REFURBISHING THE CAROUSEL IRRIGATION SYSTEM

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Abstract

This project aimed to refurbish the Southern Arava Research and Development Station's non-functioning Carousel Irrigation System. We assessed each subsystem and completed a full system analysis to identify problem areas. This team was able to repair and suggest improvements to this machine, which enables the R&D Station with the power that will increase the success of local farmers in the global produce market.

Acknowledgements

This project would not have been possible without the opportunity provided to us by Buki Katz, manager of the Arava Research and Development Station. In addition, we would like to thank everyone else at the Station for always providing answers to our questions, especially Ehud Zeelim, Gilad Hurvits, and Daryl Gillett. Repairing the Carousel Irrigation System was made possible with the support Crystal Vision's Ra'anan Shema and Muki Telman. Without their support, this project would not have reached its current level of success.

We would also like to thank Professor Isa Bar-On for advising this project. Her steady guidance and thoughtful suggestions kept our group moving forward with new possibilities and ideas. We are very grateful for her help in reviewing our work and providing such a unique opportunity for our group.

Executive Summary

The purpose of this project was to refurbish a non-operational, 25-year-old Carousel Irrigation System (CIS) used in controlled, automated experiments conducted at the Arava R&D Station. By resolving problems of the system, Arava R&D will be able to conduct future experiments and continue to support the innovative farming in southern Israel.

The area is advantageous to farmers for its high amount of sunlight, high temperatures, and cheap land, which make exports to Europe possible during the winter months (“Israel’s Agriculture in the 21st century,” 2002). The Negev has a limited amount of natural water sources. This water requires the costly process of desalination to provide clean water for the domestic and agriculture sectors. In addition, poor soil quality contributes to the difficult farming circumstances, demanding systemic fertilization. The Arava Research and Development Station (Arava R&D) improves farming techniques to help Israel achieve success in the global produce market (“Developing the Central and Southern Arava”). Arava R&D conducts research experiments with both large and small-scale experiments that “provide comprehensive support for local farmers, landscapers, and gardeners” (*Southern Arava Agricultural R&D).* We managed to return the CIS to operational conditions and ran a short experiment to prove that. In the future some investments should be made to enable fully automated system.

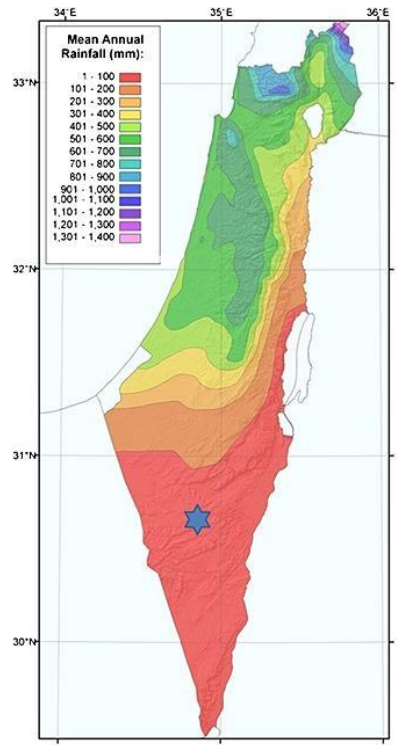


Figure 1: Long term mean annual rainfall

The Carousel Irrigation System

The Arava R&D's Carousel Irrigation system (CIS), shown below in Figure 2, is a computer controlled agricultural research system that was constructed 25 years ago. The CIS is designed for small-scale experiments, utilizing data collection devices and sensors to operate automatically. The system is located in a greenhouse to maximize the control of outside parameters. Arava R&D prefers automated experiments and operations to allow for careful computerized manipulation of the experiment to minimize human error. The Computer Operated Subsystem allows for minimal interaction after the experiment parameters are implemented into a computer program.

Figure 2: Working Carousel (2013)

The last experiment run in the CIS was over three years ago, resulting in a large buildup of sand, grease, dirt shown in Figure 3 and 4. Cleaning the carousel consisted of power washing, scrubbing, and vacuuming to later assess the status of each component. Inventory records were divided into three major subsystems and parts were labeled based on functionality. These records allowed for a complete system-analysis that identified all problem areas of the machine to repair or replace.

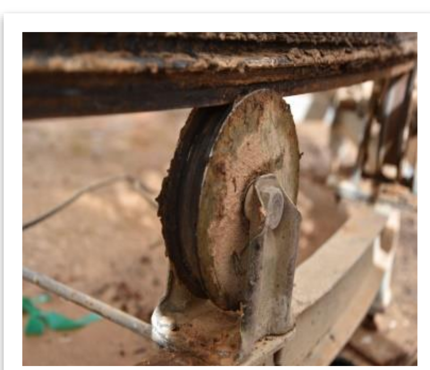


Figure 3: Before Cleaning

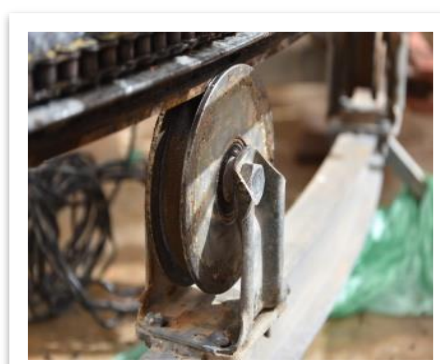


Figure 4: After Cleaning

Subsystem Repairs

The Computer Operated Subsystem has three main components: the computer, primary controller, and secondary controller. Experimental parameters are stored and implemented with the WizCon program. Repairing this system was necessary to run automated experiments in the future. These repairs included fixing: a lack of power due to a faulty transducer, restoring function to the computer, synchronic errors between the controller and the irrigation system.

The Experimental Subsystem consists of the components required for conducting the experiment. These components include the barrel used to house the plant, and the orange secondary funnel and hoses used for irrigation. The experimental portion of the system was mostly functional requiring minor repairs that included replacing broken funnels and reinforcing the drip irrigation with electrical tape.

The Irrigation and Drainage Subsystem stores, delivers, and disposes the water for the carousel's experiment. This subsystem is composed of three components: water storage, water delivery, and drainage. All components are controlled by the computer's WizCon program. The repairs consisted of returning most function to the Irrigation Subsystem with the hope of making it operable for the duration of our experiment. These repairs included fixing: non-functioning motorized ball valves, and uncalibrated irrigation and drainage scales.

Conclusion on Refurbishing the CIS

By providing repairs and improvements to the Carousel Irrigation System, partial function was returned to the automation portion and complete function to the Experimental Subsystem. The repairs to the CIS were tested with the implementation and maintenance of an experiment testing desert conditions on the coriander plant. We have provided the Station with the opportunity to find new techniques that are compatible with the Southern Arava's challenging conditions.

