VFEngineering Inc.

Vertical Agriculture

CENE 486C

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An Introduction To Vertical Agriculture

- **What:**
  - A method used to grow crops that utilizes vertical space
  - May utilize various systems including hydroponics or aquaponics
- **Why:**
  - Ensures food security by increasing the amount of crops that can be grown in limited space
  - Can be utilized in urban settings where crop land does not exist
- **Our Objective:**
  - Create a small scale prototype

Figure 1: Backyard Hydroponics [1]

Background and Relevance

Figure 2: Commercial Vertical Agriculture Hydroponic System [3]

- Most commercial scale vertical agriculture systems utilize hydroponics
- Hydroponics is a method that uses a controlled environment to grow crops without soil
- Hydroponics is a growing method of farming that accounts for only $600 million of the $140 billion industry [2]
- Hydroponic systems may be vertical or horizontal

Impacts

Social	Economic	Environmental
• Contributes to improved diets and safer food • Brings agriculture to urban settings • Reshapes rural communities • Can more effectively support a growing population	• Creates jobs in the technical sector • Improves productivity and efficient use of resources • Production in any climate, season and time of day • Will produce crops at an increased rate	• Shifts away from unsustainable methods of farming • A solution to soil degradation caused by agriculture • Decrease in pollution generated • Uses roughly 10-20% of land needed for conventional farming [3]

Design Selection: Water

Water Component Alternatives:

1. Aeroponics 2. Drip Method 3. NFT

Nutrient Film Technique (NFT):

- Most common method used for commercial scale designs
- Effective for producing leafy green vegetables

Major Design Components:

- Submersible pump
- Constant flow in the form of a thin nutrient solution film
- Water is recirculated for optimal efficiency

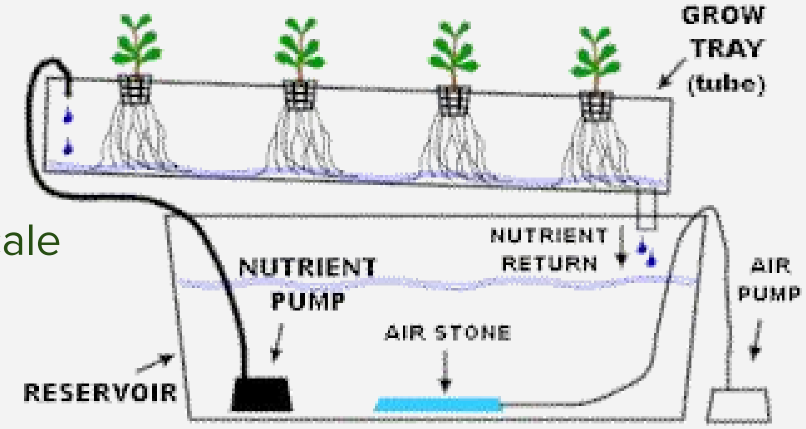

Figure 3: Nutrient Film Technique [4]

Design Selection: Lighting

Lighting Component Alternatives:

1. Fluorescent 2. Incandescent 3. LED

Light Emitting Diode (LED):

- Artificial Lighting similar to natural lighting
- Photosynthesis with 660 nm red and 445 nm blue wavelength
- Low level of thermal radiation
- Long operating life and is energy saving

