**Sustainable Horticultural Crop Production in Spain**

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**Introduction**

One of the largest of the three countries that comprise the Iberian Peninsula, Spain has been settled for millennia. During the 16th century, due to its aggressive funding of explorations and subsequent conquering of world territories; Spain became the most powerful and influential country in Europe. However, by the 19th century Spain had experienced three wars and a period of dictatorial rule from 1923 to 1931 that weakened the treasury (U.S. State Department 2009). In 1936 Spain experienced perhaps their most important war, the Spanish Civil War, which lasted until General Francisco Franco’s ascension to rule in 1939 (U.S. State Department 2009). Although Spain joined the United Nations in 1955, and began allowing trade in 1959, it remained the most closed economy in Western Europe (U.S. State Department 2009). Despite being sequestered from the rest of the world under Franco’s dominant rule, Spain was “discovered” during a huge boost in tourism in the 1960s and 1970s; this ultimately created the basis of Spain’s modern economy (U.S. State Department 2009). This critical economic expansion allowed for a more diversified income distribution among Spain’s citizens, and helped to establish Spain’s middle class. Through sheer will and economic prosperity, social changes within Spain’s borders fostered new ideas and led to the transition to a democratic society in the late 1970s (U.S. State Department 2009).
Franco’s death in 1975 set into motion the political process that established a constitution approved by Spanish voters in 1978 (U.S. State Department 2009). In the 1980s Spain joined the North Atlantic Treaty Organization (NATO) and announced its entry into the European Community which allowed full participation in trade agreements with equal import and export rights. This important membership set the stage for Spain’s economic prosperity (U.S. State Department 2009). Democratic elections continue to this day with Spain’s most recent President, Jose Luis Rodriguez Zapatero, re-elected on March 9, 2008 (U.S. State Department 2009).

Due to Spain’s powerful ancient history, its modern history under General Franco’s rule, its pursuit of becoming a democratic country and having had the pleasure of travelling to Spain three separate times over the last 30 years, provided this author with the incentive and perspective to research and study Spain on a much more personal level.

Spain is located at 40°00N latitude and 4°00W longitude. Spain is located on the southwestern side of the continent of Europe. Geographically, Spain is in proximity of the Pyrenees Mountains, Mediterranean Sea and the North Atlantic Ocean (Figure 1) (Maps of the World 2008). Spain has one of the largest land masses in Western Europe (U.S. State Department 2009). Of Spain’s total land area of 505,988 km², 57,615 km² are below 200m, 156,370 km² are between 201 m and 600 m, 198,650 km² are between 601 m and 1,000 m, 88,766 km² are between 1,000 m and 2,000 m, and 4,587 km² are higher; on average, Spain’s average altitude factors out

Figure 1 Map of Spain (Maps of the World 2008)
at 660 m above sea level (Iberia Nature 2010). Madrid, Spain’s capital is recognized as the highest capital city located in Europe, with an elevation of 650.7 meters above sea level (Iberia Nature 2010). Additionally, Spain has over 5,755 km of coastline (Iberia Nature 2010).

Spain’s geographical location gives it a type of climate that is mainly temperate; summers are especially hot in the semi-arid interior of the country and cloudy in the coastal regions, while interior winters are extremely cold, but warmer along the various coastlines (Maps of the World 2010). Spain is typically divided into three major climatic ecosystem zones:

1. **The Atlantic climate along the northern coast:** where average temperatures are 9°C in winter and 18°C in summer. This region comprises the wettest region of Spain with average annual rainfall between 800mm to 1500mm, concentrated in the fall and winter months. Typically summers are cooler and wetter here than the rest of Spain and do experience summer drought at times; and

2. **The Mediterranean continental climate of the interior central plateau:** where low winter temperatures can reach -20°C and average summer temperatures will reach 24°C. Average annual rainfall is typically less than 400mm, with heavy winter snowfalls; and

3. **The Mediterranean coastal climate:** where average temperatures are 11°C in the winter and 23°C in the summer. Average annual rainfall is between 250mm and 600mm per year (Iberia Nature 2010).

