common fertilizer sources very closely matched Resh’s recommendations.

Table 1: Recommended and actual fertility regime for hydroponic lettuce based on Hydrobuddy calculations.

<table>
<thead>
<tr>
<th>Element</th>
<th>Target (ppm)</th>
<th>Actual (ppm)</th>
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<tbody>
<tr>
<td>NO3</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>NH4</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>P</td>
<td>50</td>
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<tr>
<td>K</td>
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<td>210</td>
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<td>Mg</td>
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<td>Ca</td>
<td>190</td>
<td>189</td>
</tr>
<tr>
<td>S</td>
<td>75</td>
<td>45</td>
</tr>
<tr>
<td>Fe</td>
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<td>3.9</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Mn</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Cu</td>
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<td>0.3</td>
</tr>
<tr>
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<tr>
<td>Si</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cl</td>
<td>-</td>
<td>137</td>
</tr>
</tbody>
</table>

Nutrient Sources used;

- Magnesium sulfate – 0.55 g/L
- Calcium nitrate – 0.41 g/L
- Potassium chloride – 0.35 g/L
- Calcium sulphate – 0.34 g/L
- 10-52-10 – 0.38 g/L
- 17-5-17 – 0.58 g/L
- Potassium sulphate – 0.30 g/L
- Chelated micronutrients – 0.09 g/L
- **Manganese sulphate – 0.9 mg/L**

Yellow highlights indicate that the concentration of Zn and Cu supplied by this recipe exceeded the recommendation provided by HydroBuddy.

Manganese sulphate was the only specialized nutrient required in this regime, as the chelated micronutrient fertilizer source was not providing an adequate supply of Mn.

For Zn and Cu the amount of these nutrients provided by the “best fit” nutrient regime created by Hydrobuddy exceeded the concentration of these nutrients recommended by Resh. However the resulting concentrations of these nutrients were well below the levels regarded as phytotoxic.

All nutrient solutions were prepared in advance of the plants being introduced into the hydroponic solution. To avoid problems with solubility, nutrients containing Ca were mixed separate from the nutrients containing either S or P. The pH, EC, NO3 and K concentrations in the resulting nutrient solutions were checked to confirm that they corresponded with the levels predicted by Hydrobuddy.

**Environmental Conditions**

The hydroponic system was set up in the University of Saskatchewan Agriculture Greenhouse (E wing). This is a 15 year old glass house constructed of large (3m*2m) panels of tempered glass – resulting in excellent light levels. Heating is provided by finned pipes containing polyethylene glycol and cooling is provided by roof vents and evaporative swamp coolers. Each greenhouse bench (90 sq.ft.) is equipped with two 1000 Watt metal halide lights located 2 m above the bench. These lights provided an additional 125 umol/m²/s of illumination for 16 hours a day. The greenhouse temperature regime was set at 22C day/18C night for all
production cycles. This regime is near optimal for lettuce but it may be impractical for growers to maintain their greenhouses at these relatively warm temperatures during the winter.

**Cultivars**

Fifty four cultivars of bibb lettuce obtained from various seed suppliers were evaluated over the 24 month period covered by this project. Each cultivar was tested at least twice to confirm its performance. Wherever possible the cultivars were tested under both summer and winter conditions.

**Specific Changes in Production Practices and Growing Conditions**

In order to improve productivity and crop quality, minor modifications in the production practices or growing conditions were made over the course of the 21 times that lettuce crops were grown in this project. In all cases, plants of the various cultivars being demonstrated were randomized across these treatments in order to avoid any bias to the performance data.

**Demonstration #1 (February 2012).** In an attempt to address issues with tipburn and oedema, one system (4 troughs) were grow using the standard recommended concentrations of nitrogen (165 ppm) and sulfur (113 ppm) while the other had a lower concentrations of nitrogen (82.5 ppm) and sulfur (65 ppm). Low nutrient concentrations should slow crop development and therefore potentially reduce the incidence of tipburn”.

**Demonstration #2 (April 2012).** Operated with standard versus low N and S levels as in trial #1.

**Demonstration #3 (May 2012).** One system of 4 troughs was operated at the standard flowrate (1 liter per minute) and the other system was operated at a lower flowrate (0.2 liters per minute). This modification was made to assess the importance of flow rate as a determinant of growth rates and quality in NFT systems.

**Demonstration #4 (June 2012).** As part of another experiment a small floating culture system had been developed. We had observed that while the growth of the floating culture crop was slower than in NFT system, the quality of the crop was higher in the floating culture. We hypothesized that the reason for the superior growth of the plants in the floating culture system might be related to their roots being more fully immersed in the nutrient solution. We therefore retrofitted one of the NFT systems with a small dam on the exit side to create a 3 cm deep reservoir of water in the troughs. This allowed more volume of water for the roots to grow as well as giving some extra safety in the case of an electrical or mechanical failure. This system was subsequently referred to as the “Deep nutrient film technique” or DNFT. The concentrations of N started at 100 ppm, and Ca started at 190 ppm.

**Demonstration #5 (July 2012).** Compared the standard and Deep NFT systems.

**Demonstration #6 (Aug 2012).** Compared the standard and Deep NFT systems.

**Demonstration #7 (Sept 2012).** It was determined that the calcium sulphate fertilizer being used in the nutrient solution was not fully dissolving – leading to an under supply of Ca in the system. To rectify this problem a more soluble Ca source (CaCl2) was obtained and added at
the rate of 0.84 g/L. This substitution also reduced the S level which had previously exceeded
the recommended concentration.

Demonstration #8 (Oct 2012). As light levels in the greenhouse began to decline in October,
we began to re-test the “best” cultivars from previous trials under these low light conditions. No
supplemental lighting was used in this trial.

Demonstration #9 (November 2012). Repetition of Demonstration #8.

Demonstration #10 (January 2013). Repetition of Demonstrations #8 but with supplemental
light.

Demonstration #11 (Feb 2013). Repetition of Demonstration #8 but with supplemental light.