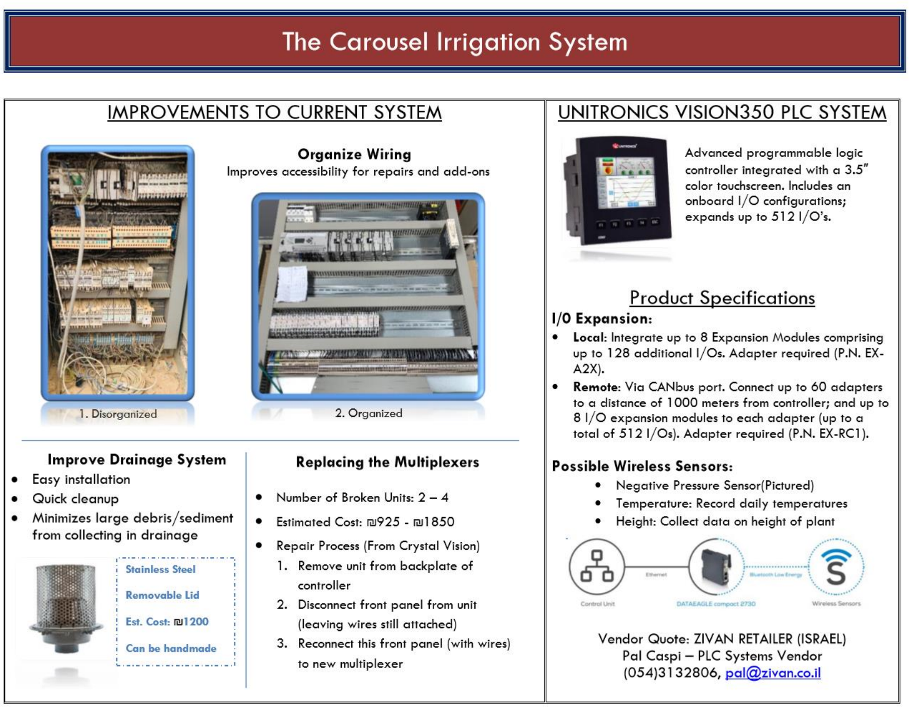
Improvement Recommendations on Best Practice

1) Since the operating system, as well as the controlling software (Windows XP) are obsolete, we recommend that both be replaced for automatic operation.

2) The drainage system can be improved to minimize the deposition of salinity into the ground. The Zurn's Green Roof Drain filter protects against sediment buildup. This perforated screen assembly has a removable lid for easy maintenance.

3) We recommend replacing the two non-functioning multiplexers, which were quoted to cost about $1000.

4) The Carousel should implement a new Bluetooth system which would communicate between a Programmable Logic Controller (PLC) and the sensors which serve many functions.



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1.0 Introduction

Israel has a limited amount of water sources and receives little amounts of rainfall. With an increasing population and agriculture sector, the nation faces an increasing demand for more water. The southern desert, known as the Arava, receives long hours of sunlight and high temperatures year-round, allowing the region to be one of Israel's main agricultural producers. This Arava is burdened with infertile soil quality and hypersaline water that requires purification through the expensive process of desalination. Arava Research and Development Station exists to conduct experiments and research to improve farming techniques and to boost local agricultural profits in the global market. The Arava R&D Station created an automated Carousel Irrigation System (CIS) in 1994 to run small-scale, controlled experiments. In addition to being non-functioning and unused for the past three years, this system is disorganized and has outdated systems and software. The broken system prevents small-scale experimentation from improving desert agricultural techniques that uniquely threaten this area.

The project has supported our sponsor, Buki Katz, in restoring function and improving the Arava R&D Station's Carousel Irrigation System. Our goal was to refurbish this system to aid the Station's mission to help farmers maximize yield potential with applied research. To accomplish this goal, we worked with local resources at the R&D Station to complete the following four objectives.

1. To conduct a full system analysis to identify all of the current problems of the Carousel Irrigation System
2. To restore function to each of subsystems of the CIS
3. To prepare and conduct an experiment using the CIS that is applicable to the R&D Station's research
4. To implement improvements and deliver suggestions on best practice

2.0 Background

The Arava region of Israel produces half of the nation's agricultural exports despite grappling with the extreme conditions inherent to its desert. The area is advantageous to farmers for its long hours of sunlight, high temperatures that can get up to 104°F, and cheap land, which make exports to Europe possible during winter months ("Israel's Agriculture in the 21st century," 2002) ("Climate Israel"). This desert's limited amount of water is naturally sourced from flash floods and Arava's aquifers. This natural hypersaline water requires desalination to remove impurities and lower the harmful salinity levels. Poor soil quality also contributes to the difficult farming circumstances, demanding systemic fertilization for proper plant development. The Arava Research and Development Station (Arava R&D) improves farming techniques through both large and small-scale research experiments to help local industries in barren areas achieve success in the global produce market ("Developing the Central and Southern Arava") (*Southern Arava Agricultural R&D*).

2.1 Water Conservation

Farmers in the Arava have adapted their irrigation techniques to minimize their water consumption. According to Israel's Water Authority, the nation has faced five years of a hydrological drought, which has affected the irrigation capacity in the agricultural industry (Gomes-Hochberg, 2018). In the Arava region, one source of water for irrigation is pumped from aquifers deep within the ground at three different depths. Water is pumped from the Hazeva and Dead Sea Group Aquifer at a depth of roughly 150 meters. The second aquifer, the Judea Group Aquifer, lies at a depth ranging from 200 meters to 600 meters. The final and deepest aquifer, the Kurnub Group Aquifer, sits at a depth ranging from 600 meters to 1000 meters.

These aquifers have minimal recharge with the majority coming from floods that occur just a few times a year, restoring roughly 32 million cubic meters of water to the Arava Region (Weinberger, 2012). This amount adds to the average national recharge of 1250 million cubic meters. In comparison to the demand for usable water, this amount is insufficient for proper farming irrigation. In Figure 6 below, the current amount of water used in agriculture is roughly 750 million cubic meters above the average recharge amount, and it is projected to grow significantly in the coming decades. This projection is based on the demand to supply food for Israel's population which increases 2.7% per year. In terms of the escalating population, Israel will deplete its water sources if water consumption continues to exceed the recharge rate.

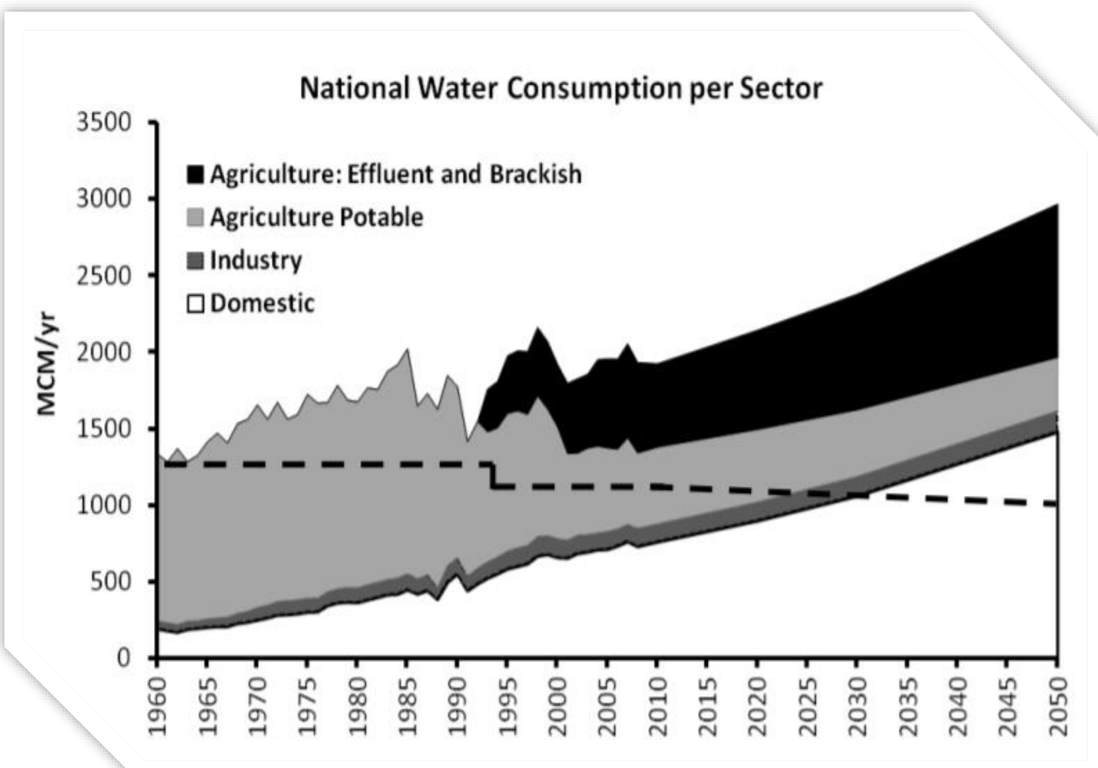

Figure 6: National Water Consumption per Sector.
Average natural water supply to all of Israel is shown by the dashed line.

