Hydroponic Tomatoes

Maximizing yields from hydroponic tomato crops has long been the main objective of commercial growers. However, there's growing consumer pressure to produce high-quality, great-tasting fruit that stores and handles well in the retail sector.

By Lynette Morgan

Top: Properly grown hydroponic tomatoes are often fit to be framed; Bottom: This single-truss crop is being grown on greenhouse benches in NFT. (Photos courtesy of Lynette Morgan)

Tomatoes, the biggest hydroponically produced crop on a worldwide scale, are complex in their physiology and response to crop management techniques since vegetative growth, flowering and fruiting all need to be continually maintained simultaneously on the plant. Obtaining economic yields of high-quality fruit while minimizing the use of pesticides and other agrichemicals has put commercial tomato growers under increasing pressure, and many are now looking to modified hydroponic systems where higher profits are possible. Many of these new tomato-growing techniques involve the production of "spray-free" crops and using organically based systems. Today's selection includes a wide range of new, fresh tomato products, such as low-acid fruit; on-the-truss, cluster or vine-ripened fruit; and many new varieties of colored, plum and Italian fruit that serve to supplement the traditional round beefsteak types.

While product diversity in commercial hydroponic tomato production has been one way many growers have maximized profits from their greenhouse operation, these newer systems require a greater degree of skill and understanding of the plant and its production. With the development of rapid and accurate nutrient analysis services now available to growers, nutrient formulation and monitoring has become a vital tool for commercial producers who aim to keep fertilizer wastage to a minimum.

Markets for fresh tomato fruit will continue to evolve, making it essential for growers to keep up with new developments, research and trialing different cultivars and techniques in their own production systems.

RECOMMENDED CULTIVARS

Often, one of the most confusing aspects of hydroponic tomato production is selecting good varieties to grow. The tomato is a crop that has been the subject of extensive plant breeding, and selection over a long period of time and the genetic diversity of tomato types to select from seems endless. Many cultivars have been selectively crossed over many generations to create plants for different types of growing systems, environments and fruit types. Also, plant breeders are continually bringing out new, improved hybrid cultivars for greenhouse production. Often, running trials on new cultivars each season is one way commercial growers can select improved varieties.

Lists of recommended tomato varieties for hydroponic production tend to rapidly go out of date. However, there are a few industry standards that have been proven in many different systems and climates to continually perform well in hydroponic systems.

Indeterminate Beefsteak Varieties. A continual favorite is 'Trust', a F1 hybrid grown by many commercial hydroponic tomato growers. This fairly large-fruited tomato is favored in the United States for its size and meaty texture. Average fruit size is 7-10.5 oz. under good growing conditions, and it is used as a single-harvest — as opposed to truss-harvested — fruit. Trust fruit have a good shelf life and firm texture and handle well after harvest. This variety is also resistant to some mold strains, including Fusarium crown and root rot. The seed, and F1 hybrid, is more expensive than many of the open-pollinated types. However, small quantities of this commercial variety can be purchased by smaller growers. Since Trust is an indeterminate variety, it's often grown over a long season (10-18 months) and layered. It can also be grown as a shorter-term crop by removing the growing point when it reaches the top of the training wire.

Another large, round type that performs well under hydroponic production with a smaller average fruit size than Trust is 'Daniela', another F1 hybrid. The average fruit size of Daniela is 5-5.3 oz., which is suited to either single or truss harvesting. The fruit ripens very uniformly under most growing conditions. This variety has an excellent shelf life and fruit firmness and is worth trailing — particularly for "vine-ripened" fruit production.

Heirloom and Open-Pollinated Types. While older, heirloom, open-pollinated tomato varieties frequently don't yield as high as F1 hybrid types, some growers prefer to grow them for fresh market sales where firmness and shelf life come second to the flavor and aroma of the fruit. Fruit quality and disease problems are common on some open-pollinated types, so selection of suitable cultivars is important.

In recent greenhouse trials where a number of different heirloom varieties were grown hydroponically, some were found to have market reject rates as high as 90 percent due to fruit cracking, splitting and color, size and shape deformities. However, the best selections did produce fruit that was marketable, although shelf life and firmness were never as high as F1 hybrids. The better heirloom varieties in greenhouse trials proved to be 'Moskvich', a large, globe-shaped fruit with a high flavor score, and 'Thessaloniki', which produces rather large, beefsteak-type fruit. Both Moskvich and Thessaloniki can be obtained as organically grown seed.