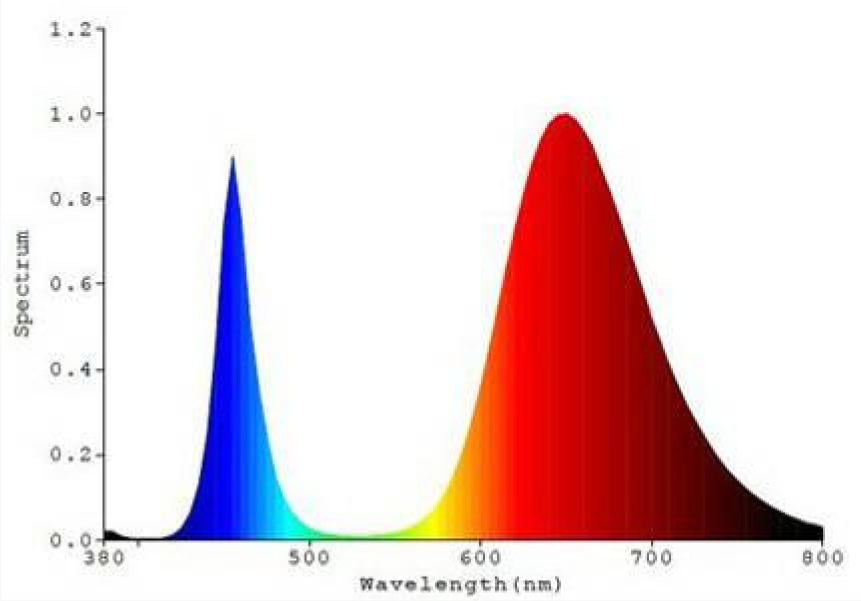

Figure 4: LED Spectrum [5]

Design Selection: Structure

Structure Model:

- Pre-fab structure requires minimal maintenance
- 5 adjustable shelves rated for 500-pounds
- Support for water reservoir and light structure
- Circulation of the nutrient solution using pump and gravity

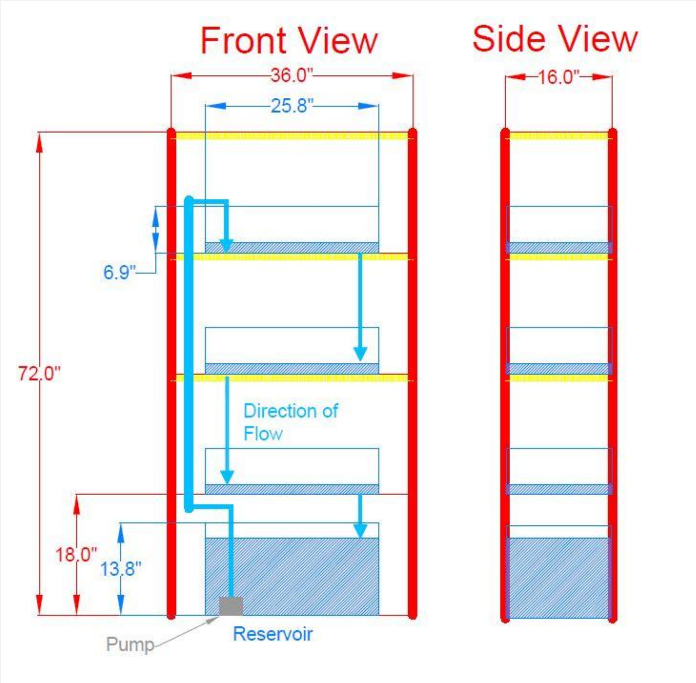

Figure 5: Elevation Schematic of System

Initial Construction Design

Materials:

- Frame: 5 levels of shelving
- Water Basins: Plastic Storage Containers
- Water Transport: ½” Plastic Tubing
- Pump: ECO 158 Submersible Pump
  - *Max head: 4 ft. Output: 158 gal/hr [6]*
- Growth Media: Clay Pebbles
  - *Porous media with stable pH and EC*
- Plant Holder: Wooden Frame
- Lighting: LED Strips
  - *440-840 nm wavelength spectrum*
- Nutrient Solution: 7-4-10 (N-P-K) Ratio
  - *Optimal for lettuce, arugula, and spinach [7]*

Figure 6: Early Construction

Final Construction Design

Improvements:

- Changed ECO 158 to ECO 396
  - *Max head: 6.5 ft.   Output: 396 gal/hr*
- Wooden frame changed to wire frame
  - *Manipulate plant placement and root height*
- Air pump and airstones added
  - *Increase DO levels of water [8]*
- Plastic adjustable pipe fittings added
  - *Adjust water levels*
- Plant screen added
  - *Keep plants leaves from dipping into reservoirs*
- Black sheet added
  - *Block out external light from reaching plants*

Figure 7: Completed System

Plant Growth Criteria & Constraints

Required Growth Parameters:

1. Dissolved Oxygen (DO)
   - Influences transport of nutrients and minerals
2. Temperature
   - Influences DO levels and uptake rates [6]
3. Electrical Conductivity (EC)
   - Influences water uptake
4. pH

Other Measures of Design Effectiveness:

1. Water uptake measurements
2. Plant growth

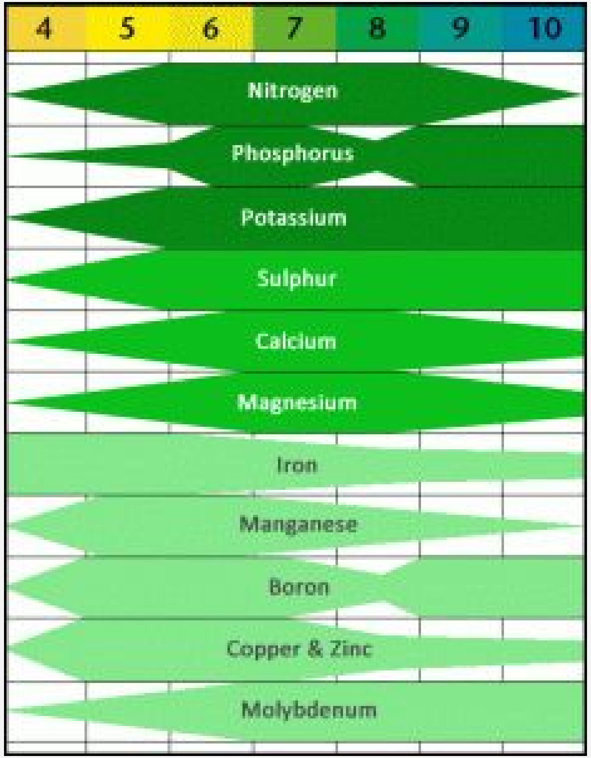

Figure 8: Influence of pH [9]

Test Results: Temperature and Dissolved Oxygen (DO)

Table 1: DO and Saturation Level Comparison

Date	11/2/17	11/7/17	11/9/17	11/14/17	11/16/17	11/21/17	11/23/17	11/28/17
Temp. (°F)	70.1	70.0	65.0	70.8	67.4	69.2	67.8	70.7
DO (ppm)	-	-	7.5	7.5	7.0	6.5	6.2	6.2
Saturation Level for DO (ppm)	6.8	6.8	7.2	6.7	7.1	6.9	7.0	6.7

- Optimal temperature range: 65-80 °F [10]
- Optimal DO range: > 4.0 ppm [10]

Test Results: pH and Electrical Conductivity

Table 2: pH Measurements								
Date	11/2/17	11/7/17	11/9/17	11/14/17	11/16/17	11/21/17	11/23/17	11/28/17
pH	7.0	7.2	7.2	7.3	7.2	7.0	7.1	7.0
Adjusted pH	6.5	6.5	6.5	6.2	6.5	6.4	6.5	6.5

- Optimal pH range: 6-7 [10]

Table 3: Electrical Conductivity (EC) Measurements								
	11/2/17	11/7/17	11/9/17	11/14/17	11/16/17	11/21/17	11/23/17	11/28/17
EC (mS/cm)	-	-	-	0.76	0.66	0.89	1.11	1.05

- Optimal EC range during growth stage: 0.8-1.2 mS/cm [11]

Test Results: Water Loss

Table 4: Volume Measurements							
Date	Top Row (in)	Middle Row (in)	Bottom Row (in)	Reservoir (in)	Total (in)	Volume ($x10^3$ in^3)	Volume (gal)
11/7/17	0.45	0.75	0.75	6.30	8.25	3.36	14.56
11/9/17*	0.45	0.75	0.75	5.80	7.75	3.16	13.68
11/9/17	0.50	0.75	0.75	6.30	8.30	3.38	14.65
11/14/17*	0.45	0.85	0.75	4.70	6.70	2.73	11.82
11/14/17	0.45	0.75	0.75	6.30	8.25	3.36	14.56
11/21/17*	0.45	0.75	0.75	6.00	7.95	3.24	14.03

