UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into New SUB Rooftop Garden Irrigations Systems

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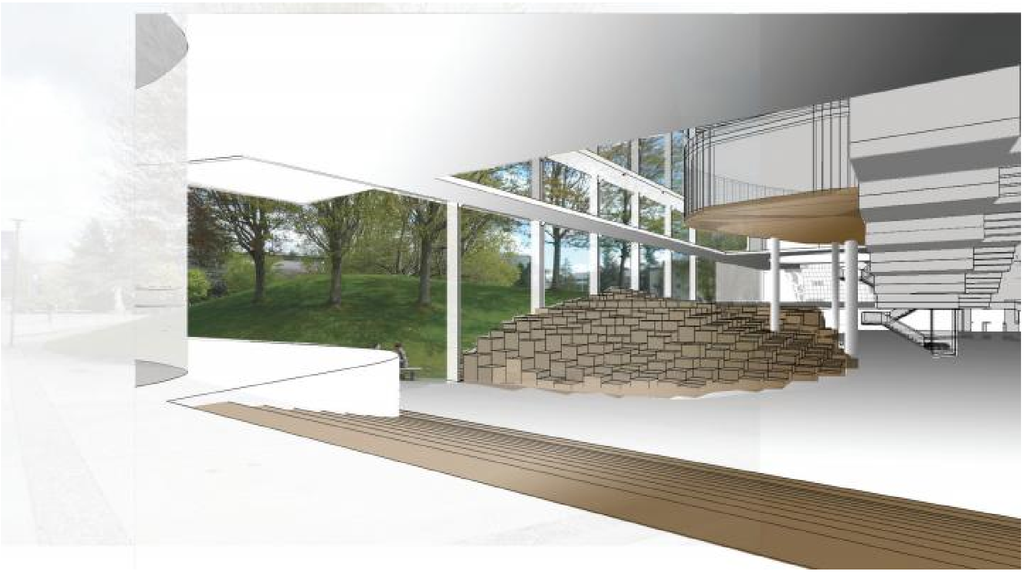
AN INVESTIGATION OF ROOFTOP GARDEN IRRIGATION SYSTEMS



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ABSTRACT

The new Student Union Building (SUB) is designed to be a Leadership in Energy and Environmental Design (LEED) Platinum + rated sustainable building. One of the new features of the SUB is a rooftop garden capable of producing food for businesses and food retail outlets. Vancouver has a very moist climate, with long, wet winters; however, hot, dry periods are common during the summer. Therefore, it is necessary to install an irrigation system to keep the garden sufficiently watered during these periods.

There is a wide range of solutions to the irrigation problem for the rooftop garden. In order to gain or surpass a LEEDS Platinum + standing, the system with the lowest carbon footprint, and highest water efficiency must be chosen. However, due to the limited space for planting crops, the system must be effective in maintaining crop health and maximizing yield. Based on these constraints, the selected system should employ micro-irrigation. These systems are designed to apply moisture directly to the plants or root zone soil. Whiffen (1991) states "an irrigation system designed to operate at 40 psi can require up to twice as much energy as an irrigation system designed for a pressure of 10 psi". As micro-irrigation systems send water near the root zone, it saves water from evaporation and runoff, reducing energy costs. Additionally, "the ability of micro-irrigation systems to place most of the irrigation water where it can be used

by the crop reduces the amount of which needs to be pumped through the irrigation system to supply the entire crop water needs" (Whiffen, 1991). An 80 percent improvement in water efficiency was observed by using micro irrigation systems, as opposed to conventional practices.

This report is a triple bottom-line assessment of the two most common micro-irrigation systems: sprinklers and drip tape. The following analysis is intended to aid in the selection and design of the rooftop irrigation system for the new SUB.

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1.0 INTRODUCTION

The architects for the new Student Union Building (SUB) have the goal of achieving a LEED Platinum+ status for the building. One of the new sustainable features for the SUB is a rooftop garden, fully capable of producing food for the SUB businesses and food retail outlets year long. Although Vancouver has a humid west coast climate, with cool summers and warm winters, it is not uncommon to have a dry and hot summer from time to time. During these dry months, it becomes necessary to implement an irrigation system into the rooftop garden as to maintain moisture all year round.