Specialty Varieties. Plum or Italian varieties are becoming more popular as specialty lines for many hydroponic producers. Often, with these types of elongated fruit, blossom end rot is more common than in round, red ➧

Nutrient Uptake in Commercial Crops

A healthy tomato crop can quickly strip certain elements from the nutrient solution. Figure 1, below, shows nutrient uptake data taken from the start of flowering in an NFT hydroponic tomato crop (day one) until day 40, when the crop had a full crop load of developing fruit. The nutrient solution has an initial high potassium concentration on day one — about 750 ppm of potassium, 340 ppm of nitrogen, 160 ppm of phosphorus and 480 ppm of calcium; the EC of the nutrient is 4.7. While it's known that high levels of potassium will result in decreased magnesium uptake and possible magnesium deficiency symptoms, even at the level of 750 ppm potassium in solution, this was not seen in the crop. The initially high levels of potassium in the solution had dropped to 230 ppm after 40 days.

This solution was replenished daily with the same standard stock solution to maintain an EC of 4.2-4.7. Over time, the ratio of elements changed considerably and, if allowed to continue, would result in deficiencies of potassium. At day 40, the levels of nutrients were: 700 ppm calcium, 340 ppm nitrogen, 230 ppm potassium, 30 ppm phosphorus and 250 ppm magnesium. While these levels are considerately different from the starting solution, they aren't yet deficient enough to cause problems. If this solution were allowed to continue for another week or two, even with the addition of the stock solutions, potassium would be reaching deficient levels and phosphorus would also start to drop below what's required by the plant. The trend in increasing calcium and magnesium levels would continue.

Based on this nutrient data, a tomato grower would have two options. The first would be to dump and completely replace the solution at about day 35-40 and start again with initial levels. This would allow another 30 days or so of growth before the solution becomes unbalanced again. The second, more sustainable option would be to change the nutrient formula at the start of flowering or fruit set so it replaces the elemental ratios that are being removed from the solution. The ideal picture would be to have roughly straight lines on the graph showing that, as time goes on, the ratio of elements in the solution stays the same.

In this example, the crop needed a nutrient formula for the stock solutions with much more potassium, a little more phosphorus and less calcium and magnesium. Nitrogen levels hadn't increased or decreased to any great degree indicating that the levels of this element that were being replaced on a daily basis were about the same that the crop was using. Since this nutrient didn't feature any problems with unwanted elements, such as sodium, the life of the nutrient solution could have been prolonged considerably — past the 40-day mark — by adjusting the formula and ratios in the nutrient stock solution used on a daily basis to maintain EC levels. Figure 2, below, shows the amounts of each element that would be obtained from new nutrient formulas that make up the stock solutions. There are five different stock solutions with a change to a new formulation every 10 days or so. This helps ensure that the quantities of each element that are removed are replaced as the crop goes through its fruiting cycle. This is a practice that many commercial growers are becoming familiar with when it comes to managing recirculating and nonrecirculating hydroponic tomato production systems.

While not every commercial tomato crop would have the same pattern of nutrient uptake as the example given above, many high-yielding tomato crops in recirculating systems show a similar uptake rate for phosphorus. This emphasizes the importance of not only regular solution analysis and monitoring but continual adjustment of the nutrient solution formula to match the changing pattern of nutrient uptake by the developing crop.

Similar patterns of uptake can be seen in media-based tomato crops. However, the changes made to the nutrient formula are different than what would be made for a recirculating system. In nonrecirculating systems, nutrient analysis of the leachate drainage from the root zone is a vital tool for commercial tomato growers to determine nutrient uptake ratios and to make changes to the stock nutrient solution as required.

Figure 1. Nutrient uptake data taken from the start of flowering in an NFT hydroponic tomato crop to day 40.

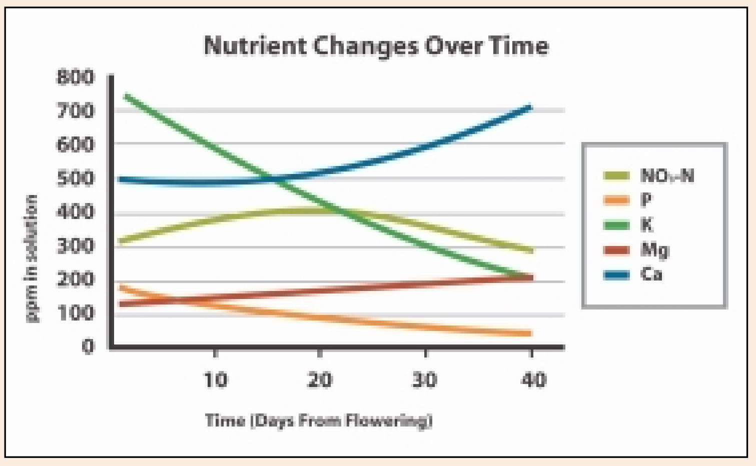

Figure 2. Nutrient stock solution element levels for each stage of growth in a commercial tomato crop.