* volume measurements taken before changing water

Test Results: Plant Growth

Table 5: Arugula Height Measurements			
Date	Top Row (in)	Middle Row (in)	Bottom Row (in)
11/2/17	5.50	3.20	2.30
11/7/17	3.50	3.50	3.50
11/9/17	4.00	3.75	3.75
11/14/17	4.05	4.10	4.00
11/16/17	4.11	4.23	4.05
11/21/17	4.26	4.40	4.07

Test Results: Plant Growth

Table 6: Lettuce Height Measurements			
Date	Top (in)	Middle (in)	Bottom (in)
11/2/17	5.5	3	4.1
11/7/17	Dead	Dead	3.5
11/9/17	Dead	Dead	Dead

- Lettuce plants weren't mature enough and couldn't handle the amount of water they were given
- Presence of aphids also weakened the lettuce
- Added more mature lettuce and are currently gathering data

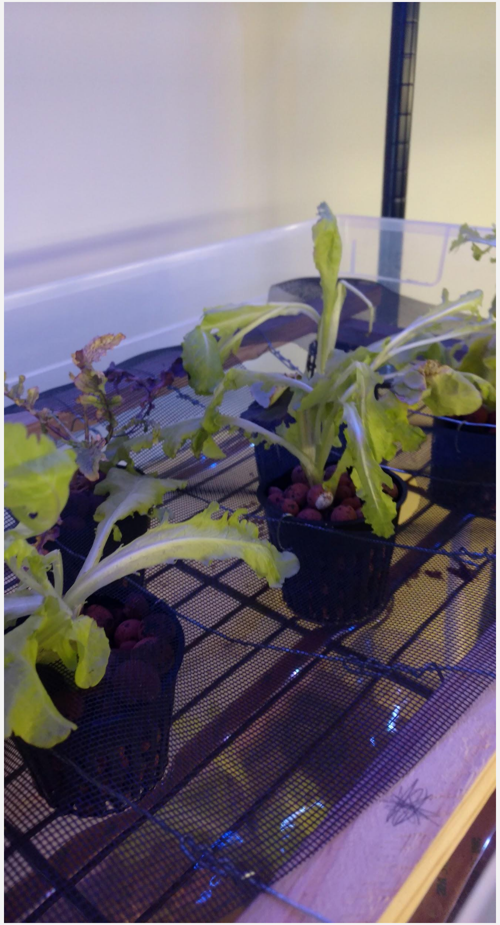

Figure 9: Plant Growth

Review of Results

1 Month Of Testing (11/2-11/28) :

- Arugula grew
  - Average growth 1.25 inches
- Spinach alive
  - Added last week (11/28)
  - Shown signs of small growth
- All components functioning

Figure 10: Spinach Growth

Recommendations

Changes to Design:

1. Improve transplanting procedure
2. Lower water-levels to prevent drowning of plants
3. Select different varieties of lettuce with stronger root systems
4. Experiment with different growth media

Potential Future Uses:

1. Prototype for future testing purposes
2. Phytoremediation studies
3. Oxygen and Carbon Dioxide Uptake monitoring

Figure 11: Middle Row of System

Schedule

- Remained on schedule & met milestones

ID	Task Name	Duration
0	**Vertical Farming Project**	**120 days**
1	**1 Task 1 Research**	**15 days**
2	1.1 Research	10 days
3	1.2 Preliminary Report	3 days
4	1.3 Selection Report	2 days
5	**2 Task 2 Design**	**20 days**
6	2.1 Structure Design	5 days
7	2.2 Lighting Design	5 days
8	2.3 Watering Design	5 days
9	2.4 Material Purchase	5 days
10	2.5 Design Memo	0 days
11	**3 Task 3 Construction**	**8 days**
12	3.1 Layout	2 days
13	3.2 Assemble	4 days
14	3.3 Inspection	2 days
15	3.4 Construction Memo	0 days
16	**4 Task 4 Testing**	**6 days**
17	4.1 Mock ups	4 days
18	4.2 Testing memo	2 days
19	**5 Task 5 Final Presentation**	**13 days**
20	5.1 90% Report	12 days
21	5.2 Final Presentation	1 day
22	5.3 Final report	0 days
23	6 Project Management	120 days
24	**7 Summer Work**	**40 days**
25	7.1 Purchase seeds	5 days
26	7.2 Starter Plants	35 days

