

Typical plant factory set-up.

Innovative Plant Factories

In their first article, **MIKE NICHOLS** and **BRUCE CHRISTIE** profiled greenhouse production in Japan with an emerging trend towards plant factories. In this article, the authors expand on the innovative developments in Japanese plant factories and the role they will play in the future.

Early in 2006 we were invited to present a paper on 'Organic Hydroponics' at the SHITA Conference in Tokyo, Japan. While in Japan we took the opportunity to visit some of the developments which were occurring in intensive horticulture in the Tokyo area. We have already reported on our greenhouse experiences in the previous issue (*PH&G Jan/Feb 2008*), and this report concerns plant factories of which Japan is probably the world leader. We were hosted by Professor Shinohara from Chiba University and his colleagues, who arranged all of our visits.

The plant factories in Japan that produce crops under controlled environmental conditions and optimised for the particular crop, have developed from ideas first proposed in the United States in the 1950s and commercialised in the 1970s. These production units were designed to produce high-quality food in all seasons with minimal pesticide usage, and very efficient use of water.

Plant factories can be classified as semi-closed where some natural light is used in plant production to offset some of the lighting costs, or as a totally enclosed facility where all the light is provided artificially and the environment is totally controlled for maximum plant productivity.

A number of totally enclosed plant factories were established in the United States, such as Phytofarms in Illinois and Geniponics in New York, and Alaska where the outdoor environment precludes all-year-round plant production. A number of these facilities developed special innovations to cope with the excess heat produced by the high intensity discharge lamps and the challenge of optimising plant spacing. These factories ultimately proved to be uneconomic and not commercially viable by the early 1990s in the United States. In Japan,

however, they built on the ideas used by the Americans to develop plant factories, and many have been economically sustainable so far over a period of about 30 years. It has been suggested the high value of land and other inputs, plus some genuine innovation, has been the reason plant factories have survived and in the main appear to be going from strength to strength.

To be economically viable, plant factories must convert as much of the energy input from electricity into light and then marketable plant material. The majority of the plant factories utilise fluorescent lights, which are very efficient at converting electricity into light. They also have the advantage of producing relatively little heat from the tube producing the light, so they can be placed close to plant leaves with little risk of damage.

Currently, there are about 40 plant factories operating in Japan, with prototypes being tested in China as proof of concept before going into large scale production in regions of the world where the climate is hostile for reliable food plant production.

In 1990, the Cosmo Plant Company, led by Hisakazu Uchiyama, developed an innovative approach to lighting using light emitting diodes (LEDs), which held considerable promise due to their long life and increasing efficiency at energy conversion to specific wavelengths close to the action spectra of many crop plants. We now know that LEDs use about 2% of the power required by standard incandescent bulbs and will last about 10 times longer than a fluorescent tube and more than a hundred times the life of an incandescent bulb. Some of the durability comes about because LEDs do not have a filament that can be broken during handling.

In recent years, significant advances have been made in the manufacturing of LED bulbs. Once used only as power indicators on

appliances, LEDs can now be used to light a room or in powerful flashlights. It is generally considered that LED's will provide the next generation of lighting for plant factories, if only because they are able to produce radiation (light) of specific wavelength.

Plant factory visits

Green Labour Shop

At the Green Labour Shop with a floor area of 60m² they produce 300 lettuce per day to supply six shops. The lights are between 220 and 250mm from the plants and the shelves are seven high, giving a productive area of 168m². About 600, 32W fluorescent lamps are operated on a 16-hour photoperiod. The operator uses ozone to clean the nutrient solution, and only replace the solution twice a year. The composition of the nutrient solution was considered part of their intellectual property and kept confidential. The air temperature and solution temperature are 20-22°C and 18°C, respectively. Plant growth is promoted by maintaining the relative humidity at 65% and the CO₂ at 1,500ppm when the lights are on. This produces a sweet lettuce with a brix of 6. The entire production unit is operated by one fulltime and three part time workers. Labour is 30% and electricity 35% of the total costs, with the balance being production consumables and maintenance costs.

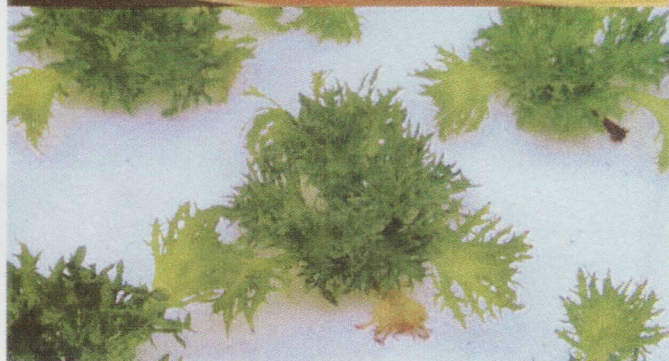
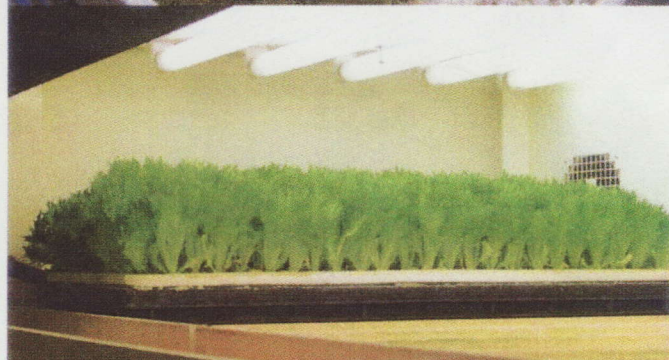
Urban Farm