Day	0 (Flowering)	10 (First fruit set)	20 (First fruit set)	30 (Full crop loading)	40 (Full crop loading)
Element	**Parts Per Million Required***				
Nitrogen	350	350	346	322	315
Phosphorus	170	176	188	202	215
Potassium	750	866	948	1,035	1,125
Magnesium	150	157	165	172	180
EC (mS/cm-1)	4.3	4.7			

Obtained from the nutrient formula.

varieties. Many growers find this to be a significant problem in warmer growing conditions. Trialing new varieties of greenhouse plum types, rather than those usually grown outdoors, is one way of reducing this problem.

'San Marzano' (F1) is one commonly grown plum or Italian type that features good fruit quality under hydroponic production. The fruit are large, averaging 4.6-5 oz. and can be used for fresh consumption or as "fresh paste" fruit. 'Azafram' is a yellow truss F1 hybrid tomato, averaging around 3.2-3.5 oz. and is a good variety for on-the-vine cluster sales of five to six fruit per cluster.

Cocktail, Cherry and Miniature Types. Cocktail tomatoes, averaging 0.7 oz. in weight, produce lower yields than larger cultivars and have a higher labor requirement for harvesting, grading and packaging. The industry standard types for red cocktail fruit are 'Cherita' (F1), 'Flavorita' (F1), 'Gardeners Delight', 'Sweet 100' (F1) and 'Chiquita' (F1). All of these produce similar fruit and yields under hydroponic production, although there have been advances in disease resistance with some of the newer varieties, such as Flavorita.

Currant, grape, olive, golden and pear-shaped versions of small-fruited tomatoes are also available, many of which have potential in specialty markets. 'Sun Gold' (F1) is a yellow cocktail tomato that performs well under greenhouse conditions. Red and yellow currant and red and yellow pear are some of the non-hybrid, small-fruited types worth experimenting with for fresh local sales.

NFT AND DFT

Nutrient film technique (NFT) and deep flow technique (DFT) are two media-free systems of production that feature a flow of nutrient solution inside growing channels that contain the root system of the plants. NFT and DFT are used in many commercial and hobbyist tomato production systems. Tomato plants thrive in well-run water culture systems. However, like with any recirculating system, monitoring nutrient levels is essential for commercial production.

NFT systems rely on a thin flow of nutrient along the base of the nutrient channel. Channels are often constructed of rigid PVC and specially designed and manufactured for hydroponic crop production or formed from thick plastic film that's folded up to form a triangular-shaped channel. Rigid PVC channels are more common for hydroponic tomato production. However, film-based channels are less expensive and can be disposed of between crops to prevent disease carryover. NFT channels for tomato production need to be larger than those used for lettuce, herbs, strawberries and other small hydroponic crops. Channel dimensions of 6 x 8 inches are common in larger tomato operations as a large area is required to contain the root systems of long-term crops. Channels with removable lids are convenient for plant removal and cleaning the inside of the gully.

DFT is less common than NFT for hydroponic tomato production and relies on a similar system of channels that are filled with a deep flow of nutrient solution rather than a thin film. DFT systems rely on the introduction of oxygen along the entire length of each growing channel so that oxygenation rates in the root zone are continually kept high enough for good root growth. As with NFT, the nutrient solution recirculates continuously and EC, pH and often temperature levels are adjusted at the main nutrient reservoir. Both NFT and DFT systems can produce yields and fruit quality similar to plants in media-based systems.

Tomato seedlings for both NFT and DFT systems are usually raised in an inert media, such as rockwool propagation cubes or small containers of soilless media. Rockwool propagation blocks are most commonly used because they don't release small particles of media into the recirculating system that could cause irrigation blockages. Many tomato seedlings are raised to the point of flowering on the first truss before planting out into NFT systems and the propagation cube provides support for the young plant for the first week until training has begun.