There is a wide range of possible solutions when looking at the irrigation problem for the rooftop garden. In order to gain or surpass a LEED Platinum+ standing, the irrigation system with the lowest carbon footprint, and highest water efficiency must be chosen. However, due to the limited amount of space available on the rooftop garden for planting crops; the system must prove to be effective in maintaining crop health, and maximizing crop yield. As water efficiency is a major requirement, it is suggested that the preferred irrigation system is a type of micro-irrigation system. A micro-irrigation system is designed to deliver water onto the soil surface near a plant or underneath the soil surface directly to the plant roots. According to the article “Energy Efficiency & Environmental News: Energy Use In Irrigation,” Helen H. Whiffen states, “An irrigation system designed to operate at 40 psi can require up to twice as much energy as an irrigation system designed for a pressure of 10 psi.” As micro-irrigation systems send water near root zones, water from evaporation and runoff are greatly reduced and energy consequently saved. Whiffen further explains, “the ability of micro-irrigation systems to place most of the irrigation water where it can be used by the crop reduces the amount of which needs to be pumped through the irrigation system to supply the entire crop water needs” The energy-efficiency of a micro-irrigation system is demonstrated well in the article; Whiffen assesses that there is at least an 80% improvement in water efficiency when using a micro-irrigation system compared to conventional practices.

Having considered micro-irrigation to be the preferred method of irrigation, we can choose between the two main micro-irrigation systems being used. The two systems are sprinkler and sub surface drip tape irrigation. This report is a Triple Bottom Line Assessment on two different micro-irrigation systems, with the purpose of aiding the selection and design of the rooftop irrigation system in the new SUB.

2.0 SPRINKLER IRRIGATION SYSTEM

A sprinkler irrigation system is classified as any system of irrigation where water is deployed via spraying, misting or sprinkling. In this analysis, the sprinkler system will be discussed in terms of micro-irrigation. Micro-irrigation systems differ from traditional irrigation systems due to the low pressure of the system and the smaller scale components. A triple bottom line analysis was performed and the environmental, economic, and social impacts of this irrigation system for the new SUB's urban agricultural rooftop garden are discussed below.

2.1 Environmental

The environmental impacts associated with a sprinkler irrigation system are numerous and both beneficial and detrimental. When implementing a sprinkler irrigation system in an intensive rooftop garden (such as the one seen in Figure 1), some of the primary environmental concerns are related to water consumption, salinity and disease control and system efficiency. These concerns are discussed below in order to create an overall representation of the environmental implications of a sprinkler irrigation system.

Sprinkler irrigation systems are commonly linked to increased rates of water waste due to the larger expanse of area to which water is delivered, however in some cases this can be beneficial. This is due to the fact that in order to increase the yield of the crops, it is recommended that the soil within the root zones maintains a soil moisture deficit above that of 50%, as this allows the soil to achieve the optimum field water capacity (Keller, 2006). With a sprinkler system, the area receiving water can range from 0 to 10 feet (Dripking, 2011). The larger water distribution ensures a greater amount of soil is achieving a soil moisture deficit of greater than 50%, which also provides a buffer should a component of the system fail. Also, with the uniformity of water distribution from the sprinkler head, it is possible to achieve a more uniform degree of saturation in the soil beds, which increases the yield of the crops. However, this can lead to ponding of water, if water is being distributed to areas outside the root zone of the crops.

Also, of great concern is the salinity and disease control of the soil. The irrigation system implemented can aid in mitigating these issues. Due to the fact that sprinkler systems are both above the surface and do not come in contact with the soil, the sprinkler head is far less likely to become plugged with sediment. This sediment blockage can lead to increased salinity of the soil, which increases the susceptibility of the soil to disease and thus decreased crop yield. Also, since most water used for irrigation contains some form of dissolved salts. Thus, by applying additional water beyond the point of field capacity, this action will push or leach the salt beyond the root zone (Keller, 2006).

ROOF TOP AGRICULTURE

Figure 1. A Roofop Garden in Current Operation.

