The Vertical Farm Project:

Maximally Viable Crop Profile

Jasmine Beria, Bryan Garber, Natalie Neu, Nicholas Sebes, Adrienne Sheetz

Medical Ecology

Dr. Dickson Despommier

April 27, 2006

Executive Summary

- There is historical precedent for farming indoors. The Vertical Farm Project just may be the twenty-first century's answer of how to provide food in urban settings to a large population.
- Commercial greenhouse crops currently produced include: tomatoes, lettuce, peppers, herbs, strawberries, fish species and others.
- Use and research into expanding indoor cultivation of food and medicinal crops farmed is necessary
- Experimental crops to be considered, based on economic profitability, yield increases, nutritional value and genetic modifiability include: sugar cane and sugar beets, corn, wheat, rice, fish (tilapia) and others.
- Indoor farming modalities proposed for the vertical farm will vary by location of the farm and the desired crop product. Systems to consider include: hydroponics systems (liquid medium and float systems), aquaponics, soilless solid systems and aeroponics.
- Partnering with the pharmaceutical industry for the creation of the vertical farm makes sense both economically and environmentally. As many of our current pharmaceuticals are products of higher plants, this collaboration will help both the industry and the population offset the cost of the project and to produce a product with high market value.

Greenhouse Evolution - from 30 A.D. to present day

One of the earliest documented greenhouses, referred to as a "specularium", was constructed around 30 A.D. for the Roman emperor Tiberius. This structure was created to promote the year-round growth of cucumbers. However, since glass had not yet been invented the greenhouse-like structure was fabricated from tiny translucent sheets of mica. The ancient Romans used these window coverings to hold in solar heat for their homes and bath complexes but also relied on such solar heat traps for horticulture so that plants would mature quicker, produce fruits and vegetables out of season, and allow for the cultivation at home of exotic plants from hotter climates. Centuries later, the first practical greenhouse was constructed by a French botanist, Jules Charles. It was built around 1599 and used to grow primarily medicinal tropical plants. Years of experimentation to improve the efficiency of greenhouse production via the implementation of heating/cooling systems, lighting technology, as well as nutrient and disease management has improved the crop yield capacities by maximizing the optimal conditions for plant growth.[1,2] These improvements to indoor crop management have allowed for the current successes of commercial crop production. Also, as current indoor agricultural techniques continue to evolve, further improve crop yield and growth efficiency, the utilization of indoor farming should be considered a viable alternative to conventional methods of staple crop production.

---

[1] http://www.spaceref.com/news/viewnews.html?id=455
[2] http://www.geocities.com/PicketFence/6769/

Today, current greenhouse producers benefit from the elimination of external natural processes, such as drought, flood, and pests, as confounding elements to food production. Currently, greenhouses are used commercially to grow such crops as tomatoes, peppers, cucumbers, lettuce, along with various vegetables, such as strawberries, and herbs such as basil, sage and rosemary. Worldwide, greenhouse vegetable production is led by Spain, the Netherlands, Mexico, Canada, and the United States. Among these countries, the Netherlands, Canada, and the U.S. utilize high technology greenhouses with significantly higher yields. Where as the production systems in Mexico and Spain range from low to high end technology greenhouses, with Spain utilizing mainly shade cloth production not glass production. Production areas in hectares (ha) include: Spain (70,000 ha), the Netherlands (4300 ha), Mexico (1,520 ha), Canada (876 ha), and the U.S. (395 ha).[3]

Country	Production Area (ha)
Canada	876
United States	395
Netherlands	4,300
Mexico*	1,520
Spain*	70,000

[3] www.agf.gov.bc.ca/ghvegetable/publications/documents/industry_profile.pdf

North American Commercial Greenhouse Production

Table 2: 2002 North American Greenhouse Vegetable Production Area (ha) of Major Crops

	Production Area (ha)			
Crop	***Canada***	***US***	***Mexico***	***Total North America***
Tomatoes	482	350	790	1,622
Cucumbers	199	25	118	342
Bell Peppers	174	20	210	404
Total	855	395	1118	2,368

Source: BC Vegetable Marketing Commission

North America is home to one of the largest greenhouse complexes in the world. Located in Leamington, Ontario, this complex houses nearly 200 acres of tomatoes and exemplifies the growth of greenhouse crop production utilized in North America. In the last decade, Canadian greenhouse vegetable production grew at a rate of 20% a year, due to new greenhouse vegetable production technology that was transferred to commercial producers. This technology has been primarily responsible for dramatic yield increases over the last 7-8 years, estimated at 100-120% for tomatoes and 70-80% for cucumbers".[4] During this time rapid expansion has also occurred in the US and Mexico, however expansion in the US and Canada appears to have stabilized while Mexican production continues to expand. The main greenhouse vegetable crops in Canada today are tomatoes [468 ha (1171 acres)], cucumbers [190 ha (475 acres)], sweet peppers [144 ha (361 acres)] and lettuce [21 ha (53 acres)].[5]

Currently, 37% of all tomatoes currently sold in the U.S. are greenhouse exemplifying the importance of greenhouse production as it relates to the U.S.

[4] http://www.attra.org/attra-pub/ghveg.html
[5] Cook, R., Calvin, L. (2005) Greenhouse Tomatoes Change the Dynamics of the North American Tomato Industry. Economic Research Report No. (ERR2) 86

food supply.[6] Tomatoes are the leading greenhouse vegetable crop, followed by European cucumbers, lettuce, peppers, and culinary herbs such as basil, sage, and rosemary. In addition, growers aiming at niche markets raise specialty crops, greens, and Oriental vegetables.[7] The leading states in greenhouse vegetable production are California, Florida, Colorado, Arizona, Ohio, Texas, and Pennsylvania–all with over one million square feet of production each.[8] Throughout the U.S., universities, commercial growers, and even NASA are currently experimenting with various indoor growth techniques and specialty crops, highlighting the growth of the industry as well as the possibilities for future improvements in crop production.

Commercial Crops	Experimental crops	Research Centers & Universities
• Tomatoes • Cucumbers • Lettuce • Peppers • Strawberries • Herbs • Raspberries • Tobacco	• Bok choi • Spinach • Chinese Cabbage • Mustard greens • Upland cress • Wheat • Corn • Rice • Sugar cane • Sugar beets	• Cornell University • Univ. of Kentucky • Ohio State Univ. • N.C. State Univ. • Univ. of Arizona • Penn State Univ. • Univ. of Minnesota • Univ. of Wisconsin • Texas A & M • Kansas State Univ. • NASA • Utah State • Univ. of Florida • Univ. of Tennessee

[6] www.ers.usda.gov/publications/err2/
[7] http://www.attra.org/attra-pub/ghveg.html
[8] Census of Agriculture. 1997. U.S. Census of Horticulture Specialties. Bureau of the Census, U.S. Department of Commerce, Washington, D.C.

Vertical Farm Crops

Vertical farming has been proposed as a possible solution to increase the world's food supply and decrease the ecological impact of farming on the earth. One vertical farm acre has been said to be equivalent to 20 acres of traditional soil acres.[9] Thus one must decide which crops are the most cost effective, nutritionally relevant, and economically plausible and which can be processed in a vertical farm setting. We have selected several crops either for their ease of growth, track record of increased yield in an indoor setting, excellent nutritional value and potential use as alterative fuel sources that will also be necessary to make the vertical farm self-sustainable. **Note:** This list is not comprehensive. It represents the primary commercial crops currently being produced along with experimental crops by various producers and research institutions.

Sugar

Sugar is an important product for cooking and for its role in energy production in the form of ethanol. Sugar is produced in 121 Countries and global production now exceeds 120 Million tons a year. Approximately 70% is produced from sugar cane, a very tall grass with big stems which is largely grown in the tropical countries. The remaining 30% is produced from sugar beet, a root crop resembling a large parsnip grown mostly in the temperate zones of the north.

[9] www.verticalfarm.com (essay II)

This map illustrates the different locations of sugar production either by cane or beets. As one can see, the sugar cane crops are primarily located in the tropical zones where as the beet sugar crops are in the temperate climates.[10]

Crops

Sugar is produced from two crops; sugar cane and sugar beets. Sugar cane is a genus of tropical grasses that require sunlight and abundant water. Many cultivars are available e.g. Saccharum officinarum, S. spontaneum, S. barberi and S sinense. Crops can grow in 2 ½ - 12 months and can be cut to yield another crop as long as the roots remain intact. The cane can grow to be up to 5 meters tall.

Sugar beets are biennial root crops that grow primarily in temperate climates (North American, Asia, and Europe). The roots are where the sugar is stored and are very sensitive to moisture. Depletion of moisture should not

[10] (www.sucrose.com- a site for Sugar Knowledge International Limited)

exceed 50% or this will have a very negative impact on the yield. Irrigation is critical and will lead to increased cost of production. Outdoor crops require increased moisture from July to September. The growing requirements and the ability to monitor and control for these requirements of sugar beets make this an ideal product for a vertical farm.

Important considerations for the location of sugar crop growth

In our urban, vertical farm, the cane sugar could be grown through subcontracts with tropical countries, such as Brazil. Alternatively, by working with environmental and architectural engineers, we could create a tropical environment in our vertical farm. The sugar cane crop is presently grown outdoors due to its large size and the length of time needed for growth. However, it may be possible in the near future with genetic engineering to create a smaller sugar cane variety that could easily be grown indoors.

Sugar beets, on the other hand, can grow in any type of soil but grow best in hot days followed by cool nights. The plants are very sensitive to moisture levels and thus a highly regulated environment such as a greenhouse maybe a reasonable site for growth. However, sugar beets reach growth depths of 6-8 feet and thus this would require some specific growing areas to support that size. Locations for growing must include space for storage. In addition, after harvesting the product needs to be transported to factories, where it is stored out doors prior to processing. Beets will keep for several weeks after harvesting without substantial loss of sugar content. This is of value as the beet will not

substantially loose value due to a short shelf life. Beets need protection from frost, overheating and must have proper ventilation when in storage sites.

Limitations of the sugar crop: Sugar processing

Sugar is produced from sugar cane in two processes: 1. Raw sugar is derived from the cane and is easily shipped to the country where it is needed; 2. Food quality sugar is created from the processing of raw sugar in the country where the product is shipped to create the white, purified sugar. The sugar content of the cane is approximately 10% of the weight of the cane and varies by season and location. Estimated values for production are 100 tons of cane per hectare or 10 tons of sugar per hectare. The sugar content of a mature beet is approximately 17% of its weight. This varies by variety and location. This yield is more than the sugar cane (10%) but the yield of beet per hectare are much lower so the expected sugar production is only approximately 7 tons per hectare, as compared with 10 tons per hectare for sugar cane. Recently there has been research into the use of genetic engineering to modify the enzymes in the sugar cane in order to enhance or ease the processing of the crop. This will help increase the yield of our sugar cane crops in the future.