Israel has set up five large-scale desalination plants to improve the quality of water containing harmful salt levels. The desalination process requires a large amount of electricity to pump water through membrane filters, removing minerals through reverse osmosis (Portable Desalination: How to Filter Salt Water, 2018). The first government sponsored desalination plant, Ashkelon, produces an average 100 million cubic meters of potable water per year. This output accounted for 7.6% of total potable water used for irrigation in 2004. Ashkelon's desalination cost to produce this percentage was roughly 66 million dollars, according to the table of Ashkelon's total production costs shown below (Dreizin, 2006).

Item	Annual costs or allowance		Unit costs	
	NIS/y	USD/y*	NIS/m^3	US¢/m^3*
Current (September 2004) contracted total water price (TWP)	256×10^6	57.5×10^6	2.56	57.5
Government assumed costs	40×10^6	8.9×10^6	0.40	8.9
Total desalinated water cost	**296×10^6**	**66.4×10^6**	**2.96**	**66.4**

*In September 2004 exchange rate of 4.45 NIS/USD

Table 1: The Ashkelon Plant's current total desalination costs (Dreizin, 2006)

The agricultural sector consumes most of Israel's water, but this amount is set by the government each year. With a 40% cut in water allocations in recent years and the high costs of the desalination process, farmers have tried other techniques for irrigation ("Israel's Fourth Aquifer", 2016). These techniques include irrigation with recycled sewage water sourced from the industrial sector. However, sewage water threatens to "damage soils, reduce crop yields, and in certain cases, cause groundwater salinity." Regulations in 2003 decreased the allowable salinity levels in sewage waste water, minimizing this source of water for irrigation ("Ministry of Environmental Protection", 2016). The minimal amount of water sources and the decrease in allocated water has driven research initiatives in utilizing lower qualities of water to bypass the costly process of desalination (AL-kharabsheh, 2019).

2.2 Brackish Water Quality

The Southern Arava region faces larger farming challenges compared to other regions of Israel due to its brackish water quality. This brackish water is classified by the amount of soluble minerals, composts, and salts in the solution, measured in parts per million or ppm (“Agriculture with Brackish Water”, 2016). Brackish water has a higher salinity of 0.5 to 30 ppm than freshwater but lower than the ocean’s water at 35 ppm (Greenemeier, 2012). Because this region pulls hypersaline water from its aquifers and artesian wells, the desalination process is necessary. Following the process of desalination, the mixing of freshwater with hypersaline water for irrigation dilutes the salinity level. This process also lowers the solutions’ additives, like magnesium, that are beneficial for crop growth. This forces farmers to compensate by adding fertilizers and minerals (Shani & Ben-Gal & Dufley, 2004) (D. Gillett, personal communication, January 13, 2019).

Hypersaline water exposure leads to the accumulation of salts in a plant’s root zone and causes specific-ion toxicity. The specific-ion toxicity creates nutritional deficiencies because salt build-up restricts osmotic flow, meaning it takes more energy to exclude salt during a plant’s water intake process. This decrease in water amount results in osmotic stress and prevents a plant from growing to its full potential (Tavakkoli, Rengasamy, and McDonald, 2010). In addition, the brackish water’s ability to starve plant cells has negative effects like leaf burning (Mian & Senadheera & Maathuis, 2011) (Caprile, 2014). Continued research aims at optimizing the water and fertilizer use for desired crop yield.

2.3 Soil Quality

Soil quality is determined by its composition and minerals within the ground. Loam soil is characterized as an effective topsoil, with a composition of 20%, 40%, and 40% clay, silt, and sand. The varying particle sizes in loam increases the soil's water retention by preventing the water runoff and evaporation. This keeps the soil sufficiently moist to support plant growth without drowning the plant. With a pH of six, loam soil contains a neutral amount of organic matter and natural fertilizers, promoting plant growth (Lerner, 2017). Loam soil quality is further improved by nematode colonies (worms) that process the minerals into a plant usable form (Curell, 2013).

By contrast, the Arava's soil is classified as salorthid, having a composition of "4.1%, 61.1%, and 34.7% of clay, silt, and sand" (Pen-Mouratov, 2010). Salorthid has a high concentration of silt that prohibits water from flowing because of the dense soil structure. The water stored in the topsoil can easily evaporate. This soil needs organic matter and fertilizer additives to supplement nutrients. The high pH of 7.5 to 8.5 makes the ground infertile for nematode colonies (Pen-Mouratov, 2010). Ultimately, the salt in the ground, the low nutrient levels, and the lack of adequate water retention makes farming difficult in the Arava.

2.4. The Arava R&D's Research

Farming in the Arava region is unique for its inventive approach to overcoming desert farming conditions. Researchers at Arava R&D have been involved with improvements in water-use efficiency for over 40 years that began with the creation of the first modern drip irrigation systems. Drip irrigation, diagramed in Figure 7, utilizes a series of hoses that directly irrigate the soil and have 90% water use efficiency compared to the estimated 50% efficiency of sprinkler irrigation ("Water Use Efficiency"). This efficiency has driven farmers in other nations to implement drip irrigation, such as date farmers in California (Kloosterman, K. 2014).

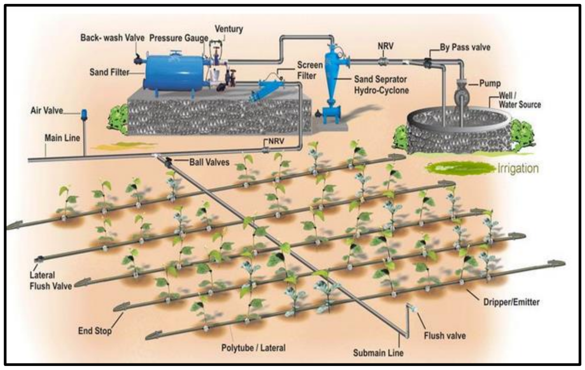

Figure 7: Drip Irrigation

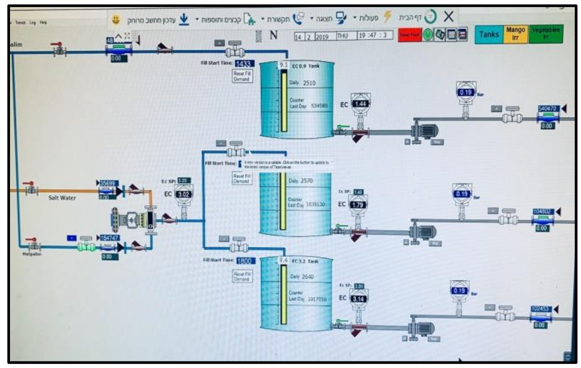

Figure 8: Example of automated system

The R&D Station improves desert farming capabilities through experiments that vary in condition and size. These experiments have automation technology for controlled irrigation and data collection on the 26-hectare (62 acre) farm. Automation minimizes costs necessary for off-hour manual operation. It allows for remote adjustments of the pumps that push water through drip irrigation hoses directly to the plants. This computer automated interface for irrigation, shown in Figure 8 above, is currently being used to test the effects of different salinities on the growth of the subtropical Mango fruit in an arid climate. If successful, not only could this crop be introduced to southern Israel's farming industry, but the expected month-early harvest time would equate to new profits within the sector's market (Southern Arava Agricultural R&D). Arava R&D experiments have improved agricultural techniques, allowing for new crops to successfully grow in the arid climate of southern Israel.

