Sustainable horticulture production in the United Kingdom

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Introduction.

Figure 1. Map of the United Kingdom (U.S. Central Intelligence Agency 2009)

The United Kingdom includes the islands located between the Irish Sea and North Sea, and the northern one sixth of the island of Ireland located in Western Europe (Figure 1) (U.S. Central Intelligence Agency 2009). Approximately 60,943,912 people reside on the 241,590 sq km of land while the remaining 3,230 sq km is water (U.S. Central Intelligence Agency 2009). Rugged hills and low mountains that level off to rolling plains in the east and southeast are what make up the land (U.S. Central Intelligence Agency 2009). Their climate is temperate which means that it is moderated by prevailing southwest winds over the North Atlantic Current making over one half of the days overcast (U.S. Central Intelligence Agency 2009). Many natural resources including coal, petroleum, natural gas, iron ore, lead, zinc, gold, tin, limestone, salt, clay, chalk, gypsum, potash, silica sand, slate and arable land are present (U.S. Central Intelligence Agency 2009). Only 23.23% of their land is arable, 0.2% has permanent crops on it and 76.57% falls under the "other" category (U.S. Central Intelligence Agency 2009). 1,700 sq km of the land is irrigated which contributes to the 11.75 cu km/ year of freshwater that is used every year (U.S. Central Intelligence Agency 2009). Natural hazards that they experience the most of include winter windstorms and floods (U.S. Central Intelligence Agency 2009). One of their current

environmental issues as a country is meeting the Kyoto Protocol of a 12.5% reduction of greenhouse gas emissions by 2010 (U.S. Central Intelligence Agency 2009). They intend to meet this legally binding contract and then some by cutting a total of 20% of their emissions (U.S. Central Intelligence Agency 2009). Some major achievements so far include the reduction of 85% of commercial waste at landfill sites since 1998 and increasing the amount of compost to 25%. Of the 1.26 trillion pounds ($2.788 trillion) of GDP that is brought in every year 0.9% is from agriculture, 22.8% is from industry and 76.2% is from services (U.S. Central Intelligence Agency 2009). Of the 31.2 million people employed in the United Kingdom, 1.4% of them are in agriculture, 18.2% work in industry and 80.4% make up services (U.S. Central Intelligence Agency 2009). A total of 329.26 billion pounds ($468.7 billion) of manufactured goods, fuels, chemicals, food, beverage, and tobacco are exported yearly while 453.6 billion pounds ($645.7 billion) of manufactured goods, machinery, fuels and foodstuffs are imported (U.S. Central Intelligence Agency 2009). Overall, the United Kingdom is very similar to the United States it is just smaller, and is more adamant about making changes towards sustainability.

Sustainability.

The United Kingdom defines sustainability as "a dynamic process which enables all people to realize their potential and improve their quality of life in ways which simultaneously protect and enhance the Earth's life support systems" (Enabling Projects Limited 2009). They have five principles of sustainability: 1) living within environmental limits, 2) ensuring a strong, healthy and just society, 3) achieving a sustainable economy, 4) using sound science responsibly, and 5) promoting good governance (Parliamentary Copyright 2009). Sustainable development is "about meeting the needs of the present while safeguarding the interests of future generations" and their objectives in doing so are to make social progress, use natural resources prudently,

maintain high levels of economic growth, and have effective protection of the environment (Enabling Projects Limited 2009). Finally, sustainable communities are defined as being "places where people will want to live and work, now and in the future, in enjoyable, well functioned, high quality environments" with their objectives being to balance and integrate the social, economic and environmental components of their community, meet the needs of existing and future generations, and respect the needs of other communities (Enabling Projects Limited 2009). I think that the United Kingdom has a lot of definitions which is fantastic, but they are so broad that it would be hard to implement them. An example demonstrating this is when they define sustainable communities as being places where people will want to live and work. Not all people have the same idea of a place where they would want to live and work and it definitely does not mean that they will be sustainable places. I do like how they use the phrase "a dynamic process" because this implies that it is not something that can happen overnight, it is a series of actions that lead to the ultimate or desired result. Currently, the United Kingdom has a lot of action plans that are in progress. Their newest addition is to upgrade some 24 million homes to be near-zero carbon by 2030 which will help in their other plan which is to have an 80% reduction in carbon emissions by 2050. Accomplishment requires enabling, engaging, encouraging, and exemplifying. Enabling involves removing the barriers of creating a sustainable built environment and raising the knowledge base of building performance, engaging includes working with all of the built environment stakeholders to develop ambitious, deliverable policies, encouraging incorporates creating incentives and regulations to catalyze the action, and exemplifying embraces public sector leadership and influence to stimulate the markets (Sustainable Development Commission 2009). This is just one example of the United

Kingdom's efforts of becoming more sustainable. They demonstrate that a broad definition may not be such a bad thing after all.

Production in the Past.

The United Kingdom has been around since 1707, and therefore has been producing horticultural goods for an equal amount of time if not more. Early on production was primarily home production, but that soon changed when new farming systems such as the rotation of turnips and clover allowed more food to be produced from the same area of land (Overton 2002). The increase in agricultural land was also aided by land reclamation, clearing of woodland and the reclamation of upland pastures (Overton 2002). Crops switched from being low yielding to higher yielding types such as wheat and barley. Between 1700 and 1800 the amount of wheat yields increased by 25% and by the early 19th century by 50% (Overton 2002). Nitrogen was the key factor in this sudden increase as it is the limiting factor cereal yields. To conserve nitrogen, farmers would feed livestock in stalls, and then would collect the manure and place it where it was needed (Overton 2002). New nitrogen was added to the soil by using legumes that convert atmospheric nitrogen into nitrates that can be used by plants (Overton 2002). Later in the mid-17th century farmers began to grow clover, and by the 19th century the quantity of nitrogen in the soil had drastically increased (Overton 2002). These methods of production were all very sustainable because the viability of the soil was not harmed. This changed when the introduction of chemical fertilizers and other harmful substances and methods occurred. As agricultural changes were occurring so were the horticulture practices.

The first sign of a shelter for plants occurred in the 1500s in Beddington, England when royalty became interested in growing citrus fruits such as oranges (Warren 1988). The structures were called Orangeries and first consisted of a high wall that protected the trees from the north

and a roof in which was erected in the winter (Warren 1988). In England, they used wooden boards instead of terracotta tiles as roofing material; this as you would imagine was quite labour intensive (Warren 1988). There were also two iron stoves that were lit during cold spells. I would imagine that this way of growing was somewhat, if not completely, sustainable. The only reason that it wouldn't be a sustainable method of producing would be because of the iron stoves, but as they were only used when the cold posed a threat, they would not have that big of an impact. Previous to this gardeners would place plants in movable tubs that would be transported from the outdoors into frost free outhouses, halls or long galleries when cold posed a threat. I would imagine that this would be a very sustainable method, even if it were a tedious task. These methods were used until Olivier de Serre's influence in the 1600s began to take hold.