(BH + Dialog, 2010)

Lastly, the efficiency of the system can be calculated according to Howell (2006) by relating the amount of actual storage of water in the root zone required to meet the crops needs to the amount of water applied to the crops. This calculation accounts for evaporation, seepage due to surface water channels or furors, leaks in the sprinkler, percolation beneath the root zone, drift from sprinklers, evaporation of droplets in the air and runoff from the field (Howell, 2006). Using this criteria it was determined that the micro spray sprinkler irrigation system has an attainable efficiency of 95%, while on average achieving an efficiency of 85% (Howell, 2006). This high efficiency rating is due to the fact the sprinkler heads are situated fairly close to the ground, which decreases the amount of evaporation and the effects of wind.

2.2 Economic

In order to determine the feasibility of a specific irrigation system, an economic assessment is vital. Therefore, an economic analysis of a sprinkler irrigation system was performed to establish the overall cost of the system. The overall cost included component costs, installation costs, labour and maintenance costs, and repair and system costs.

A typical sprinkler irrigation system is composed of pipes, tubes, water emitting devices, fittings, flow control equipment, installation tools and accessories (Hla and Scherer, 2003). Three typical emitting devices are depicted in figure 2. A chart listing a selection of the common components used to construct a micro-sprinkler irrigation system are displayed in table 1. With 4,575 sq. ft. for crops, and an additional 680 sq. ft. for a research garden area, the total area requiring irrigation is 5,255 sq. ft (Mynewsub, 2011). Based on this area, the cost of materials required to construct a functional micro sprinkler irrigation system would range from $5,000 to $7000. This estimation was calculated based on the assumption that a micro jet stake and sprinkler head would be placed every 5 feet (Dramm, 2011).

Figure 2. Typical Microspray Water Emitters
(Hla and Scherer, 2003)

Table 2. Costs of Common Micro-Sprinkler Irrigation System Components
(http://www.dripking.com/drip-irrigation, 2011)

Component	Cost	Application
¼" Vinyl Tubing	$6.50/100 ft	Extends from the mainline tubing; to be used no more than 30 ft from the main line.
½" Polyethylene Tubing	$9.95/100 ft	Mainline tubing; to be used no more than 300 ft from water source.
Micro Jet Stake Assembly	$1.00/stake	12" stake, with 18" of ¼" tubing with ¼" barbed connector to attach a fixed micro jet/sprinkler.
Threaded 360° Adjustable Stream Spray Bubbler	$0.44/Bubbler	Can be adjusted to spray water from 0-8 GPH in a 0-4 ft diameter. Attaches to a micro jet stake assembly.
6 GPH Multi-Outlet Emitter	$4.50/Emitter	Compensates for the pressure difference when converting from a sprinkler head to drip irrigation. Distributes to 6 plants via 6 ¼" vinyl tubing outlets.
¼" Connector / ¼" Tee / ¼" Elbow	$0.10/Connector $0.14/Tee/Elbow	Used for transferring from ½" tubing to ¼" tubing.
WeatherTrak ET Plus Six-Station Indoor Controller	$306.00/controller	Weather based irrigation management system that delivers precise weather data from over 14,000 weather stations across North America.

According to Janine K. Hasey, et al. (1994), due to the fact that all components of the system are fairly portable, the installation costs are approximately 50 percent less than that of other irrigation systems, and range from $4.00 - $9.00 per sq. ft (Peck and Kuhn). This can also be supported by the fact that all components being placed above ground, meaning that the system can be installed relatively quickly and efficiently. However, the labour costs of maintaining the micro sprinkler irrigation system are higher due to the fact that with the increased number of mechanical parts, system inspections are more frequently required.

Lastly, for the repair and long term system costs, it can be noted that although the lifespan of the system on a whole is long, that of the individual components is not. Although individual components are constructed from durable material, the high number of mechanical parts leads to these components tending to have a much shorter life span. However, this does not have a significant impact on the repair cost, as replacements are both inexpensive and locally available. On the long term scale, the wider radius spray of the sprinkler heads ensures that the soil has a decreased potential for overcoming the field capacity of the soil, as any irrigation received to the soil beyond this value is considered an economic loss (Keller, 2006).