The computer automation stores continuously collected amounts of data from advanced lysimeters used for precise water and solute balance studies. Lysimeters are used to measure plants' initial and final weights before and after irrigation. This data measures the plant's water absorption and evapotranspiration (the plants' transpiration and evaporation). Large-scale lysimeters, with a 25-ton max load capacity, are used to identify the unique environmental stresses to the root system of a pomelo tree, shown in Figure 9. The root system has been divided, one half receiving freshwater while the other receives hypersaline water. Just like the Mango experiment, the irrigation is controlled automatically. Researchers want to understand how the tree will react, and if it will choose a dominant side and a water quality.

Figure 9: Pomelos trees with a split root

3.0 The Carousel Irrigation System

The Arava R&D's Carousel Irrigation System (CIS), shown in Figure 10 below, is a computer controlled automated research system that was constructed 25 years ago. The CIS is designed for small-scale agricultural experiments, utilizing sensors, lysimeters, and a salinity probe for accurate data collection. The system is in a greenhouse to maximize the control of outside parameters, limiting these as a source of error on the results. A greenhouse provides consistent humidity and temperature as well as shelter from the wind and bugs. The carousel mechanism rotates continuously to cycle the barrels for specified irrigation and drainage while equally distributing each of the plants' light exposure, mimicking conditions out in the field. This uniform environment increases control of independent variables, improving the accuracy of the results and ultimately bolstering the relevance of the results for farming in the future.

Figure 10: Carousel Irrigation System overview

Computer Automated Subsystem

Computer automation is ideal for researchers to remotely adjust and analyze experiment conditions (Crystal Vision Manuel, 2018). The Computer Operated Subsystem allows for minimal interaction after the experiment parameters are implemented into the WizCon Program. This program utilizes a user-controlled interface that runs automatically after irrigation and drainage amounts have been specified within time schedule, as seen in Figure 11.

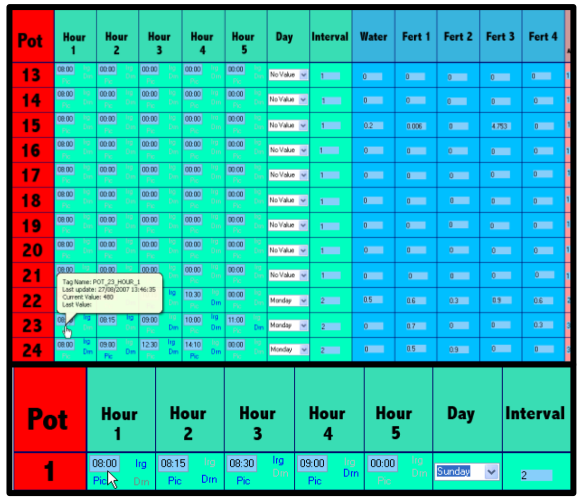

Figure 11: WizCon Time Schedule

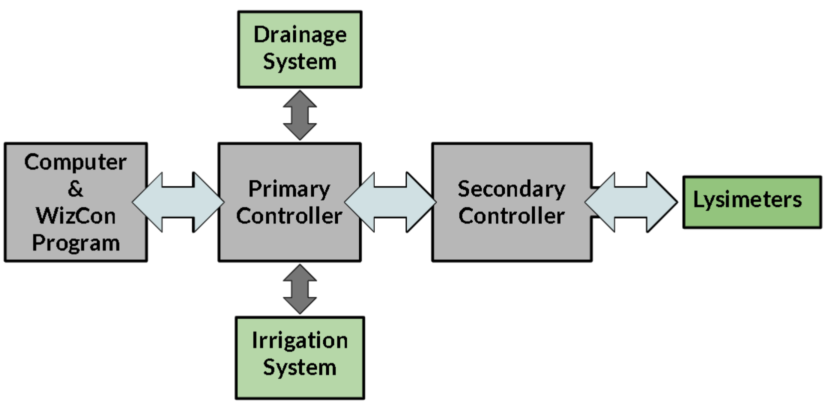

Figure 12: Communication flow of automation

The functions of the experiment, like irrigation and drainage, operate directly according to the parameters specified within the time schedule. Figure 12 demonstrates the flow of communication that allows for automatic operations. Instructions from the time schedule are sent to the primary controller housed in the control room of the greenhouse, outside the carousel. The primary controller organizes and stores these specific instructions and distributes commands to the correlating subsystems, including the irrigation, the drainage, and the secondary controller.

For each command, the Rotary Subsystem is halted using signals sent to the primary controller from the radio frequency identification (RFID) scanner that determines the position of each barrel. Once the commands for irrigation, drainage, and data collection have been completed, the primary controller receives a signal that continues the rotation until the next barrel is aligned to be processed.

The secondary controller collects the data from lysimeters and additional sensors to send it wirelessly to the WizCon program. To power the secondary controller and data collection devices, the standard voltage of 220V must be converted to the 24V using a transducer. The power is supplied using a swivel that is centrally located below the secondary controller.

A swivel, pictured in Figure 13, uses a "brush" contact between the stationary structure and the rotating slip ring. This mechanism allows for voltage to flow from the stationary structure to the rotating structure without entangling the wires.

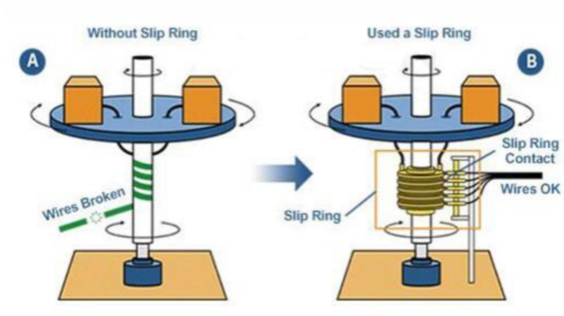

Figure 13: Uses of Slip Rings in Alternators

The Experimental Subsystem

Experiments are conducted in the barrel where the plant are housed, pictured in Figure 14, and use the orange secondary funnel and drip irrigation hoses for irrigation. The 75-liter barrel allows for experimentation with a variety of sized root systems for different plants. The data collection equipment includes separate lysimeters directly located under each barrel to collect the total barrel's weight to be compared to the amount of water drained into the primary drainage bin.

Figure 14: Section of the experimental system

Another lysimeter, located outside of the carousel and pictured in Figure 15, records the weight of sediment left behind in the secondary drainage bin after the water is disposed of. The weight of the sediment is omitted from the final drainage amount to distinguish the accurate amount of output water. The weights of the irrigation, the barrel, and the final drainage are used to calculate the water balance equation, referenced in Appendix A. This equation determines the plant's desired amount of water by comparing the waters' input and output weights. This calculation is used to improve the plant's growth by observing its reaction to different salinities or amounts and adjusting these parameters accordingly (Elsevier, 2015).

Figure 15: Secondary drainage bin

Tests are conducted on the salinity of water drained from each barrel using a probe that measures electrical conductivity. The drainage salinity is compared to the irrigation salinity to calculate the plant's leaching fraction. When the absorption rate reaches capacity, the minerals stored within the water pass through the soil without being absorbed by the plants, resulting in higher leaching fraction. The higher the fraction the more salinity within the drainage. This calculation estimates the plant's mineral absorption rate, which is referenced when adjusting the irrigation amount and quality to further improve the growth of the plant (Westcott, 1989).

Irrigation and Drainage Subsystem

The Irrigation and Drainage Subsystem aids the ongoing operations of the Experimental Subsystem for the carousel. In addition, irrigation consists of three components: water storage, water delivery, and drainage. The first component, water storage, stocks three different salinities, 0.9, 1.4, and 3.2, separated into three 1000-liter water drums. The second component consists of a filter that removes large sediments from the water before being pumped into the greenhouse using underground piping. The potential energy of the raised water stored at height of roughly 10 feet, 3.1 meters, forces the flow water from the drums to the equally raised irrigation delivery system. Motorized ball valves (MBV) use an electrically powered actuator to open and close a valve, controlling the flow of water into the primary funnel, shown in Figure 16 ("Sagiv: Motorized Ball Valve"). Attached to the support frame of the primary funnel, a scale measures the primary funnel's weight which is transmitted back to the WizCon program to close the valve once the desired irrigation amount has been reached. A second MBV is opened, and the water flows from the primary funnel into the secondary funnel of the designated barrel specified within the time schedule. This time schedule consists of set parameters on irrigation amounts, requiring the rotary system to align and halt the designated barrel with the water delivery hose and drainage mechanism. The program uses radio frequency identification (RFID) to determine the position of the RFID tag attached to each barrel.