Modern day Spain includes a land mass which encompasses approximately 505,988 km², about the size of Arizona and Utah (USA) combined; a diverse population of 46,662,000 citizens; language diversity, with Spanish comprising 74%, Catalan-Valencian 17%, Galician 7% and Basque 2%; religious delineations include a predominate Roman Catholic population, with Protestant and Islamic faiths as well (U.S. State Department 2009). Major cities include: Madrid (Spain’s capital) population 5.5 million; Barcelona, population 4.9 million; Valencia,
population 2.3 million; Seville, population 1.8 million; Malaga, population 1.3 million (U.S. State Department 2009).

Economically, Spain’s Gross Domestic Product (GDP) in 2008 was €1,133 trillion (US $1.556 trillion) and per capita GDP was €24,045 (US $33,100) (U.S. State Department 2009). Major natural resources include: coal, lignite, iron ore, uranium, mercury, pyrites, fluorspar, gypsum, zinc, lead, tungsten, copper, and hydroelectric power (U.S. State Department 2009). Major industries included in the agricultural production model that contribute approximately 2.4% of the overall GDP of Spain are: livestock, dairy and poultry, which account for about 39% of production; the horticultural crop sector, which includes citrus, deciduous fruit, olives and olive oil, nuts, wine and vegetables comprises approximately 40% of production. Field crops, which include grain, tobacco, cotton, forage, sugar beets, and oil seeds, accounting for a larger land area than horticultural crops, yet comprise 15% of the total value of agricultural production. (Encyclopedia of the Nation’s 2007) In 2009, Spain had exports of €150 billion (US $206 billion) comprised of automobiles, fruits, minerals, metals, clothing, footwear and textiles, as well as, imports of €217 billion (US $298 billion) comprised of petroleum, oilseeds, aircraft, grains, chemicals, machinery, transportation equipment and consumer goods. Major trade partners for both exports and imports were the European Union countries, 69% and 58% respectively (U.S. State Department 2009).

**Sustainability**

Before outlining how sustainability is defined in Spain, it is important to recognize that several branches of the Spanish Government have been very aggressive in creating a process and work plan which benchmarks the necessary pathways to sustainability. In 2007, the Spanish government published a watershed treatise on its vision of sustainability. This effort titled
“Spanish Sustainable Development Strategy, November 23 2007,” lays out three areas of sustainability that are modeled for a more sustainable Spain; environmental sustainability, social sustainability, global sustainability (Spanish Sustainable Development Strategy 2007). More critical to Spain’s success, this strategy further defines how to execute this process. The development strategy clearly defines objectives, indicators to measure, actions for implementation, and even suggests the laws that will need to be in place to insure compliance.

Heading into the analysis, preparation and publication of this effort in 2007, Spain had the advantage of a very long and positive economic cycle. Its Gross Domestic Product (GDP) growth rate as compared to other European countries was well above average. Government planners recognized that the requisite social dynamics and the critical collaborative conditions were in place, and seized the opportunity to make a huge stride towards a higher degree of sustainability in their country (SSDS 2007). Leveraging this opportune time in Spanish history, planners would not let the modernization of their country slip by. There was a sense of responsibility and demand that they take on the tasks, challenges and opportunities to form a sustainable development model; a model that clearly combined the dynamics of economics, with the increased value on social well-being for its citizens and an overall improvement for the environment (SSDS 2007). This favorable situation which Spain found itself in, allowed the drafting of their benchmark document. Generally the plan called for a longer term outlook towards a more sound society in terms of the organized use of its resources and a more balanced and cohesive approach in terms of its land use (SSDS 2007).

Spain’s overarching definition of its sustainability principle is “determining and elaborating measures that allow the continuous improvement of the quality of life for the present and future generations by means of the creation of sustainable communities having full capacity to
efficiently manage and use resources, to take advantage of the potential for ecological and social innovations offered by the economy, and at the same time, ensuring prosperity, environment protection and social cohesion” (SSDS 2007). This definition is further delineated and defined by the 3 sustainable dimensions that are modeled in the SSDS which focuses on environmental sustainability, social sustainability and global sustainability.