2.3 Social

The implementation of an urban agricultural rooftop garden is in itself widely beneficial from a social standpoint. This is due to the opportunities it provides for both the surrounding community and the students of UBC (as seen in Figure 3). This intensive agricultural garden can act as both a tool for learning and a stepping stone in the process of increasing the presence of sustainable buildings and actions on campus. The direct social impact of a specific irrigation system implemented for this urban garden can be surprising. These social impacts can be broken down into labour maintenance requirements, material used, and long term effects of the system.

Due to the longevity of the core components of a micro sprinkler irrigation system, less intensive replacement or maintenance of the system is required. However, the individual parts, due to their mechanical nature, tend to require replacement more often due to constant use. Since the majority of the components are fairly easy to install and require little to no specialized knowledge, the irrigation system could be installed without the use of a professional (MIST Misting System, 2006). This would also create an educational opportunity for either the community or UBC students on how to construct and implement an agricultural irrigation system. Due to the increased area of soil that receives moisture, there is an increase in the production of weeds, that is to say a native or non-native plant that grows and reproduces aggressively (Janick, 1979).

Figure 3. An Example of a Working Urban Rooftop Garden.
(BH+ Dialog, 2010)

All components listed in table 1 are constructed of material that can be recycled after use, due to the fact that all components are above ground with little contact with the surrounding soil. This has a huge influence on the direct social impact of the irrigation system, as all sub surface irrigation systems are constructed of recyclable material. However due to the direct interaction with soil, most individual components are unable to be cleaned and thus rendered nonrecyclable. Also, the fact that most components are above ground and visible enables easier replacement of broken or malfunctioning components.

Lastly, a fairly large long term social impact of the use of a micro sprinkler irrigation system would be the potential damage to the structure of the roof from continued pooling of water. This issue highlights the importance of the installation of a proper drainage system, especially with a sprinkler system, due to the extra water use and the increased potential for pooling of water. To decrease the potential for this pooling, the use of multiple layers of waterproof material should be implemented (Peck and Kuhn). This ensures that if the acids in the soil cause a layer to disintegrate, there is still at least one additional layer providing protection for the roof.

3.0 SUB SURFACE DRIP IRRIGATION SYSTEM

3.1 Environmental

The environmental impact of the sub surface drip irrigation system is important in managing an intensive rooftop garden for urban agricultural purposes. The following environmental factors will be discussed in terms of irrigation efficiency: crop yield, water efficiency (i.e., availability, consumption, monitoring), and pollution control.

The average soil depth for the new UBC SUB rooftop garden will be approximately 4 feet and will include an upper topsoil layer (Steward et al, 2010). A recommended soil type for Vancouver's humid climate is a very fine (clay) to fine grained sand that is able to hold a large water capacity (Keller, 2006). An irrigation system such as the sub surface drip irrigation system can provide sufficient water to the crops without creating ponding. This enhances plant growth and increases crop resistance. The system is beneficial for rooftop gardens as the harmful environmental impacts from strong winds, freezing temperatures, and wet soil surfaces will be greatly reduced (Lamm, 2002). Furthermore, plant health may be improved as there is a decreased potential for disease and fungal pressure from the less-humid crop canopies.

Water efficiency is a key component of the sub surface drip irrigation system. The amount of water available for the UBC SUB was calculated to be 2,450 m^3 (annual rain water capture) from a 2,179 m^2 roof catchment area (BH+Dialog, 2010). If all rain water that is not infiltrated into the soil was to be captured in cisterns, an approximated 87% of the total annual water fixture demand could be met (Figure 4). The water from the cisterns will be used in the sub surface irrigation system and is highly efficient as factors including soil evaporation, surface runoff, and deep percolation are greatly reduced (Lamm, 2002). In addition, the water application is distributed uniformly and sufficient soil wetting can be achieved. The sub-surface irrigation system should, however, be monitored daily and managed accordingly to ensure a minimum negative impact on the environment.

