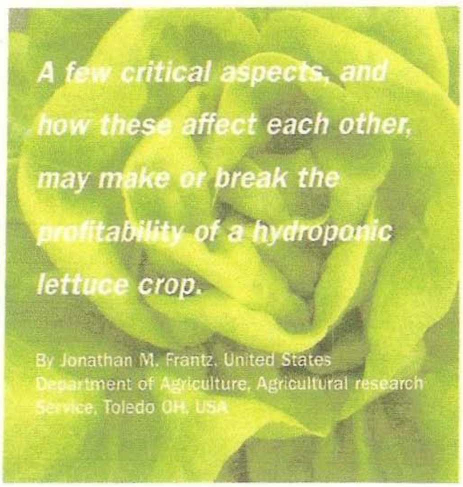
Maximising hydroponic



Horticulturists have long sought to maximise yield and quality. Light capture, quantum yield or quantum efficiency, and respiration or carbon use efficiency are the three physiological determinants which control yield in all plants. By managing the light, temperature, and CO_2 environment of plants, these three determinants of yield can be optimised. In addition, with hydroponic lettuce production, manipulation of nutrition can influence the plant's response to an altered environment and ensure high quality of fast growing lettuce plants.

Temperature- It has been well established that the single biggest driver for yield improvement per area is increased light interception. Therefore, any opportunity to increase light capture per area should be investigated, including elevated light and denser spacing.
Leaf emergence and leaf expansion rates are greatly influenced by temperature so increasing temperature is another indirect way to improve light capture. In our studies, we found yield to be greatest in temperatures between 28 to 30°C (Figure I). There was a significant and steep decrease in yield beyond 31°C, so to be safe, temperatures above 28°C should be avoided in order to provide some margin for error in temperature control.

Why is yield greatest at around 28°C?

Did you know...

1. 28°C is the optimum temperature for large leaf production. Avoid temperatures over this.
2. Low blue light may stimulate leaf expansion.
3. The beneficial effect of CO_2 increases at warmer temperature.
4. CO_2 can protect plants against minor temperature fluctuations.
5. Lettuce has a tendency to suffer from calcium deficiency. Use dilute nutrient solutions to increase calcium uptake.
6. Tipburn can be more severe at faster growth rates.
7. High humidity can also increase tipburn.
8. Supplement with boron to avoid misshapen or lack of heads, excessive branching and leaf glossiness.

Leaf expansion and emergence is greatly accelerated by this high temperature. Larger, or more, leaves lead to greater light capture that leads to greater photosynthetic productivity, which leads to more leaves, and so on, in a positive feedback loop for the plant.
On any given day, larger leaves or more leaves can easily be seen with warmer temperatures (Figure 2). As an added benefit, some lettuce cultivars have more chlorophyll in elevated temperatures, as seen in Figure 2, thereby improving the appearance of the lettuce.

How much light?- Lettuce is typically grown in "lower" light than most crops, often between 300 and 400 Fmol m^{-2} S^{-1}, in order to improve quality. In terms of maximising yield, increasing light is an easy, albeit potentially expensive, way to improve yield. How high is high enough? Many experiments have shown lettuce yield to plateau around 400 Fmol m^{-2} S^{-1}, but we have found yield can increase up to and probably beyond 1000 Fmol m^{-2} S^{-1} if other environmental parameters are optimised as well. This does not mean that growers should spend a fortune on electric lamps to squeeze a few extra micro-

lettuce yields

moles of light in their greenhouses, but it does mean that growers should not be averse to allowing light (and temperature) to rise in the day for fear of saturating photosynthesis or photo-bleaching leaves, provided other environmental and management issues are optimised.
An interesting point about light is the issue of light quality, especially when selecting electric lamps. Research done at Utah State University, USA, indicates that high pressure sodium (HPS) lamps may stimulate leaf expansion due to their lower blue light fraction. This means that HPS instead of metal halide (MH) lamps may enhance productivity through their stimulation of leaf expansion caused by blue light deficiency. This work was done in controlled environments so the light environment was determined solely by the selection of amp type. It is not known if this stimulation would occur in a sunlit greenhouse environment already containing ample blue light with HPS lamps used only as a supplement.