Cost/benefit analysis

The benefits yielded from sugar cane crops depend on the cost of the processing. Processing is quite complex with several steps that require energy, labor and factory infrastructure to yield a good and sufficient product. Sugar

cane processing requires the following steps: Harvest of the cane crop and transport to a processing plant; Extraction of the sugar, as the cane juice is crushed and mixed with water; Evaporation- during which the factory will clean up the juices with slaked lime, a relative of chalk. This process removes a lot of the dirt, which is sent back to the fields. The juice is then thickened into a syrup by boiling off the water using steam; Boiling is the last stage, where the syrup is boiled down to sugar crystals and dried with hot air; The raw sugar can be stored in a clean, dry location and shipped out as requested by countries.

Beet sugar is easier to process than cane sugar in that it requires only one stage, and the purified white sugar is the only product. Southern Minnesota Beet Sugar Cooperative Factory represents a typical processing plant, and is built on one square mile of land. It is designed to process 6500 tons of sugar beets per day and 11,250 cwt of sugar per day. Sugar beet processing includes the following: The beets are cleaned and trash removal is by a by wet hopper system; The beet is then sliced into long noodle-like pieces called cossettes; Diffusion occurs when the cossettes are dropped into hot water to dissolve out the sugar through osmosis as water passes through the porous membrane of beet. This produces raw juice and beet pulp which goes to the dryer; Purification and filtration of raw juice is done by heating the mixture with milk of lime and CO2 which then thickens the product; Boiling, evaporation and centrifuging the material to get sugar crystals from liquor of sugar syrups in the final step. This removes the impurities. By products from pressing the beet slices into pellets can be used for animal feed. One of the challenges with sugar beet processing

is the tremendous energy requirement for drying of the beet pulp. In addition, and unlike with sugar cane, processing of the sugar beets does not yield any potential energy byproducts, such as the bagasse of sugar cane.[11]

Products and byproducts of sugar cane and sugar beet processing beyond the sugar product:

1. Molasses is a byproduct which is used to feed cattle, and is thus a byproduct which may help sustain other food sources.

2. Alcohol is created from the juices at distilleries. Alcohol is of high demand in a market economy, and if the alcohol is of good grade, this byproduct can help increase the capital income coming back into the Vertical Farm.

3. Bagasse is the fiber that comes from crushing the sugar cane. The electricity and the steam for the factory can be generated using the bagasse. When the bagasse is burnt in furnaces, the heat given off can be used to boil water to create the steam to drive a turbine to make electricity and create low-pressure steam for the sugar making process. As bagasse fuel is renewal energy and the CO2 it produces is used in growing new cane, the system and factory can be environmentally friendly.

4. Ethanol

A recent article from the Associated Press on April 18, 2006 stated that in Brazil, 7 out of 10 cars will use ethanol as a fuel source. Currently the cane harvest in

[11] http://www.sbreb.org/brochures/SugarCoop/

Brazil yields 92,500 gallons of ethanol daily. In addition, the sugar cane waste is burned to generate steam for the turbines, meeting all of the plant's electricity needs. Excess power will soon light up half the homes in São Tomé, a southern Brazilian town of 6,000. Thus, the energy created from the processing of the cane can be sold back to the energy grid of the city/town that is associated with it.[12]

Ethanol is currently being investigated and supported as a fuel alternative especially in South American. The U.S.government has recently become more interested in the potential of this alternative fuel as the price of oil increases. As a transportation fuel, ethanol can be used as a total or partial replacement for gasoline. Gasoline containing ten percent ethanol, E10, is used in many urban areas that don't meet clean air standards. Some states promote more widespread use of E10. Minnesota, for example, requires almost all gasoline sold in the state to contain 10 percent ethanol. All vehicles that run on gasoline can use E10 without making changes to their engines. Over 90 percent of the ethanol produced in the United States is mixed with gasoline to make E-10. E85 is an alternative fuel that is 85 percent ethanol and 15 percent gasoline, used mainly in the Midwest and South. Vehicles are not modified to run on E85; they are specially manufactured as flexible fuel vehicles (FFV). Flexible Fuel Vehicles can use any mixture of ethanol and gasoline up to E85. There are about 146,000 cars and trucks using E85. Almost half of these are private vehicles; the rest are fleet vehicles.[13]

---

[12] http://www.chron.com
[13] http://www.eia.doe.gov/kids/energyfacts/sources/renewable/ethanol.htm

Green beans

Crop

Most commercial green bean cultivars grown today are bush-type. This is primarily because they are mechanically harvested and thus eliminates the cost of a picking crew. Growing the beans in an indoor setting would allow for mechanization and automation which ultimately would significantly decrease cost due to limiting labor costs. However, we must still consider growing pole beans and half runner beans for these types of beans tend to have more flavor. Beans with enhanced flavor have an added value to consumers and will increase the income to the Vertical Farm. Additionally, pole beans mature throughout the growing season and therefore yield a larger overall harvest in the same amount of garden space as bush-type beans. A ten-foot row of pole beans should provide the average family of three or four with fresh beans about twice a week through the season.[14]

[14] http://www.victoryseeds.com

Varieties of beans[15]

Snap Beans	Pinto Beans	Lima Beans
Topcrop	UI-114	Jackson Wonder
Tendercrop	Luna	Florida Butter
Tendergreen	Dwarf Horticultural	Henderson Bush
Greencrop		
Kentucky Wonder		

Why beans are well suited to indoor farming

Green beans grow best in well-drained soil and plenty of sunlight. Beans grow best when the garden soil is well fertilized. If beans are picked when they are ready, the plants will continue producing for several weeks. Monitoring moisture and fertilizing will significantly increase the yield of the crop. A 15-foot row of pole beans will produce about 12 lbs of beans over a 6-8 week period. Thus this is a short crop season, which ultimately increases the yield due to repeat plantings.[16] In addition, green beans are susceptible to may pests and these factors may be easily controlled in an indoor setting.

Specific considerations and requirements for planting beans

If grown outdoors, beans should be planted in the spring. Indoor planting would not limit us to seasonal plantings. One needs approximately 1/4 to 1/2

[15] http://aggie-horticulture.tamu.edu/extension/easygardening/beans/greenbeans.html
[16] www.amazon.com-- Gurney's vegetable products

pound of seed for each 100 feet of row of green beans. For bush beans, the seeds should be planted about 1 inch deep and 1 to 2 inches apart in the row. The rows should be 2 1/2 to 3 feet apart. After the beans are up, thin the plants to 3 to 4 inches apart.

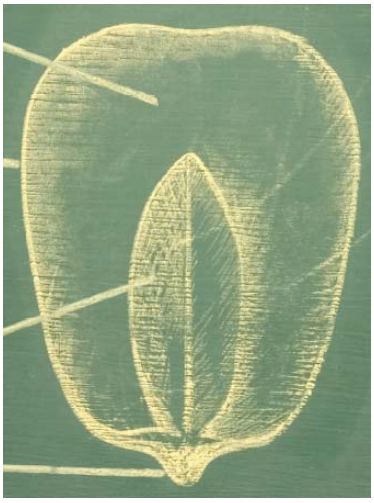
For pole beans, plant the seed in rows 3 to 4 feet apart. Pole beans grow on stakes vertically reflecting and mimicking the whole concept of the Vertical Farm. The Miracle Farms Commercial Hydroponics Greenhouse Complex uses a nutrient film technique to grow vegetables, namely green and yellow beans, in a water solution free of material based growing medium. This farm states that their green beans grow faster and larger than regular green beans.[17]

Processing of green beans

No processing is required for beans, but harvesting is labor intensive and thus merits an automated system. Bean product can be canned and frozen for future use, thus extending its shelf life.

Corn

In 2004, as the number one corn producer the United States planted 80.9 million acres and harvested 73.6 million acres, yielding 11.8 billion acres and a crop value of 23 billion dollars.[18] The



[17] http://www.astralstar.com/hydroponics.html
[18] http://www.ncga.com/WorldOfCorn/main/WorldOfCorn2005.pdf

vertical farm offers a viable solution for a reduction in stress put on natural ecosystems as a result of the tremendous acreage required for the production of this crop. Although the size of a typical corn plant (ranging from 5 feet to 12 feet tall, with a root system reaching 6.5 feet into the ground) offers a problem to indoor farmers, the container system of growing provides a suitable option for commercial indoor corn production.[19]

Crop Uses

The dynamic potential of the corn crop as a product of vertical farming exists in its multifaceted applications on both a consumer and industrial scale. To highlight the diverse uses of corn the Corn Refiners Association (CRA) has conducted surveys by sending researchers into a typical supermarket to read all the labels and tally all the products containing corn ingredients. The last CRA study found corn ingredients in almost 4,000 products not including all the meat, dairy, and poultry products that depend on corn for livestock feed or the many paper products that don't have ingredient labels but do contain corn.[20] The vertical farm needs to incorporate corn production to capitalize on the economic diversity the crop offers.

One Bushel of Corn
(56 lbs.) Provides:

31.5 lbs. of starch
OR
33 lbs. of sweetener
OR
2.8 gal. of fuel ethanol

Plus

13.5 lbs. of gluten feed*
2.6 lbs. of gluten meal**
AND
1.5 lbs. of corn oil

[19] http://www.clac.edu.eg/soilless_rof.htm
[20] http://www.iowacorn.org/cornuse/cornuse_20.html

Beyond the supermarket

Today, active research continues to rapidly expand the potential for corn. Perhaps the most significant application of this research is the use of corn energy to alleviate the current global energy crisis. Ethanol plants now have the capacity to produce 2.7 gallons of ethanol and about 18 pounds of animal feed from each bushel of corn. One acre of corn can produce 300 gallons of ethanol this is enough to fuel four cars for one year with a 10% ethanol-blend. The process of this production is so efficient that it takes less energy to grow the crop and process it than the amount of energy in the ethanol itself. When compared to fossil fuels the environmental benefits of ethanol is seen in its ability to lower harmful carbon monoxide (CO) emissions by 30%, reduce carbon dioxide (CO2) emissions by 27% and reduce the amount of noxious fumes and volatile organic compounds (VOCs).[21] As technology improves and the ethanol extraction is streamlined, corn fuel has the potential to address an even larger segment of the energy market. Within a vertical farm this energy could ether be used within the system or sold for a profit. Another alternative use of corn within the chemical industry is its potential to create esters

[21] http://www.iowacorn.org/ethanol/ethanol_3a.html

that can be used in solvents and plastics at a lower cost then conventional separation techniques.[22]

Pharmaceuticals

The indoor farm seems to provide a viable solution for the problems facing the further development of corn based pharmaceuticals. Today, strict regulation within the US limits the economic potential of the corn pharmaceutical industry. Plants being grown for the manufacture of biotechnological medicines can only be grown under USDA APHIS permit.[23] In addition, The USDA's rules require that fields be inspected seven times before, during and after production. And to prevent cross-pollination of conventional corn, the pharmaceutical plots must be kept a half-mile to a mile away from other cornfields and planted later in the growing season.[24] As a result, the USDA reports that in 2002, total U.S. test trials only consisted of 20 permits governing 34 field sites for a total of only 130 acres.