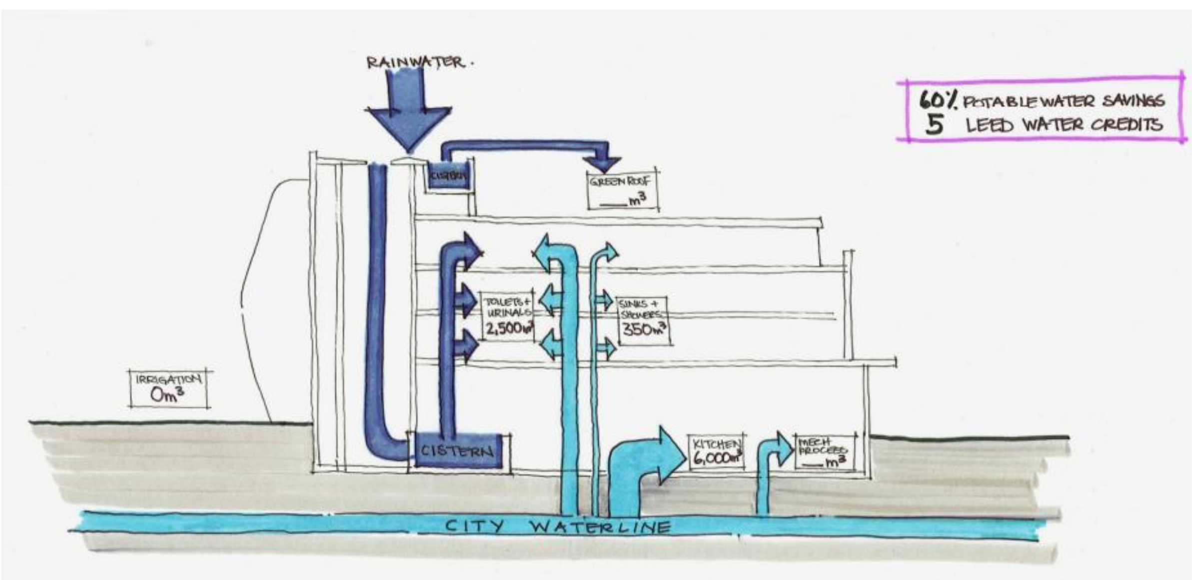

Figure 4. Overall Rain Water Collection Section

(BH+Dialog, 2010)

The sub surface drip irrigation system is designed to reduce runoff into streams and leaching of nutrients and chemicals due to deep percolation (Lamm, 2002). A study has shown that the sub surface drip irrigation system has reduced NO_3^- leaching and contamination of lettuce production by providing incremental applications of nitrogen and water (Thompson and Doerge, 1996).

Product Recommendation:

A recommended sub-surface irrigation system that has been widely used on green roofs worldwide is the KISSS (Kapillary Irrigation Sub-Surface Systems) system. This KISSS system is composed of drip tape and a unique geo-textile mat It achieves water savings by evenly distributing sub-soil moisture content to attain optimum water efficiency (Guenter and Sullings). A real life project assessment illustrates the annual water demands and irrigation systems. Note that the KISSS system is the most efficient of the four (Figure 5).