In order to support their sustainability goals, Spain’s planners worked hard to include methodical and goal oriented action plans directed towards the protection of the atmosphere, air quality, water, land nature and health (SSDS 2007). It calls for an in-depth analysis on the efficiency of resource use, as well as responsible production and consumption. Additionally, Spain’s environmental goals addresses the initiatives to mitigate the impact of climate change in terms of clean energy, industries concerned with pollution, how the marketplace adapts to potential climate change and water resources (SSDS 2007).

In terms of efforts, Spain’s recognition that economics are a critical filter to the success of their initiatives is largely a testament to their commitment. One of the key objectives, sustainable production, is taken into account under the larger context of social responsibility and a strong economy. Being able to raise the efficiency of natural resource consumption as a whole, as well as its influence on each aspect of the country, will have positive effects on environmental sustainability; the reduction of pollution, both locally and globally; reduction in waste; all while improving the competitiveness of the economy. This efficiency will reduce costs and risks associated with energy independence and resource use inefficiencies (SSDS 2007).

Clearly, major risks associated with any planning document lies in its broad strategic initiatives, and while usually inclusive of methods of execution, rarely delineate quantifiable
results to measure success or failure. Spain’s planners have seen this common pitfall and established indicators to judge their efforts. For example, with respect to sustainable biodiversity, Spain’s defined objective is to “stop biodiversity and natural heritage loss, by means of the conservation, restoration and suitable management of natural resources in a way which is compatible with environmentally sustainable exploitation” (SSDS 2007). It is a broad and admirable goal, unwieldy if left on its own housed in some 300 page government document. However, attached to this goal are measurable indicators to ascertain levels of achievement of these initiatives. Planners will gather data specific to habitat, land protections, forest stability, national wetland inventories, and threatened bird species (SSDS 2007). To further support Spain’s commitment and execution of its goals, out of these indicators a law called the “Spanish Strategy for the Conservation and Sustainable Use of Biological Diversity” was enacted. One of the key components of this law was to place parameters on urban uses that could seriously affect the environment, which enabled the enforcement of plans to allow for the support of environmental and natural resources goals (SSDS 2007).

In another example of Spain’s clearly defined and measureable sustainability efforts, they have considered land use and its effects on their sustainable progress. In considering key components to land use the main objective is “to promote a sustainable and balanced land and urban development model, by stimulating sustainable development in rural areas, in particular” (SSDS 2007). The model again defines measurable indicators that can be used: polluted land, farming acreage, available land along Spain’s coasts and State ownership of coastal regions for protected parcels (SSDS 2007). To ensure the same process through its stated goal and measurable performance indicators, Spain has further defined an action plan that called for a land use scheme promoting programs to develop land with low population densities based on taking
advantage of each individual region’s unique environmental resource. This is further clarified by
establishing stabilization areas in low demographic density as areas that must adapt to the
specific environmental resource capacity of that area. To that end, Spain adopted the
“Sustainable Development of Rural Areas and National Strategic Plan for Rural Development
Law.” This law has one clear goal in mind; the preservation and recovery of the natural and
cultural heritage and resources of rural areas (SSDS 2007).

Spain appears to have achieved verifiable successes in their pathway to sustainability.
Clearly delineated definitions, goals, measurable indicators and even the passage of legislative
action have rallied the various branches of government. Spain’s objective is that all aspects of
government support and manage the various strategies outlined in the “Spanish Sustainable
Development Strategy, 2007” perceive these strategies as statewide initiatives, and that they act
from within their own scope of government influence to foster competition and ensure successful
achievement (SSDS 2007). Spain demands from its planners, transparency and an accounting of
the activities to its citizens that will continue to lift its country by following the sustainable
environmental practices it has clearly defined.

**Historical Horticultural Practices**

In the second century BC, the Romans came to Spain and established the present language,
religion and laws. By the early 1500’s, Spain was able to unify and form its present day
constitution.