Carbon Dioxide (CO_2) -
Depending on the area of the world, greenhouse style, and season, growers have the option to elevate CO_2. Often, extension agents and consultants recommend against the use of CO_2 from burners because of the threat of ethylene from incomplete combustion. Ethylene can significantly decrease lettuce productivity primarily through altered canopy and leaf structure at concentrations as low as 50 ppb. Burners are improving, however, and ethylene scrubbers are improving to the point that the threat of ethylene from incomplete combustion is being minimised.
The beneficial effect of CO_2 increases at warmer temperatures, so much so that photosynthetic efficiency can actually be higher in warm (28°C) temperatures than cool temperatures (20°C). In Figure 3, the yield from four groups of lettuce plants grown at two different temperatures and CO_2 are shown.
There was only a benefit from warm temperatures when CO_2 was elevated, which emphasises the importance of minimising the photorespiration reaction for maximising yield.
In this study, CO_2 was elevated to 1200 ppm to ensure saturation of the CO_2 effect. However, it is important to note that a benefit from CO_2 can be achieved even with a small increase in available CO_2. For example, in the results in Figure 3, a 115% yield increase was obtained with elevated CO_2 at 30°C. Assuming that is the maximum improvement from elevated CO_2 at this temperature, a grower could expect about a 7% increase in yield for every 50 ppm above 400 ppm.
An added benefit that we have observed when using elevated CO_2 is that plants are less sensitive to temperature extremes (either cold or hot) during short (hours) temperature stresses. Therefore, the use of CO_2 could potentially protect plants against minor temperature malfunctions in a grower facility. In the winter, when ventilation of greenhouses and controlled environment facilities are minimized, CO_2 is likely to be below that of outside air. As a result, yield reductions can occur from CO_2 depletion as significantly as yield improvements can occur if CO_2, was raised.

Calcium- Whenever someone speaks of lettuce nutrition, the discussion usually turns to calcium (Ca^{2+}) and boron (B) nutrition. Lettuce has a tendency to become Ca^{2+} deficient, which, when localised in the meristem, centre of the plant, or leaf margins, is referred to as tipburn.
There is consensus that tipburn is the result of Ca^{2+} deficiency, but what specifically Ca^{2+} causes within the plant to result in tipburn is still open to debate. There are some who believe that a lack of Ca^{2+} weakens the cells containing latex (called laticifers) within the plant, which burst and cause black spots that expand and lead to the discoloration of tipburn. Others believe laticifers are not important in this case and suggest that tipburn is caused by Ca^{2+} deficiency in other cell types. Since tipburn-like symptoms are noticed in other crops not containing laticifers (i.e. ripburn in strawberry), and those disorders are also caused by Ca^{2+} deficiency, it is possible that there are two distinct mechanisms which cause tipburn. Regardless of the mechanism, the observation with lettuce is that the faster the growth rate, the more severe tipburn can be.
Wind reduces tipburn by reducing the vapour pressure deficit around a meristem thereby increasing transpiration. Low day-time humidity can increase tipburn because more water is disproportionately transpired through exposed leaves while the interior

Figure 1 -Lettuce yield in relation to temperature

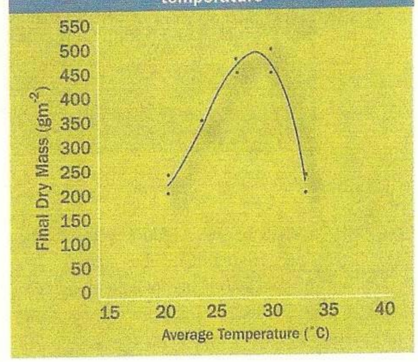
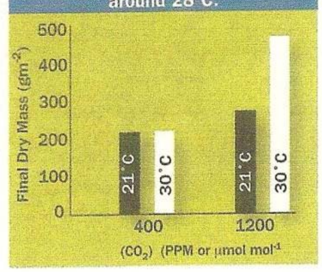


Figure 2 - Leaf size increases with warmer temperatures up to around 28°C.