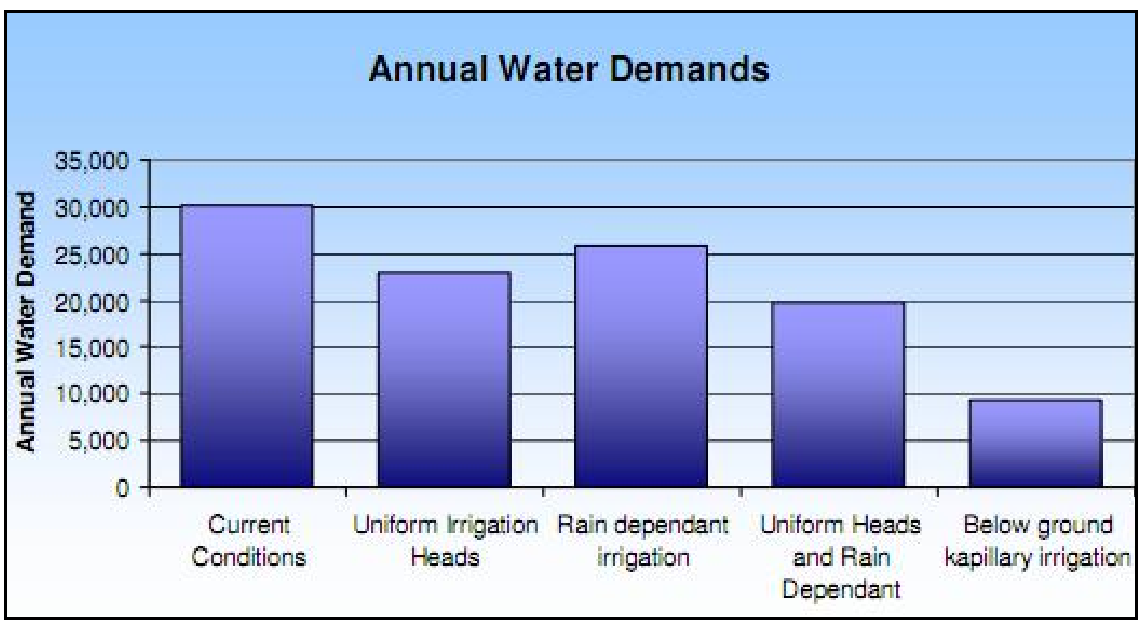

Figure 5. Comparison of Irrigation System Annual Water Demands

(Guenter and Sullings, 2010).

The sub surface drip irrigation system would be ideal for the UBC SUB rooftop garden, as it is beneficial in producing crop yield, achieving optimum water efficiency, and managing the leaching of nutrients and pesticides into the soil.

3.2 Economic

The total cost for implementing and managing a sub surface drip irrigation system for the UBC SUB rooftop garden will be analyzed and discussed in this section based on the following underlying factors: area of land being irrigated, water consumption, and climate considerations.

According to the new SUB design, the 5th level will consist of approximately 4575 sq. ft. crop area, 48 sq. ft. garden research, 742 sq. ft. sustainable demonstration, and 290 sq. ft. green roof (Figure 6). Moreover, the 6th level will consist of an estimated 23,811 sq. ft. green roof. A total green space area of roughly 29,466 sq. ft. will require irrigation.

As mentioned in the Environmental section of this report, an annual 2,450 m^3 of rain water will be captured in cisterns, providing 87% of the annual water demand (BH+Dialog, 2010). This water will supply the irrigation system for the rooftop garden, which will consequently have no water consumption costs.

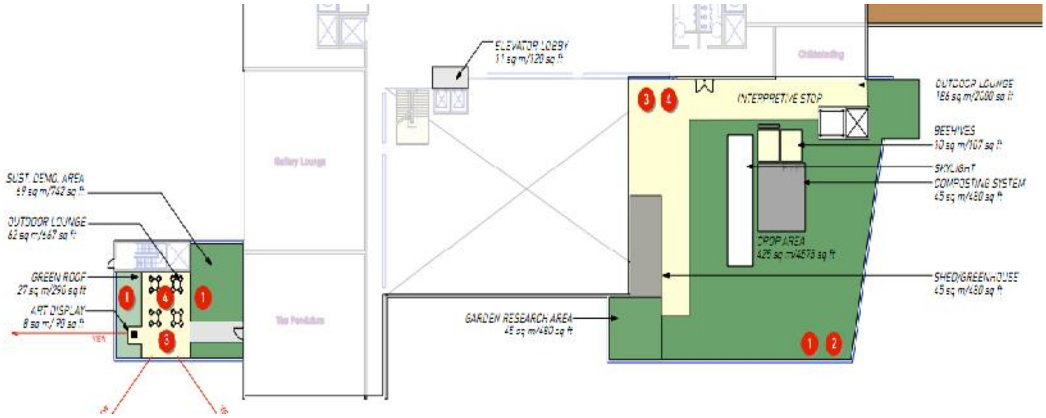

Figure 6. SUB Level 5

(BH+Dialog, 2010)

Climate is a major concern for the rooftop garden. In Vancouver, the growing season ranges from March to October, during which the mean total precipitation is 39.1 to 114.3 mm (worldweather.org, 2011).