The vertical farm, because of its controlled environment, is the ideal for the development of corn pharmaceuticals through an application of biotechnology to plants that enables them to produce therapeutic proteins that could ultimately be used by the medical community to combat life-threatening illnesses. In this process, plants become "factories" that manufacture therapeutic proteins. These proteins are then extracted, refined and used in pharmaceutical production. Although normally biologists use bacteria to grow human proteins, corn has

---

[22] http://www.ncga.com/WorldOfCorn/main/WorldOfCorn2005.pdf
[23] http://www.iowacorn.org/cornuse/cornuse_13d.html
[24]http://www.checkbiotech.org/root/index.cfm?fuseaction=news&doc_id=12597&start=1&control=149&page_start=1&page_nr=101&pg=1

become a practical alternative because the plants have cellular structures that are much more like those of humans, making them easier to manipulate.[25] Today, researchers are currently in various stages of field trials and clinical trials of PMP production. It is estimated that it will be at least three to five years before full commercialization of the first corn pharmaceutical. However, corn has already been used to create proteins with medical applications ranging for the treatment of cystic fibrosis to antibodies effective at killing sperm.

Rice

Although largely in experimental projects, rice has been shown to be capable of indoor growth. Nearly 2.5 billion of the world's population relies on rice as a primary dietary staple, and advancements in the cultivation of rice can help to feed the next 50,000 people.[26] As the world's population grows, so to does the demand for greater supplies of rice. Growers have had to increasingly depend on nitrogen-based fertilizers to increase yield. Use of nitrogen-based fertilizers can negatively impact the environment, through pollution of groundwater and increased nitrogen oxides emissions.[26] If rice was able to be hydroponically grown with greater yields and on a large-scale, this may alleviate increased demand and ease the stresses on the environment.

Hydroponics systems are currently used in rice seedling cultivation programs, and several initiatives have proven the hydroponics capabilities of the crop. The Pasona O_2 underground farm in Japan has laid claim to the first

[25] http://www.biotech-info.net/conception.html
[26] Biwas, JC et al. Rhizobia Inoculation Improves Nutrient Uptake and Growth of Lowland Rice. Soil Science Society of America Journal. 2000. 64:1644-1650

harvest of a hydroponics rice crop.[27] The farm was able to produce 60 kilograms of rice daily, which is quite small by most standards. These figures suggest, however, that farmers would be able to harvest rice four times annually rather than just one harvest.[27] The yield of the indoor rice paddy was maximized through the addition of a fan system to mimic the winds, and through the increase in oxygen-content of the water to mimic the rains.[27] Great potential exists for hydroponic rice to benefit regions adversely affected by climatic conditions, such as typhoons.

NASA has also researched the potential for hydroponic rice, and was able to produce crops with protein content twice that of rice traditionally grown in a paddy.[28] Nitrogen occurs naturally in soil and can become fixed to soil particles and root systems, which decrease the amount absorbed into the plant. The rice plant readily absorbs nitrogen in a hydroponics system, and it is nitrogen that the plant converts into protein.[28] It is worth a note of caution, however, that increased nitrogen uptake may result in accumulation of nitrate compounds in the leaves of a plant, which may be converted into carcinogenic compounds.[28]

A study by NASA's Controlled Ecological Life-Support System was designed to research the effects of hydroponics growth modalities on the micronutrient content of rice, as well as wheat and potatoes.[29] Although nitrogen content was increased in the leaves and roots of plants produced in the hydroponics system, nitrates were not found in grains and tubers.[29] The authors

---

[27] http://www.timesonline.co.uk/article/0,,25689-1980829,00.html
[28]http://www.highbeam.com/library/docfree.asp?DOCID=1G1:17909382&ctrlInfo=Round19%3AMode19a%3ADocG%3AResult&ao=
[29] McKeehan, JD. Excess nutrients in hydroponic solutions alter nutrient content of rice, wheat and potato. Adv Space Res. 1996; 18(4-5):73-83.

suggest such increases or decreases in micronutrient levels through hydroponics cultivation have implications for ideal plant selection, genetic engineering and environmental controls to select for more nutritious crops.[29] Hydroponics growth systems may also affect the zinc and iron content of rice, and such variations will need to be addressed in future projects.[30]

NASA and Wheat Growth Indoors

NASA has been conducting an extensive research on wheat production. They have successfully cultivated both the common bread wheat, *Triticum aestivum* and Apogee wheat; more commonly referred to as "dwarf wheat".

Video screen shot of *Triticum aestivum* 20 days after planting inside the BPS, on ISS during Expedition 4

NASA experimentation is conducted with plants that offer a promising solution in providing food to astronauts thousands of miles from Earth. They could grow crops that would not only supplement a healthy diet, but also remove toxic carbon dioxide from the air inside their spacecraft therefore creating life-sustaining oxygen.

[30] Trostle, CL et al. HEDTA–Nitrilotriacetic Acid Chelator-Buffered Nutrient Solution for Zinc Deficiency Evaluation in Rice. Soil Science Society of America Journal. 2001. 65:385-390.

Many of the early Advanced Life Support studies with plants focused on developing large-scale systems envisioned for planetary outposts or colonies.[31] As a result, much of the effort focused on crops that were highly productive and that could provide sufficient quantities of carbohydrate, protein, and fat for the diet, such that of wheat. NASA's efforts on space have hopes to benefit us on Earth in that their research helps people on Earth understand how to better recycle waste and how to be better stewards of earth resources in general. For instance they are able to achieve five times the world record wheat yield and still recycle the nutrients for the next crop.[32]

One of the most current studies on wheat is that of the PESTO (Photosynthesis Experiment and System Testing and Operation). It studied the photosynthetic response of plant tissues grown in microgravity.[33] Gary Stutte is the principal investigator behind this experiment. This expedition was the first mission to use the Biomass Production System (BPS). Plants were sent to ISS in the BPS system and compared to that of the plants that remained on Earth in a BPS. BPS consisted of four plant growth chambers. PESTO operations grew Triticum aestivum in three to four chambers. Each chamber has 264cm square growth area, while the roots of the plant were place 3cm below the growth area. Thirty-two plants were cultivated in a period of 73days on ISS. The plants were exposed to 20 hours of light and 4 hours of dark. Temperature was held at 24°C and 78 percent relative humidity. A control group on Earth was treated with the

[31] http://pet.jsc.nasa.gov/crops/
[32] http://quest.arc.nasa.gov/space/chats/archive/09-26-01gg.html
[33] http://www.exploration.nasa.gov/programs/station/PESTO_lite.html

Close-up view of Apogee Wheat Plants grown as part of the PESTO investigation during ISS Expedition 4

same conditions and compared which yielded similar results. The PESTO investigation was successful in creating dwarf wheat plants.[34]

Gail Bingham from the chief scientist at the Space Dynamics Laboratory at Utah State University in North Logan has also done extensive research on wheat. Bingham has been working in this field since 1992. He originally pitched the idea of growing plants in space to NASA in 1985. Even though it was approved, it was never funded, hence in their frustrations; they turned to the Russians who have proposed funding. [35] In 1994 Bingham and his team launched their first study with the Russians and have been collaborating with them since. The first growth chambers, called Svet, were designed for the Mir space station, but the Russian station was deorbited into the ocean.

The first plants were grown in "Greenhouse" Svet, a small growth chamber originally built in Bulgaria during the late 1980s according to a joint Russian/Bulgarian design. The hardware was sent to Mir in 1990. Svet has a compact growing area of about one square foot and can accommodate plants up to 16 inches tall. Light was provided by fluorescent lamps which provide light at about one fifth the intensity of sunlight which is ample for plant growth. The wheat was grown in a substrate material similar to kitty litter but loaded with plant

[34] Ibid 33
[35] http://www.space.com/scienceastronomy/050719_ibmp_plants.html

nutrients. Water was injected directly into this material and transferred to the wheat seeds by a system of wicks. Day length and water injection into the plant growth medium were both controlled automatically to set points adjusted throughout the experiment by project scientists.[36]

In September 2002 the resulting growth chamber called Lada was launched aboard a Russian Soyuz rocket to the international space station which is expected to be used through 2006. Lada has since been used to harvest fast-growing plants such as peas, mizuna (a Russian leafy vegetable), wheat, peppers and rice with "no detrimental effects.

Soyuz 5 Commander Sergei Zalyotin examines plants grown in the Lada growth chamber located in the Zvezda Service Module on the International Space Station. Since its inception, the Lada chamber has been used to repeatedly harvest fast-growing plants such as peas, mizuna (a Russian leafy vegetable), wheat, peppers and rice. Image Credit: NASA.

The key to being able to repeatedly grow plants in space is to know how to

[36] http://www.scienceblog.com/community/older/archives/D/archnas2577.html

develop the hardware so the plants think they are in an environment where they originally developed," Bingham said. The Lada system is composed of two growth chambers, a control module and two water reservoirs, allows for the growth of plants without gravity, which on Earth pushes water into the soil and also opens up air pockets to allow oxygen to reach the roots. Two growth chambers require about 90 watts to operate on the station. They use a granulated mixture with time-released fertilizer instead of conventional soil. Fans in the growth chambers resemble Earth-like convections, which help to force oxygen through the water clumps blocking the openings to reach the roots. The oxygen-water balance in the root zone is balanced through sensors. As far as manual labor, station crew members typically devote about an hour a week to Lada experiments as per Bingham.

The advancements in space can allow us to advance greenhouse and controlled environment agricultural systems as that of the Vertical Farm and it will help farmers produce better, healthier crops in a small space using the optimum amount of nutrients. As land becomes scarce, and less fertile, the availability to grow food declines dramatically. Alternative agricultural systems such as he Vertical Farm and indoor greenhouses, will efficiently produce greater yields of high quality crops.

Lettuce Crop

Supply and Demand

Lettuce is believed to be one of the first vegetables brought to the new world by Christopher Columbus and has been grown since colonial times.[37] Today in terms of production value, it is the leading vegetable crop in the United States. It generally comes in three different varieties: iceberg, known crisphead or head lettuce, leaf and romaine.