OTHER SYSTEMS

There are a number of other systems that are often used for hydroponic tomato production on small and large scales. Ebb-and-flow, continual flow gravel bed, capillary, soilless organic and aquaponic systems, which integrate fish and crop production, are all used for hydroponic tomato production, often with good success. As with other systems, the way the plants and nutrients are managed tends to be dependent on whether the system is recirculating or runs to waste and the method of irrigation.

RECIRCULATING VS. NONRECIRCULATING SYSTEMS

One of the most important aspects of hydroponic tomato production is nutrition. Tomato plants, particularly modern hybrid cultivars, have the potential to be extremely high yielding compared to crops grown a few decades ago. Top producers can now expect to obtain over 1.4 oz. per square inch per year of high quality tomato fruit compared to only around 0.6 oz. per square inch per year from older varieties grown a few decades ago. This huge increase in yield potential has also seen massive increases in the amount of nutrients taken up by the plant to support these yields and vigorous plant growth in controlled environments. There isn't one ideal or optimal nutrient formulation for hydroponic tomato crops. Each crop is different and requires continual monitoring of the nutritional status of the plants.

Recirculating systems require a very different nutrient formulation

Cocktail tomatoes are popular in some markets.

and management system than nonrecirculating systems. Recirculating systems tend to start off with a well balanced nutrient formula that features plenty of each element for plant uptake. However, by the time the solution has passed through the root systems of the plants, certain nutrients may have been taken out more than others, causing imbalances in the nutrient solution that are unknown to the grower. As the EC is adjusted each day with more stock solution and additional water, some of the nutrients under heavy demand are replaced — but sometimes not to sufficient levels. One example is potassium. In recirculating systems where tomato plants are carrying a heavy crop load, potassium can be depleted within a few days despite frequent additions of concentrated nutrient stock solutions.

In nonrecirculating systems, which are often seen as wasteful of nutrient solution since the excess runoff drains to waste, fresh nutrient solution is applied at each irrigation. Therefore, there is less of a chance that elements will be depleted over the long term (as long as a well-balanced nutrient formula is continually being applied). However, even in these systems, the nutrient needs to be monitored on a regular basis to determine plant nutrient uptake rates and to modify the nutrient formula. Tomatoes are extremely heavy feeders, particularly when carrying a heavy fruit load, and samples of runoff often show potassium and micronutrient depletion during certain crop stages.

SINGLE-TRUSS CROPPING

Single-truss tomato production was originally developed in the 1960s by Dr. Allen Cooper of the Glasshouse Crops Research Institute in the United Kingdom and has been examined by a number of researchers over the last four decades. In fact, the NFT method of tomato cropping was initially devised for single-truss production.

In the single-truss system, the plants have the growing point removed after the production of 2-3 leaves above the first fruit cluster. All lateral shoots are removed as they form and the plants are grown at a high density of 12-16 plants per square meter in order to maintain maximum yields. The concept behind the development of this system was to produce at least four crops per year per greenhouse and attempt to increase the efficiency of tomato production.

Single-truss cropping is usually carried out on growing benches at a convenient working height. Since the average single-truss plant doesn't grow any higher than around 30 inches tall, the plants can be grown in small (4 x 6 inch) NFT channels on growing tables. This makes planting, harvesting and crop care more comfortable for workers and also means that artificial lighting can be used to maximum efficiency on the shallow canopy that single-truss plants create.

Perhaps the most interesting advantage of single-truss crop production is the improved quality of the fruit. Since the fruit truss develops on the plant after the growing point has been removed, there isn't any competition for assimilates from new leaves, other flowering trusses, or fruit on the same plant. Single-truss fruit tend to develop rapidly larger-than-average fruit size and have extremely high compositional quality in terms of sugars, acids, dry matter content and overall flavor. In fact, the compositional quality of single-truss tomatoes has been proven to be significantly greater than the same tomato cultivar grown under similar conditions — even in poor light during winter production. The most significant finding, however, was that single-truss fruit not only had a higher compositional quality but that applying high EC levels to get increases in quality didn't result in the type of yield losses that occur in multi-truss crops growing under high EC conditions. Therefore, single-truss cropping has the potential to produce the highly flavored tomato fruit that consumers are continually asking for without the yield losses to the grower than normally accompany such quality.