During the Roman rule of Iberia, vineyards and wine production escalated to serve the troops
(Perez-Camcho 2009). The Spanish citrus industry has had a long historical record. *Citrus
medica* was imported by the early Romans during the fifth century; *C. aurantium, C. limon,* and
*C. maxima* were brought in by the Arabs during the tenth and eleventh centuries (Navarro 2009).
A confirmed early record of Spanish horticultural practices dates back to the eleventh century when the Arabic people introduced various aspects of flower culture, ornamental plants and the concept of botanical gardens. During the subsequent five hundred years, as Europe descended into a state of war, plague and barbarism, botany and the sciences all but disappeared (Turner 2010). In the beginning of the 17th century under the reign of Philip IV, a revival of gardening and horticultural practices began surfacing (Turner 2010). The gardens Jardin del Monasterio de El Escorial, located near Madrid, utilized different plot size and rows for specimen separation, there is also evidence that trellis structures were used for vine crop production. Most evident however, was the planning of water use for irrigation. “The water was collected in streams from the surrounding mountains, and made to unite in a torrent which then precipitates itself into gardening reservoirs” (Turner 2010).

The garden located at La Granja de San Ildefonso, north of Madrid, was known to utilize proper plant spacing with a respect towards air circulation; establishment of a “propagating” nursery for fruit and tree replacement; a “covered” flower garden, “in which are cultivated various species of saxifrage, anemone, and ranunculus, which, being peculiar to cold climates, cannot be cultivated in the other royal grounds” (Turner 2010). The important resource of water and its irrigative properties were highlighted. Its garden design seemed to revolve around the distribution of water, with channels built in and around the garden plots by which a “continual stream of water passes through” (Turner 2010). Reviewing records of the Botanical Garden of Madrid, founded in 1755, shows that in 1802, a “covered house” is used for growing fruit trees and as a “depot for the residence of plants” which were used for education and demonstration of their medicinal properties (Turner 2010). Additionally, there is historical evidence that the garden beds were laid out specifically to be watered with a “garden engine” and that during the
winter months many plants died due to lack of stoves to heat the house, as well as the poor construction of the greenhouses (Turner 2010).

Additional 19th century historical horticultural practices, included the selection of “cucurbitaceous tribes, some sorts of which, as the onion and winter-melon” which are very successful in a specific types of soil. The most notable practice was recognizing that specific regions of Spain while seemingly unproductive, merely required the addition of common walls to protect plants from the wind which hampered insect pollination (Turner 2010).

Spanish horticulture has changed dramatically in the 20th century. Historically, traditional horticulture was implemented in small orchards, farms and garden plots by the local farmers within their regions (Echevarria 2009). The Spanish census of 1982 determined that 50.0% of the country’s farms were 200 or more hectares while only making up 1.1% of the country 2.3 million farms (Iberia Nature 2010). In comparison to the 61.8% of Spain’s farms that had fewer than 5 hectares of land; these farms actually made up over 5.2% of the country’s farmland (Iberia Nature 2010). Additionally, 25% of all farms contained ≤ 1 ha of land (Iberia Nature 2010).

Due to its unique and varied climate, Spanish growers have been able to select specific horticultural crops to produce in their regions. Since the interior of Spain is mainly semiarid at higher elevations, with wide temperature swings, most of the productive areas tended to be along the coastal regions (Iberia Nature 2010). During the 1980s, apple and pear orchards, as well as potatoes flourished in this area (Iberia Nature 2010). Catalonia, located along the Mediterranean coast, was the location of Spain’s most aggressive and concentrated use of irrigated horticulture during the 1980s; with increased production of orange trees, orchard fruit trees, figs and nut trees, as well as vegetable production (Iberia Nature 2010). The southern region of Andalusia,
which contains much of the tillable land in Spain, saw an increase during the 1980s in olive tree production, along with other warm season crops of cotton, tobacco, sugar cane and grapes (Iberia Nature 2010).

During the early 1970s, a growing technique used to speed up harvest and increase yield was employed in various regions of Spain. “Enarendos” entailed covering the soil with a layer of sand and using a very simple greenhouse structure called “parral,” (akin to the modern day pergola) which to this point had only been used for growing grapes; this really became the genesis of modern day protected horticultural production in Spain (Echevarria 2009). With the rise of industrial development, there was a vast improvement in the transportation network, and along with the advancement of refrigeration, large scale vegetable production and distribution exploded (Echevarria 2009). Long distance transport of vegetables is directly related to the emission of carbon dioxide into the atmosphere. This should present a strong argument to come full circle and impose limits on the export and transportation of horticultural products (Echevarria 2009).