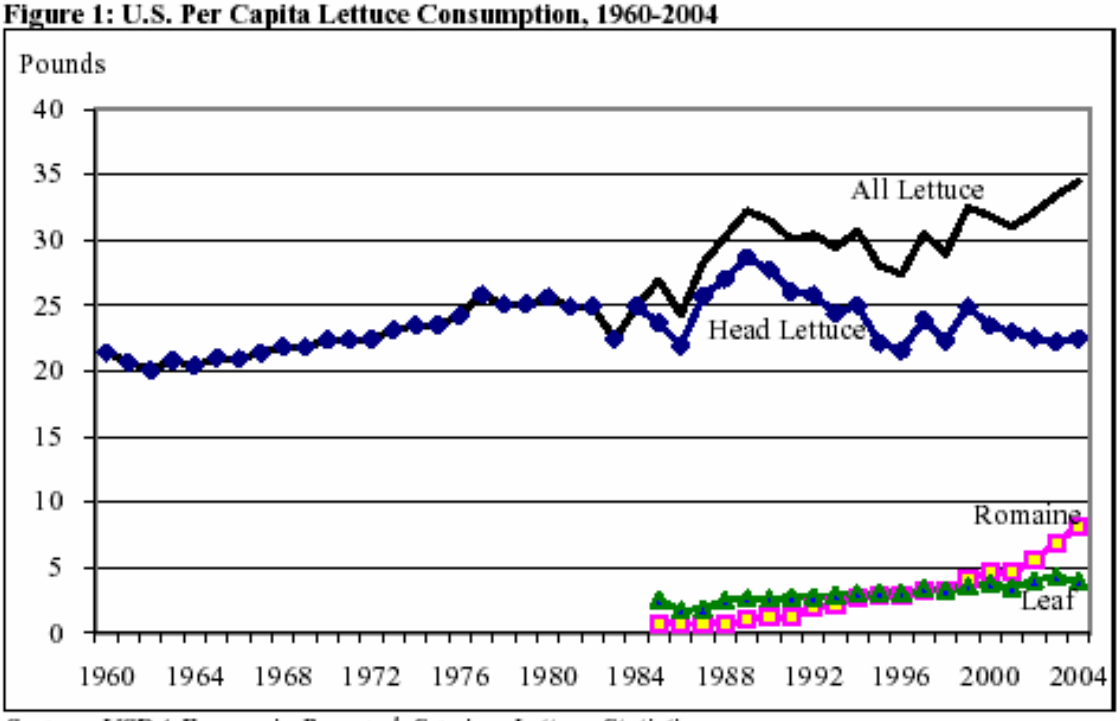
Per-capita consumption exceeds 25 lb annually.[38] In 2004, total lettuce consumption reached a high of 34.5 pounds per capita. In terms of variety, iceberg lettuce is the most popular, however more recently, per capita consumption has been declining and consumption of both romaine and leaf lettuce has been increasing (Figure 1).

The United States ranked second behind Spain in 2004 as one of the world's leading lettuce exporters, accounting for nearly 19 percent of global

[37] http://www.calettuceresearchboard.org/
[38] http://www.ces.ncsu.edu/depts/hort/hil/hil-11.html

exports.[39] Lettuce exports have inflated in value since 1989 when an estimated $60.5 million worth was exported compared to a whopping $275.2 million in 2004 (Figure 2).[40] The biggest shares of U.S. exports are shipped to Mexico and Canada (Figure 3).

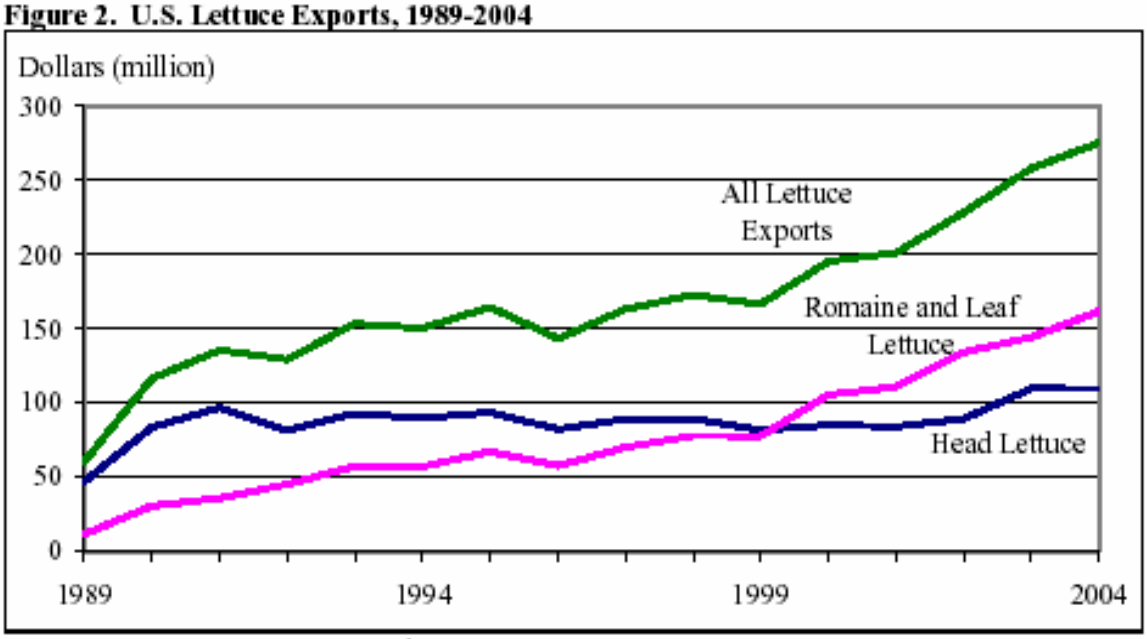
Figure 1: U.S. Per Capita Lettuce Consumption, 1960-2004



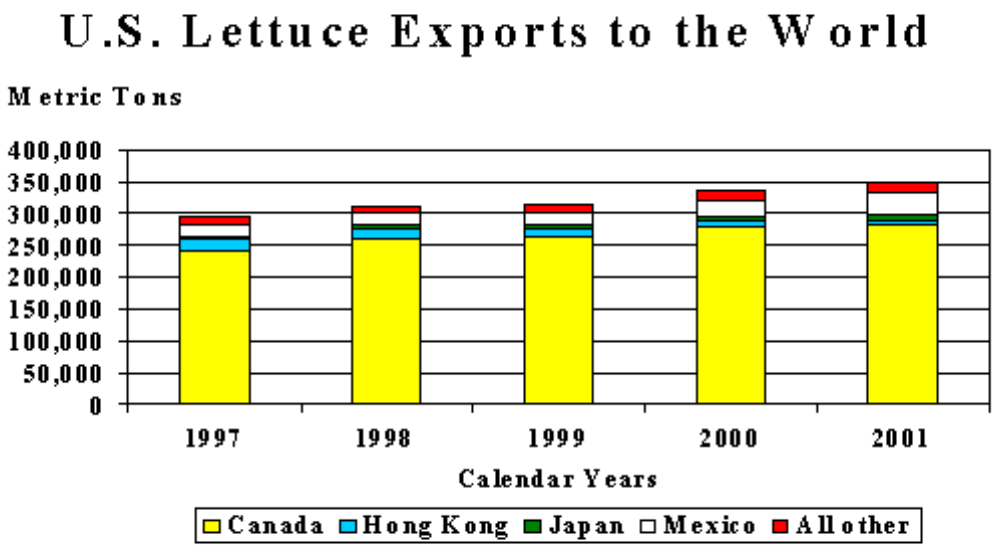
Source: USDA Economic Research Service, Lettuce Statistics

[39] http://faostat.fao.org/faostat/collections?subset=agriculture
[40] http://aic.ucdavis.edu/profiles/lettuce-2005.pdf

Figure 2. U.S. Lettuce Exports, 1989-2004



Source: USDA Economic Research Service, Lettuce Statistics

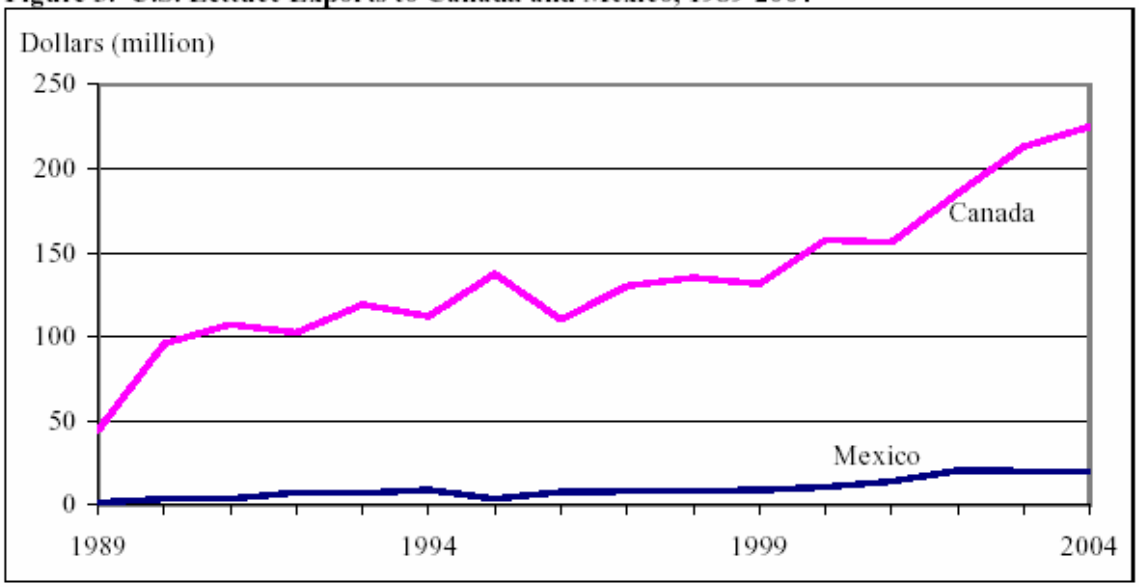


http://www.fas.usda.gov/htp/Hort_Circular/2002/02-09/Lettuce.htm

Production and Acreage

In 2004, the value of lettuce production totaled more than $2 billion, making lettuce the leading vegetable crop in terms of value. The total acreage of all lettuce plantings reached 325,400 acres in 2004. Two thirds of the total acreage can be is responsible for growing of head lettuce (Figure 3). In the United States, California and Arizona are responsible for nearly all lettuce (Figure 4).[41]

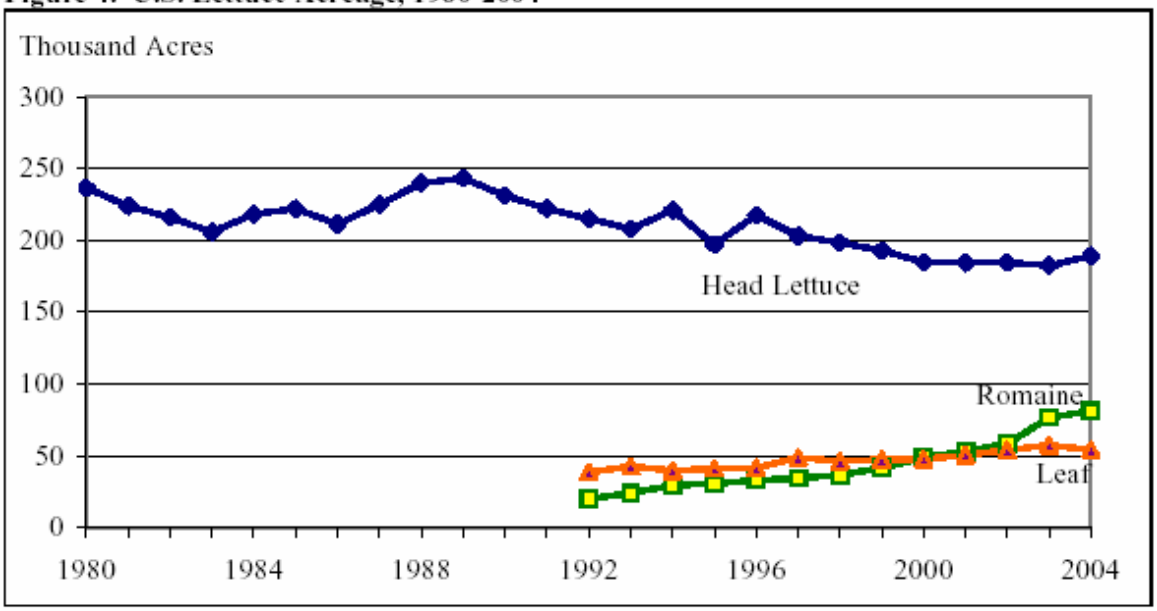
Figure 3. U.S. Lettuce Exports to Canada and Mexico, 1989-2004



Source: USDA Economic Research Service, Lettuce Statistics

[41] http://aic.ucdavis.edu/profiles/lettuce-2005.pdf

Figure 4. U.S. Lettuce Acreage, 1980-2004



Source: USDA, Economic Research Service, Lettuce Statistics

United States: Lettuce Production and Area

		Head	Leaf	Romaine	Total
Area Planted					
1999	Hectares	79,080	19,970	17,220	116,270
2000	Hectares	74,950	20,170	20,050	115,170
2001	Hectares	78,590	22,540	22,820	123,950
2002	Hectares	NA	NA	NA	NA
Harvested					
1999	Hectares	78,020	19,950	17,150	115,120
2000	Hectares	74,830	20,030	20,010	114,870
2001	Hectares	78,350	22,460	22,700	123,510
2002	Hectares	NA	NA	NA	NA
Production					
1999	Metric tons	3,189,690	502,400	595,750	4,287,840
2000	Metric tons	3,158,260	533,650	718,030	4,409,940
2001	Metric tons	3,289,070	532,240	739,030	4,560,340
2002	Metric tons 1/	3,265,869	582,419	733,000	4,581,288

Source: National Agricultural Statistical Service. 1/ Forecast by Economic Research Service.
NA = Not Available.