Figure 16: Irrigation subsystem

3.1 Inventory Records

Inventory records were created to conduct a full system-analysis of the Carousel Irrigation System. We classified the different subsystems as Experimental, Water Storage, Water Delivery, Motor, and Rotary, and labeled their parts based on functionality. The inventory included an assessment on each part's status of function, verifying each part's condition as "functional", "needs repairs", or "needs to be replaced." As shown below in Figure 17, each part's description, photo, and other noteworthy information were documented for efficient reference at a later time. These records allowed us to complete a system-analysis that identified all problem areas of the machine to repair or replace.

EXPERIMENTAL SUB-SYSTEM					
Description + Photo	**ID Number#**	**Equipment Name(23)**	**Quality Test**	**Other Remarks**	**Location**
The Barrel acts as a container for the experiments (soil, plants, water). The attached exit pipe allows excess water to trail into the bucket below and be disposed of. The large Barrel is coated in a white paint, while the Exit tube for trailing water has a black plastic apperence.	**BP**	**Barrel and Exit Pipe**			The Barrel is located at the top of this system on the Scale Platform. The Exit tube is located directly under the Barrel towards its back and runs through a hole in the Scale Platform to the top of the box collecting the buckets excess water.
	BP-1	Barrel and Exit Pipe 1	Drains slower	Chiped paint, - dirt. pipe intact	
	BP-2	Barrel and Exit Pipe 2		CP, +dirt, pipe intact, foam present.	
	BP-3	Barrel and Exit Pipe 3		CP, +dirt, pipe intact, foam present.	
	BP-4	Barrel and Exit Pipe 4		CP, +dirt, pipe intact, foam present.	
	BP-5	Barrel and Exit Pipe 5		CP, +dirt, pipe intact, foam present.	
	BP-6	Barrel and Exit Pipe 6		CP, +dirt, pipe intact, foam present.	
	BP-7	Barrel and Exit Pipe 7		CP, +dirt, pipe intact, foam present.	
	BP-8	Barrel and Exit Pipe 8		CP, +dirt, pipe intact, foam present.	
	BP-9	Barrel and Exit Pipe 9		CP, +dirt, pipe intact, foam present.	
	BP-10	Barrel and Exit Pipe 10		CP, +dirt, pipe intact, foam present. metal staple in dirt.	
	BP-11	Barrel and Exit Pipe 11		CP, +dirt, pipe intact, foam present.	
	BP-12	Barrel and Exit Pipe 12		CP, +dirt, pipe intact, foam present.	
	BP-13	Barrel and Exit Pipe 13		CP, +dirt, pipe intact, foam present.	
	BP-14	Barrel and Exit Pipe 14		CP, +dirt, pipe intact, foam present.	
	BP-15	Barrel and Exit Pipe 15		CP, +dirt, pipe intact, foam present.	
	BP-16	Barrel and Exit Pipe 16		CP, +dirt, pipe intact, foam present.	

Figure 17: Example of inventory

3.2– The Process of Repairing the Carousel Irrigation System (CIS)

3.2.1 Cleaning the Systems

The cleaning process consisted of power washing, dusting and sweeping to remove the dirt, dust, and grease covering the CIS. Power washing was effective for removing the thick layers of grease and sand that covered the frame. Water was flushed through the irrigation pipes, drainage bins, and hoses to remove dust, sand, and dried salt. In addition, the control room and more sensitive electronics were swept and vacuumed for dust and sand. Cleaning revealed a significant amount of parts to repair, which were organized in the inventory.

All unnecessary equipment from past experiments was removed from the CIS. This was accomplished by following each wire, hose, and piping from start to end, separating unnecessary components from the rest of the system. The equipment included negative pressure sensors, wires, broken piping, pumps, and controllers. Figure 18 shows the excess equipment that was removed. This improved the accessibility to components that needed repair or further assessment.

Figure 18: Cleaned CIS system

3.2.2 Repairs, Replacements, and Removals

Computer Automated Subsystem

The Computer Operated Subsystem has three main components: the computer, primary controller, and secondary controller. Repairing this system was necessary for Arava R&D to run automatic experiments, in the future, from the central office.

Figure 19: Transducer

The lack of power stemmed from no amperage at the source of the secondary controller caused by a faulty transducer, shown in Figure 19. Power was returned to the system after this transducer was replaced along with multiple repaired short-circuits within the secondary controller. The repairs allowed for the assessment of communication of the system as a whole, from computer to primary and then on to the secondary controller.

Restoring function to the computer allowed us to assess the level of communication between the WizCon program and the rest of the system. The WizCon program was out of date, which allowed for two hours of use before needing to restart. Purchasing an update to the program would have been costly. Ra'anan, the electrician, was able to forgo the need to purchase an updated version and continued to repair the program's code. Shown in Figure 20, synchronic errors between the controller, irrigation system, and the WizCon program prevented auto irrigation, rinse, and draining features. These errors were due to the faulty communication with the WizCon program on the carousel's position. The WizCon

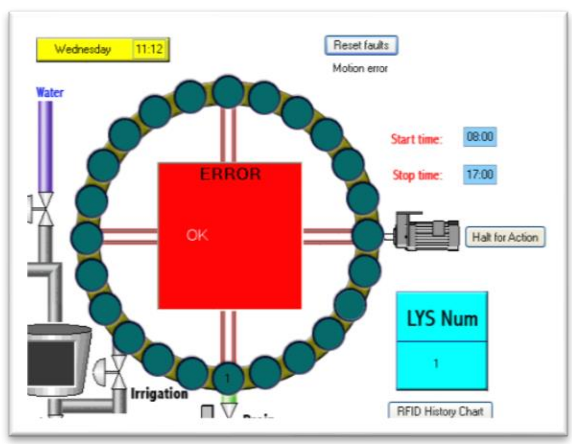

Figure 20: WizCon Interface

program indicated that unaligned or broken RFID tags caused faulty recognition of each barrel's position. These damaged tags were repaired or replaced, resolving the synchronic error. Unfortunately, this was not enough to make the automation of the system fully operational.

Experimental Subsystem

The experimental portion of the system was mostly functional and only needed minor repairs. The broken parts consisted of cracked hoses, leaky primary drainage bins, chipped secondary funnels. All were assumed to be caused by sun damage, over-use, and a lack of maintenance. Leaks in the drainage bins were repaired using a hot-glue gun to seal and reinforce components necessary for an experiment. Chipped secondary funnels were replaced with spare funnels left on the farm. These repairs ensured the effectiveness of results from experiments in the future.

Irrigation and Drainage Subsystem

The Irrigation Subsystem was repaired to be operational for future experimentation. Before the computer system was functioning, we ran hard-wire tests on the four unlabeled motorized ball valves to check that the valve opened and closed. One semi-functional MBV was replaced with a unit found on the farm while another completely broken unit was removed.

The non-responsive irrigation system needed the calibration of the irrigation and drainage scales to effectively communicate with the WizCon program. The excessive use of these scales resulted in inaccurate weighing of the contents in the primary funnel and the secondary drainage bin. Errors occurred when the scale miscalculated the primary funnel's weight, preventing irrigation. The irrigation scale was successfully calibrated using a known weight to zero the scale. Similarly, this technique was used to calibrate the drainage scale, so that the WizCon program received weights with an error percentage of only 4%. In conclusion, communication back to the computer was repaired, but not from Computer-to-Irrigation and Drainage Subsystems. This problem has yet to be assessed, but our team has informed Crystal Vision on the status of the computer automation.