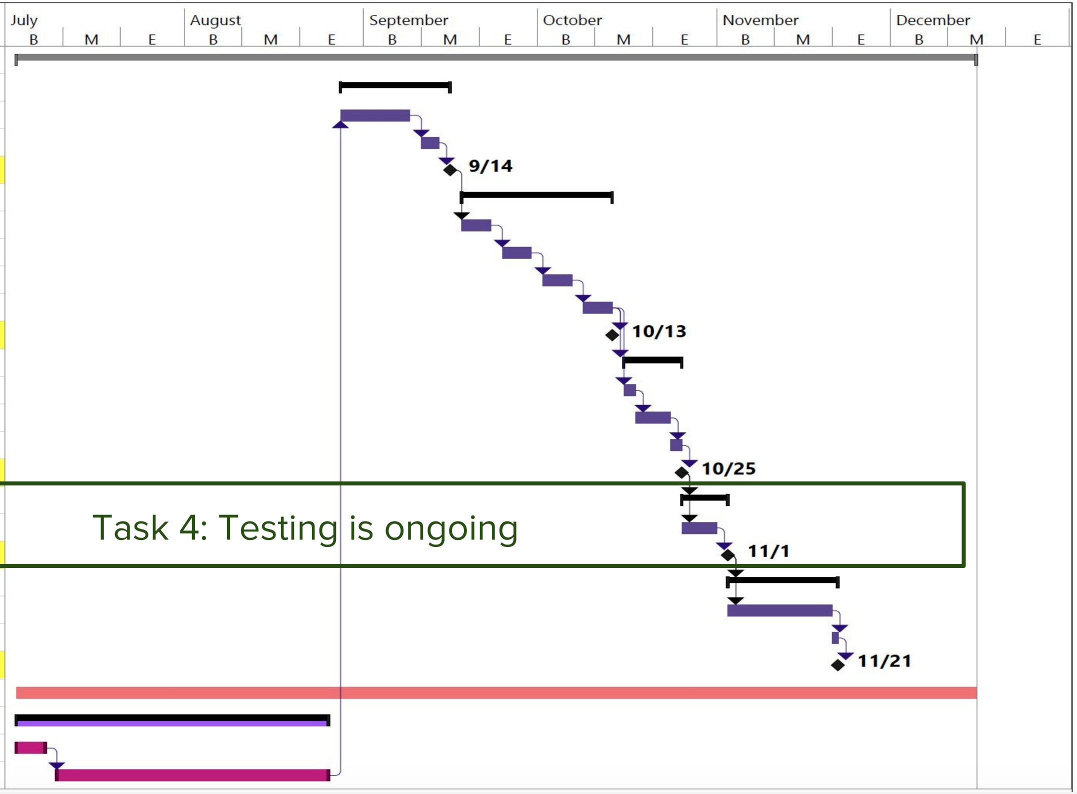

Figure 13: Gantt Chart

Engineering Hours

Table 7: Staffing Hours					
Position	Rate of Pay [12]	Hours		Cost	
		Proposed	Actual	Proposed	Actual
Project Manager	$140/hr	120	110	$16,800	$15,400
Senior Engineer	$130/hr	190	180	$24,700	$23,400
Engineering Technician #1	$75/hr	240	300	$17,250	$22,500
Engineering Technician #2	$75/hr	240	300	$17,250	$22,500
	Total	790	890	$76,000	$82,540

Cost of Implementation

Table 8: Cost of Implementation		
Item	Quantity	Cost
LED Lights	3 rolls	$84.00
Shelf Rack	1 rack	$40.00
Reservoir/Tubing/Fittings	Lot	$67.00
Plant Holders (All Components)	Lot	$89.00
Water Pump	1 pump	$40.00
Air Pump/Air Stones/Hoses	Lot	$43.00
Testing Kit (ph, buffer, EC, TDS)	Lot	$38.00
Nutrient Solution	1 bottle	$26.00
Starter Plants	24 plants	$30.00
	Total To-Date	$457.00

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