**Current Production Statistics**
Due to Spain’s climate and soil variations, there are different regions of the country producing a wide range of diverse horticultural products. The four top types of species farmed range from temperate climate crops like grapes, olives, citrus fruits and vegetables (Figure 2).

Currently, fruit and vegetable productions accounts for over half of Spanish agricultural production, supplying crops such as, tomatoes, peppers, oranges, mandarins, lemons, peaches, lettuce, melons, strawberries, sunflower, olives and apples (Figure 3) (Spanish Agrofood Sector and Rural Environment 2002).

Figure 2 Areas of Production by Major Crop Groups Ha & Tons (Subdirectorate General for Agrofood Statistics 2009)

Figure 3 Production Trends in Spanish Horticulture (1,000 tons) (Subdirectorate General for Agrofood Statistics 2002)
Sustainable production has grown dramatically in Spain. In 1991 there were only 4,235 ha with 396 growers. By 2003, the number of growers reached 17,028 comprising over 725,254 ha of organic production (SSDS 2207). Currently agricultural production amounts of approximately 2.4% of total GDP, or about €21.8 billion (US $30 billion) contributing to the overall Spanish economy (U.S. State Department 2009).

**Current Production Practices**

In the Spanish province of Almeria, there are currently 48,300 ha of greenhouses in use (Downward & Taylor 2005). Unlike the rigid, rounded, metal framed, glass structures used in other places; in Spain, the parral greenhouse is made by a vertical structure of pillars, usually wood, iron, or steel, which then a grid of wire is placed and a plastic film is attached. When looking at the larger “plastic” sheeting movement, the Almeria greenhouses are part of what seems to be a global expansion in the use of plastic sheeting over the last 25 years (Echevarria 2009). The modern long-lasting plastic sheets are now used as mulch, low tunnels and greenhouses.

Water has always been a limiting factor for Spanish greenhouse production. In Almeria the Spanish government has drilled wells to overcome this limitation. The sudden availability of a reliable source of water in the once arid region has been a huge catalyst for production. Spain’s climate, which prior to fully understanding a plants water demand was assumed an inhospitable environment, now provides several advantages for horticultural production. There is no freezing weather in this coastal region, and it is almost always sunny. Wind is even an asset; “it ventilates the greenhouses, preventing excess heat in the summer, reducing humidity and condensation in the winter and allowing outside air to replace CO²” (Wilvert 1993). These benefits result in some of the earliest ripening produce in Europe.
The ornamental horticulture sector lends itself to creativity and innovation due to a highly competitive market and an insatiable consumer demand for variety. Ornamental horticulture production has gone through a rapid expansion that includes innovative production designs (Costa and Sacristan 2009). Some of the most important horticultural evolutions to occur were:

1. **crop diversification:** with the monoculture production house so prevalent in the 1980s being replaced by a wide range of ornamental species;

2. **greenhouse structure improvement:** with the mostly wooden, 2m high, non-air tight houses being replaced with high tunnel greenhouses, 5m in height, with computerized controls;

3. **increased water efficiency:** with the ever increasing knowledge base on species specific water requirements allowing for deficit irrigation (Costa & Sacristan 2009).

Most notably however, there has been a rapid sophistication of production methods employed. During the 1980s harvest yields and quality were fully dependent on temperature during a specific crops’ growth period, which provided very little opportunity to control the outcome (Costa & Sacristan 2009). Currently, in covered greenhouse production, it is possible to control both harvest time and quality with a diverse list of ornamental crops such as rose, lily, chrysanthemum and potted plants such as poinsettia and hydrangea (Costa & Sacristan 2009).

Currently, there are 2.5 million ha of olive tree orchards which produce more than 1,100,000 tones of olive oil. Traditional olive groves and new olive orchards represent the foundation of the olive oil industry in Spain (Rallo, 2009) Current strategies involve increasing planting densities for higher yields, early bearing cultivars, and mechanical harvesting in the newer orchards. Drip irrigation has become the most efficient way to increase yield and key to current production yields (Rallo 2009).