Beyond the Traditional Scope of Lettuce Production

Knowing what we do about lettuce cultivation and demand, we can better understand the reasoning of this crop being viable in a vertical farm setting in which it will reach its peak production. During recent years with the advancing of technology, lettuce has been commercially grown and produced. Cornell University's Controlled Environment Agriculture (CEA) Program has been involved in greenhouse hydroponic vegetable production.[42] The primary objective was to construct a system in which they could produce fresh, high-quality, pesticide-free vegetables. The vertical farm offers a viable solution in which a crop as such or any crop for that matter can be grown free of pesticides, herbicides, or fertilizers. With the aid of accurate greenhouse control, including the integration of supplemental lighting and carbon dioxide enrichment of the greenhouse air, rapid year round production is attainable.

Yield

Operating at maximal performance, the greenhouse, now owned by Challenge Industries can produce 1,245 heads of lettuce daily.[43] Central New York produces year- round production of lettuce at 20 times the rate of California lettuce fields which is about 80 heads per square foot.[44]

Production

[42] http://aesop.rutgers.edu/~horteng/floating_hydroponics.htm#pictures
[43] http://www.aboutchallenge.org/CHALLENGE/frames/challenge%20home%20page.htm
[44] http://www.news.cornell.edu/stories/Sept05/Lettuce_pr_ag.html

Each day, 1200 naked lettuce seeds are sown with a vacuum seeder in rockwool slabs, placed in plastic trays, and moved into the growth room. For three days, the seedling trays are covered with transparent lids to maintain a high humidity around the germinating seeds. In addition, a shade screen is placed over the lids for the first 24 hours after seeding to reduce light levels during the germination process. Six days after seeding, a careful selection of the seedlings is performed and small and poorly developed seedlings are removed to ensure a uniform plant size at the time of transplant. After 12 days, the seedlings are transplanted into the greenhouse. In the greenhouse, the rockwool slabs are separated into individual seedling cells, which are snugly fitted into large washer-like plastic holders. Each holder filled with a rockwool seedling cell is then placed over holes cut in 0.6 m (2 feet) by 1.2 m (4 feet) extruded polystyrene boards (2.5 cm or 1 inch thick) which are floated on top of the nutrient solution. Initially, the

plants are kept at 81 plants-m^{-2} (7.5 plants-ft^{-2}) for 10 days before they are re-spaced to a final spacing of 28 plants-m^{-2} (2.6 plants-ft^{-2}). The polystyrene boards

The plants remain at the final spacing for another 14 days. After a total of 36 days, the plants are ready to be harvested.

used for the initial spacing contain 60 rectangular spaced holes with a diameter of 3.2 cm (1.25 inch). At the final spacing, each polystyrene board contains 21 rectangular spaced holes with a diameter of 3.8 cm (1.5 inch). This larger hole size allows for a more easy passage of the plant roots during the re-spacing procedure. The plants are grown for 14 days at the final spacing. Of the 1200 seeds sown, 12 days later 960 seedlings are manually transplanted to the greenhouse and, 22 days after seeding, 945 plants are manually re-spaced. The final harvest size of 150 g (5.3 ounces) is reached 36 days after seeding.[45]

[45] http://www.aesop.rutgers.edu/~horteng/fhlettuce.htm

Applied Technology

The technology behind Challenge's greenhouse credits Cornell's Hydroponics Facility (CHF) in which improvements in lettuce "plugs" and precision lighting- two of the most important factors contributing to the greenhouse's express production of lettuce.

Cornell researcher Lou Albright developed the process behind the computer program that controls the lighting, or "daily light integral". The program adjusts the light reaching the plants through a combination of high-pressure sodium supplemental lights and automated shades under the roof of he greenhouse, therefore resulting in speedy growth.[46]

Professor Robert Langhans and doctoral student David Dressen worked to improve the production of flower and garden vegetable "plugs"-2-inch tall seedlings are the initial stages of production. Before their work had begun, the industry standard was four to five weeks before seedlings reached marketable height. This figure was reduced to an astounding 16 days.

[46] http://www.news.cornell.edu/stories/Sept05/Lettuce_pr_ag.html

Fingers Lakes Fresh assistant manager Jeff Gilbert, left, helps a new staff member at the hydroponics greenhouse, which Cornell University recently licensed, to Challenge. The greenhouse produces herbs and 6,000 heads of lettuce weekly.

MATTHEW HINTON / Journal Staff[1]

Current Events: From production to the market

Challenge Industries have taken the next step in getting the produce onto store shelves via it's newly founded Finger Lakes Fresh, the marketing and distribution arm of the facility.[47] Finger Lakes Fresh generates income from the sale of Boston bib lettuce and a mix of salad greens grown in the tightly controlled greenhouse. Locally, Wegmans, P&C, Dryden's Ludgate Farms and the Shur Save in Ulysses all buy greens produced at the site.

Pasona O_2 is an underground vertical farm in Japan, which is currently growing tomatoes, rice, lettuces and strawberries. The viable production of organic vegetables occurs regardless of the weather and with reduced energy expenditures. It was stated that the farm was able to save approximately 577,000 USD on its annual energy. The lettuce crops require one month to grow from seed to harvest, which is a growth rate 3-4 times faster than lettuces traditionally cultivated in outdoor farms, and the farm is capable of producing 7,000 lettuce heads daily, all year long. The project has concluded its 1000 square meters of growing space are 4000 times more efficient than traditional agricultural practices.[48] [49]

[47] http://www.fingerlakesfresh.com
[48] http://web-japan.org/trends/lifestyle/lif050317.html
[49] http://futurefeeder.com/index.php/archives/2005/06/20/urban-underground-farming/

Aquaculture

Tilapia

Several tilapia species are used in aquaculture, including Nile Tilapia, Red Tilapia, and Mozambique Tilapia, and of these, the Nile tilapia (Oreochromis niloticus) is the primary cultured species.[50] Much research is currently being conducted to select viable genetic variants to increase yield and survival.

Under fast growing conditions, the tilapia species attain maturity in three months at a weight of 60 to 100 grams. Tilapia require 8-10 months reach a marketable size, as compared to 2-3 years for salmon. Ideal market size is currently 400 to 500 grams for whole fish, and is reached in 8 to 10 months, and 700 to 1000 grams for production of processed fillets, which is at 11 to 14 months.[51] Cage culture is recommended to prevent overcrowding, as a result of fast maturity and rapid breeding.[50] Tilapias are grown in various culture systems, and concrete tanks and raceways may be best for indoor aquaculture.[50]

Tilapias tend to be more resistant to diseases than other aquaculture species, although recent experience suggest that tilapia are not resistant to disease.[50] The fish tolerate a wide range of salinity conditions and do best in

[50] http://www.thefishsite.com/FeaturedArticle/FATopic.asp?Display=139
[51] http://www.worldseafoodmarket.com/analysis/Final_Tilapia.html

water temperatures between 29° and 31°C., and growth rates decline rapidly at temperatures below 20°C.[52] It is recognized that the tilapia's sensitivity to low water temperatures is a limitation to aquaculture in temperate regions, unless the conditions could be standardized, as in the vertical farm.

The International Center for Living Aquatic Resources Management (ICLARM) based in Malaysia, has selected an improved strain of tilapia under the Genetic Improvement of Farmed Tilapia (GIFT) project. As compared with other farmed strains, the GIFT tilapia can grow 60 percent faster and has improved survival rate and shorter farming periods.[51]

The increase in global production of tilapia is attributed to aquaculture practices, and according to the FAO, the global trade and the value of tilapia has significantly increased in recent years.[49] Tilapia is now the sixth largest seafood import into the US, and ranks second only to salmon in aquaculture species.[49] The domestic price of tilapia has increased by nearly 19 percent. In 2003, 50 percent of the total US tilapia imports were from China, with 90 percent of frozen imports from China and Taipei, and 75 percent of fresh filets were imported from Costa Rica and Ecuador.[49] U.S. tilapia imports have increased 19 percent to over 297 million pounds in 2005, although prices are expected to stabilize in the face of increased numbers of and competition among producers.[50]

[52] http://www.thefishsite.com/FeaturedArticle/FATopic.asp?AREA=Markets&Display=68

The Aquatic Research and Environmental Assessment Center (AREAC) of Brooklyn College, New York is involved in urban tilapia aquaculture, with the production of marketable sized tilapia and walleye in tanks carefully controlled by vast filtration systems and computerized climate and chemical controls.[53] [54]

Pharmaceuticals from Higher Plants

The pharmaceutical industry comprises a huge proportion of the business market in the world. There are more than 200 pharmaceutical companies world wide.[55] The global volume of sales in 2004 was $550 billion, a 7% increase over the figures from 2003. Forty-six percent of the world pharmaceutical market in the U.S.[56] Drug discovery in the form of research and development are the corner stone of the pharmaceutical industry. Using plants and natural products for pharmaceuticals is a growing industry. In addition, since the most pharmaceutical products require strict regulations for growth and processing, the vertical farm will provide the ideal setting for this production effort and enterprise.

The following table is a summary of some commonly prescribed drugs that are made from higher plants.[57] This list is only a fraction of the drugs formed from

[53] http://northeastaquaculture.org/schreibman02.pdf
[54] http://www.cityfarmer.org/fish.html
[55] http://en.wikipedia.org/wiki/Pharmaceutical_company#History
[56] http://www.pharmexec.com/pharmexec/article/articleDetail.jsp?id=177964
[57] Overview: Higher plants and Medicine (Biodiversity and Conservation: A Hypertext Book by Peter Bryant. http://darwin.cio.uci.edu:80)

plants. In fact approximately ¼ of all prescriptions are from plants or chemically modified plant substances. Many pharmaceutical companies are now working with countries which have rainforests to test the plants available for medicinal purposes. Some plants and trees are in danger because of their harvesting for medicinal purposes. An example of this is the Pacific Yew. This tree is rare and is slow growing in the Pacific Northwest. It is the only source of taxol, a drug used to treat ovarian cancer. Recently chemists have found a way to synthesize taxol. In addition, the English Yew, an ornamental plant, has a chemically similar compound and if chemically modified, this may be a source of taxol for the future. This type of experimentation needs to continue to help with drug discovery and supply.

