# Controlled Environment Agriculture:


# A Sustainable Option

*Hydroponically grown tomatoes (above) in the CEA greenhouse at the University of Arizona (left) .*

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Controlled Environment Agriculture (CEA) is an agricultural production procedure providing high-valued fruits, vegetables, and flowers to world markets. The University of Arizona's Controlled Environment Agriculture Center (CEAC) is pursuing research, education, and outreach programs aimed at further developing CEA as an economically, environmentally, and socially sustainable agricultural option.

CEA uses an integrated science and engineering approach to establish the most favorable conditions for plant productivity, while optimizing resources such as water, energy, space, capital, and labor. Regulating the aerial and root environment is a major concern in CEA systems; therefore crops are grown, often without soil, inside greenhouses designed to control air and root temperatures, light, water, plant nutrition, and climate.

Greenhouses are typically covered and have environmental control hardware to prevent wind, rain, extreme temperatures, excessive solar radiation, insects, and animals from damaging the crops. Evaporative cooling and natural ventilation cool crops during the day, and natural gas provides heat as required. Plant growth is further enhanced by using the natural gas exhaust from heaters to raise carbon dioxide levels in the greenhouse from the ambient 355 parts per million (ppm) to a target range of 800-1,000 ppm.

## *What Is Being Grown?*

CEA can grow virtually any crop, including root crops, although the method may not be economically viable for some, such as tree crops. The best choices are high-valued, high-productivity crops, such as tomatoes, cucumbers, sweet peppers, and flowers, for which there are economic rewards for year-round availability and high quality. Peaches, avocados, papayas, pineapples, and grapes do not appear to be economically feasible options, but strawberries, raspberries, and other berries may prove to be.

## *Optimal CEA Locations*

The ideal climate for CEA has clear, sunny skies, low humidity for effective evaporative cooling, and temperature ranges typical of those in the semi-arid Southwest at elevations of 4,000 to 6,000 feet above sea level. Sites should also have low risk of such natural disasters as heavy snow, hurricanes, violent thunderstorms, and hail that could damage greenhouses. In addition, a reliable, high-quality water supply is critical.

> *CEA can produce crop yields that exceed field production as much as tenfold, with greater consistency and quality.*

CEA vegetable production is developing rapidly in semi-arid regions of Mexico and the southwestern United States. Arizona is the largest greenhouse vegetable producer in the country, with about 250 acres under cultivation. The United States has about 1,460 acres of CEA vegetable production of an estimated 29,500 acres of total greenhouse production that includes nursery, floriculture, seeds, mushrooms, and sod (USDA, 2002). Mexico traditionally has about 1.65 million acres of vegetables in field production, but the greenhouse vegetable industry grew from about 1,100 acres in 1999 to more than 2,350 acres in 2003 (Benavides and Ramirez, 2003).

## *Hydroponics Well-Suited to CEA*

Greenhouse food production usually includes hydroponics, a nurturing procedure without soil. The hydroponic solution consists of water and elemental salts. In addition to standard fertilizer components (nitrogen, phosphorous, and potassium), calcium and magnesium are added to the solution in lieu of applying lime to soil. Fourteen minor elements normally found in soil, including iron, manganese, and zinc, are added to the hydroponic solution as soluble compounds. Solution pH is monitored continuously to maintain a range of 6.2 to 6.5, and electrical conductivity is monitored to keep total dissolved solids between 2.5 and 3 milliSiemens per centimeter. Lab analyses of the 19 elements typically are run twice per month.

Hydroponic systems are of two basic types: open systems that discharge a portion of the hydroponic solution, and closed recycling systems. The trend is toward the more efficient closed systems, despite their greater requirements in terms of capital costs and expertise requirements. Note that even in "closed" systems, built-up salts must be periodically discharged, and in "open" systems, some discharged water and nutrients may be captured and re-used.

While greenhouses and hydroponic systems employ cutting-edge technology and are capital-intensive, most employees need only basic agricultural skills. Supported by the control technology, growers match plant varieties, production age, and market demands to current and projected climate conditions to obtain optimal marketable yields.

## High Water-Use Efficiency

Hydroponic greenhouse systems consume much less water for a given crop yield than traditional cultivation. On average, the tomato hydroponic system has a system water use efficiency of about 288 gallons of water per pound of tomato yield, compared to around 1,670 gallons of water per pound with traditional field production. This savings is attributed to precise application of water, appropriately timed irrigation scheduling, less demand from wind-induced evapotranspiration, greater plant yields, year-round production, and generally healthier plants with controlled conditions. Recirculating hydroponic systems save even more water.

## Other Advantages

**High Production Rates**: CEA can produce crop yields that exceed field production as much as tenfold, with greater consistency and quality. Compared to seasonal field production, CEA has been shown to increase annual production of cucumbers, tomatoes, and sweet peppers from 2 to 16, 1 to 12, and 1 to 6 pounds per square foot, respectively.

**Salinity Issues Minimized**: A great benefit of environmental control in greenhouses is that increased soil salinity, an issue in field production because of its negative effect on marketable yield and quality, is minimized. These benefits are achieved through daily management of root zone salinity and atmospheric humidity to modulate plant transpiration. As a result, CEA that employs a recirculating hydroponic system not only ensures total reuse of water and nutrients, but also improves fruit quality while saving water and decreasing nutrient emissions.

**Pest Control**: By keeping out most harmful insects and keeping in those that are beneficial, greenhouses provide an environment conducive to chemical-free, integrated pest management. Thus, CEA can generate higher yields of improved-quality, pesticide-free crops, using less land than traditional field agriculture.

## Looking Ahead

Today, CEA research focuses on improving fruit quality, taste, and nutrition. Efforts are also underway to improve water use efficiency with respect to both plant evapotranspiration and evaporative cooling. One research goal is to replace light and infrared sensors that were originally developed for environmental monitoring of field crops with sensors inserted directly into the plants to monitor photosynthesis and other plant processes.

The future of CEA lies beyond standard food production, to such areas as production of "nutriceuticals," plants grown for their healthy byproducts, such as high-lycopene tomatoes (believed to help prevent cancer) and antioxidant-rich watermelons. "Farmiceuticals," plants that are genetically modified so as to produce vaccines, may be well suited for CEA because they would not be grown in open fields where cross-pollination could occur. Phytoremediation, a procedure to harness plant bioprocesses to extract soil or water contaminants and provide for their disposal, may also benefit from CEA techniques. For example, contaminated land could be made suitable for soil-grown crops by erecting a greenhouse over it and extracting soil contaminants. It may also be feasible to pump water from a contaminated river or aquifer into a greenhouse hydroponic system that then cleans the water before returning it to the environment.

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## References......................................

*Benavides, A., and H. Ramirez, 2003. The world of horticulture: horticultural science and industry in Mexico – an overview. Chronica Horticulturea 43(3):20-25.*

*USDA National Agricultural Statistics Service, 2002 Census of agriculture. nursery, greenhouse, floriculture, mushrooms, sod and vegetable seeds grown for sale. www.nass.usda.gov/census.*