Demonstration #12 (April 2013). Performance of plantings in the two hydroponic systems was
compare to plants grown in 10 cm diam pots filled with soilless media (Sunshine Mix #4). Plants
in pots were fertigated daily with 20-20-20 + micros diluted to supply 200 ppm N.

Demonstration #13 (May 2013). Repetition of Demonstration #11.

Demonstration #14 (June 2013). Crop growth using a fertilizer formulation based on Resh
was compared to growing the plants using a readily available “complete” fertilizer (20-20-20 +
micros) diluted to supply 400 ppm N. No supplemental lighting was used in this trial.

Demonstration #15 (Sept 2013). Performance of plants grown on the standard rockwool plugs
was compared to plants grown using Jiffy 7’s. Standard Resh fertilizer formulation was
compared to 20-20-20 + micros at 400 ppm N. No supplemental lighting was used in this trial.

Demonstration #16 (October 2013). – Crop growth using a fertilizer formulation based on
Resh was compared to growing the plants using standard 20-20-20 + micros diluted to supply
400 ppm N. No supplemental lighting was used in this trial.

Demonstration #17 (November 2013). – Crop growth using a fertilizer formulation based on
Resh was compared to growing the plants using standard 20-20-20 + micros diluted to supply
400 ppm N. Supplemental lighting was used in this trial.

Demonstration #18 (December 2013). – Crop growth was compared using 20-20-20 + micros
diluted to provide either 200 or 400 ppm-N. Supplemental lighting was used in this trial.

Demonstration #19 (January 2014). – Crop growth was compared using 20-20-20 + micros
diluted to provide either 200 or 400 ppm-N. Supplemental lighting was used in this trial.

Demonstration #20 (February 2014). – Crop growth was compared when one system had the
nutrient solution heated to 25C using an immersion heater. The other system was left to follow
ghse temps. Nutrients were supplied as 20-20-20 + micros at 400 ppm-N. Supplemental
lighting was used in this trial.

Demonstration #21 (March 2014). – One NFT system had an oxygen generating compound
added to the nutrient solution. Nutrients were provided as 20-20-20 + micros at 400 ppm-N.
Supplemental lighting was used in this trial.
Demonstration #22 (April 2014). – One NFT system had an oxygen generating compound added to the nutrient solution. Nutrients were provided as 7-14-27 + micros at 200 ppm-N. Supplemental lighting was used in this trial.

Demonstration #23 (April 2014). – One NFT system had 200 ppm N as 7-11-27 and the other had 400 ppm N as 7-11-27. No supplemental lighting was used in this trial.

Demonstration #24 (May 2014). – One NFT system had 200 N ppm as 50% Ca(NO₃)₂ and 50% 7-11-27 and the other had 200 ppm N as 50% Ca(NO₃)₂ and 50% 20-20-20 + micros. No supplemental lighting was used in this trial.

Demonstration #25 (June 2014). – One NFT system had 200 N ppm as 50% Ca(NO₃)₂ and 50% 7-11-27 and the other had 200 ppm N as 50% Ca(NO₃)₂ and 50% 20-20-20 + micros. No supplemental lighting was used in this trial.

Production Information Collected

The trials were harvested when the fastest growing cultivar in the trial had reached full marketable size without experiencing any growth check due to overcrowding (Fig. 4). At harvest, each head was weighed and plant quality evaluated based on;

a) Overall appearance
b) Incidence and severity of tipburn
c) Flavor and texture

Fig. 4. Harvesting marketable sized bibb lettuce after 4 weeks in the NFT system.

Statistical Design and Analysis
Plants were arranged in a randomized complete block design in the deep and standard NFT systems – with each trough representing a block. Statistical analysis involved calculating the mean and variance (standard errors) for the different yield parameters measured for each cultivar in each trial. As each cultivar was evaluated in two or more – the overall mean for the performance of each cultivar was then calculated.

One or two of the best performing cultivars (Optima, Harmony or Red Sails) were included in each trial to serve as an internal “check” of growing conditions.

Results and Discussion

Greenhouse conditions

The photosynthetically active radiation (PAR) levels over the course of the year provided by sunlight and the metal halide supplemental lights are presented in Fig. 5.

Fig. 5. Light levels in the test greenhouse from January to December of 2012, with and without supplemental lighting.

The total PAR levels provided by sunlight in June and July were 4-5 times greater than the levels in November. In winter, using the supplemental lights more than doubled the total amount of light received by the crop. In summer using supplemental lighting would have only added about 25% to the total daily light input.

Plant Health
No problems with disease were observed in any of the trials – except if the aeration pumps in the nutrient holding tanks. When that occurred the root systems became oxygen deficient – this led to the leaves beginning to wilt. If the problem with oxygen deficiency persisted, the tips of the roots began to die – and this opened the plants to a range of root diseases.

Thrips were abundant in the greenhouse throughout the trial period. They appeared to prefer crops other than the lettuce – but from time to time thrip populations increased to the point where some damage to the foliage was observed. Some cultivars appeared to be attractive to thrips than others.

Tip burn which is caused by a deficiency of calcium is a common problem in both field and greenhouse grown lettuce (Fig. 6). Tipburn was the most common cause of grade out in this project. Tip burn was usually first observed approximately two weeks after transplanting (two weeks prior to harvest). The timing of onset of tipburn usually coincided with the period of most rapid growth of the lettuce crop – this makes sense as Ca demand peaks during periods of rapid growth. Some cultivars were more severely affected by the tipburn than others – with the cultivars that formed a tight head were also more prone to tipburn than cultivars that had a more open head architecture. This also makes sense as movement of Ca via transpiration flow would be restricted in leaves that were largely shaded by others – as occurs in cultivars with a tight head type.

Attempts were made to address the tipburn problem by; a) increasing levels of Ca in the nutrient solution, b) by slowing the rate of crop growth by reducing levels of other key nutrients or by changing other aspects of the growing conditions or by altering the light levels. Insuring that the Ca fertilizer source fully dissolved and then stayed dissolved helped reduce the problems with severe Ca deficiency observed in Trials 1-6 (see Demonstration #7). Subsequent trials involving further increasing the quantities of Ca in the nutrient solution did not fully resolve problems with tipburn. Factors that slowed crop growth such as operating at low temperatures and reduced light levels did reduce the incidence of tipburn – but the slower growth reduced production efficiency. Selection of cultivars that combined rapid growth with minimal problems with tipburn was the most efficient and effective solution to the problem.