Olivier de Serre's suggestions on how to build an orangery were published in *Le Theatre d'Agriculture* (Warren 1988). He said that the trees should be planted in the ground in front of a wall with a row of columns 13 feet high and 8 feet apart (Warren 1988). The rafters should be placed in order to create a lean-to roof with a shallow angle that would be thatched with opening skylights (Warren 1988). In colder zones, the house would have to be airtight preferably with well-fitted glass windows, and the interior should be heated with charcoal or dry wood (Warren 1988). In the summer, the windows or frames would be removed. An attempt at making such a greenhouse was made by De Caus, but due to the Thirty Years War, he was unable to finish and fled England to France (Warren 1988). A more primitive version suggested by John Parkinson in 1629 was to plant orange trees in square boxes which could be transported to a closed gallery in the winter (Warren 1988). An alternative was to plant the tree against a brick wall and protect it with boards covered with seare cloth and warm them with a stove (Warren 1988). Once again, the method of heating poses the biggest threat to being non-sustainable, but the wood, brick and

thatching used would all biodegrade. These materials however, would soon be replaced with those of much more décor and aesthetic qualities.

As the main focus continued to be on the production of citrus and exotic plants, royalty also became increasingly focused on the architecture or "fashion" of the greenhouses. Queen Henrietta was left in charge of a 262 foot shed with a coal house adjoining it; together the shed and coal house adjoined the house (Warren 1988). The walls were made out of brick and for a high quality appearance; the queen covered the ridge roof with blue slate (Warren 1988). Louis XIV later placed orange trees in silver tubs and brought them inside for decoration; only the best were picked, size varied on location, and different types of pruning were done to get a desired shape (Warren 1988). Queen Henrietta led the way in the fashion of these buildings and opened the doors for creative architects.

Jule Hardouin Mansart built his second Orangerie in 1685 for Louis XIV who was also known as the Sun King. It was deep and long with projecting wings at the end of which are flights of one hundred steps (Warren 1988). He removed a vast amount of dirt to lower the level of the garden in front. Stonework was done, and there were wooden doors that were recessed and very thick (Warren 1988). The upper part of the orangerie was double-glazed with several inches separating the two layers of wood and glass (Warren 1988). There was no heating system due to the fact that there was only one external wall; it was thermally efficient. Also at this time, having heat under the building in a vaulted brick space was becoming increasingly popular because it created an uniform heating system that did not allow the toxic fumes from iron stoves to reach the plants (Warren 1988). This is an extremely sustainable method of production. No heat was needed because it came from the Earth and the attached home, and it was made out of

natural materials. The glass was the only downfall because it could break and would then have to be replaced. However, this did not stop people from using it.

In the early 17th century, windows/ glass walls were only found on the south side of the building. Later in the century glass roofs became popular. Also during this century, John Evelyn became focused on how to heat the greenhouse. The new idea called for having the stove outside of the house. The heat would be transferred inside by air passing through very hot pipes; cold air was drawn through a ground pipe to fan the fumes of the furnace (Warren 1988). This allowed for fresh air and heat to reach the plants, but was not very efficient in thermal terms. Evelyn's total design of a good greenhouse had the same dimensions as Olivier's, but the roof had a ridge instead of being a lean-to and there were no skylights (Warren 1988). He also suggested that there be cork on the walls for increased insulation, that the thermometer be placed opposite of the furnace, there be large and ample windows, and finally, for there to be a porch with a door that would prevent cold air from rushing in (Warren 1988). Due to the fact that the heating methods were very inefficient, this way of producing was not very sustainable. It did take advantage of the house heat and good insulation, but due to the fact that the heat source was outside a lot more heat was lost then there should have been. The best part about the way this greenhouse was being designed was the fact that there was a porch; it created a buffer zone in which the cold would not rush in and the heat would not rush out when someone entered the building. Owing to the fact there was increased technology, interest and ideas the assortment of plants grown in the greenhouses grew notably over a short period of time.

The variety of plants had increased significantly from 1630 to 1656. Early on the focus was primarily on citrus, oleander, pomegranate and myrtle (Warren 1988). Due to better practices and knowledge there were all sorts of additions including: hibiscus and passion flowers,

mimosas, canna lilies, geraniums, and tender jasmine just to name a few (Warren 1988). It was not because of this increase that greenhouses shifted to a more architectural focus, but was instead due to royalty influence and money.

The Golden Age of the greenhouse occurred between 1715 and the 1800s. It was during this time that the focus shifted from production of plants to the architecture of the building. Windows that were sized for human use could provide the old citrus trees with the amount of light that they required, but could not support the new varieties in which were arriving (Warren 1988). They needed more light and heat which required stoves. The desire for fashionable greenhouses led them in a direction that was quite unsustainable because they weren't using heat efficiently and lacked greenhouse efficiency for the plants. Dr. Richard Bradley was a distinguished botanist and rarely disguised his disgust in the current greenhouse practices of the time (Warren 1988). He got a chance to show that fashion and practicality could be combined when he was given a job with the Duke of Chandos at Cannon in Hertfordshire (Warren 1988). He worked with an Italian architect, Alessandro Galilei, who produced an elegant, sophisticated design and was able to incorporate his thoughts about how a good greenhouse for plants would be built (Warren 1988). The central feature was a decagonal rotunda under a cupola that faced south; this would catch winter sunlight from morning to night, but was also aesthetically pleasing (Warren 1988). There were windows around the rotunda that could be moved from the external façade to the inner side which allowed the plants to be open to the elements in the summer (Warren 1988). Old fashioned charcoal was the choice heat source by Bradley. He proposed having a room at each end of the greenhouse with a furnace in each. Again, due to the lack of efficiency because of the location of the furnaces it required that more heat be produced and therefore more charcoal which does not burn cleanly. In fact, it gives of noxious fumes that are

not only harmful to humans but also to plants (Warren 1988). The creation and design of this greenhouse opened a possibility for growing bananas, pawpaws, guavas, mangoes, and the biggest delicacy of all at the time, the pineapple (Warren 1988).

The thought of producing pineapple spurred new horticultural practices. New plants were propagated in a hot bed that was brick lined and five feet deep (Warren 1988). It was filled with a 12 inch layer of fresh horse dung, and then covered with a much thicker layer of tanners bark (Warren 1988). After being grown in the hot bed the plant would then be transferred to another hot bed which was known as the succession house (Warren 1988). From February to October, pots containing the pineapple plants were set into this warm mixture and were covered with a glass frame, in the coldest months the plants were moved to another hot bed in a stove house with glass walls and roof (Warren 1988). All of the materials that were used were natural which made this method of producing pretty sustainable. They also took advantage of the time of year when they could. Like pineapples, being the fancy delicacy that they were, greenhouses began shifting towards a new more fanciful shape.

Instead of having a basic greenhouse, squared glass sides and an angular roof, a shift towards a new shape in 1815 occurred, this being a half dome curved from side to side and top to bottom which was set against a straight wall (Warren 1988). It was heated with an under floor flue which lead to a chimney disguised as an urn (Warren 1988). There was good ventilation provided by sliding shutters at the base of the dome and more shutters along the top of the back wall (Warren 1988). William Atkinson aided in the creation of such inventions due to his idea of heating greenhouses via hot water in cast iron pipes that could either be routed above the floor along the sides and front of the building, but they could also be sunk into the floor where the flue had been and covered by an iron grill (Warren 1988). The boiler would then be under the

greenhouse. This type of heating was less labor intensive and was more controllable. It also reduced the amount of unfiltered charcoal emissions that were going into the air. It was a self contained heating system that was very efficient and effective. Having more heating options also led to the creation of another common greenhouse that we see today, the ridge and furrow.