Purpose	**Drug**	**Source**
Painkillers	Codeine, Morphine cocaine	Opium poppy Erthroxylum coca
Antimalarial	Quinine	Cinchona tree
Heart stimulant	Digoxin	Foxglove Digitalis
Pupil dilator	Atropine	Nightshade (belladona)
Antispasmodic for intestinal disorders	Scopolamine	Nightshade (belladona)
Cancer therapy	Taxol	Yew (Taxus brevifolia)
Cancer therapy	Vincristine, vinblastine	Rosy Periwinkle

Examples of specific medicinal products from plants

Poppies

Poppy, *Papaver somniferum L.*, is an annual herb native to Southeastern Europe and western Asia. Also known as opium poppy, the species is cultivated extensively in many countries, including Iran, Turkey, Holland, Poland, Romania, Czechoslovakia, Yugoslavia, India, Canada, and many Asian and Central and South American countries.

Growth

Poppies are annual plants. The entire growth cycle for most varieties of this plant takes about 120 days. The main stem of a fully-matured *P. somniferum* plant can range between two to five feet in height. The green leaves are oblong, toothed and lobed and are between four to fifteen inches in diameter at maturity.

The opium poppy grows best in temperate, warm climates with low humidity. It requires only a moderate amount of water before and during the early stages of growth. In addition, it is a 'long day' photo-responsive plant. As such, it requires long days and short nights before it will develop flowers. The opium poppy plant can be grown in a variety of soils; clay, sandy loam, sandy, and sandy clay, but it responds best to sandy loam soil. This type of soil has good moisture-retentive and nutrient-retentive properties, is easily cultivated, and has a favorable structure for root development. Clay soil types are hard and difficult to pulverize into a good soil texture. The roots of a young poppy plant cannot readily

penetrate clay soils, and growth is inhibited. Sandy soil, by contrast, does not retain sufficient water or nutrients for proper growth of the plant.

The seed capsules contain the alkaloids needed to create the product. The seeds are ready for harvest, 2-3 weeks after flowering. The milky exudates in the green seed pod is collected and dried. Opium and the isoquinoline alkaloids morphine, codeine, noscapine, papaverine, and thebaine are isolated from the dried material. Crop yield depends on the plant, the location and timing of the harvest. [58]

Medicinal use: morphine, codeine and thebaine

Poppy is one of the most important medicinal plants. Traditionally, the dry opium was considered an astringent, antispasmodic, aphrodisiac, diaphoretic, expectorant, hypnotic, narcotic, and sedative. Opium and its derivatives are used as narcotic analgesics, hypnotics, and sedatives. These compounds are also used as antidiarrheals, antispasmodics, and antitussives. Opium and the drugs derived from opium are addictive and thus farming these flowers in the vertical farm will require strict regulation and monitoring. Oxycontin is a chemically derived cousin of morphine and is currently highly used and abused in the U.S. [59]

Currently, there is interest in developing a poppy plant rich in thebaine and low in morphine as the former could be converted to codeine and other legal

[58] http://opioids.com/poppu.html
[59] http://arthritis.about.com/od/prescriptionabuse/a/abuseofdrugs.htm

pharmaceutical products with less morphine available for illegal conversion into heroin.

Quinine

This natural product is extracted from the bark of the South American cinchona tree. It was first discovered and named in 1820. The genus *Cinchona* contains about forty species of trees. They grow 15-20 meters in height and produce white, pink, or yellow flowers. All cinchonas are indigenous to the eastern slopes of the Amazonian area of the Andes, where they grow from 1,500-3,000 meters in elevation on either side of the equator (from Colombia to Bolivia). They can also be found in the northern part of the Andes (on the eastern slopes of the central and western ranges). They are now widely cultivated in many tropical countries for their commercial value, although they are not indigenous to those areas.

Quinine bark is harvested today much as it has been for hundreds of years. The tree trunks are beaten and the peeling bark is removed. The bark partially regenerates on the tree and, after a few years and several cycles of bark removal, the trees are uprooted and new ones are planted. The commercial quinine market today is difficult to calculate. It is thought that 300-500 metric tons of quinine alkaloids are extracted annually from 5,000-10,000 metric tons of harvested bark. Nearly half of the harvest is directed to the food industry for the production of quinine water, tonic water, and as an FDA-approved bitter food additive. The remainder is utilized in the manufacture of the quinidine prescription

drug. Quinine is very bitter tasting and commercially sold tonic waters often use quinine as its bitter ingredient/component. Commercially produced tonic water usually contains around 100 to 300 parts per million quinine and up to a maximum allowable concentration of 70 milligrams of quinine per liter.[60]

Medicinal use

Quinine is primarily used to treat malaria. It is especially important for resistant malaria. It may also be used for arthritis. In addition, a form of quinine, quinidine maybe used to treat arrhythmias.[61]

Taxol

Drug and Uses

Taxol® (paclitaxel) is a drug that is used in the treatment of cancer. It was discovered in 1967 and is isolated from the bark of the Pacific Yew Tree. Paclitaxel has become a valuable tool of oncologists who treat patients with lung, ovarian, breast cancer, and advanced Kaposi's sarcoma.[62] Paclitaxel is also used for the prevention of restenosis (recurrent narrowing of coronary stents).

---

[60] http://www.rain-tree.com/quinine.htm
[61] http://en.wikipedia.org/wiki/Quinine

[62] Saville MW, Lietzau J, Pluda JM, et al. Treatment of HIV-associated Kaposi's sarcoma with paclitaxel. Lancet 1995;346(July 1):26-8

When delivered locally to the wall of the coronary artery, a paclitaxel coating limits the growth of neointima (scar tissue) within stents.[63]

Origins

The anti-tumor qualities in the Pacific Yew Tree were first discovered in a forest near Mount St. Helens.

Pacific yew foliage and bark (http://en.wikipedia.org/wiki/Taxus_brevifolia)

Yield

A 40 foot Pacific yew tree, which may have taken 200 years to reach that height can, yields only a half gram of paclitaxel.[64] Unfortunately, the Pacific is one of the slowest growing tress in the world. The treatment for one patient would require the cutting down and processing of six, 100-year old tress. We also pose a possible threat to the spotted owl, which is and endangered species that lives in trees as such. Over-harvesting has hence resulted in the Pacific Yew becoming an endangered species, though the drug is now produced semi-

[63] Heldman AW, Cheng L, Jenkins GM, Heller PF, Kim DW, Ware M Jr, Nater C, Hruban RH, Rezai B, Abella BS, Bunge KE, Kinsella JL, Sollott SJ, Lakatta EG, Brinker JA, Hunter WL, Froehlich JP. Paclitaxel stent coating inhibits neointimal hyperplasia at 4 weeks in a porcine model of coronary restenosis. *Circulation* 2001;103:2289-95. PMID 11342479
[64] http://en.wikipedia.org/wiki/Taxol

synthetically from cultivated yews, without the need to further endanger the wild populations.[65] Again, since these processes are not economically feasible, paclitaxel is produced by semisynthesis. Cultures of a similar yew plant produce a similar compound. This is then extracted from the culture medium and converted to paclitaxel via petrochemical chemistry.

Out of the Lab- into Vertical Farming

This is where vertical farming can provide a viable option for its growth and production. If we were able to genetically "minituarize" these trees and grow them in a vertical farm, we would be able to produce mass quantities of the drug without destroying land and without the long waiting periods for it to age.

Digoxin [DIGITALIS]

Drug and Uses

Digoxin is a cardiac glycoside extarcated from the foxglove plant, digitalis. It is used in an array of treatment, ranging from various heart conditions, namely atrial fibrillation, atrial flutter, and congesitve heart failure that cannot be treated by other medications.[66] It is a biennial plant, often grown as an ornamental plant due to its violet flowers. The first year of growth produces only the long, basal leaves, while in the second year the erect leafy stem 0.5-2.5 m tall develops. A

[65] http://en.wikipedia.org/wiki/Taxus_brevifolia
[66] http://en.wikipedia.org/wiki/Digoxin

group of pharmacologically active compounds are extracted mostly from the leaves of the second year's growth, and in pure form are referred to by common chemical names such as ***digitoxin*** or ***digoxin***, or by brand names such as *Lanoxin*, or *Purgoxin*.[67]

Origins

This plant is widley distributed throught Europe and is common as wild-flower in Great Britain. The plant is both cultivated and collected in quantities for

commercial purposes in the Harz Mountains and the Thuringian Forest. Digitalis has lately been grown in Government Cinchona plantations in the Nilgiris, Madras, India.[68]

Yield

The Foxglove plant needs a precise and ordered cultivation from planting to processing in order to receive the maximal quality of the drug. It is best grown when allowed to seed itself, however if it is done by sown seed, two pounds of seed is needed per acre. Sown in spring, the plant will not blossom till the following year. The flowers for this medicinal purpose must be pure and dull pink or magenta in color. Only green and perfect leaves will be picked, all those that are insect-eaten or diseased, or tinged with purple or otherwise discolored, must be thrown away. Leaves from seedlings are valueless, and they must also not be collected in the

[67] http://en.wikipedia.org/wiki/Digitalis
[68] http://www.botanical.com/botanical/mgmh/f/top#top

spring, before the plant flowers, or in the autumn, when it has seeded, as the activity of the alkaloids is in each case too low.

It is estimated that one acre of good soil will yield two ton of the Foxglove foliage, producing ½ ton of dried leaves. The amount and character of the active constituents vary according to season and soil nevertheless, 100 parts of dried leaves yield about 1.25 of Digitalin. [69]

Vertical Farming and the Common Foxglove

Again, here is another example of a drug that is widely used within the medical field. Vertical farming yet again would provide an ideal environment for us to cultivate this plant, insect free and pesticide free with optimal light and precise care. Therefore providing into the demands of our population.

Atropine and Scopolamine

Drug and Uses

Atropine is a tropane alkaloid extracted from the plant deadly nightshade (Atropa belladonna). The secondary metabolite of these plants serves as the drug. Atropine has a multiplicity of effects and uses including ophthalmic use,

[69] http://www.botanical.com/botanical/mgmh/f/top#top

resuscitation, secretions and bronchoconstriction, and an antidote for organophosphate poisoning.[70]

Atropine delivers an effective cure for the effects of poisoning by potent cholinesterase inhibitors such as parathion, Malathion and, most infamously, sarin, VX, and similar nerve agents used in warfare. In Europe, it is specifically cultivated for that reason.