Fig. 6. Tip burn on the margin of the inner leaves of lettuce

Crop Performance in Specific Trials

Demonstration #1 (February 2012). Impact of Nutrient (N and S) Concentrations.
There were no obvious differences in plant health or appearance between a NFT system operated with the standard concentrations of N (165 ppm) and S (113 ppm) versus with ½ the recommended concentration of these nutrients. Tip burn was severe in all cultivars in both systems – suggesting that:
   a) The concentration of N and S were not limiting crop growth.
   b) Given a) above, another method of managing the tipburn issues had to be determined.

Demonstration #2 (April 2012). Repeat of standard and low nutrient concentrations.
Some cultivars showed poor vigor in both nutrient regimes. The onset and severity of tipburn were not influenced by the nutrient regime.

Demonstration #3 (May 2012). Flow rate trial
With the arrival of clear spring weather light levels increased dramatically in this trial relative to the previous trials. This led to more rapid growth and bigger heads at harvest. Tipburn was again problematic. The high flow rate system (1 L/min) had slightly better yields and quality than the low rate system (0.2 L/min)

Demonstration #4 (June 2012). Standard versus “Deep” NFT
Plants grew well in the “Deep” NFT system and appeared to have less tipburn.

Demonstration #5 (July 2012). Standard versus “Deep” NFT
Plants again grew slightly better in the “Deep” NFT – and the largest plants were consistently harvested from the deepest end of each trough.

Same crop performance observations as in Demonstration #5.

Demonstration #7 (Sept 2012) – Standard versus “Deep” NFT
Excellent head quality was seen in both systems – likely in response to providing a more consistently soluble Ca source. Heads harvested from the deep NFT system were significantly larger in all but one of the cultivars.

Demonstration #8 (October 2012). Re-Testing “Best” Cultivars under Low Light Conditions
The combination of short cloudy days plus no supplemental light slowed growth and reduced yields in this trial. There were no consistent differences in performance between the standard and Deep NFT systems.

Demonstration #9 (November 2012). Re-Testing “Best” Cultivars under Low Light Conditions
A further reduction in light levels as a function of the shorter days resulted a slow growing crop with pale, spindly, lank and weak plants harvested in both the standard and Deep NFT systems.
Demonstration #10 (January 2013). Re-testing of “Best” Cultivars but with Supplemental Light
Adding back the supplemental light clearly enhanced the growth of all cultivars tested. Differences in growth between the standard and Deep NFT systems were minimal.

Demonstration #11 (February 2013). Re-testing of “Best” Cultivars but with Supplemental Light
Adding back the supplemental light clearly enhanced the growth of all cultivars tested. Growth in the standard regime was better than in the Deep NFT system.

Demonstration #12 (April 2013). Comparison of Crop growth in Pots versus the Hydro systems
The plants grown in the pots were slightly smaller than corresponding cultivars grown in the hydro systems – but they were also more uniform in size and shape.

The standard cultivar Optima produced plants that weighed on average 184 g in this trial. Optima plants were considerably larger than any of the other cultivars included in this trial.

Forlina - produced relatively large heads
Flandoria -
Volare -
Natalia - small but good looking heads
Vincenzo - medium sized heads

Demonstration #13 (May 2013).
No difference in crop performance was observed between the two NFT systems

The standard cultivar Optima produced heads that weighed on average 146 g in this trial. Optima produced the highest yields of the lines tested in this trial.

Vincenzo - very prone to tipburn
Volare - very uniform size
Natalia - steady growth
Forlina - prone to tipburn
Flandoria -

Demonstration #14 (June 2013). Comparison of Crop Performance based on Resh’s Fertility Program versus 20-20-20 + micros.
In the NFT system, growing the plants with 20-20-20 + micros diluted to supply 400 ppm N produced far better growth for all the cultivars tested than was achieved using a modified version of Resh’s recommendations. Additional advantages to basing the fertility program on 20-20-20 were that;
  a) 20-20-20 + micros is more readily available than the specialize chemicals required to follow Resh’s recommendations.
  b) Using the 20-20-20 did not require mixing multiple fertilizers as required in Resh.
c) There were fewer problems with precipitates plugging the filter screens screen when using the 20-20-20 compared to Resh’s formulation.

The standard cultivar **Optima** had an average wt of 130 g and an average tipburn rating of 0.8 in this trial. **Optima** produced the largest heads of any of the cultivars tested in this trial.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
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<tbody>
<tr>
<td>Santoro</td>
<td>- produced good yields but had higher levels of tipburn</td>
</tr>
<tr>
<td>Hungarina</td>
<td>- produced large heads but it was very prone to tipburn</td>
</tr>
<tr>
<td>Natalia</td>
<td>- produce compact good looking heads but it was prone to tipburn</td>
</tr>
<tr>
<td>Cosmopolitan</td>
<td>- produced small sized heads with some tipburn</td>
</tr>
<tr>
<td>Gardia</td>
<td>- produced small sized heads with severe tipburn</td>
</tr>
</tbody>
</table>

**Demonstration #15 (August 2013). Comparison of Jiffy 7 versus rockwool plugs as support media for seedlings**

Using Jiffy 7s to support the seedlings resulted in a small yield advantage compared to rockwool.