In 1832, Joseph Paxton developed a ridge and furrow roofed greenhouse and created the Great Conservatory at Chatsworth (Warren 1988). In the mid-19th century, glass houses and conservatories became the public winter garden. There were also many different styles of greenhouses including the Republican greenhouse, Hudson River style, and the Victorian glass house (Warren 1988). From the 1850s on up, private conservatories were a normal part of upper and middle class life. They were usually attached to the house and almost always had glass roofs (Warren 1988). Eventually, having just glass roofs would be considered a minimal because instead, glass would be used for the whole building.

From 1900 to 1988, it was the "more glass than walls" era. Frank Lloyd Wright said that "A building should appear to grow easily from its site, shaped to harmonize with its surroundings" (Warren 1988). Eventually, the cost of these buildings became too much and the everyday person wanted a greenhouse for production of their own. Other materials were made that were cheaper and served the same purpose.

Current Production Practices.

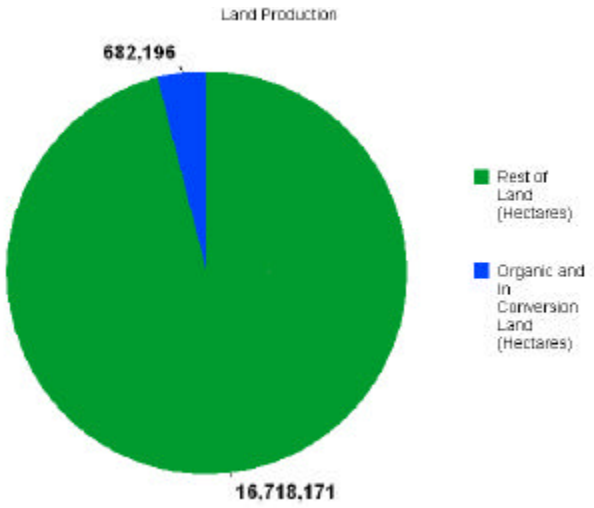
Today's construction of greenhouses consist mainly of aluminum, but since the early 1970s a revival of interest in conservatories in England have led to more of them being brick based, having arched windows, lantern ridges, cast-iron braces, cresting and finials all of which were derived from their past (Warren 1988). Recently, it was found by Clack's farm in Worcestershire that cedar greenhouses produced better production results than aluminum (Alton

Greenhouses). Three different experiments were performed in both greenhouses. The first was on frost sensitive plants that were grown under unheated conditions over a three month time span, the next experiment kept a variety of plants at a controlled temperature of 65 degrees Fahrenheit using electric meters to measure consumption of energy used up by the blower heaters that were controlled by a thermostat, and finally conditions were kept constant in both greenhouses so crops could be grown to determine if the cedar greenhouse held less disease (Alton Greenhouses). It was found that the cedar greenhouse used 20% less electricity, produced a twelve pound heavier tomato fruit yield, used less water due to lack of radiated heat, and plants were on average nine inches taller than those in the aluminum greenhouse (Alton Greenhouses). The upfront costs of a cedar greenhouse are a bit pricier than aluminum, but in the long run the cost of an aluminum greenhouse will supersede the cedar. The fact that cedar is sustainable is another advantage; the only problems that could arise would be that the number of cedar trees would be highly impacted, termites could easily damage the structure and fire could occur. I imagine the latter two would require an increase in harmful chemicals which would then be unsustainable. Common glazing materials used include 3mm horticulture glass which is cheap and easy to replace; this type of glazing has historically been preferred for these very reasons even though it was extremely dangerous when broken (Dovetail Greenhouses 2003). Another glazing option is 4mm single sheet toughened safety glass which has been noted to be the best of the British float glasses (Dovetail Greenhouses 2003). SAN safety glazing is better than both of the previous glazings except when comparing prices. It is safe, rigid, and clear like glass and is ultraviolet stable. According to Dovetail Greenhouses in the United Kingdom it costs “considerably less than both toughened glass and polycarbonate which are the only real safe alternatives (Dovetail Greenhouses 2003)”. When polycarbonate is used it is often double glazed

which makes heating more efficient (Greenhouse 2009). It does not seem that any of these glazing methods would be sustainable, but SAN safety glazing would last the longest. Ventilation consists of ridge vents, side vents, and fans all being operated by a computer system. A unique ventilation system, however, are louvre windows which have a number of blades made of glass (Dovetail Greenhouses 2003). Most ventilation systems are relatively sustainable as they tend to take advantage of the season and allow natural airflow to occur when opened. When the blades are shut the vent looks like a window and allows light to get in, but when the blades are open it looks like a classic aluminum vent. Heating can be achieved by using electric fans to move the air around, increased insulation with double glazing, under floor hot water pipes, balanced flue heaters, electric and gas furnaces (Warren 1988). They also use natural gas, propane and paraffin heaters; which are run by kerosene (Surflink Systems Limited 2003). They are only primarily used for back up as they can only keep the temperature around 45 degrees Fahrenheit, and they also can cause disease in the winter due to an increased amount of water vapor being given off (Hessayon). Like the glazing materials, heating methods and materials still have a long way to go when it comes to sustainability. Although some methods such as using water to heat is better than gas or kerosene, it still is a very unsustainable method of heating. When it comes to irrigation, the United Kingdom uses the same methods and materials that most others do which are drip and other automatic watering systems. The use of automatic watering systems is sustainable in the manner that less water is wasted because all of the water is applied directly to the plants themselves. As time has gone on, people in the United Kingdom have gone on a sustainability roller coaster ride due to changing technologies and the discovery of new ideas. The United Kingdom is working on becoming a more sustainable country which means that their production methods are becoming better for the environment and will be more efficient

at using the resources available. Currently the UK, is working on trying to find peat alternatives in order to reduce the amount of peat that is used by horticulturists. This falls under the UK Biodiversity Action Plan (Lowland Raised Bog Habitat) (Departmental of Environmental Food and Rural Affairs 2007). This shows that their semi broad definition of sustainability works for them because they know that there is no other way to include everyone in the process of becoming more sustainable.

Figure 2. The amount of land in the United Kingdom that is organic or in conversion, in comparison to the amount that is neither keeping in mind that this is out of 17,400,367 hectares (ICES n.d).

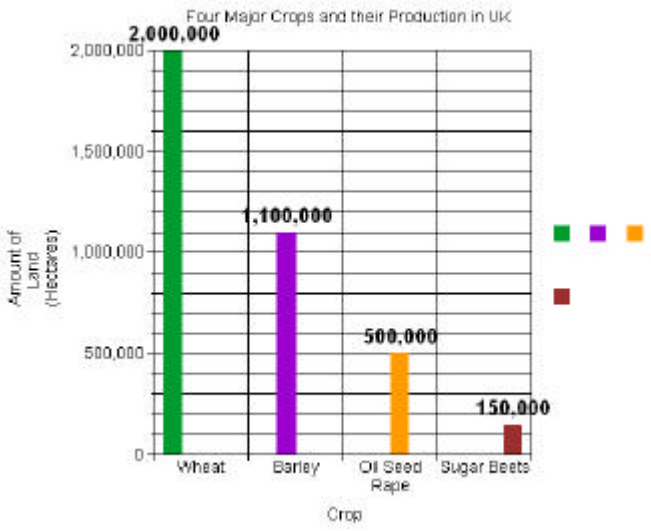


The United Kingdom is also working on doing more organic practices and converting more land to organic production. In 2008, it was reported that in 2007, 157,893 hectares of land was in conversion and 524,303 was organic which totaled 682,196 hectares of land out of 17,400,367 hectares (Figure 2) (Department of Environmental Food and Rural Affairs 2007). This means that 3.9% of the land in the United Kingdom is or is becoming organic which is a 10% increase from the previous year (Department of Environmental Food and Rural Affairs 2007). There are currently 7,631 producers, growers, processors and importers of organic goods (Department of Environmental Food and Rural Affairs 2007).