The Spanish citrus industry in the past has been largely shaped by diseases. Early research indicated that psorosis, impietratura, tristeza, and concave gum were producing direct
damage to trees (Navarro 2009). In the mid-1970’s Spain established a programs to rescue healthy citrus plants and established a germplasm bank with these pathogen-free plants. This storage bank is the only mandated supplier of nursery production stock. Nurseries have sold over 130 million plants which now represents over 95% of the Spanish citrus industry (Navarro 2009).

There are obvious environmental challenges to the future of horticultural production in Spain. One tenet of sustainable management on the rise is recycling and composting of horticultural materials. The current over use of plastic based materials must also be considered when striving for true sustainability. In the Almeria area of Spain, practically all the greenhouse plastic cover residues as well as the crop residues are recycled (Meneses & Castilla 2009).

However, the always ubiquitous concern for water use and preservation; seems to make all the major discussions, as water scarcity could become a major limitation of irrigated production. It will be critical to conduct research on increasing efficiency of irrigation (Costa & Sacristan 2009).

**Integration of historical and current production practices**

There have been many developments in Spanish horticulture over the past several centuries. Many of these developments, while increasing production efficiencies, have not fared so well on the environmental sustainability grade card. Below is a discussion of the two major factors facing a sustainable production model in Spain. These are measured through time and summarized in Table 1.

Water is the main limiting factor in sustainable production in Spain. This is true to the extent that the dearth of water has limited further expansion of production. Even during the 17th century the importance of water and an organized irrigation process was utilized. At some of the most famous gardens of that period; Jardin del Monasterio de El Escorial, La Granja de San
Ildefonso and the Botanical Garden of Madrid there is historical evidence that planners considered the source and distribution of water critical to plant growth success.

In the specific province of Almeria, with its 48,300 ha of irrigated houses, the sheer explosion of this region was only due to the existence of important groundwater reserves. Over time, this water has been allowed to be systematically extracted without any type of regulation. In 1986 the regional government banned, by law, any further increase in greenhouse construction to protect the aquifers (Martinez-Paz & Calatrava-Requena 2001). In spite of these legislative limitations, greenhouse construction has continued to increase. Clearly the continued disregard for water resources is not a sustainable action.

Historically only 8-10% of olive orchards were irrigated. Most of the traditional olive growing technology is local small grower based utilizing pruning practices either to train or renew the trees and increase fruit size. Once again, irrigation has been the most effective way at increasing production yields. A small number of irrigated plantations were in production in the 1970’s, followed by steady increases of growers afterwards. As recent as 1997, more than 40% of the new orchards received irrigation (Rallo 2009). By 2009 most of the new orchards were irrigated by using a deficit irrigation schedule; which has allowed production to increase from 600,000 tons in 1980 to over 1,100,000 in 2008 (Rallo, 2009).

As previously discussed, with water came production; with production came parral structures. These growing houses utilize mass quantities of plastic. Currently this is a petroleum product and is one of the most unsustainable product growers can use.
Table 1: Summary of sustainable and unsustainable production practices in Spain since 17th century.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Unsustainable Practices</th>
<th>Sustainable Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>17th and 18th Century</td>
<td>1. Random location of gardens</td>
<td>1. Earliest evidence of planning efficient use of water</td>
</tr>
<tr>
<td></td>
<td>2. No thought of plant health</td>
<td>2. Spacing for air circulation and disease control</td>
</tr>
<tr>
<td>19th and 20th Century</td>
<td>1. Random species location around the country</td>
<td>1. Increase yields with climate selected variety</td>
</tr>
<tr>
<td></td>
<td>2. Disregard for regional soil conditions</td>
<td>2. Little use of greenhouse structure material in production capacities</td>
</tr>
<tr>
<td>Modern Day</td>
<td>1. Disease in citrus industry</td>
<td>4. Germplasm bank to all but eradicate diseased rootstocks in citrus industry</td>
</tr>
<tr>
<td></td>
<td>2. Plastic covered petroleum products used extensively in greenhouse production</td>
<td>5. Plastic covered greenhouses and groundwater exploitation continue to this day, fostering an unsustainable production model</td>
</tr>
<tr>
<td></td>
<td>3. Extensive exploitation of groundwater</td>
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</tbody>
</table>

It is important to consider the production practices and determine the practices that lend themselves to a more sustainable model. Clearly most production practices have their virtues, but are saddled with their own flaws. Being able to grade the long term feasibility of these practices in the future, they should be ranked in terms of their sustainability characteristics. It is also critical to consider the economic advantages and disadvantages of sustainability.