The standard cultivar **Optima** had an average wt of 232 g and an average tipburn rating of 2.7 in this trial. The large head size and severity of the tipburn could both be attributed to this trial being conducted for a longer period during which time light levels and temperatures within the greenhouse were high. **Optima** produced the largest heads of any of the cultivars tested in this trial. Flavor of **Optima** was rated as mild in this trial.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherokee</td>
<td>- produced good yields and the heads looked and tasted good - Cherokee had less tipburn than any other cultivar in this trial</td>
</tr>
<tr>
<td>Continuity</td>
<td>- produced very small heads with unacceptable flavor</td>
</tr>
<tr>
<td>Natalia</td>
<td>- produce compact good looking heads but it was prone to tipburn</td>
</tr>
<tr>
<td>Cassandra</td>
<td>- produced good sized heads with some tipburn</td>
</tr>
<tr>
<td>Santoro</td>
<td>- produced good sized heads with moderate tipburn</td>
</tr>
</tbody>
</table>

**Demonstration #16 (September 2013). Standard rockwool plugs vs. Jiffy 7’s. Standard Resh fertilizer formulation vs 20-20-20 + micros at 400 ppm N**

The seedlings grown in the Jiffy 7’s were larger and a deeper shade of green at transplanting than the seedlings grown in the standard rockwool. This performance advantage persisted through until the final harvest – at which time the plants grown in the Jiffy 7’s were on average 3X larger than the plants grown in rockwool. We could find no obvious differences in root zone health to explain this difference. The results of this trial correspond with the finding of Trial # 15. As Jiffys cost about 40% less than rockwool – all subsequent trials were based on growing the transplants in Jiffy pots.

The plants growing in dilute 20-20-20 + micros were clearly slower growing than the plants grown using Resh’s nutrient solution – and at the final harvest the plants grown with Resh’s solution were 3X larger than plants provided with 20-20-20. This ran contrary to previous findings where the 20-20-20 had outperformed the Resh’s. This caused us to check the 20-20-20 nutrient solution. This check showed that an equipment malfunction had caused the system to apply far more 20-20-20 than stipulated (2000 ppm N versus the requested 400 ppm N).
The standard cultivar **Optima** had an average wt of 131 g and an average tipburn rating of 0.2 in the Resh system where “normal” growth occurred. **Optima** and **Cassandra** were about the same size in this trial. The flavor of **Optima** has rated as good to slightly bitter in this trial.

**Cassandra** - produced large very loose pale green heads with little tipburn - its flavor was acceptable  
**Natalia** - was the only cultivar to receive consistent high ratings for flavor in this test  
**Santoro** - produced medium sized heads that were bitter  
**Continuity** - produced small bitter tasting heads with severe tipburn - leaves were green and red  
**Cherokee** - produced small bitter tasting heads - leaves were red/bronze

**Demonstration #17 (October 2013). – Comparison of Resh vs 20-20-20 as the nutrient source**
Average plant weights were 23% higher when Resh’s formulation was used to create the nutrient solution versus 20-20-20 + micros at 400 ppm-N. However, there was much less tipburn in the 20-20-20 system (average rating of 0.1) than in Resh (average rating of 0.8). In previous trials we have seen that tipburn tends to increase whenever trial conditions promote rapid growth.

The standard cultivar **Optima** had an average wt of 153 g and an average tipburn rating of 0.2. **Optima** was far larger than any of the other cultivars included in this trial. The flavor of **Optima** has rated as good in this trial.

**Deer Tongue** - produced the 2nd highest yields, with moderate tipburn - its flavor was bitter but acceptable - it had distinctive elongated leaves  
**Santoro** - had good flavor and little tipburn  
**Rhazes** - produced a “miniature” head - no tipburn  
**Natalia** - had good flavor and no tipburn  
**Prizehead** - produced relatively small heads - it had moderate tipburn and a slightly bitter flavor

**Demonstration #18 (November 2013). – Comparison of Resh vs 20-20-20 as the nutrient source**
Average plant weights were slightly higher when the plants were grown with 20-20-20 + micros at 400 ppm-N versus Resh’s formulation. The severity of tipburn was about the same (0.9) in the two production systems. As was seen in previous trials, the cultivars that grew the fastest (**Optima** and **Natalia**) had the most tipburn.

The standard cultivar **Optima** had an average wt of 184 g and an average tipburn rating of 1.6. **Optima** was far larger than any of the other cultivars included in this trial. The flavor of **Optima** has rated as ok to slightly bitter in this trial.

**Deer Tongue** - produced the 2nd highest yields, with moderate tipburn and a mild flavor - it had distinctive elongated leaves  
**Santoro** - had good flavor and little tipburn  
**Rhazes** - produced a “miniature” head  
**Natalia** - was slightly bitter with moderately severe tipburn
Prizehead - produced relatively small heads that looked and tasted good - it had very little tipburn

Demonstration #19 (December 2013). – Comparison of two concentrations of 20-20-20 + micronutrients as the nutrient source
Average plant weights were comparable when the systems were run with 20-20-20 + micros diluted to provide either 200 or 400 ppm-N. Similarly, there were no differences in the incidence of tipburn between the two fertilizer concentration treatments.

The standard cultivar Optima had an average wt of only 66 g in this trial – which is far smaller than the size of heads produced by this cultivar in other trials. This likely reflects the fact that this trial was harvested early due to scheduling concerns. Optima showed no tipburn in this trial – again indicating that the crop was growing slowly prior to harvest. The flavor of Optima has rated as slightly bitter in this trial.

Adriana - heads were heavier than the standard Optima - some tipburn and bitter flavor
Nancy - heads were heavier than the standard Optima - some tipburn but good flavor
Livigna - very small and slightly bitter
Santoror - small heads with some tipburn - slightly bitter
Natalia - nice looking compact head - some tipburn

Demonstration #20 (January 2014). – Comparison of two concentrations of 20-20-20 + micronutrients as the nutrient source
Average plant weights were better when the system was run with 20-20-20 + micros diluted to provide 200 versus 400 ppm-N. There were no differences in the incidence of tipburn between the two fertilizer concentration treatments.

The standard cultivar Optima had an average wt of 65 g in this trial – which is once again far smaller than the size of heads produced by this cultivar in other trials. This likely reflects the fact that this trial was harvested early. Optima showed no tipburn in this trial.

No flavor data could be collected from this trial due to problems with insect infestation.