The United Kingdom is currently the fourth largest producer of cereal crops (Department of Environmental Food and Rural Affairs 2007). They produce a lot of wheat, barley, oil seed rape, oats and sugar beets yearly. Wheat is their most widely grown arable crop covering 2

million hectares or about 4,942,107.63 acres, and producing 15.5 million tons each year (Figure 2) (Department of Environmental Food and Rural Affairs 2007). Barley is grown on approximately 1.1 million hectares or 2,718,159.2 acres, and producing 6 million tons every year; 2 million in the production of malt alone (Figure 3) (Department of Environmental Food and Rural Affairs). Oil seed rape covers .5 million hectares of land each year which is around 1,235,526.91 acres producing 1.5 million tons of seed (Figure 3) (Department of Environmental Food and Rural Affairs 2007). Finally, sugar beets are grown on 150,000 hectares of land or 370,658.07 acres which is equivalent to 9 million tons (Figure 3) (Department for Environmental Food and Rural Affairs).

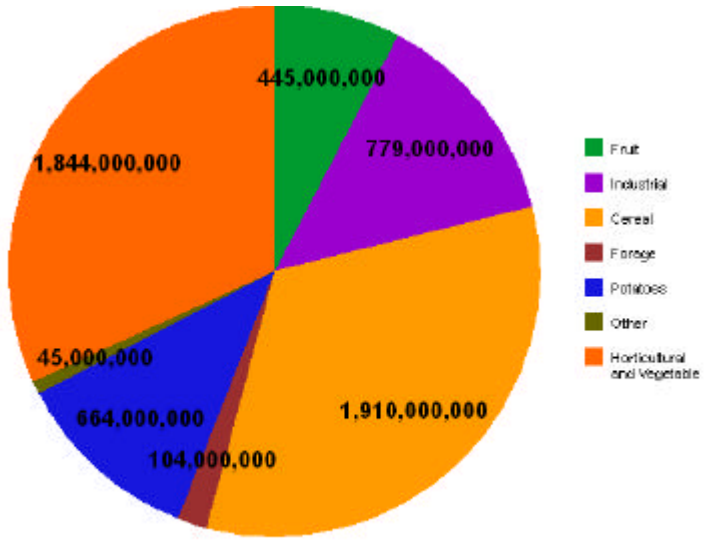
Figure 3. The amount of wheat, barley, oil seed rape and sugar beets that are produced in the United Kingdom every year (ICES n.d).



The main flowers and plants grown in the UK include flowering houseplants such as African Violets, Azaleas, Begonia, Kalanchoes, potted bulbs, Daffodils (largest grower of cut flower Daffodils in the world), Narcissi, Tulips, Chrysanthemums, *Lisianthus*, *Alstroemeria*, and seasonal summer flowers such as Asters, Delphiniums, Peonies, Sweet Williams, Stocks, Solidaster and Sunflowers (Flowers and Plants 2009). Of course there are many more that are grown in the United Kingdom. They grow all sorts of annuals, bulbs, and bulb like plants, cacti and succulents, conifers, culinary herbs, ferns, fruit, grasses, greenhouse and houseplants, orchids, perennials, rock garden and alpine plants, trees and shrubs, and vegetables.

Common fruits grown in the United Kingdom include apples, blackberries, blueberries, currants, gooseberries, pears, raspberries, and strawberries (Fruit Expert 2009). In 2007, 27,580 hectares of fruit was grown (Department of Environmental Food and Rural Affairs 2007). 27,434 hectares was outside and the last 146 hectares were grown in a glasshouse (Department of Environmental Food and Rural Affairs 2007). Common vegetables grown include tomatoes, cucumbers, cabbage, beets, carrots, peas, spinach, etc. In 2007, 116,311 hectares of land was used to produce vegetables, 115,642 hectares of which were outside and the last 668 hectares were in protected areas such as a glass house, or hot bed (Department of Environmental Food and Rural Affairs 2007). Together fruits and vegetables were grown on 143,891 hectares of land (Department of Environmental Food and Rural Affairs 2007).

Figure 4. The amount of money the United Kingdom received from the production of their many crops (in Euros) (NCES n.d).



The amount of money received from cereal crops in 2007 was 1.910 million Euros, industrial crops earned 779 million Euros, forage plants earned 104 million Euros, vegetables and horticultural crops earned 1.844 million Euros, potatoes earned 664 million Euros, fruit earned 445 million Euros and finally all other crop products including seeds earned 45 million Euros (Figure 4) (Department of Environmental Food and Rural Affairs 2007).

The United Kingdom is very dependent on the production of crops in their country not only for food, but also for exports. They are trying to become more self reliant in order to reduce the amount of travel miles on their food products. This will reduce the amount of fuel burned to get crops from other countries but will also increase the amount of food that is grown and bought locally. They are well on their way to becoming a sustainable country, it is only a matter of time.

Some of the current nurseries that are producing in the United Kingdom include Country Garden Roses, Standard Trees, P Davis Nurseries, DAYDAWN Nursery, GLENACRES Nursery, Eden Point Nurseries and The Alpine and Grass Nursery. They grow many different plants including bamboo, *Berberis*, camellias, climbing plants, conifers, fruit trees, fuchsia, hedging plants, magnolia, ornamental grasses, *Philadelphus*, *Prunus*, *Pyrus*, rhododendrons, roses and topiary (Wholesale Nursery and Garden Directory 2009). There are also many licensed organic farmers such as Glebe Farm, Hadleigh Farm, Purely Organic, Beans and Herbs, and Welsh Farm Organics. The United Kingdom has a lot of growers and producers that produce a wide range of goods for the people of the United Kingdom and for those who receive their exports. As of 2003, there were 5,100 growers of fruit and vegetables, and as of 2006 there were around 9,000 sugar beet growers (Department of Environmental Food and Rural Affairs 2009). As I could not locate the total amount of growers throughout the country, it can be concluded from this information that there are many in the United Kingdom because sugar beets, and fruits and vegetables aren't even the greatest annual producers.