3.3 – Improvements and Suggestions for the Carousel Irrigation System

The 25-year-old computer system utilizes the outdated Windows XP software from 2001. The operating system is faulty and with obsolete software, this computer should not be used for future experiments. We recommend that both the computer and operating system be replaced for successful automatic operation.

The CIS' drainage system can also be improved to minimize the deposition of salinity and fertilizer into the ground. Currently, the drainage is directed towards the top soil outside of the greenhouse using piping. This system could be improved by utilizing pipes with filters. For example, Zurn's Green Roof Drain filter protects against sediment buildup, shown in the bottom left corner of Appendix B. This perforated screen assembly has a removable lid for easy maintenance ("Z110 15" Diameter Main Green Roof Drain with Perforated Screen Assembly").

The barrels' lysimeters are functionable but fail to communicate with the computer due to a failure with the multiplexer. The multiplexer, Figure 21, creates a single analog output from the 16-channel digital input used for weight calculations. It is unclear as to what exactly is causing this failure, but an expert assessment of the units concluded that wiring is not the issue but rather unit itself. Replacing the part would was quoted to cost about $1000 for two units by Muki Telman.

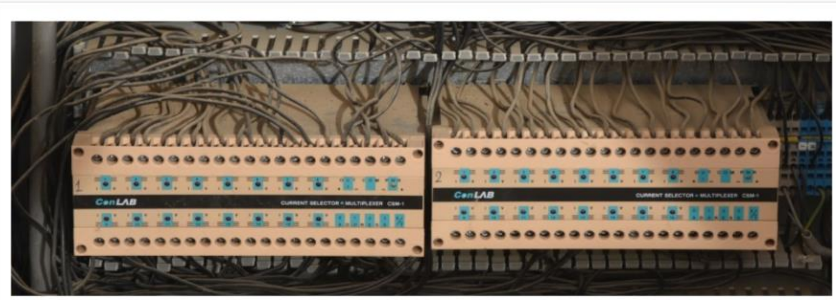

Figure 21: Multiplexers

Many technological improvements have been implemented to the controller systems in industries with needs for complete automation. With the help of Compost Equipment Manager, Richard Nicoletti, our team researched an updated Programmable Logic Controller (PLC) system for its easy installation, cost, and a wide range of applications. This system utilizes Bluetooth technology, demonstrated below, to communicate between a PLC and the sensors which serve many functions. The DATAEAGLE compact 2730 is an example of the products that act as the “gateway” between the signals of the blue-tooth and the control unit. The PLC system would bypass the need for major rewiring, allowing for quick initial installation. Also, the lack of wires would allow the R&D center to add or remove sensors in future experiments, easily adjusting the system to the needs of the experiment. Depending on the experiment’s specifications, the PLC can be setup with virtually an unlimited number of sensors which are small and can be easily attached to the desired system with ease. These sensors can be used to detect temperature, infrared light, touch, proximity, pressure, level and many more forms of data. The array of available sensors would allow Arava R&D to continue experimentation in a similar process used currently.

Figure 22: Connect Wireless Sensors to the Control Unit via Bluetooth Low Energy

4.0 – The Effects of Desert Soil and Water Quality on the Growth of the Coriander Plant

4.1 Making the Carousel Irrigation System (CIS) Experiment-Ready

We conducted an experiment in the repaired CIS that investigated growth of Coriander plants as a function of water conditions. From our research, we concluded that multiple factors could be manipulated to increase the ability to compare results: seed soaking, irrigation, and uniform soil composition. Seed soaking softens the shell for quicker germination by leaching the natural inhibitors used to prevent germination. The fragile coriander seeds prefer water salinity below 0.5 during the germination stage to minimize osmotic stress. Coriander also likes moist and uniform soil to compensate for evaporation and to prevent excessive water drainage (Ramasamy, 2015).

To prepare the CIS, we removed a four-inch layer of topsoil from the barrels and replaced it with uniform salorthid soil to establish similar conditions for each of the 23 habitats. The Experimental Subsystem's barrels were flushed four times with 0.9 water quality to remove impurities. The coriander seeds were soaked in warm water for eight hours to soften their shells. 10 seeds were planted in 21 barrels and 10 parsley seeds were planted in the two remaining barrels. The Water Storage Subsystem's three drums were updated with three new water qualities, 0.9, 1.4, 3.2.

4.2 Experimental Method

The purpose of this experiment was to understand the effects of brackish water and saline soil qualities on the coriander plant. After the plant broke the surface of the soil, three salinities (0.9, 1.4, 3.2) and two different amounts were used to irrigate the seedlings. Data collection consisted of measuring the change in height of the plant day to day. This change in height would be used to calculate the rate of growth to determine the effects of salinity on coriander.

4.3 Materials and Procedures Chart

Materials

- (3) Water Drums with (3) different water salinities (0.9, 1.4, 3.2)

- (4) Water delivery pipes
    - -3 pipes for the 3 salinities
    - -1 pipe for groundwater for flushing

- (23) Funnels connected to (23) drip irrigation pipes
    - Drip irrigation pipes are secured to the side of the barrel an inch from the top, and protrude through the center of the barrel.
    - The funnels are connected to the upward facing elbow joint of the drip irrigation pipe.
    - Drip irrigation pipes have two ports for dripping water that are about 4 inches apart and 2 inch from the side of the barrel.

- The soil in the (23) Barrels
    - Uniform salinity and composition

- Barrels (75 Liter)
    - 23 total
    - Barrels are the experiment's habitat

- (10) Coriander seeds per barrel (210 total)
    - Presoaked for 8 hours

- (10) Parsley per barrel (20 total)
    - Presoaked for 8 hours

Experiment Procedure

Groups	Salinity	Irrigation amount	Barrel numbers			
A	0.9	100 ml	1	24	23	X
		300 ml	13	14	15	16
B	1.4	100 ml	20	21	22	X
		300 ml	9	10	11	12
C	3.2	100 ml	17	18	19	X
		300 ml	5	6	7	8
D	0.9	100 ml	3			
		300 ml	2			

4.4 Experiment Results

This experiment's goal was to determine how the frequency of irrigation in combination with three water salinities affects the Corianders' growth time, final height, and crop yield. The experiments' results were inconclusive due to the project's limitations on time. Sprouting was first observed nine days after the seeds were planted. Groups A, B, and C received the change in salinities of irrigation. However, the growth of the coriander was not significant enough to identify significant differences in height. For this reason, results on the effects of three different salinities were inconclusive. However, the successful operation of the experiment confirmed the effectiveness of our repairs. For success in future experiments, an additional month of time for the coriander to grow would increase the ability to record observations and data.

5.0 Conclusions

Arava R&D's loss of interest in small-scale experiments resulted in the dormancy of the CIS for roughly three years. As a functioning system, the carousel is a resource for developments in irrigation efficiency and research into plant responses to environmental stresses. Although components within the system have been updated, the core of the system utilizes outdated technology from 1994. The system was initially found with grease build up, excessive and disorganized wiring, and in need of repairs to the experimental system. Damaged components, including funnels, MBVS, and hoses, were repaired using spare parts supplied from previous experiments. A full system analysis concluded major problems to the automation, Irrigation and Drainage Subsystems requiring extensive knowledge of the automated system. Our team worked with Crystal Vision experts to resolve these major issues, returning partial function to the automation portion and complete function to the Experimental Subsystem.

In conclusion, the repairs to the CIS were confirmed with the successful implementation and maintenance of an experiment testing desert conditions on the coriander plant's growth. The experiment results, improvements made to the system, and suggestions on best practice were given to our sponsor. By providing repairs and improvements to the Carousel Irrigation System, we provided the R&D Station an opportunity to conduct for future controlled experiments. This will lead to increased export market production and improved crop quality.