Adriana - heads were twice the size of the standard Optima - no tipburn
Nancy - heads were heavier than the standard Optima - only cultivar to show any tipburn in this trial
Livigna - heads about the same size as Optima
Santoror - heads larger than Optima
Prizehead - small heads

Demonstration #21 (February 2014). – Comparison of heated versus ambient temperature nutrient solution in the NFT system
Run was terminated early as disease had begun to show up in both NFT systems. Plants were wilting and growth was slow. Roots looked brown and unhealthy. No corresponding problems occurred in the floating culture. There were no problems with the air stones or flow rates in the NFT systems. Strawberry and basil plants had been introduced into the gaps in the NFT system. These plants died – and they could have been the source of the disease which spread
through the NFT system. The system was thoroughly cleaned out prior to the start of the next run.

Some small/inconsistent positive effects of heating the nutrient solution were observed.

The standard cultivar **Optima** had an average wt of only 50 g in this trial – which is once again far smaller than the size of heads produced by this cultivar in other trials. This likely reflects the fact that this trial was harvested early due to disease problems. **Optima** showed no tipburn in this trial. Its flavor was rated as mild/good.

**Adriana** - heads were slightly larger than Optima - but flavor was rated as slightly bitter  
**Hilde** - very small heads, with some tipburn - heads were chewy, bitter/sweet  
**Starfire** - medium sized heads - good quality/flavor  
**Santoro** - heads slightly smaller than Optima - good flavor and quality  
**Prizehead** - small heads

**Demonstration #22 (March 2014). – Addition of Oxygen Generating Chemical to Nutrient Tank** – the effects of this trmt were;

a) Immediate formation of a brown slightly slimy compound that settled out to the bottom of the tank in the floating culture but remained soluble enough to get into NFT system – clogging the filters and emitters.

b) The oxygen generating compound caused root pruning – but above the pruned zone the roots looked healthy – very white and branched.

c) The oxygen generating compound caused no obvious changes in plant growth.

d) The oxygen generating compound slowed the growth of algal contaminants on the surfaces of the NFT system.

e) By the end of the trial, plants in the NFT and floating systems where the oxygen generating compound was added were 15% larger on average than in the control system. This seemed to be related to plant health – plants in the control system began to look unhealthy by the 2nd week. Roots were dying and the plants were wilting.

The standard cultivar **Optima** had an average wt of 118 g in this trial and looked very good. **Optima** showed no tipburn in this trial and its flavor was rated as mild/good.

**Adriana** - heads were slightly larger (123 g) than Optima – but its flavor was rated as slightly bitter and its texture was dry and chewy - its color was excellent – but the heads are a bit loose  
**Hilde** - very small heads, with excessive tipburn  
**Starfire** - small heads with ruffled dark green leaves - no tipburn - starts sweet but slightly bitter after taste  
**Santoro** – heads slightly similar in appearance and size as Optima - good flavor but some tipburn  
**Prizehead** – small heads - purple/red tips on light green leaves - OK flavor

**Demonstration #23 (April 2014). – Run #2 of Addition of Oxygen Generating Chemical to Nutrient Tank** – the effects of this trmt were;
a) Less formation of a brown slightly slimy compound that settled out to the bottom of the tank in the floating culture – this resulted in less clogging of the filters and emitters relative to the previous run.
b) The oxygen generating compounds caused more severe root pruning than in the previous run – virtually no roots grew out of the Jiffys pellets following transplanting into the NFT system with the added oxygen generating compound.
c) The test compound caused no obvious changes in plant growth habit – except that it clearly slowed plant growth.
d) The oxygen generating compound stopped algae growth through to the end of the project.
e) By the end of the trial, plants in the systems where the test compound was added were 55% smaller on average than in the control system.
f) The standard cultivar Optima had an average wt of 185 g in this trial. The semi-heads looked very good – except for severe tipburn. Flavor of Optima was rated as only fair in this trial.

Adriana - heads were smaller (142 g) than Optima – but its flavor was rated as slightly bitter and its texture was dry and chewy. Its color was excellent – but the heads are a bit loose
New Red Fire - light green ruffled leaves with red tips - small heads - mild taste, nice texture - fairly severe tipburn
Ruby Sky - nice color dark green with red tips - starts sweet but slightly bitter after taste
Focca - nice looking heads but smaller than standards - chewy and slightly bitter
Tiede - small heads - purple/red tips on light green leaves - OK flavor

Demonstration #24 (May 2014). – Ca NO3 + 7-11-27 or 20-20-20 at 200 ppm N.
There were no problems with any of the systems – growth was rapid and healthy. Some tipburn was seen in both production systems.
The two nutrient regimes gave yields that were very similar (avg wt = 109 for 7-11-27 and 103 for 20-20-20). Slightly less tipburn occurred in the 20-20-20 regime.
The standard cultivar Optima had an average wt of 153 g in this trial. Quality and flavor of Optima in this trial were very good – except that some tipburn occurred in both nutrient regimes.

Greenstar - good size with no tipburn in either nutrient regime
Barbados - good size with no tipburn in either nutrient regime
Nevada, Mottistone and Magenta - were all smaller and had some tipburn

Demonstration #25 (June 2014). – CaNO3 + 7-11-27 or 20-20-20 at 200 ppm N.
There were no problems with any of the systems – growth was rapid and healthy. The 7-11-27 nutrient regimes gave yields that were significantly higher than the 20-20-20 (avg wt = 145g for 7-11-27 versus 86g for 20-20-20) - but there were also more problems with tipburn in the 7-11-27 regime.
The standard cultivar Optima had an average wt of 233 g in this trial. The semi-heads looked very good – with good flavor – but there was substantial tipburn – especially in the faster growing 7-11-27 system.
**Greenstar** - good size with no tipburn in either system

**Barbados** - good size in the 7-11-27 system but some tipburn - poorer growth in the 20-20-20

**Nevada, Mottistone and Magenta** - were all smaller and had some tipburn

**System performance**

Throughout the project, observations were made about the performance of the hydroponic system. The NFT system was relatively easy to construct and maintain. The button emitters performed fairly well once in-line filters were installed to protect the emitters from plugging. Each emitter was good for several crops before it became too plugged with root debris, algae or mineral precipitates to continue to perform well. The main in-line filters had to be cleaned weekly otherwise they plugged up.