Comparing and Contrasting Past and Present Production Practices

First, I will briefly describe past and present methods of production by use of a facility or other building materials. The first method discussed earlier in this paper was the use of wooden boards and iron stoves that were only used in the winter to protect orange trees. Olivier de Serre

then created a greenhouse that had a lean to and thatched roof with open skylights. In cold zones, this same greenhouse would have to have had well fitted glass windows with interior heat coming from charcoal or dry wood furnaces in order to maintain a sufficient temperature. Soon thereafter, citrus production consisted of a tree being planted against a brick wall, boards, seare cloth and a stove. The boards were used to protect the citrus tree in the winter; the seare cloth would be wrapped around the root ball of which would then be heated by the stove. Queen Henrietta followed with a greenhouse that was made of brick, had a blue slate roof for style and an attached coal house where the heat came from. Jule Hardouin Mansart created a deep, long greenhouse with projecting wings. There was a lot of stonework done, doors were recessed and made of thick wood. He used both wood and glass to double glaze the greenhouse for heat efficiency. The fact that the greenhouse only had one exterior wall also made it possible to have no heating system. Next, John Evelyn modified Olivier's idea and made a ridge roof greenhouse without skylights. He also insisted on having cork on the walls for increased insulation, and a porch for prevention of cold air rushing in.

It was during the Golden Age that new cultivars of citrus trees were not being satisfied by the large windows; they did not supply enough light and required a lot more heat. Galilei and Bradley combined their individual specialties to create a greenhouse that had a decagonal rotunda under a cupola that faced south. There were ample windows around the rotunda and the building was heated by charcoal furnaces located in a room at each end of the greenhouse. When pineapple, became a delicacy the desire to produce it also increased. A great method of production was to start them in hot beds that were brick lined, 5 feet deep and filled with a fresh 12 inch layer of horse dung which was then covered by a thicker bark layer. The next innovative method of growing came when a half dome greenhouse was built. It was innovative because the

heat source came from under the building itself through a series of cast iron hot water pipes that led to a boiler.

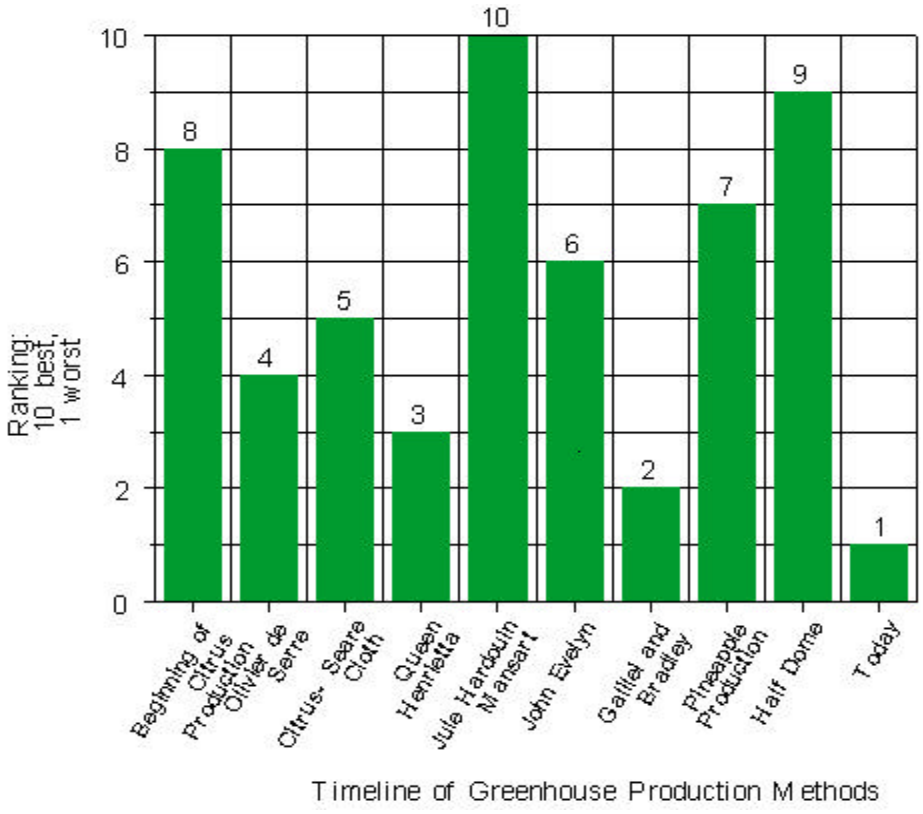
Finally, we arrive at production today which consists primarily of aluminum, plastic, and polycarbonate. Other materials for building include cedar among other woods. Glazing materials also consist of SAN, horticultural glass, and other forms of poly. Heat comes from propane, natural gas, electric, hot water and kerosene. There are side vents, and ridge vents. Water is distributed via automated systems that spread throughout the greenhouses.

When it came to ranking the different methods of production, I first considered the heating efficiency of the building as I feel like that is a crucial aspect of production. All of the sustainable materials in the world will not make one bit of a difference in the middle of a cold spell under non-efficient heating conditions as we have yet to discover a truly sustainable heating method; for now all we can do is reduce our use. Then I considered the type of heat being used because some types of heat are healthier for the plants themselves, and are more efficient at giving off heat per unit used. Next, I considered what materials were used in construction, some are obviously better for the environment, for example, the use of wood would be more sustainable then aluminum. Finally, I took into account the ability to take advantage of the natural weather, i.e. ventilation, water, etc. The results of my ranking methods can be seen in figure 5. I ranked Jule Hardouin Mansart's greenhouse design the highest because it had the highest heat efficiency, so good in fact that there was no heat source in the building. The materials used were also quite sustainable as they were wood and glass. I then ranked the half dome design the next best at sustainability due to the fact that heat came up from under the building itself via hot water flowing through pipes. This is a very efficient and effective heating method that produces the least amount of carbon emissions. It was for this very reason that I

ranked this type of greenhouse higher than the method that was used at the beginning of the citrus production era; the only important difference regarding sustainability being the heating method and efficiency. Pineapple production methods followed early citrus production methods because heat was needed year round whereas with citrus it was only used when necessary. John Evelyn's greenhouse had great insulation but lacked efficiency in heating due to where the heat source was located which was outside of the building. The citrus seare cloth method was only ranked lower because it did not have the level of insulation that John Evelyn's design did which made the heat efficiency even lower. Olivier de Serre's greenhouse design followed because of the type of heating that was being used which was charcoal or dry wood, both gave off high levels of harmful fumes and unfiltered emissions. Queen Elizabeth followed with a design that had both poor insulation and an unfiltered heating system. She only ranked higher than Galilei and Bradley's design because her materials were more sustainable and her system only required one heat source whereas the other required two. In general, past materials were all very sustainable, but it was the heating method that was not. Today greenhouses use better heating methods, but the materials that are used are usually quite unsustainable with most of them being petroleum-based and are not biodegradable. I ranked the United Kingdom's methods of production for the present last because the primary sources of heat use non-renewable resources, glazing and building materials are unsustainable, and a lot of pesticides and fertilizers are being used to increase production and reduce disease. Figure 6 is a representation of the United Kingdom's sustainable greenhouse production methods over time based on my rankings. From the figure it is evident that the United Kingdom has truly been on a sustainability roller coaster over the past hundred years or so.

Figure 5: Sustainable rankings of greenhouse production in the United Kingdom.

Figure 6. The trend of sustainability in greenhouse production in the United Kingdom (NCES n.d).



Next, I will be discussing the past and present field production methods performed by the United Kingdom. I will then be evaluating them based on their level of sustainability. The United Kingdom used to rotate turnips and clover which increased production per land area. They also planted high yielding types of crops such as wheat and barley. Once the importance of nitrogen to plants was discovered, they began using methods that conserved the amount of nitrogen in the soil. This was done by planting legumes such as carrots. Eventually, the demand for a single crop i.e. barley overtook the previous methods and natural nitrogen was replaced by fertilizers and pesticides were then used for diseases.