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Figure 2: Working Carousel [Personal photograph taken in Arava R&D]. (2019, January)

Figure 3: Before Cleaning [Personal photograph taken in Arava R&D]. (2019, January)

Figure 4: After Cleaning [Personal photograph taken in Arava R&D]. (2019, January)

Figure 5: Recommended improvements [Personal photograph taken in Arava R&D]. (2019, January)

Figure 6: Rejwam, A. (2011, April). National Water Consumption per Sector [Digital image]. Retrieved February 20, 2019, from http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/2012/24-The-State-of-Israel-National-Water-Efficiency-Report.pdf

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Figure 7: Drip Irrigation system [Digital image]. (2010). Retrieved February 18, 2019, from

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Figure 8: Example of automated system [Personal photograph taken in Arava R&D]. (2019, January).

Figure 9: Pomelos trees with a split root system [Personal photograph taken in Arava R&D]. (2019, February)

Figure 10: Carousel Irrigation System overview [Personal photograph taken in Arava R&D]. (2019, January)

Figure 11: WizCon time schedule Telman, M. (n.d.). *Rotating Lysimeter System for Controlled Plant Growth (Carousel)* [User Manual].

Figure 12: Communication flow for automation

Figure 13: Uses of Slip Rings in Alternators, Lee, J. (2018). Uses Of Slip Rings In Alternators Retrieved 2019, from https://www.moflon.com/showen143.html

Figure 14: Section of the experimental system [Personal photograph taken in Arava R&D]. (2019, January).

Figure 15: Secondary drainage bin [Personal photograph taken in Arava R&D]. (2019, January)

Figure 16: Irrigation subsystem [Personal photograph taken in Arava R&D]. (2019, January).

Figure 17: Example of inventory

Figure 18: Cleaned CIS system [Personal photograph taken in Arava R&D]. (2019, February).

Figure 19: Traducer [Digital image]. (n.d.). Retrieved February 20, 2019, from https://www.picclickimg.com/d/w1600/pict/183480984134_/perfect-Telemecanique-Abl7-Re2405-Power-Supply-100.jpg

Figure 20: Wizcon Interface Telman, M. (n.d.). *Rotating Lysimeter System for Controlled Plant*

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Figure 21: Motorized ball valve wiring controller [Personal photograph taken in Arava R&D]. (2019, February).

Figure 22: Multiplexers [Personal photograph taken in Arava R&D]. (2019, February).

Figure 23: Connect Wireless Sensors to the Control Unit via Bluetooth Low Energy [Digital image]. (n.d.). Retrieved February 17, 2019, from https://www.schildknecht.ag/en/funkanwendung/wireless-sensor/

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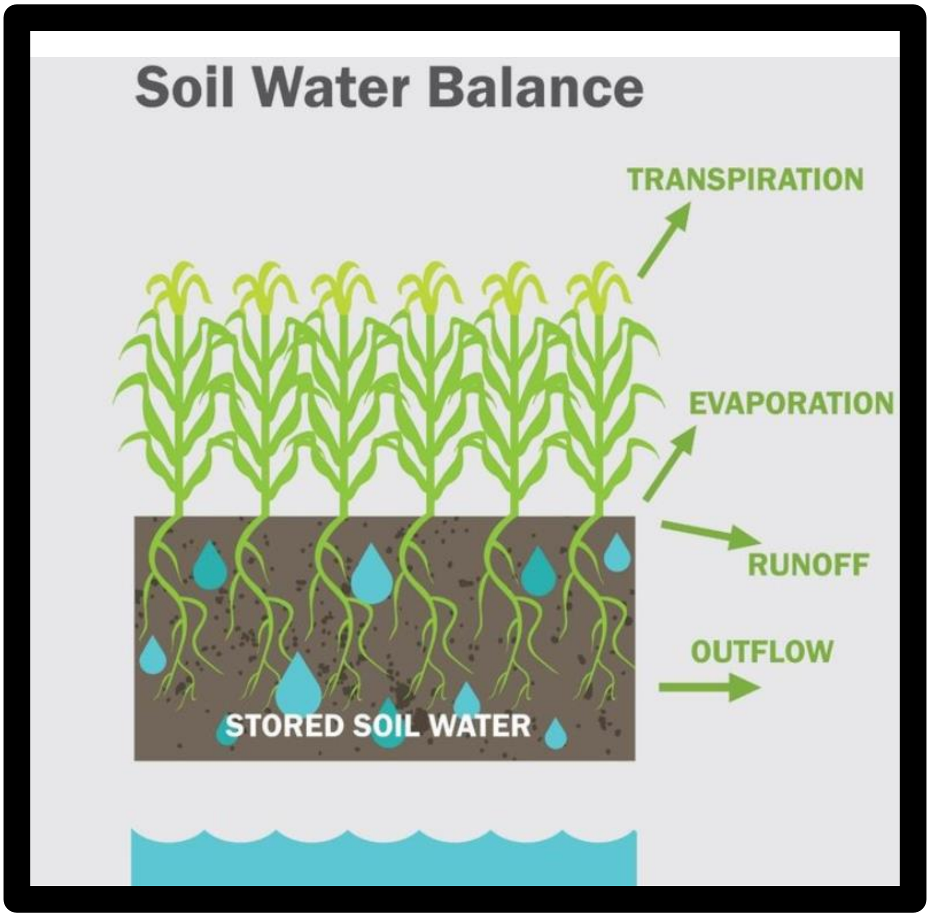
7.0 Appendix

Appendix A: Water Balance Equation



Gillreath-Brown, 2016

OUTFLOW + RUNOFF + TRANSPIRATION + EVAPORATION = INPUT

Appendix B: Inventory of Final Status

Experimental Subsystem					
Description	Notes on Selected Parts				
	ID Number#	Equipment Name(23)	Quality Test	Other Remarks	Location
The Barrel acts as a container for the experiments (soil, plants, water). The attached exit pipe allows excess water to trail into the bucket below and be	BP - #	Barrel and Exit Pipe	All functional	Insulation used as filter found at the lower 1/3 of the barrel	On top of scale plate, with pipe protuding through scale plate
The Scale Platform acts the weighing podium for the attached scale directly below. It also surves the purpose of supporting the load of the Barrel and Exit tube. The scale platform looks like a silver square plate under the Bucket and has a hole located towards the back of the plate for the Exit Pipe.	SP - #	Scale Platform	Functional	N/A	Bellow barrel
The Scale is responsible for recouding measurements of the Barrel's water intake. The Scale is depicted with a gray plastic coating.	S-#	Scale	Funtional but the data does not reach the computer do to the Multiplexers	Multiplexers are broken	Bellow Scale platform
These scale arms that extend from to the Scale Platform holds the box collecting water. This box collects the excess water recieved from the exit tube and sends it to the drainage system. These two "Arms" are coated in a white paint and curve inwards towards eachother underneath the Scale Platform.	DSA - #	Drainage Scale Arms	All functional	Some arms were bent	Lower part of frame, connected to drainage hose
The Support Frame acts as skeleton that holds up the Barrel and Exit Pipe, the Scale Platform, Scale, and Scale Arms. This Support Frame is a metallic silver and is in the shape of a rectangle.	SF - #	Support Frame	Functional	Not Level	Bottom of CIS
This part allows for the box containing excess watter to be emptied by pulling the arm downwards. The drain arm is a dull gray color with a rough apperence.	DA - #	Drainage Arm	Functional	Needed slight adjustment (level with top of drainage bin and tightening)	Lower part of frame, connected to drainage hose
The spring allows the Drain Arm to be bent back and forth, which aids in the excess water removal process. The spring has the same finish as the Drain Arm (dull gray).	DAS-#	Drain Arm Spring	Functioning	Good	Attached to drainage arm
The Chain segment moves against the upper rotary. The Chain links are most likely composed of steal and have a slightly rusted apperance (as it is 25 years old and has been weathered by the elements).	CS - #	Chain Segment	Functional	Needed WD-40	Attached to Upper Rotary Frame
The Upper Rotary Frame has a silver slightly shinny metallic apperance and acts as the spining stand that the Support Frame is welded to.	URF - #	Upper Rotary Frame	Functional	Power Washed Scrubbed Greased (X2)	Attached to each Barrel's Supporting Frame. Chain attached to the Upper Rotary Frame.
Front Right Drum from Entrance position of the Drum Station	WD-#	Water Drum	Filled with 0.9 EC water	Black water drums with holes for piping	Outside the greanhouse
Lets water leave from Drum to the inside of the greenhouse	EV-#	Exit Valve	Opens without issue		Attached to the water drum
Takes water from Drum to the inside of the greenhouse	EP-#	Exit Pipe	Functioning	Intacted	Runs from the BF's to the greenhouse
Fillers the water from the drums	BF-#	Blue Filter	Functioning	The filters needed cleaning.	Attached inbetween the EV's and the EP's
Exit pipes from outside continued inside	EV-#	Entrance Valve	Functioning	N/A	Enters the greenhouse and connects the Water drums to the irrigation system
Takes water from the drums to the MBV	OP-#	Outlet Pipe	Functioning	N/A	Located at the top of the Irrigation system. Connects the EV's to the MBV
Located on top of the ending of the Entrance Valves	MBV-#	Motorized Ball Valve	Functioning	Specific to the outlet pipes	on top of the Irrigation system
Metal Frame supporting Irrigation Sub-system	IF-#	Irrigation Frame	Sturdy	over all solid quality, sturdy, minimal signs of rust, some dirt, few turning mechanisms for adjustment of height are rusted together.	In the greenhouse next the the carousel
Pipes follow under valves with servos	VP-#	Vertical Pipes	Functioning	N/A	Connected to the MBV and leads the the Main funnel