During the final 2 weeks of each production cycle it was common for the filters to become plugged with algae that began to accumulate on surfaces that were exposed to both light and the nutrient solution. To reduce this algal growth we modified the systems in a number of ways designed to minimize exposure of the nutrient solution to the light that drives growth of algae. Small leaks were a persistent problem in the NFT systems, but in most cases the leaks were small enough that a crop could be grown to maturity (3-4 weeks) without needing to re-fill the 212 L nutrient supply tanks. Very little drift in the pH or electrical conductivity of the nutrient solutions was observed over the course of each production cycle. On several occasions we successfully grew a second crop using the nutrient solution remaining after the first crop had been harvested.

**Fertility Program**

The fertility program used at the start of the testing program was based on addition of a range of products containing one or two mineral nutrients (ie CaSO4). The resulting fertility program involved weighing out and mixing nine or more individual fertilizers. This took considerable time and required significant effort as many of the nutrients were difficult to dissolve. We also noted that during the first 2 weeks of each production cycle the filters became plugged with a mineral deposit – this suggests that some of the fertilizer sources were reacting to form an insoluble mineral precipitate. This is potentially important as the formation of precipitates in the filter (and their subsequent removal from the filter during cleaning) would render these nutrients unavailable to the crop. We also found a small amount of precipitate in the bottom of the nutrient holding tank following each production cycle where the nutrient solution was created using based on Resh’s formulation.

In an effort to find an easier to use fertilizer mix that did not have problems with precipitation of nutrients, this project looked at a number of nutrient sources and mix options. **Ultimately it was determined that a mixture providing 200 ppm N, with 46% of the N coming from calcium nitrate (CaNO3), 46% from 7-11-27 + micros (HydroVeg Plant-Prod) and the remaining 8% of the N coming from ammonium sulfate (NH4SO4) resulted in excellent growth.** To prepare 100 L of nutrient solution, 100g of CaNO3 was dissolved in 50L of water and this was added to another 50L of water containing 75g of 7-11-27 and 7g of NH4SO4. The three fertilizer sources required in this regime were affordable ($0.63 to prepare 100L of nutrient solution), easy to obtain and fully water soluble. The resulting nutrient solution had a relatively low EC of 1.8 dS/m – this level of salinity is easily tolerated by lettuce.
Table 2: Recommended fertility regime for hydroponic lettuce (from Resh) and regime achieved using just three fertilizer sources (NH4SO4, CaNO3, and 7-11-27+micros).

<table>
<thead>
<tr>
<th>Element</th>
<th>Target (ppm)</th>
<th>Actual (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO3</td>
<td>185</td>
<td>171</td>
</tr>
<tr>
<td>NH4</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>P</td>
<td>50</td>
<td>82</td>
</tr>
<tr>
<td>K</td>
<td>210</td>
<td>204</td>
</tr>
<tr>
<td>Mg</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Ca</td>
<td>190</td>
<td>210</td>
</tr>
<tr>
<td>S</td>
<td>75</td>
<td>76</td>
</tr>
<tr>
<td>Fe</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Mn</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Cu</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Mo</td>
<td>0.05</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Labor requirements for each production cycle (150 plants grown for 4 weeks as seedlings and 4 weeks in the NFT system).

1 person hour  Seeding, thinning, maintaining seedlings over 4 weeks
1 person hour  Preparing initial nutrient solutions, checking pumps, setting up troughs, transplanting seedlings into grow system
1 person hour  System maintenance, adding nutrient solutions, scouting over 4 weeks
1 person hour  Harvest, trim and bag
1 person hour  Clean up of troughs and tanks

Total 5 person hours @ $15/hour = $75/150 plants per run = $0.50 labor per plant.

The cost/plant of several of these steps could be reduced through economies of scale and mechanization. For example, all seeding was done by hand – that step could be mechanized. The system maintenance, scouting and clean up steps would also benefit from economies of scale.
Production Costs

Capital costs strictly associated with the hydroponic production systems would include:

- holding tanks (2) @ $50 apiece = $100
- production troughs (8) @ $8 apiece = $64
- pumps (4) @ $16 = $64
- filters and other miscellaneous plumbing supplies = $100

Total - $328.00

Assuming 12 production runs/year and 150 plants/run

- total production = 1800 plants/year

It would cost $0.18/plant ($328/1800 plants) to recover all capital costs of the hydroponic system within a single production year. The lifespan of most of the system components would be considerably longer than 1 year.

Major Operating Costs would be;

**Power** – 2 *1000 W lamps per bench operating 16 hours/day * 30 days = 480kWh * $0.10 kWh (Saskatoon) = $48.00

2 circulation pumps + 2 aeration pumps * 7W * 24h * 30 days = 20 kWh * $0.10 kWh = $2.00

Total power cost = $50 for 150 plants = $0.30/plant.

**Total Cost of Production** = $0.50 (labor) + 0.18 (system) + 0.30 (power) = $0.98/plant

NB – this does not include the cost to heat the greenhouse, depreciation on the greenhouse space and operating systems or the cost of seed, fertilizer, pest control measures or post-harvest handling.

NB – the troughs used in this project were just standard vinyl eavestroughs. These troughs were not designed for this use and therefore cannot be considered to be “food safe”. There is a potential concern that plasticizers or other chemicals leaching from the troughs could accumulate within the closed recirculating NFT systems. “Food Safe” PVC pipes are available but at about 10X the price of the troughs used in this project.
Crop Growth Rates

The rate of crop growth varied with the season and the efficacy of the crop management treatments applied to the production systems. The maximum length of time from transplanting through to harvest of marketable sized heads was 5 weeks, while the shortest production period was 3 weeks. The fastest growth occurred when well adapted cultivars were grown in mid-summer.

The cv. Optima was used as an internal standard in 16 crops grown from April 2013 through June 2014. While growth of cv. Optima was influenced by the various production treatments utilized in each trial, some overall trends in productivity of cv. Optima were observed. Daily growth rates – determined by dividing the final weight of the harvested heads by the number of days it took from seeding until the heads reached marketable size indicated that growth of cv. Optima in summer was significantly higher than in winter. This was expected as light levels would be much higher in the summer. Growth slowed in the winter months, even when artificial lighting was used to supplement light intensity and increase daylength. The exceptions to this trend were in November and April – when use of artificial lights increased productivity relative to crops grown without artificial light in October and May.