As shown in Table 2 my ranking of the historical and modern day production practices presents an interesting consideration when thinking about long term sustainability. The practices that have scored highest on a scale of 1 to 5, with a total up to 10, show the highest levels of sustainability for long term production.
Table 2: Ranking of production practice and/or structure in terms of sustainability and economic feasibility for long term production in Spain. (Scale is 1-5 with a total score) The higher the score, the more potential that category has for long term viability.

<table>
<thead>
<tr>
<th>Production Practice and/or Structure</th>
<th>Sustainability</th>
<th>Economic Feasibility</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic covered greenhouses</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Unrestricted groundwater exploitation</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

While both production issues are not totally sustainable I ranked the plastic covered greenhouses as more sustainable. This received a total score of six out of ten. Although the material is a petroleum product, which challenges sustainability, it is a readily available material. As noted, the bulk of Spain production comes from small farms and the cost of materials is a strong consideration. When combining both sustainability and economic feasibility together plastic covered greenhouse wins.

The ground water issues; which include fully irrigated orchards, greenhouse production and drip irrigation, are more troubling. As previously described, this sector depends heavily on groundwater resources for intensively grown production. I ranked this unabated exploitation as the lowest for sustainability; scored with a three. Spain is bordered on three sides by saltwater, which makes its precious aquifers so valuable that care must be considered when drawing from them.

When determining the best production strategy to advance as a potential sustainable model, it is important to consider the crops that are most important in Spain. However, to be truly valuable, this discussion must consider the most troublesome component of production—groundwater. This valuable resource is clearly critical for production, but as discussed the least
sustainable. Both crop and water will be measured for developing production practices that help
to define sustainability.

**Sustainable Development Strategy**

The increase in water demand and consumption required to meet the future agricultural
and horticultural demands, while considering environmental impacts, is quickly ramping up to be
one of the most critical challenges facing the planet. Water has been, and will continue to be, a
mandatory component of this industry; however the pace of growth is far out pacing the existing
natural resources (von Medeazza 2004). It’s an irony that one of Spain’s most arid regions is
also home to one of the most productive horticultural areas. This is only possible due to
Almeria, in southeast Spain, also being the most highly irrigated land (Perez 2002). This
conundrum has led to certain people wondering if the horticultural industry is unsustainable.
Without planning and proper research, the question is not if Almeria will run out of good
sustainable water resources, but when.

Historically the ever constant availability of water located in the groundwater aquifers of
the Almeria region meant that water was inexpensive and considered inexhaustible. One
problem is the general uncertainty of water availability. It is very difficult to regulate what has
always been considered a naturally occurring natural resource. Due to this philosophy it has
been difficult for many to consider that there really is even a ‘problem.’ This poor regulation
equates to not having reliable information. This lack of information has resulted in not knowing
exactly how much water, where and at what rate it is being pumped from the aquifers and what
are the re-charge rates. However it is critical to consider that Almeria’s present rate of water
consumption is not balanced with a constant recharge to the aquifers (Junta de Andalucia 2004).
Over the long run these deficits cannot be sustained. There are many ways to consider researching how to mitigate the groundwater exploitation:

1. **Water supply management**—enacting a rationing program, but not very effective to continue production numbers

2. **Water transfers**—facilitated by the Spanish government shifting water resources from other regions within the country to the highly productive Almeria region, which ultimately will affect other regions with their own shortages

3. **Desalination**—converting seawater to freshwater inventory, extremely expensive to build plants and very labor intensive to manage, coupled with high energy costs

4. **Water reuse**—utilizing waste water for irrigation needs in both plastic covered house and orchard production

   Although there are several research possibilities, I believe that water reuse has the most potential and will be considered further in a possible design scheme. Several research questions should be posed and considered prior to full scale implementation.