Funnel Deliveray system to Experiment Sub-System	MF-#	Main Funnel	Functioning	no notable damage, dirty needs cleaning before use.	The VP run into it and the Drainage port is bellow it with the irrigation arm above that
Supports upright funnel	FH-#	Funnel Hanger	Functioning and talking with the computer	functional, signs of rust but no other damage, rust does not seem to effect the part. Is also a scale	Attaches the funnel the Irrigation frame
Controls water flow through irrigation arm	IV1-#	Irrigation Valve	Funtioning	intacted, no obvious signs of damage, unknown if functional.	Connect the funnel to the irrigation arm
Black Irrigation Servo	ID-#	Irrigation Delivery Motarized Ball Valve	Functioning and talks with computer	no sign of major or minor damage, all wired intacted. unknown if operable	Attached the the IV
T-Junction between darin and irigation	TJ-#	T-Junction	Functioning and not leaking	no signs of damage, unknown if it is functional	Connects the funnel, irrigation arm and the drainage
Delivers water to secondary funnels	IDA-#	Irrigation Delivery Arm	Functioning	sturdy and undamaged. unknown if fictional	Attached to T-Junction
Controls flow of water to drainage pipe	DV-#	Drain Valve	Functioning	intacted, no obvious signs of damage, unknown if functional.	Bellow main funnel
Controls drain valve	DMBV-#	Drain Motarized Ball Valve	Functional after replacement	no sign of major or minor damage, all wired intacted. unknown if operable (was not and needed replacement	Attached to DV1
Directs water into the drainage hole	DP-#	Drain Pipe	Functioning	intacted, no obvious signs of damage, unknown if functional.	Exist for DV1
Motor for Rotary Sub-System	M-#	Motor	Working - no viable signs	If broken replace. motor work to expected levels, minimal rusting and wiring looks solidly intacted. case is also intact with no obvious damage.	Attached to the caroucel
Controller	CT-#	Controller	Disorganized but fonctioning now	Lots of damage, a trasducer needed to be replaced, the internet connection was broken and the a few things needed to be rewired in order to get the drainage and Irrigation scales working	Located in the control room
Receiver	REC-#	Receiver	Semi functional/. Power was restored and with it the comunication to the computer. However, the multiplexers remined broken.	No power. Unsure on if it can be restored	In the center of the caroucel

Wheels the support the CIS as it spins	RW-#	Rotary Wheel	Spins and greased	Covered in old grease and dirt (Cleaned)	Can be found under the carousel system but on top of the stand. Numbering starts with the first wheel to the right of the motor and continues to the right.
Lowest Rotary to the ground	RF-#	Rotary Frame	Sturdy	N/A	Under caroucel
These elevate the Rotary Frame from the ground continuosly around the circle	RFSS-#	Rotary Frame Support Stand	Lightly rusted.	Scrap wood and metle plates were used to level the support frame. That weight of the carousel and years in the elements has rusted or rotted them. It was not an issue as the researchs did not care to have it fix. We focues our efforts on more relivent problems.	Under rotary frame

Appendix C: Consulting with Experts throughout our Project

In order to successfully complete our goals, the team needed to develop a greater understanding of the CIS by consulting experts throughout our project. To better understand the CIS' automated problems, we spoke with Ra'anan Shema and Muki Telman from Crystal Vision. They were responsible for originally installing the electronics and computer systems for the CIS. Muki Telman shared the old operational files and a PowerPoint of the CIS. Ra'anan Shema is a programmer and skilled in electronic. Ra'anan helped us troubleshoot multiple issues with the computer program and the electronic system. Over a series of meeting and phone calls he has directed us on the WizCon program, getting materials and restoring power. We talked with Arava researchers, Ehud and Gilad, in regards to establishing an experiment and setting up the CIS' water. Ehud designs the farms experiments and oversees their set up. Gilad is in charge of the irrigation systems in place at the R&D station and oversees all of the watering the farm does. Gilad offered us background information on the CIS that brought us up to speed on what the system was designed for and some basics on how each subsystem worked as well as the information we were looking for on how the automated irrigation subsystem worked. Our sponsor, Buki, helped use navigate and find tools around the farm that made our repairs and experiment possible.

Appendix D: The Deliverable

The Carousel Irrigation System

IMPROVEMENTS TO CURRENT SYSTEM

Organize Wiring

Improves accessibility for repairs and add-ons

1. Disorganized

2. Organized

Improve Drainage System

- Easy installation
- Quick cleanup
- Minimizes large debris/sediment from collecting in drainage

Stainless Steel

Removable Lid

Est. Cost: ₪1200

Can be handmade

Replacing the Multiplexers

- Number of Broken Units: 2 – 4
- Estimated Cost: ₪925 - ₪1850
- Repair Process (From Crystal Vision)
  1. Remove unit from backplate of controller
  2. Disconnect front panel from unit (leaving wires still attached)
  3. Reconnect this front panel (with wires) to new multiplexer

UNITRONICS VISION350 PLC SYSTEM

Advanced programmable logic controller integrated with a 3.5" color touchscreen. Includes an onboard I/O configurations; expands up to 512 I/O's.

Product Specifications

I/0 Expansion:

- **Local**: Integrate up to 8 Expansion Modules comprising up to 128 additional I/Os. Adapter required (P.N. EX-A2X).
- **Remote**: Via CANbus port. Connect up to 60 adapters to a distance of 1000 meters from controller; and up to 8 I/O expansion modules to each adapter (up to a total of 512 I/Os). Adapter required (P.N. EX-RC1).

Possible Wireless Sensors:

- Negative Pressure Sensor(Pictured)
- Temperature: Record daily temperatures
- Height: Collect data on height of plant

Vendor Quote: ZIVAN RETAILER (ISRAEL)
Pal Caspi – PLC Systems Vendor
(054)3132806, pal@zivan.co.il