![Daily growth rate of Optima lettuce crops grown over a year of production in a NFT-type hydroponic system. During months with *, natural light was supplemented with HPS lights (16h/day at 125 umol).](image-url)
Cultivar Performance

Total and marketable yield, head appearance and taste were considered for each cultivar (Table 3). Head quality considered the head size, whether the head was tight or loose and the % heads that were free of market defects such as tipburn. Flavor assessments were conducted by a panel – who evaluated each cultivar for overall flavor, sweetness and any bitter notes to the flavor. Texture of the leaves was also noted.

While the semi head types of bibb lettuce are most sought after in the marketplace they had a much higher incidence of tip-burn than the open head types – and this often reduced their marketable yield and appearance rankings.

Red Sails (Johnny’s) – was outstanding for taste, yields and appearance. The only limitations to this cultivar are that it forms a relatively loose head and its color (mauve tips on green leaves) is not “traditional”.

Two Star (Stokes) – produced excellent yields, but its flavor and overall appearance were only average. Again, Two Star produces a relatively open type head.

Simpsons Elite (Stokes) – very large loose heads with mild flavor. Minimal tipburn
**Optima** (Osborne) – was the best cultivar with a standard semi-head configuration. Optima was less susceptible to tipburn than most semi-head types but often had some tipburn – especially under conditions that drove rapid growth. Optima looked very good with nice bright green soft texture leaves. Its flavor was consistently excellent.

**Adriana** (Johnny’s) – consistently produced very large attractive light green semi-heads. Adriane was also fairly resistant to tipburn. Its main limitation was its flavor which was mild with significant bitter notes.