**Future Sustainable Production**

The tomato is the number one most important horticultural crop in the world in terms of production and trade. According to the Food and Agricultural Organization of the United Nations, world production of tomatoes is around 100 million tons annually. This statistic accounts for about 15% of the total worldwide vegetable production. (Peet and Welles 2005)

The majority of fresh tomato imports to the European Union come from the southern Spanish region of Almeria. At present, tomato production covers over 60,000 hectares which is equal to 14% of the total land area used in Spanish horticulture production and over 20% of total
production value. This makes the tomato one of the most important crops in Spain (Lawrence 2004).

Covered growing houses (high tunnels, aka parrals), are the dominate system in Spanish tomato production. This type of protected growing system is typically the first choice for farmers to help extend the season and help maintain a controlled environment. This type of production facility has the added benefit of creating optimal growing conditions, increased yields and maximizing profits. The tomato production season usually starts in August when seeds are planted and harvesting begins the following April. Harvesting can typically continue through December. Tomatoes are typically grown in an open environment until late November and then they are covered with the previously described system (Mema et al. 2005).

As previously discussed, the main environmental issue associated with tomato production and cultivations in Spain is water consumption. The over-exploitation of the groundwater aquifers from horticultural production has affected water quantity and quality. This overuse has had a ripple effect on water salinity, decreasing water tables, loss of biodiversity and landscape degradation across the region (Martinez-Fernandez and Selma 2004). Current water use in the Almeria region is around 4 to 5 times more than annual rainfall and is mainly retrieved from deep wells. Due to these critical factors, additional research and a research test facility should be located in the Almeria region of Southern Spain. To be more specific, the facility and subsequent research would benefit by being located in the town of Campohermoso, in the sub-region of Almeria, near Cabo de Gata. This area is known to have one of the lowest rainfall accumulations in the area, receiving on average only 171 mm annually (Lazaro et al 2001). The increasing water demand and the diminishing lack of natural water resources justify the research of re-using wastewater as a viable irrigation alternative. The use of purified wastewater in
horticulture today should be considered a resource, especially in the dry Mediterranean regions of Almeria.

The goal of this research project would be to evaluate the effects of wastewater irrigation on a covered tomato crop. The experiment should be run for one full tomato crop maturity season. The research experiment should be set up in a randomized complete block design with two treatments and four replications. The two treatments to be considered should be irrigation with fresh water (standard desalinized well water) and with purified wastewater. In designing the research facility, a standard construction of metal structure and polyethylene cover should be used. The test facility house should be 20’ x 40’ with standard openings at either end for ease of access and air flow. The irrigation process should be accomplished by drip methods. A trouble shooting process should be established to scout for insects, mechanical breakdown of the irrigation system, and consistency of the wastewater supply make-up. A strict control of wastewater, soils, and plants will be required to avoid pathogen introduction. It will be important to study plant growth and yield, soil fertility and cost savings from potential reduction of inputs (N & K) due to nutrient content of wastewater. Equally important to study would be the potential for metal accumulation in the soil, as well as, plants for the potential of infection of by plant pathogens. Methods for obtaining various data would be as follows (Lozano et al 1995):

1. **Yield**—would measure the mass of marketable yield
2. **Soil Fertility & Nutrient Input**—would be calculated by standard analysis looking at pH, electrical conductivity, salts and N & K concentrations in treatments
3. **Heavy Metal Concentration**—would be measured in the water, soil, leaf and fruit by spectrometry
4. **Pathogens**—fecal matter would be determined by filtration techniques

Finally, ANOVA tests would be run on this data to determine results of the research project. The goal of this research project would be to interpret the results to see if irrigated
tomato with re-used wastewater negatively affected tomato yields, soil chemical properties, heavy metal accumulation that could be seen as toxic to plant growth or health.

All participants in the supply chain of tomato production in Spain play a key part in changing the exploitation of water resources. Growers can be encouraged to look at alternative practical solutions where water has exceeded sustainable limits. Future water depletion will eventually force the Spanish horticultural industry in Almeria to be more accountable for the water they are dependent on.

**Literature Cited.**