The sub surface drip irrigation and sprinkler system costs were determined using an Excel Sub-Surface Drip Irrigation Cost Calculator provided by EPA and GreenScapes (epa.gov, 2011). The tables below show a cost comparison of the sub-surface drip irrigation and sprinkler irrigation system based on the factors previously mentioned (i.e., irrigation area, water consumption, and climate). The tables below illustrate high and low cost levels for both systems and facilitate a comparison of initial, annual, and life-span costs. The calculator found that the sub surface drip irrigation system is more cost effective (spanning a Total Average Annual Cost over Lifetime of $516.49) than the sprinkler irrigation method (spanning a Total Average Annual Cost over Lifetime of $1,446.28).

Table 2. Sub-surface Drip Irrigation Cost Calculator

Inputs	
Irrigated Area (Sq. Feet)	29466
Does your facility pay for water?	No
Estimate the amount of days with rain over 1/2" per month during growing season.	15
How long is your growing season? (months)	8
How often will you irrigate without rain? Once every ____ days. (Assumes 2/3 – 3/4 inches per irrigation)	15

Table 3. Sub Surface Drip Irrigation Factors

Sub-surface Drip Irrigation System with Rain-Shutoff Device	**Low Cost Estimate**	**High Cost Estimate**	AVERAGE
Rain Sensor	$27.00	$69.99	
Sub-surface Drip Irrigation Materials and Installation Cost	$7,071.84	$8,250.48	
Initial Cost	$7,098.84	$8,320.47	$7,709.66
Number of Irrigations Per Year Without Rain-Shutoff Device	16.00	16.00	
Gallons of Water Used Annually Without Rain-Shutoff Device Per Year	192,920	230,765	211,843
Average Number of Irrigations Saved by Rain-Shutoff Device Per Year	16.00	16.00	
Gallons of Water Used Annually With Rain-Shutoff Device Per Year	0	0	
Water Cost (annual)	$0.00	$0.00	$0.00
Annual Maintenance and Repair Cost (average over lifetime)	$168.00	$165.00	
Average Annual Maintenance and Water Cost over Lifetime	$168.00	$165.00	
Lifespan (years)	25	20	$22.50
3 year Cost	*$7,423.84*	*$8,645.47*	$8,034.66
6 year Cost	*$7,823.84*	*$9,045.47*	$8,434.66
10 year Cost	*$8,773.84*	*$9,995.47*	$9,384.66
Total Average Annual Cost over Lifetime	*$451.95*	*$581.02*	$516.49

Conventional Sprinkler System	**Low Cost Estimate**	**High Cost Estimate**	
Initial Cost	$6,482.52	$9,429.12	$7,955.82
Gallons of Water Used Annually	257,226	292,303	274,765
Water Cost (annual)	$0.00	$0.00	$0.00
Annual Maintenance and Repair Cost (average over lifetime)	$951.00	$831.67	
Average Annual Maintenance and Water Cost Over Lifespan	$951.00	$831.67	
Lifespan (years)	20	12	$16.00
3 year Cost	*$8,142.52*	*$11,089.12*	$9,615.82
6 year Cost	*$10,582.52*	*$13,529.12*	$12,055.82
10 year Cost	*$14,302.52*	*$17,249.12*	$15,775.82
Total Average Annual Cost over Lifetime	*$1,275.13*	*$1,617.43*	$1,446.28

Table 4. Cost Comparison of Sub Surface Drip and Sprinkler Irrigation Systems

3.3 Social

Drip tape is a highly water efficient means of irrigation, typically resulting in a increased levels of crop survival. The social impacts of implementing drip irrigation do not differ significantly from other micro-irrigation systems. Drip tape requires a single installation, is low maintenance, and can be easily replaced if damaged. Installation and replacement of the tape requires some labour, and which can lead to downtime in crop production. In comparison with a sprinkler irrigation system drip tape is more visually appealing, as the tape is typically buried under the soil surface. It is presumed that the depth of installation is great enough, such that tilling and working of the soil will not interfere or damage the tape. In this regard, drip tape can greatly increase efficiency in crop production, as there are no obstructions for gardening tools or movement around the garden. Cleaning of removed drip tape is time consuming, making recycling often unfeasible. Alternatively, undamaged portions of the tape can be sold for reuse in smaller farms or gardens. This may allow cheaper development of other food gardens on campus or in the city, as it enables more local people to start their own irrigation systems.