**Natalia** (Paramount) – small but very uniform compact heads. Good texture and flavor. Moderate tipburn.

**Santoro** (Rijk Zwaan) – medium sized light green attractive heads. Moderate tipburn.
Table 3. Performance data lettuce cultivars grown hydroponically under greenhouse conditions. Recommended cultivars are highlighted in yellow.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Supplier</th>
<th>Comments</th>
<th>Average Head Wt (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adriana</td>
<td>Johnny's</td>
<td>Large slightly open dark green heads. Slightly bitter.</td>
<td>137</td>
</tr>
<tr>
<td>Alkindus</td>
<td>Osborne</td>
<td>Variable taste - sometimes bitter, sometimes good.</td>
<td>91</td>
</tr>
<tr>
<td>Australe</td>
<td>High Mowing</td>
<td>Very small but good appearance and flavor</td>
<td>44</td>
</tr>
<tr>
<td>Barbados</td>
<td>Hazzards</td>
<td>Moderate tipburn</td>
<td>114</td>
</tr>
<tr>
<td>Bennet</td>
<td>Osborne</td>
<td>Attractive dark green heads. Average taste.</td>
<td>111</td>
</tr>
<tr>
<td>Bergams Green</td>
<td>Stokes</td>
<td>Big open heads. Looks and tastes ok. Minimal tipburn.</td>
<td>139</td>
</tr>
<tr>
<td>Black Jack</td>
<td>Stokes</td>
<td>Severe tipburn. Mild flavour.</td>
<td>91</td>
</tr>
<tr>
<td>Buttercrunch</td>
<td>Johnny's</td>
<td>Very large loose heads. Average flavor.</td>
<td>183</td>
</tr>
<tr>
<td>Cassandra</td>
<td>Salt Spring</td>
<td>Large loose heads</td>
<td>144</td>
</tr>
<tr>
<td>Cherokee</td>
<td>Johnny's</td>
<td>Red/brown leaves</td>
<td>75</td>
</tr>
<tr>
<td>Continuity</td>
<td>Salt Spring</td>
<td>Small heads with v. dark green leaves. Poor flavor</td>
<td></td>
</tr>
<tr>
<td>Cosmopolitan</td>
<td>Misionero</td>
<td>Small but attractive semi-heads. Good flavor and texture</td>
<td>88</td>
</tr>
<tr>
<td>Dancine</td>
<td>Osborne</td>
<td>Bitter and susceptible to thrips</td>
<td>71</td>
</tr>
<tr>
<td>Deer Tongue</td>
<td>Johnny's</td>
<td>Distinctive elongated leaves. Some tipburn</td>
<td></td>
</tr>
<tr>
<td>Ermosa</td>
<td>Johnny's</td>
<td>Big loose heads. Leaves curling under.</td>
<td>151</td>
</tr>
<tr>
<td>Esmerelda</td>
<td>West Coast Seeds</td>
<td>Average size.</td>
<td>113</td>
</tr>
<tr>
<td>Fidel</td>
<td>Paramount</td>
<td>Bolted and had severe tipburn</td>
<td>65</td>
</tr>
<tr>
<td>Flandoria</td>
<td>Paramount</td>
<td>Dark semi-heads. Bitter.</td>
<td>117</td>
</tr>
<tr>
<td>Foea</td>
<td>Johnny's</td>
<td>Mild flavor but not attractive</td>
<td>70</td>
</tr>
<tr>
<td>Fortina</td>
<td>Johnny's</td>
<td>Moderate tipburn</td>
<td>138</td>
</tr>
<tr>
<td>Gardia</td>
<td>Rijk Zwaan</td>
<td>Severe tipburn</td>
<td>84</td>
</tr>
<tr>
<td>Gem</td>
<td>West Coast Seeds</td>
<td>Bitter. Susceptible to thrips. Uneven growth.</td>
<td>144</td>
</tr>
<tr>
<td>Green Bay</td>
<td>Stokes</td>
<td>Nice but open head. Good strong flavor.</td>
<td>138</td>
</tr>
<tr>
<td>Green Star</td>
<td>Johnny's</td>
<td>Large heads with little tipburn</td>
<td>154</td>
</tr>
<tr>
<td>Green Salad Bowl</td>
<td>Stokes</td>
<td>Big plants. Oak leaf. Mild flavor</td>
<td>155</td>
</tr>
<tr>
<td>Harmony</td>
<td>Shamrock</td>
<td>Nice, open head. Fair taste</td>
<td>128</td>
</tr>
<tr>
<td>Hilde</td>
<td>Salt Spring</td>
<td>Small heads with some tipburn</td>
<td>42</td>
</tr>
<tr>
<td>Hungarina</td>
<td>Rijk Zwaan</td>
<td>Severe tipburn</td>
<td>114</td>
</tr>
<tr>
<td>Variety</td>
<td>Grower</td>
<td>Description</td>
<td>Score</td>
</tr>
<tr>
<td>--------------</td>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Livigna</td>
<td>Johnny's</td>
<td>Small heads are slightly bitter</td>
<td>59</td>
</tr>
<tr>
<td>Magenta</td>
<td>Johnny's</td>
<td>Small heads</td>
<td>66</td>
</tr>
<tr>
<td>Margarita</td>
<td>Seed Way</td>
<td>Good taste, open head.</td>
<td>144</td>
</tr>
<tr>
<td>Mottistone</td>
<td>Johnny's</td>
<td>Small heads with moderate tipburn</td>
<td>62</td>
</tr>
<tr>
<td>Nancy</td>
<td>Johnny's</td>
<td>Uniform compact heads but some tipburn</td>
<td>82</td>
</tr>
<tr>
<td>Natalia</td>
<td>Paramount</td>
<td>Uniform compact heads. Good texture and taste. Moderate tipburn</td>
<td>87</td>
</tr>
<tr>
<td>Nevada</td>
<td>Johnny's</td>
<td>Small heads with moderate tipburn</td>
<td>82</td>
</tr>
<tr>
<td>New Red Fire</td>
<td>Stokes</td>
<td>Good flavor but some tip burn.</td>
<td>87</td>
</tr>
<tr>
<td>Optima</td>
<td>Osborne</td>
<td>Nice looking, large, tight heads. Good flavor. Some tip burn.</td>
<td>146</td>
</tr>
<tr>
<td>Prizehead</td>
<td>Early's</td>
<td>Small heads with purple tips on pale green leaves. Good flavor.</td>
<td>62</td>
</tr>
<tr>
<td>Pybas Red Butter</td>
<td>Pybas</td>
<td>Poor appearance</td>
<td>145</td>
</tr>
<tr>
<td>Red Cross</td>
<td>Johnny's</td>
<td>Small, chewy and bitter</td>
<td>48</td>
</tr>
<tr>
<td>Red Express</td>
<td>Stokes</td>
<td>Dense, unattractive head with severe tipburn</td>
<td>109</td>
</tr>
<tr>
<td>Red Sails</td>
<td>Johnny's</td>
<td>Large open head with nice mild taste.</td>
<td>131</td>
</tr>
<tr>
<td>Resi star</td>
<td>Osborne</td>
<td>Bitter. Susceptible to thrips. Bolts</td>
<td>96</td>
</tr>
<tr>
<td>Rex</td>
<td>Johnny's</td>
<td>Small, firm leaves, mild taste, nice texture.</td>
<td>126</td>
</tr>
<tr>
<td>Rhapsody</td>
<td>Shamrock</td>
<td>Small, bitter heads with lots of tip burn</td>
<td>140</td>
</tr>
<tr>
<td>Rhazes</td>
<td>Johnny's</td>
<td>Miniature heads have minimal tipburn</td>
<td>47</td>
</tr>
<tr>
<td>Roxy</td>
<td>Osborne</td>
<td>Not very good looking.</td>
<td>168</td>
</tr>
<tr>
<td>Ruby Sky</td>
<td>Johnny's</td>
<td>Sweet. Some tipburn</td>
<td>93</td>
</tr>
<tr>
<td>Sangria</td>
<td>Osborne</td>
<td>Small.</td>
<td>76</td>
</tr>
<tr>
<td>Santoro</td>
<td>Rijk Zwaan</td>
<td>Moderate sized, bright green attractive heads with good texture and flavor. Some tipburn</td>
<td>93</td>
</tr>
<tr>
<td>Scarlet Letter</td>
<td>Osborne</td>
<td>Nice mild favour. Some tipburn</td>
<td>113</td>
</tr>
<tr>
<td>Simpsons Elite</td>
<td>Stokes</td>
<td>Big. Mild taste.</td>
<td>123</td>
</tr>
<tr>
<td>Starfire</td>
<td></td>
<td>Ruffled leaves with minimal tipburn</td>
<td>52</td>
</tr>
<tr>
<td>Teide</td>
<td>Johnny's</td>
<td>Small heads with purple tips on green leaves</td>
<td>53</td>
</tr>
<tr>
<td>Two Star</td>
<td>Stokes</td>
<td>Very large, loose heads. Good taste and minimal tipburn</td>
<td>159</td>
</tr>
<tr>
<td>Vincenzo</td>
<td></td>
<td>Moderate tipburn</td>
<td>139</td>
</tr>
<tr>
<td>Volare</td>
<td>Enza Zaden</td>
<td>Uniform heads</td>
<td>123</td>
</tr>
</tbody>
</table>
**Recommendations for further work** – while this project quite exhaustively demonstrated and evaluated the potential for hydroponic production of lettuce through lettuce, there are many opportunities for additional work, considering ….

a) That we did not identify a single cultivar that met all of the desired objectives. We identified several cultivars that had exceptional yields, excellent flavor and a high degree of resistance to tipburn (Red Sails, Simpson’s Elite and Two Star, – but all of these cultivars formed loose heads - and semi-head types of lettuce command a price premium. Optima was the best semi-head type tested, but grade out to tipburn in this cultivar was a concern. Natalia, Adriana and Santoro were all identified as good semi-head types.

b) There are additional cultivars of buttercrunch lettuce that could be evaluated.

c) By manipulating many production parameters over the course of the 25 production cycles covered in this project we were able to enhance overall yields and crop quality – but there was still considerable opportunity for further improvement. Tipburn and other problems related to nutrient imbalances were still too common.