When evaluating these methods, I not only considered the method they were using, but also the amount of production that was able to come from the land. As evident in Figure 7, I chose to rank their method of conserving nitrogen the highest as I feel the amount of production

of more useful crops was high while maintaining healthy high natural nitrogen soil. This was followed by the rotation of turnips and clover only due to the fact that the usefulness of these crops was lower than those that were used to conserve the nitrogen levels. Finally, I ranked the methods of today the worst because a lot of nitrogen received by the crops is from fertilizers, and there is an increase in disease and pest potential as a result of growing a single crop which also increases the amount of control chemicals sprayed. Figure 8 is a graphical demonstration of how the methods have changed sustainably over time.

Figure 7. Sustainable rankings of field production in the United Kingdom: Past and present (Microsoft Office Excel 2007).

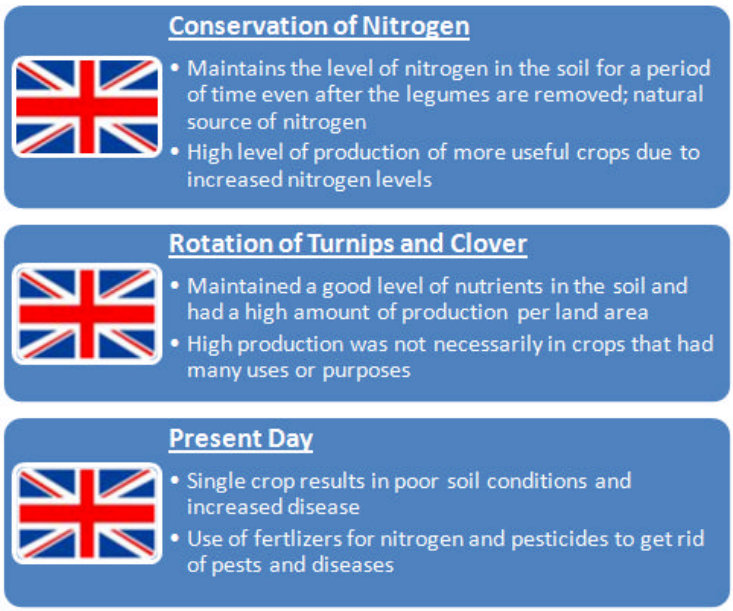
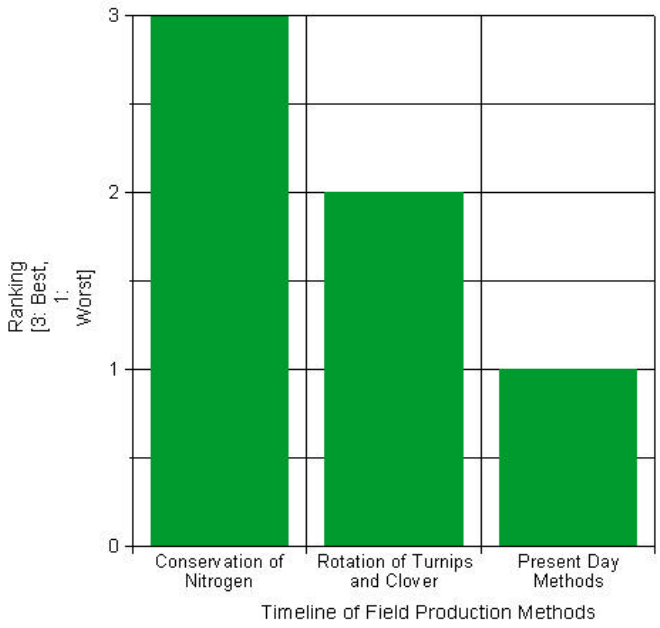


Figure 8. Graphical demonstration of field production rankings over time (NCES n.d.).



Sustainable Development Strategy.

Although the United Kingdom's current production methods are worse than in the past, it is only a matter of time before they start to improve. The standards and legislature are extremely supportive of becoming sustainable and reducing their greenhouse emissions. Lord Turner of Ecchinswell called for a

decrease in emissions of 34% from the 1900 levels by the year 2020 with hopes of an 80% decrease by 2050 (Carr 2009). They have a budget for reducing emissions and greening their economy which means that it is a legally binding contract (Carr 2009). A serious problem that will have to be overcome is the need for fossil fuels to produce the very materials that make up a greenhouse and are used in the horticulture industry.

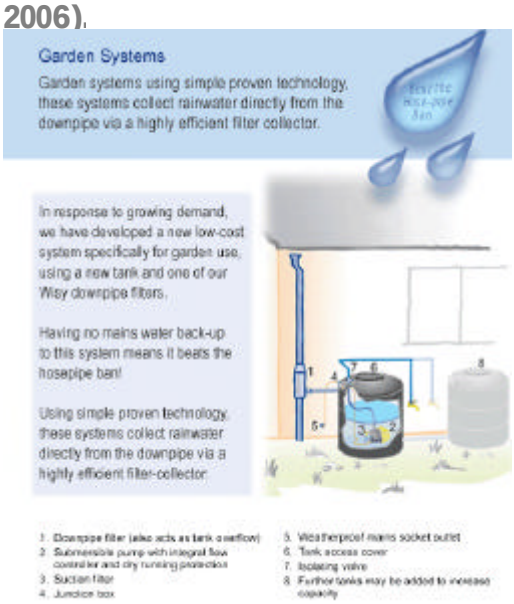
There has yet to be discovered an efficient sustainable glazing material. Glass is sustainable, but it is inefficient and breaks easily, while acrylic and polycarbonate are efficient but lack sustainable quality. Plastic pots are another big issue as they are the "gardener's equivalent to the shopper's plastic carrier bag" (BBC 2009). Although handy and cheap, they are extremely wasteful and use up seven percent of the world's annual oil production when made and manufactured for the first time (BBC 2009). However, pots and trays currently have new solutions. Coir products are popular and are said to biodegrade in the soil after planting while reducing water loss, suppressing weed growth and slowing slugs and snails (Kirton Farm Nurseries Ltd. 2008). Pots can also be made from wood chips, rice husks, *Miscanthus* and seaweed, some biodegrading after a few months while others lasting as long as three years.

Heating is a tricky issue if complete sustainability is desired as most electricity comes from nonrenewable carbon producing resources such as coal, oil, petroleum and natural gas (BERR 2008). "Solar panels are one of the least cost-effective ways of combating climate change and will take 100 years to pay back their installation costs" stated Martin Hickman in his article on solar panels (Hickman 2008). Geothermal methods can also be considered when it comes to heating a greenhouse. They are becoming increasingly popular in the United Kingdom as they are very energy efficient and cost effective (BERR 2009). Currently there are 250 ground-source heat pumps installed in the United Kingdom every year (BERR 2009). This method of producing heat is limited to areas where hot rock is relatively close to the surface, there are estimated to be around 1,550 of these sites that can be found in the North Pennines, parts of southern England and Derbyshire that could produce an average size of 800 kilowatts of thermal power (BERR 2009). This leaves the rest of the United Kingdom to use other methods such as wind,

biomass, tidal and hydroelectric to produce electricity that will create heat for their greenhouse. The United Kingdom has the largest potential wind energy resource in Europe and is the most developed and cost-effective of the renewable energies (BERR 2009). Electricity from waves and tides is currently in its infant stages which make it very expensive (BERR 2009). Biomass has huge promise in Europe, and has already made great strides. As of 2003, biomass created 87% of the heat and electricity generated by renewable energy sources in the United Kingdom (BERR 2009). Most of what was burned was landfill waste, but others came from sewage, domestic wood and industrial wood. Biomass produced 1.55% of the total electricity supply in 2003 (BERR 2009). To sum up the heating issue, greenhouses must consider efficiency, and the method by which they are going to heat their greenhouses. For example, some greenhouse growers may be able to afford purchasing their own wind turbine to produce their own electricity while others could purchase electricity from a company that uses that renewable resource. Their method may also depend on where they are located within the country, for instance, if the grower is located near the North Pennines they may consider geothermal as their primary heat source.