4.0 A COMPARISON OF THE TWO SYSTEMS

A comparison of the two irrigation systems was performed in order to determine the system better suited for implementation in the new SUB's rooftop agricultural garden. The systems were compared based on their impacts socially, economically, and environmentally.

Although sub surface drip irrigation only requires a minimal amount of system maintenance following the initial installation, and it is more aesthetically pleasing due to the buried nature of components; it is the sprinkler irrigation system that prevails from a social standpoint as the material involved can be more effective recycled, due to the lack of soil interaction.

With respect to the economic feasibility of either irrigation system, it must be noted that table 4 illustrates the costs of a conventional sprinkler irrigation system, and not that of a micro sprinkler irrigation system. The costs of a micro sprinkler irrigation system would be lower, but not significantly, thus allowing table 3 to illustrate the fact that the sub surface drip irrigation system is more cost effective. This is predominantly due to the fact that the annual maintenance and labour costs for a sub surface irrigation system as significantly lower than that of a micro sprinkler system. L.K. Oosthuizen et al. include the cost of purchasing, disposal, maintenance, and the cost of supplies in order to calculate the overall cost of an irrigation system. In Table 5, a cost breakdown for both a drip irrigation system and a micro sprinkler irrigation system are detailed. Although the labour costs for the drip irrigation system are listed as higher than those of a micro sprinkler irrigation system, this is due to the heightened initial installation and labour costs. Taking into account all of the factors listed in Table 5, (such as the electricity, labour, water, repair and maintenance, etc) the drip irrigation system is estimated to be approximately $11,000 less expensive than the micro sprinkler system.

TABLE 5 Summary of the total annual costs of a drip, micro and furrow irrigation system, the cost allocation, and the marginal factor cost, Onderberg area, Mpumalanga Province, 2002			
Irrigation System	**Drip**	**Micro**	**Furrow**
Total annual ownership/fixed cost (R)	28 509.87	39 817.10	17 763.61
Operating costs (R)			
Electricity	6 088.61	7 175.66	7 624.83
Water	24 938.70	28 340.97	67 535.14
Labour	1 884.55	1 131.65	29 600.14
Repairs and maintenance	4 045.52	2 331.77	1 615.43
Total operating costs (R)	36 957.38	38 980.05	106 375.54
Total annual fixed and operating costs (R)	65 467.25	78 797.15	124 139.15
Cost allocation per unit			
Fixed costs/ha (R)	1 147.50	1 598.77	352.45
Labour cost/m^3 water pumped (R)	0.0106	0.0056	0.0613
Repairs and maintenance/m^3 (R)	0.0227	0.0115	0.0033
Electricity costs/m^3 (R)	0.0287	0.0306	0.0138
Water costs/m^3 (R)	0.1398	0.1398	0.1398
Marginal factor cost of water applied (R/m^3)	0.2018	0.1875	0.2182

Table 5. Summary of the Total Annual Irrigation Costs

Finally the irrigation system that is the most environmentally friendly is the sub surface drip irrigation system. This is mainly due to the minimal water waste through either the surrounding soil or by evaporation, or transportation by wind. This decreases the potential for ponding of water, which increases the presence of bacteria, leading to plant disease. Also, with the lack of excess water ponding at the roof zone, the plant health increases, which in turn increases the crop yield. However, micro sprinkler irrigation systems are able to better distribute water in a uniform manner, and lack the potential to become plugged by sediment. Yet, with a sub surface drip irrigation system, nutrients can be incorporated into the water stream and ensure that the nutrients are injected directly in the root zone.

5.0 CONCLUSION

From the comparison and the triple bottom line analyses performed above, the sub surface drip irrigation system is proven to be ideal for the UBC SUB rooftop garden. This system is beneficial in producing increased crop yield, achieving optimum water efficiency, and managing nutrient and pesticide leaching into soil. However, it is recommended that further investigation and research be conducted on the Kapillary Irrigation Sub-Surface System (KISSS), as this is a relatively new product on the market of sub surface drip irrigation systems. The KISSS system differs from typical sub surface drip irrigation systems as it employs capillary action within the soil grains to attain the optimum water efficiency (Guenter and Sullings). From the current findings it appears to be the best option within drip irrigation systems.

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