The Urban Farm commenced operation in the year 2000 and comprises of a 546m² building with a 400m² growing area. Within the growing area there are seven sets of shelves and eight layers on the shelf, which gives a growing area of 1,200m². Each bench is filled to a depth of 6cm with a constant circulating nutrient solution, with young plants added to polystyrene rafts at one end. As new plants are added each day the plants on the bench are floated closer to the other end of the bench where they are harvested.

The Urban Farm crop range includes basil, chervil, and several different types of lettuce. Daily production, if devoted solely to lettuce, would be 1,500 plants per day. Lettuce seed is sown and germinated in an incubator, then transplanted at five to six days into plugs, thereafter set out at final spacing at 18 days. Normally, harvesting will occur 45-46 days from sowing.

The air temperature is 20-23°C, the nutrient solution temperature is kept at 20°C, the EC is 3.0 and a pH between 5.5 and 6.5. The light intensity at the top of the plants from the 1568 (100W) fluorescent lamps is 15,000 lux (ca. 250 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). Plant growth is promoted by maintaining the relative humidity in the light at 60-70% and in the dark 90-98%. The CO₂ is maintained at 800-1,000ppm with the lights on for 14-15 hours per day.

Only half of the fluorescent lights have been replaced in the last seven years and electricity is approximately 25% of the operating costs at the Urban Farm. Vegetable products are promoted as pesticide-free and free of soil. The farm has a uniform supply with a fixed-price throughout the year. In addition, vegetable products contain higher levels of vitamin A and sugar than those produced outdoors.



Right - Top to Bottom:

- Tomato seedlings ready for transplanting.
- General view of a Japanese plant factory.
- Basil seedlings.
- Seedlings would appear to have the greatest merit for plant factories.
- Lettuce plants are grown to maturity on polystyrene rafts.



Cosmo plant factories

Also in the year 2000, the Cosmo plant company opened the world's first commercial plant factory growing plants using light emitting diodes. The Cosmo farm uses mainly red (660nm) and some blue LEDs. Until recently, most Cosmo plant factories were producing up to 7,000 lettuces per day when the company got into financial difficulties. Uchiyama is credited with most of the experimentation and technical innovation behind the Cosmo plant production units. All their factories had a similar design - a normal height building where seeds were raised into small plants in a germination and nursery area for up to two weeks, then moved to a specialised growth room about 11m high where plants grew to maturity about two weeks later. The environment was kept at 23°C and relative humidity at 75% to get good vegetable growth without any external environmental effects. Cosmo researchers found they could use less CO₂ enrichment to improve the final yield.

We met with the CEO of Cosmo at the SHITA meeting and had lunch with him, but unfortunately his English was not good and our Japanese was non-existent, so there was little communications. In any case, Cosmo went bankrupt a few weeks after the meeting.

The future

There is little doubt in our minds that plant factories will be the way of the future, but in the short term the use of plant factories for propagating young vegetable seedlings would appear to have the greatest merit.

Consumers, whether they are the final consumer or the supermarkets/shops, require two things from vegetables - continuity of supply and quality.

Growing vegetables in the field (or even in a greenhouse) is weather dependant, and by growing the seedlings for a significant part of the life cycle in a totally controlled environment means that variations in maturity time can be significantly reduced, raising the possibility of producing two crops in the time when one would normally be grown.

One interesting factor to appear is that the leaf growth in a plant factory is different from that in a greenhouse [see images].

Conclusion

Plant factories would appear to be the way of the future, perhaps not today, or even tomorrow, but with their greatly enhanced water efficiency, it will only be a short time before improved lighting systems will permit high value crops to be grown anywhere on the globe for local consumption.

In the short term, plant factories are already capable of providing an enhanced environment for producing high quality vegetables seedlings for industry.

About the authors

Mike Nichols and Bruce Christie are horticultural research scientists at the College of Sciences, Massey University, Palmerston North, New Zealand.

Email: m.nichols@massey.ac.nz or C.B.Christie@massey.ac.nz

Right - Top to Bottom:

- Seedlings are grown in small plant factories.
- Vegetable seedling plant propagation factory.
- Plant factory shelves are seven high, optimising space.
- Lettuce harvesting occurs 45-46 days from sowing.
- Plant factory lettuce ready for market.