One of the main reasons why single-truss cropping has been studied is the fact that the time from planting to harvest can be precisely estimated, and computer models have been developed to calculate such figures. This means that if a grower wants to target a particular market date with an entire crop, it can be determined exactly when plants need to sown or planted. Single-truss crops develop rapidly once the growing point has been removed and have been used as filler short-term crops in greenhouses that are used for other plants and are empty for a few months a year. This is also useful where growers want to produce one last crop before winter sets in and growing becomes economically prohibitive. It's also possible to produce fruit continually by planting out blocks of seedlings every three weeks so that there's always a block of mature fruit being harvested while others are in various stages of development.

The single-truss system has proven to produce yields as high as 1.4 oz. per square inch per year, which is compatible to top tomato producers using the multi-truss system — although there's a higher requirement for growing seedlings, planting and plant removal.

Long-term tomato crops are frequently lowered and layered.

YIELDS AND FLAVOR QUALITY

There are numerous reports from all over the world stating that consumers are often disappointed with fresh tomato flavor, and out-of-season greenhouse tomatoes are often described as watery or tasteless. This may be due to the fact that many modern varieties haven't been bred for flavor or because they're grown intensively with emphasis on yield, good visual quality and long shelf life. This is unfortunate since tomato crops can be manipulated by the nutritional program used to improve fruit quality. Selection of different cultivars also plays a major role when looking to improve fruit flavor, and many growers are now producing "high flavor" lines.

A number of factors influence tomato fruit flavor: plant genetics, light levels, temperature, water stress, raised salinity, fertilizer additions and leaf area (as influenced by the training system used). Many of these variables can be manipulated by growers to increase the flavor of tomato fruit.

Light is the chief factor that determines the level of photosynthesis of the plant and thus the amount of sugars and dry matter available to the fruit. Poor light results in low sugar and dry matter content by limiting photosynthate production. Researchers have found that the soluble solids of tomato cultivars increase significantly under a 16-hour day as compared to a 12-hour day but that fruit acidity isn't affected. The effect of season is linked to changes in both light and temperature, which have a major influence on fruit quality. Both temperature and light affect color in tomato fruit, while soluble solids are known to increase with a reduction in available media moisture and periods of high temperature. High air temperatures (above 84° F) are detrimental not only to tomato fruit yields but also quality. Fruit needs to be protected from direct radiation in areas of high light intensity. High greenhouse temperatures have been linked to lower-quality fruit and lower yields with a high incidence of soft fruit with a limited shelf life as well as ripening disorders, such as blotch and crazing. Excessive leaf removal around the lower fruit trusses is also another common cause of poor fruit quality. Leaves are required to produce sugars for importation into the fruit and leaf removal has been shown to significantly lower fruit quality on surrounding trusses.

One of the easiest ways to improve tomato flavor lies within the root zone. How the grower manages water and fertilizer inputs has a major effect on both the yield and quality of the fruit produced. The simplest way of increasing the flavor constituents of tomato fruit is to increase the EC of the nutrient solution. This will help produce fruits ➧

Cluster tomatoes are popular in many high-end markets.

with a higher percentage dry matter, sugar and acid and, consequently, better taste and firmness. This has been found to be the case with both large-fruited and cherry tomatoes. It has been found that both sugars and acidity levels increased in the cherry cultivar Gardeners Delight with fruit grown at an EC of 10 mS/cm^{-1} as compared to an EC of 2.5 mS/cm^{-1}. Other studies have reported that the dry matter content, sodium content and acidity of fruit grown at an EC of 8 mS/cm^{-1} was greater than fruit grown at 3 mS/cm^{-1}.

Increasing the EC to boost fruit dry matter content reduces the rate of water accumulation and subsequent cell enlargement, so a loss in yield is almost inevitable. Therefore, there has been little incentive for a commercial grower who is paid by the pound to increase fruit quality — until recently, with the increased consumer interest in fruit taste.

HIGH YIELDS, EXCEPTIONAL TASTE

Hydroponic tomato production involves a number of complex interactions between plant genetics, the environment, and management of the crop, each of which plays a role in fruit yield and quality determination. However, the tomato fruit provides many opportunities for growers — both large and small — to manipulate both plant growth and the flavor quality of the fruit with the use of nutrition, training and cultivar selection. With the right information and experimentation, tomato fruit of exceptional taste and high yields can be achieved from a wide range of different soilless production systems. GPN

Lynette Morgan holds a Ph.D. in Vegetable Production from Massey University, New Zealand and contributes regularly to* The Growing Edge *magazine. She may be reached by E-mail at suntecnz@xtra.co.nz.

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