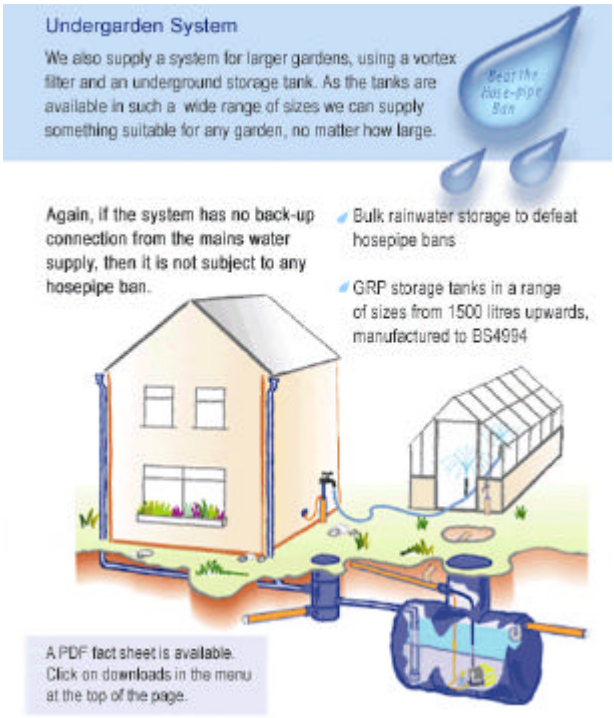
Water is crucial for the survival of all life on Earth which is why it is important that horticulturists recycle to reduce their water waste. Rain harvesting systems are becoming increasingly popular as they are inexpensive and eco-friendly. Each harvester contains a filter that filters out unwanted particles and minerals, while preventing the water from becoming stagnant (Rainharvesting Systems 2006). Figure 9, is a diagram of a rain harvester commonly used by small growers in the United Kingdom while figure 10 is an example of what a large grower would use. The difference is the underground storage tank which allows for a larger amount of water to be captured for later use when

Figure 9. Diagram of a rainharvesting system that would be used in smaller facilities (Rainharvesting Systems 2006).



water is sparse. A disadvantage to the rainharvesting systems would be if there was an extended period of dry weather and the amount of water used exceeded that of what was being gathered. The only method to combat this would be to recycle the water back into the tank.

Figure 10. Diagram of a rainharvesting system that would be used in a larger facility (Rainharvesting Systems 2006).



Chemical restrictions in the United Kingdom have tightened since the eco-friendly trend has come into play. According to Members of the Crop Protection Association, the United Kingdom has “some of the strictest pesticide regulations in the world” (BBC 2009). It is because of these regulations that the amount of chemicals available to home growers is limited, and they are instead encouraged to use them sparingly (BBC 2009). They are advised to use beneficial microorganisms and to practice good gardening practices such as crop rotation, careful crop placement, and good feeding and watering methods (BBC 2009). Fertilizers are also suggested to be used sparingly as they increase the amount of lush growth which pests especially slugs and snails love (BBC 2009).

The latest methods of becoming eco-friendly are slowly gaining popularity. It will take time and money for people to implement them into their horticultural production facility. Once growers begin shifting to an economically and environmentally sustainable heating system, using efficient building materials and creating an efficient structure, using biodegradable pots, recycling and harvesting water, and learning to practice good growing methods that reduce the amount of pesticides and fertilizers needed, the United Kingdom will be well on their way to having a sustainable horticulture industry. As

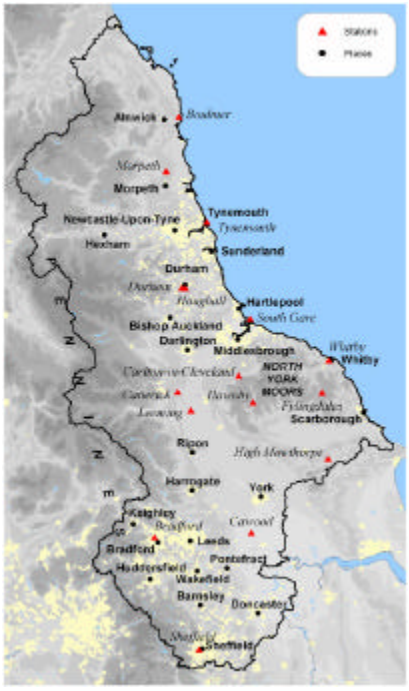
they are a very ambitious and innovative country, there is no doubt that they will set the standards for the rest of the world.

A Future Sustainable, Controlled-Environment Production Facility.

As the United Kingdom is the largest grower of cut daffodils in the world, my future sustainable production facility will be producing them as the primary crop (Flowers and Plants 2009). In order, to understand what sustainable methods of growing would work well for these plants, it is important to understand what is required to grow them.

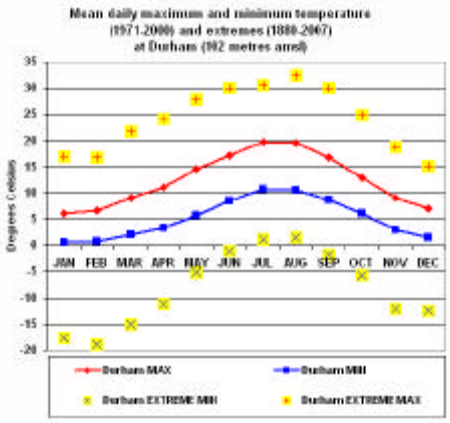
Prior to planting the daffodil bulbs must be pre-cooled for six weeks in a dry space at 40-48 degrees Fahrenheit (Bulbmark.com 2007). This process should begin in early September (Bulbmark.com 2007). The bulbs can be planted outside under a 6 inch sand or straw cover buffer layer (Bulbmark.com 2007). This can only be done in places where outside soil temperatures make it possible to do this (Bulbmark.com 2007). After fourteen weeks of outside growing, or when a sprout is visible the plants can be moved to a low light level greenhouse (Bulbmark.com 2007). Bulbs are planted into containers containing a sterilized, well draining planting medium with a pH of 6-7(Bulbmark.com 2007). It is recommended that bulbs be dipped in a fungicidal solution to prevent disease (Bulbmark.com 2007). A half inch of heavy sand should be placed as a top dressing on the growing medium (Bulbmark.com 2007). The soil should be kept slightly moist with most of the watering occurring in the morning (Bulbmark.com 2007). Fertilization should occur once a week once the plant is two inches tall (Bulbmark.com 2007). Calcium Nitrate is desired as it will prevent stem topple; it should be applied at a rate of two pounds per one hundred gallons (Bulbmark.com 2007). After the bulbs are brought into the greenhouse it usually takes four weeks to get plants to market stage (Bulbmark.com 2007). An ideal greenhouse for growing daffodils would be one that was medium lit with good ventilation (Bulbmark.com 2007). Nighttime temperatures should be 55 degrees Fahrenheit (13 degrees Celsius) with a daytime temperature of 65 degrees Fahrenheit (18 degrees Celsius) (Bulbmark.com 2007).