Topical atropine is has an ophthalmic use as a pupil dilator. Atropine is contraindicated in patients predisposed to narrow angle glaucoma. It can also be used in homeoathic remedies as a treatment for pinkeye.[71] Injections of atropine are used in the treatment of bradycardia in a cardiac arrest. Atropine's action on the parasympathetic nervous system inhibits salivary, sweat, and mucus glands. This can be used in treating hyperhidrosis, which is abnormal increased perspiration and can prevent the death rattle of dying patients. It has not been offically indicated for either purpose.[72]

Scopolamine also known as hyoscine, is another tropane alkaloid drug which has a hatful of uses. It is used as an antiemetic (prevents vomiting), antivertigo, and an antispasmodic. It can be used as pre-anestheic sedation, as an antiarrhythmic during anesthisia, and for prevention of motion sickness. It aslo has uses in phthalmology and otolarygology. Opthalmologists use it as they use atropine as mentioned previously. It is also used in the treatment of

[70] http://en.wikipedia.org/wiki/Atropine
[71] http://en.wikipedia.org/wiki/Deadly_nightshade
[72] http://en.wikipedia.org/wiki/Atropine

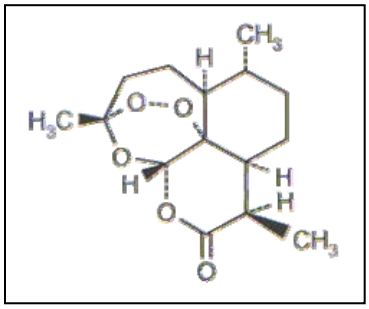
iridocyclitis, which is a condition in which the uvea of the eye suffers from inflamattion. Otolarygologist use this drug to ease trauma of intubation.[73]

Origin of the Deadly Nightshade

The Deadly nightshade plant is native to Europe, North Africa, and West Asia, and has become naturalized in parts of North America. The plant is not as common in the wild as many field guides might suggest, as it is readily attacked by mint flea beetles and has a very low tolerance for sunlight. In areas where it has become naturalized it can often be found in shady, moist areas with limestone rich oil.[74]

Artemisinin

Drug and Uses



The sweet wormwood plant, *Artemisia annua*, has been used medicinally in China for over 2000 years. Scientists isolated the chemical compound artemisinin in 1970, which is found in very low concentrations in the leaves, and in even lower concentrations in the roots. The derivatives artemether and artesunate were later found to have anti-malarial properties.[75]

[73] http://en.wikipedia.org/wiki/Scopolamine
[74] http://en.wikipedia.org/wiki/Deadly_nightshade

WHO estimates malaria kills nearly 3 million people each, with most of the deaths occurring in young children.[76] Between 300 and 500 million new cases are diagnosed globally every year, with the largest disease burden occurring in sub-Saharan Africa, Asia and South America. The malaria parasites, including Plasmodium falciparum and Plasmodium vivax, are transmitted by the Anopheles mosquitoes. According to several studies conducted in Africa, nearly half of all malaria cases caused by P. falciparum are resistant to the standard therapeutic agents chloroquine and sulfadoxine-pyrimethanine [SP].[75] The WHO and UNICEF are now advocating the use of artemisinin combination therapies that are much more effective against resistant malaria strains, which in turn has created high demand for artemisinin and its derivatives.

Artemisinin is presently commercially grown in only China and Vietnam, albeit in insufficient quantities; Kenya, Tanzania and Uganda have begun small and large-scale cultivation programs.[77] In order to meet world demand of ACT, growth and production of artemsinin will have to be ramped up. Current world production of artemisinin is approximated at 30,000 to 40,000 kg in its artesunate form. 60,000 kg is required for every 100 million courses of ACT. The WHO forecasted 120 million courses of ACT would be required for

[75] www.irinnews.org
[76] www.who.int
[77] www.essentialdrugs.com

2006.[78] Novartis produced 5 million courses of its ACT, Coartem, and was expected to increase production to 20-30 million courses by 2005.[77] Tanzania produced another 5 million courses, although primarily from imported Artemisia leaves.[77]

Such low availability worldwide also influences the cost of therapy; with the current price over 2 USD per treatment; effective anti-malarial therapy has proven too costly for most in sub-Saharan Africa.[77]

Although *Artemisia annua* is capable of growth in various ecological zones, increased production of artemisinin has important quality control implications, as differences may occur in artemisinin concentrations within the leaves and seasonal growth cycles.[77] In a study by Simon et al, wide variations of artemisinin concentration exist among regions of growth, such that the authors suggest the production of artemisinin could be enhanced with plant selection and breeding.[79] U.S. and European supplies of the plant are found to have lower artemisinin content, with yields of 0.06%, as compared to yields of 0.01-0.5% in China.[79]

A plant species such as *Artemisia annua* may benefit from alternative growing strategies, and may have a rightful place within the vertical farm. Cultivation of the plant from seed to harvest requires 6-8 months, with an additional 2-5 months required for the extraction, processing and manufacturing of the therapeutic agents.[78] Perhaps hydroponic or aeroponic growing modalities can decrease time to harvest, thereby increasing overall supply of artemisinin.

---

[78] www.rbm.who.int

[79] Simon, JE. et al. 1990. Artemisia annua L: A promising aromatic and medicinal. p. 522-526. In: J. Janick and JE Simon (eds.), Advances in new crops. Timber Press, Portland, OR.

Because artemisinin is found in such low concentrations in the Artemisia leaves, and even lower concentrations within the roots, the crop has low economic viability, although its public health implications are extraordinary. An unpublished study conducted at the Worcester Polytechnic Institute focused on the root tissue of the Artemisia plant, which grows faster than the leaves. The rootstock was transfected with a bacteria vector capable of inducing“heavy root” morphology with a much higher artemisinin concentration.[80]

> *“Hydroponically growing a genetically superior plant in a controlled environment will allow for unforeseen capabilities.”*[80]

MODALITIES AND METHODOLOGIES FOR INDOOR CROP PRODUCTION

I. Hydroponics Systems

The word hydroponics is derived from the Greek ‘hydro’, meaning water, and ‘ponos’, meaning labor; in Latin, it means ‘water-working’.[81] It is the process of cultivating plant life in a bath or continuous flow of oygenated, nutrient-rich water. Hydroponics processes were even employed during WWII, to grow fresh vegetables for the soldiers stationed in the Pacific. Plant growth in an ecosystem usually requires soil, which becomes enriched with basic nutrients through decomposition of ogranic matter. As water flows into the soil, the nutrient salts dissolve, and the roots of the plant absorb what is necessary to sustain the plant.

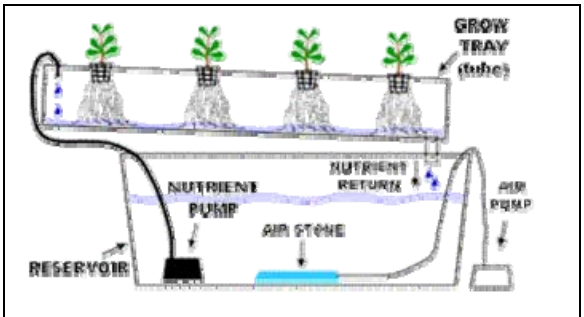
[80] www.maximumyield.com
[81] www.howtohydroponics.com

Ideal growing conditions are rare in a naturally occurring environment, and current stresses on the environment decrease the possibility.[81] However, in hydroponics systems, the ideal growing conditions are artificially created, as plants are supplied with nutrient-rich water and are supported in an inert soilless culture medium. As the hydroponics system is contained within itself, the potential for environmentally hazardous, agricultural runoff is minimized. Additionally, very little water is lost to evaporation processes, which has profound implications for regions frequently threatened by drought.[81]

Liquid-medium systems:

Nutrient-flow technique (NFT):

An NFT growing system consists of a network of narrow channels through which a nutrient solution is re-circulated with a tank supply. Most NFT channels are fed continuously at a rate of approximately 1 liter per minute but some systems are operated intermittently to ensure adequate aeration for the root systems.[82] The channels are generally assembled on waist-high stands that slope 4 to 6 inches per 100 feet to allow for gravity flow and for the nutrient solution to drain to one end. Although round pipes have been used in NFT production, most growers have found that flat bottomed channels or gullies provide greater surface area for root development and oxygen uptake, resulting in better, faster plant



Nutrient Flow Technique System

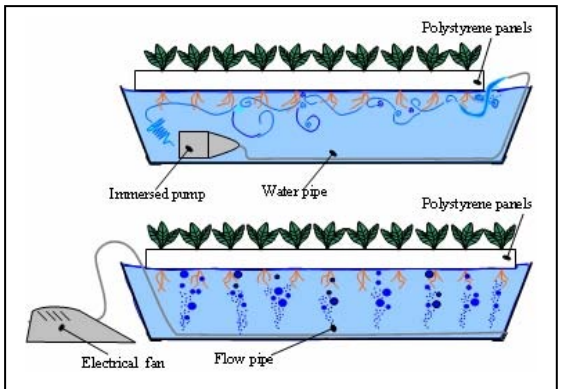
[82] http://www.comhydro.com/hydroponic%20methods.htm

Lettuce Grown with NFT

development.[83] Usually the cannels are designed with a width of 6-8 inches to accommodate a single row of plants but, wider channels of 12 to 15 inches can be used to grow two rows of plants. An increase in width beyond this results in nutrient flow problems. In NFT systems the temperature of the media also plays a role in plant development. For tomatoes, the ideal temperature has been identified as 68-77 degrees Fahrenheit.[84]

Float System:

A float system uses long rectangular reservoirs filled with nutrient solution. Plants are grown in net pots that sit in holes cut into a foam board raft that floats on the surface. The nutrient solution should be stirred up every day by hand or by an immersed pump to ensure that the roots are adequately aerated. Floating is a low-cost hydroponics technology suitable for growing leafy vegetables indoors. Today, many greenhouses in Italy use a float system for growing leafy vegetables and herbs, such as rocket salad, particularly for minimally-processed vegetables.[85]



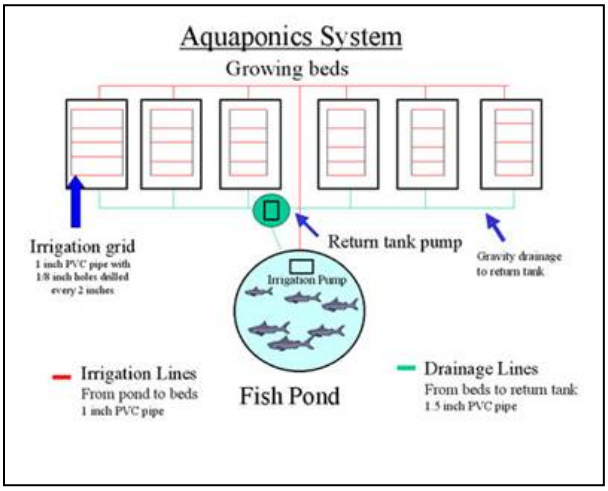
Float System

[83] http://www.comhydro.com/hydroponic%20methods.htm
[84] Johnson, H., Jr.. " Soilless Culture of Greenhouse Vegetables." UC Davis, Vegetable Research and Information Center, Univ. of California.
[85] http://www.fao.org/hortivar/scis/scis.htm?TRX=Redirect&TO=DOC&ID=1#3