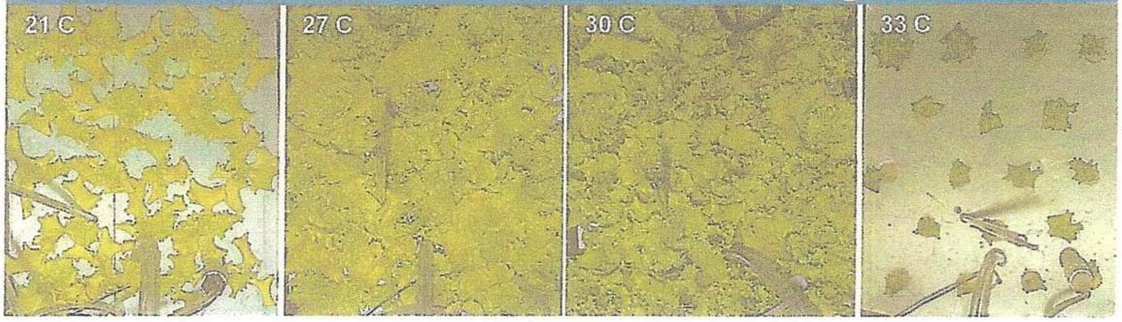


Figure 3 - A benefit in yield is observed at warm temperatures when CO_2 is elevated.

meristem is in a high-humidity environment. High humidity can increase tipburn by slowing transpiration in the meristem and thus reducing the flow of Ca^{2+} to the meristem. Low humidity at night may decrease plant turgor potential, and result in less Ca^{2+} being translocated to leaf tips and meristems by guttation (root pressure).

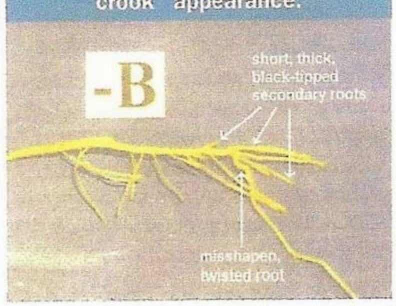
Lettuce growers can not simply add more Ca^{2+} to the nutrient solution because high salinity (or solution electrical conductivity) can also reduce night-time leaf water potential and guttation. Lettuce is so sensitive to solution EC that increasing Ca^{2+} by only 1 mM can significantly increase tipburn (personal communication). Ca^{2+} uptake is also inhibited by other cations, so increased levels of NH_4^+ and K^+ typically reduce Ca^{2+} uptake. Hydroponic lettuce growers can use more dilute solutions than are commonly used. As solution EC (fertiliser concentration) decreases, growers must be sure to increase their flow rates of the solution to ensure adequate nutrient delivery to the roots. This will also assist in root aeration, which will reduce the likelihood of other problems associated with hydroponics (i.e. low O_2, Fe deficiency). Dilute nutrient solutions will improve Ca^{2+} uptake in lettuce at night.

Boron- Because lettuce contains latex, it may require higher B than many other crops. In this way, lettuce is more akin to poinsettia in its B requirement than spinach. Marschner (1995) recommends significantly higher amounts of B for latex-containing crops than other dicotyledonous species. If there is not enough B supplied, misshapen or lack of heads, excessive branching (less apical dominance), and leaf glossiness can appear.

LETTUCE PRODUCTIVITY CAN BE DOUBLED WITH MINOR CHANGES

Boron deficiency happens to be easier to detect than many other nutrient deficiencies prior to foliar symptom development. B-deficient roots have a distinctive morphology of a "shepherd's crook" with numerous, short, thick, stubby roots developing at the root tip, typically with blackened or necrotic ends (Figure 4). This root form is often called "witches broom."

Figure 4 - Boron deficient roots have a distinctive "shepherd's crook" appearance.



There are other nutritional issues that may come up in certain, specific instances. For example, if ozone is used to disinfect or de-sulfonate water, manganese deficiency can become problematic. Metal toxicities can also be an issue and manifest themselves as small necrotic spots on the leaf margins and blades. However, these disorders are generally less common than B and Ca^{2+} issues.

Conclusion- Growers must walk a fine line in profitable lettuce production between rapid growth and reduced quality. With minor changes in temperature, light, and CO_2, productivity can be more than doubled in lettuce. Is it worth it? The larger the plant, the less room for error in managing lettuce for high, marketable quality. Optimising plant nutrition for your production environment provides the key to achieving high lettuce quality. The faster the growth rate, the greater likelihood of encountering nutrient deficiencies such as Ca^{2+} and B. Using more dilute nutrient solutions, especially at night, with higher flow rates may provide a wider safety margin for high growth rates in order to deliver adequate Ca^{2+}. ❑

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