Figure 11. Map depicting location of test facility (Met Office 2004).



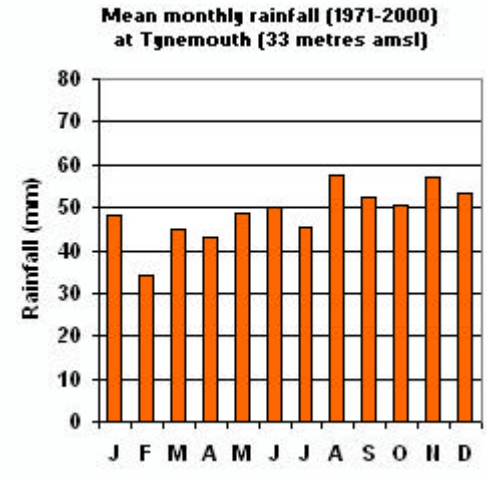
The following is a facility that I believe would be a good example of an energy efficient and sustainable greenhouse that could be used for the production of daffodils. The facility will be located in the North Pennines near the town of Durham (Figure 11). There are a three primary reasons for choosing this location: 1) wind produced electricity would be easy to get as it is a very windy area and hot rock is available for use of geothermal energy,

Figure 12. Graph depicting the temperature range throughout a year in Durham (Met Office 2004).



2) the climate gets cold enough to facilitate growing the bulbs outside for fourteen weeks (Figure 12) and 3) there is a fair amount of rain that could be stored, harvested and used for watering of the crop (Figure 13)(Met Office 2004). The size of the facility will consist of three 20' by 30' A-frame greenhouses with no wall separating the interior space. There will be an attached head house that surrounds the north and east sides. The reasoning for this is to provide extra insulation from northern winds and easterly winds coming from the cold sea. The structural components of the greenhouse will be made of cedar wood, while the glazing material will be single glazed glass as it makes more sense for plants that prefer cool temperatures like the daffodil (Ward 2000). The curtain walls will be made of 8 inch concrete block while the head house will be made of brick, purchased locally.

Figure 13. Graph that is representative of the amount of average rain that Durham receives annually (Met Office 2004).



After doing the heating calculations, it was determined that geothermal alone would not produce enough kilowatts to keep this facility heated to the proper temperature. A boiler that would be able to produce 286 mBtu of heat would have to be implemented. This boiler could be run by local wind produced electricity or from a turbine that could potentially be placed on site with the addition of geothermal heating underneath the greenhouse itself. The boiler will be placed in the basement of the greenhouse with pipes extending up into the greenhouse itself. The pipes will be made out of cast iron and will have fins; they will extend around the curtain walls of the greenhouse and up along the ridge.

Also located in the basement, will be the rain harvester. The water will run into the gutters located in the crevices, or Vs between connecting roofs of each greenhouse. The head house will also have a one way slanted roof facing away from the greenhouses themselves; the water will funnel into a gutter placed at the base of the slanted roof. Once water is collected it will run down pipes through a filter and into a big rainharvester tank where it will be stored. The idea of having the tank in the basement is to use indirect boiler heat to warm the water which helps to prevent root shock which can occur when cold water is used to water plants. Once water is used, it will drain back through a filter and be recycled into a separate tank which can also be used for watering and other processes. The idea is that little water will be wasted. When the tanks fill up the gutters will "close off" meaning the pipes that extend down into the harvester will have a valve that will shut.

One process that rain water will be used for is the production of microorganisms such as aerobic bacteria that help prevent disease and pests from killing the plant. An example of this would be to take worm castings and turkey manure, put that into a big tub of water. Aerate the water for 24 hours and spray that on the daffodil soil. Worm castings contain many beneficial microorganisms and the turkey manure provides food for the small organisms. The daffodils would be grown in renewable containers such as rice hull pots that would at least last a couple of growing seasons.

Methods to cool the greenhouse will include evaporative cooling, ridge vents, side vents and fans. Evaporative cooling pads made of cellulose will be place along the east side of the greenhouse facility. The head house on that side will have windows that will be allowed to open all of the way in the summer

to allow for wind coming from the sea to come through. Fans will be placed on the west side of the greenhouse; there will be three of them each spaced 10' apart. Water for the evaporative cooling will come from the rainharvester tanks positioned below in the basement. There will be three ridge vents as there are three ridges present in this facility. There will also be six horizontal air flow fans lined up down the middle of the greenhouse going east to west. They will face opposite directions every other fan; this will keep the air circulated.

There are many design aspects of this greenhouse that may need alteration after the structure is built and tested. Each design aspect will have to be tested for economic efficiency, energy efficiency and production efficiency. These tests could take many years before being completely perfected.

There are also other sustainable methods for the production of cut daffodils that will have to be put through a series of experiments to find the best results. For instance, determining the best sustainable fertilizer that would produce the best results for a daffodil crop is something that would need to be tested. This would be a simple experiment that would require a control, replicates and the fertilizers to be tested. The control of course would be no fertilizer at all, and the other fertilizers would be organic and of a large variety keeping in mind that Calcium Nitrate is crucial in order to prevent stem topple in daffodils being produced for their cut flowers.

It would also have to be determined if the daffodil bulbs could be put outside for fourteen weeks to receive their required cold period. If this wasn't efficient and reliable the bulbs would have to be placed in a cooler which would then have to be implemented into the facility.

Placement of the wind turbine would also pose another issue as the best wind location would have to be chosen. This is crucial as it is important that adequate energy be produced in order to keep the facility running and to prevent crop damage. This would be a difficult experiment to run and would require a couple of seasons of testing before stating the final conclusions.

Finally, organic soil would have to be tested to ensure high success of the daffodil crop. Many different mixes of soil could be tested including a compost mixture made up of old rice hull pots. This

seems like a simple experiment, but soil is a huge part of a plant's success; small changes could have large impacts.

Once the details have been tested, altered, and confirmed the greenhouse facility could begin running and producing cut daffodils. Of course, along the way new technology and ideas may come into play and may make components of this facility such as the rainharvester a thing of the past. There may also be complications that would require a change in growing methods. Nothing is permanent as growth can only occur with change. It is important that facilities be continually maintained, and updated. An inefficient greenhouse is more wasteful and less productive than that of an efficient one. Sustainability is not only about the materials being used, but also the manner and the rate at which they are being used.

Efficiency is not only implementing the proper machinery during production, but also worker implementation and management of the production processes. It is crucial that everyone be trained to use the new technology and that they know how to handle any problems if they may arise. The method of production also needs to be managed so that it is done correctly.

By combining the efficiency of the building, the efficiency of employees and by using sustainable production methods and materials the United Kingdom could have a very successful sustainable production facility for daffodils located in the North Pennines.

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