Nutrient-Solution for Liquid-Medium Systems

Liquid-medium systems should use complete nutrient solutions prepared from soluble inorganic salts containing various elements. Pre-made mixes of all required elements are available, which are simply dissolved in water to prepare the nutrient solution. These mixes are available in various concentrations and ratios of elements. Nutrient solutions can also be prepared by the grower using readily available soluble salts. Many complete nutrient-solution formulas have been developed and used successfully. All contain the same elements and are generally prepared from the same compounds, although in somewhat different proportions. No one formula is necessarily the best for all plants, but all are capable of providing adequate nutrition.[86]

Aquaponics:



Aquaponics is a method of indoor, soilless culture that combines hydroponics and aquaculture (fish farming) into one integrated system. In aquaponics, the fish waste provides nutrients for the growing plants and the plants provide a natural filter for the water the fish live in. Ideally, this creates a sustainable

[86] Johnson, H., Jr.. " Soilless Culture of Greenhouse Vegetables." UC Davis, Vegetable Research and Information Center, Univ. of California.

ecosystem where both plants and fish can thrive. The key to this mutual success is the establishment of beneficial bacteria that convert the ammonia from the fish waste into nitrite and then to nitrate that the plants can easily utilize.[87] Although commercially aquaponics is still in its infancy it provides solutions to both the fish farmer's problem of finding a safe mechanism for the disposal of their nutrient rich water and the hydroponics growers problem of establishing an

environmentally friendly source of nutrient rich water. When the technology is fully developed, aquaponics, has the potential of allowing hydroponics growers to eliminate the cost and labor involved in mixing a fertilizer solution and commercial aquaculturists may be able to drastically reduce the amount of filtration needed in re-circulating fish culture. For commercial application of aquaponics, designs that show great promise include the float system, NFT and ebb and flow.[88]

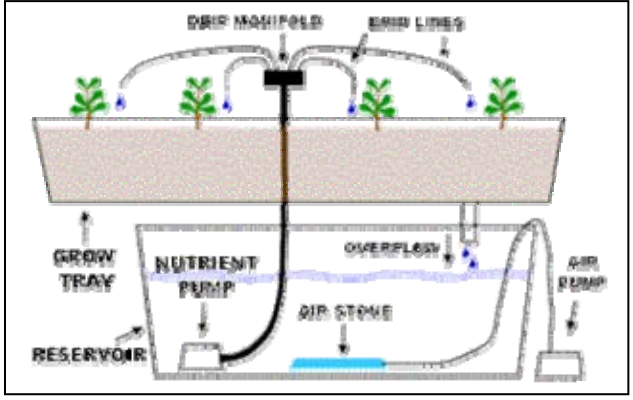
[87]http://www.comhydro.com/hydroponic%20methods.htm
[88]http://www.aquaponics.com/InfoAquaponics.htm

Solid System

Drip or container Culture:

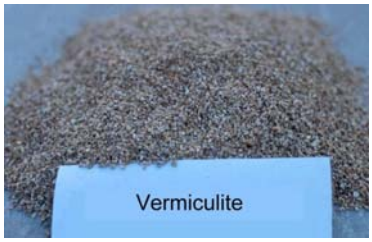
Drip or container culture is one method of soilless indoor growing in which you place media bags, pots or troughs. The bag or pot systems are already in common use throughout the United States and offer some major advantages over other types of soilless culture. First, you can select a medium with excellent water and nutrient retention. Second, the containers are lightweight and individual allowing them to be easily moved in, out and around the growing area. Third, the containers are relatively inexpensive and are easy to install. Fourth, the nutrient-solution system is easier to maintain and less expensive to manage than in a recirculated-hydroponic systems. In the bag or pot system the volume of soilless media varies from approximately ½ cubic foot in vertical bags or pots to 2 cubic feet in lay-flat bags. The vertical-bag system usually uses 4-mil black poly bags with pre-punched drain holes at the bottom. With this setup, one or two tomato or cucumber plants are conventionally grown in each bag. The lay-flat bags can accommodate two or three plants and in both cases, the bags are aligned in rows with spacing appropriate to the type of crop being grown. The nutrient solution is delivered to these containers by supply lines leading to spaghetti tubing, spray sticks or ring

drippers. The appropriate application device is dependent on the texture and porosity of the grow media.[89]



Growing media for drip or container culture:

In traditional agriculture plants are cultivated in field soil, a medium that acts as a reservoir for nutrients and water and a scaffold of support for plant growth. Today, however, it has been well established that artificial soil systems can provide these essential functions of plant growth with equal or greater growth and yield results. For indoor farming the ideal growing medium used for container culture must be chemically inert, provide good aeration to the root system, and have good nutrient and water holding capacity. In addition the media should be light weight for easy handling, and should be free of any



pathogenic organisms. Today's most popular materials that meet these prerequisites are perlite, rockwool, expanded clay pebbles and vermiculite.[90] Perlite is derived from volcanic rock which has been heated to extremely high

[89]Johnson, H., Jr.. " Soilless Culture of Greenhouse Vegetables." UC Davis, Vegetable Research and Information Center, Univ. of California.
[90] http://www.comhydro.com/hydroponic%20methods.htm

temperatures where it explodes, transforming into a porous, white medium. Rockwool comes from basalt rock that is then heated and spun into fibers which are then formed into cubes that can accommodate 3-4 large plants. Vermiculite is formed by the hydration of certain basaltic minerals and expanded clay pebbles are small bake spheres of clay. All of these products each have the before mentioned characteristics. In addition to these newer products, several byproducts of agriculture can also be recycled as growth media. For example, bark, shavings, sawdust, peat moss, coco coir, bagasse and rice hulls all exhibit the properties necessary for a good soil substitute.[91] The table below describes some of the physical characteristics of these materials:

Table: 1

Material	Bulk density (weight)	Water holding capacity	Porosity	Cation exchange capacity	Decomposition rate (Carbon:Nitrogen)
bagasse	L[2]	H[2]	L	M[2]	H
sawdust	L	H	M	H	H
rice hulls	L	L	H	M	M–H
shavings	L	M	H	M	M–H
vermiculite	L	H	M	H	L
peat moss	L	H	H	H	M
bark	L	M	M	M	M
sand	H	L	M	L	L

[1]Adapted from R. T. Poole, C. A. Conover, and J. N. Joiner; *Foliage Plant Production* (Englewood Cliffs, NJ: Prentice Hall, 1981).

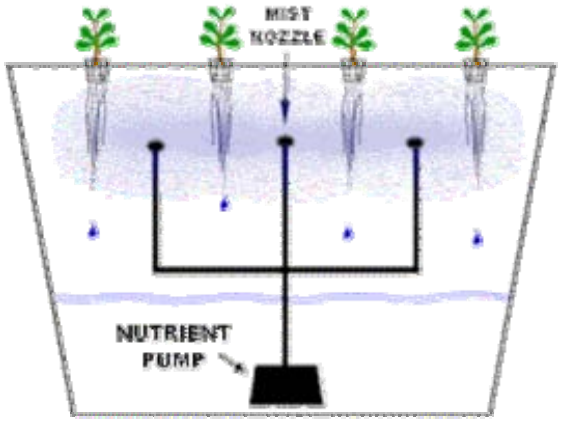
[2]Low	0.25 gm/cm³	20%	5%	10 meg/100 cm³	1:200
Medium	0.25–0.75	20–60%	5–30%	10–100	1:200–1:500
High	0.75	60%	30%	100	1:500

However, because many of these medias only express a few of these requirements, they should be used in mixture rather than alone. To maximize the positive attributes of bagasse, rice hulls, sawdust, and vermiculite they should be

[91] Johnson, H., Jr.. " Soilless Culture of Greenhouse Vegetables." UC Davis, Vegetable Research and Information Center, Univ. of California.

mixed with other materials in the range of 20 percent to 50 percent of the total volume. In addition, because of their high C: N ratios, bagasse and most sawdust material should be limited to no more than 20 percent of the total volume of a mix for container culture.[92]

There are a number of proven mixes that incorporate good weight, water holding capacity, porosity and C: N ratio. One example mix that provides an ideal growing media by combining all of these basic factors is the combination of sphagnum peat and horticulture vermiculite or peat-lite. This product can be easily purchased or prepared for use in container culture.[93] Bark form pine, fir, cypress, and redwood are also proven medias for the soilless culture of cucumbers and tomatoes. The gradient of particle size from 1 mm to 10 mm results in good aeration, and good water and nutrient-holding characteristics. In addition a bark soil substrate can be used in successive crop cycles without a significant loss of volume to decomposition. This basic material can be improved by adding a material like as sawdust or bagasse by increasing the water holding capacity of the media.[94]



Aeroponics System

II. Aeroponics Systems

[92] Johnson, H., Jr.. " Soilless Culture of Greenhouse Vegetables." UC Davis, Vegetable Research and Information Center, Univ. of California.
[93] Boodley, J. W., and R. Sheldrakejr. 1977. "Cornell peatlite mixes for commercial plant growing." Informational Bulletin 43. New York State College of Agriculture and Life Sciences.
[94] Johnson, H., Jr.. " Soilless Culture of Greenhouse Vegetables." UC Davis, Vegetable Research and Information Center, Univ. of California.

Aeroponics systems apply hydroponics techniques, without a growing medium, although growing medium are sometimes used to germinate or root cuttings. An aeroponic system suspends the plant within a chamber, such that the roots of the plant are exposed. A nutrient-rich mist is continually pumped into the chamber, so that the chamber is kept at 100% humidity. The exposed roots absorb the nutrients and oxygen directly from the surrounding air, which purportedly increases the plant's metabolic rate, which can result in a nearly 10-fold increase in growth rate compared to that grown in soil.[81] The continual spray system causes extensive growth of the root system, which allows for greater uptake of oxygen and nutrients, and translates into increased plant growth. In a Singapore aeroponic program, butterhead lettuce can be cultivated from seed to harvest in 35-45 days, as compared to 60 days for soil-cultivated lettuces.[95]

Aeroponics has gained support in recent years, as a technology most appropriate for urban agriculture and agricultural programs in more tropical regions.[95] Significant limitations to hydroponics systems exist, including the large volume of water required and the additional

[95] www.scholars.nus.edu.sg/student_work/global_programme/sungei/aero.htm

energy expenditure to heat/cool the water to a temperature appropriate for growing temperate crops.[95] An aeroponic system uses only 10% of the water used in hydroponics.[95] The design of an aeroponics system also ensures no water is lost to evaporation, and the lack of soil means the elimination of pests.

The use of aeroponics technology may also benefit the growth of medicinal plants, particularly those plants from which the compound of interest is extracted from the root system. In a study conducted at the University of Arizona's Controlled Environment Agriculture Center, aeroponics is used to maximize delivery of oxygen and nutrients to the roots of the Echinacea and Burdock plants.[96,97] As the root systems can grow to be much larger, yields of the medicinal compounds can increase.

Conclusion:

"A vertical farm is **needed** in order for the human species to be sustainable."

[96] http://ag.arizona.edu/CEAC/
[97] http://ag.arizona.edu/ceac/research/archive/aeroponic_medicinals.pdf