Comparing hand watering, automated, and subsurface irrigation treatments for cost, labor, and water use in community gardens.

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Comparing hand watering, automated, and subsurface irrigation treatments for cost, labor, and water use in community gardens.

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Community gardens are places where people gather to share the experience of gardening. However, users often struggle to find time in their busy schedules to care for their plots and crops. This research explores the impact of different watering systems on gardening based on plant quality, cost, labor, and time for. The study analyzed the inputs and outputs of hand watering, automated, and subsurface irrigation treatments in hopes of identifying how to design community gardens for the most efficient application of water, ultimately striving to increase crop production, crop quality, and community interest. Results indicate that subsurface irrigation systems are more likely to save time, reduce water use, and produce a higher quality crop when application and setting is adequate.
DEDICATION

I would like to dedicate this research to my husband, Josue Gonzalez, my parents, Martha and Edgar De Leon, and my brother, Ariel. Throughout the years, they have always supported and encouraged me to venture out and become the best version of myself. Without their constant support, I would not have been able to accomplish many things throughout my academic career. I also want to recognize my Mississippi family and friends for keeping me grounded and motivated throughout these past years.
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CHAPTER I
INTRODUCTION

As popularity of urban agriculture increases, gardeners continue to seek optimal ways to grow and provide fresh produce to those who have limited access to it. Unfortunately, urban agriculture still faces limited accessible, healthy lands on which to grow (Draper & Freedman, 2010). The lack of open land to plant where soil is not contaminated or heavily compacted by the urban development has resulted in different garden trends such as raised planters. This type of planter has become a popular practice for growing fresh produce due to its flexibility of placement and design. In addition, it offers better management of soil content and plant diseases. Dense cities like New York, Chicago, and Portland are commonly known to use raised planters in community gardens (Draper & Freedman, 2010).

Community gardens have had a positive impact on food shortages in the past (McKelvey, 2015; Smithsonian Gardens, 2016; Lawson, 2004). So, it is no surprise that they are still relevant as more people learn how food insecurity is a reality that many families are subjected to across the United States. These gardens have become a popular and sustainable way of acquiring fresh produce among Millennials, who care about healthy living and locally grown produce in urban areas where space is limited and time is of most importance (NGA, 2014). Recent water shortage has led to increased water costs in urban areas, and community gardens may be adversely affected (Meyers et al., 2014). As a result, people are rethinking ways of watering community gardens while striving for a common goal: improved yield and reduced time
investment. Many community gardens are hand watered due to their manageable size and amount of people involved, but different methods must be explored for gardens that lack the resources required for time and labor efficiency.
CHAPTER II
LITERATURE REVIEW

Background

A community garden is defined by The American Community Gardening Association (ACGA) as “any piece of land gardened by a group of people” (ACGA, no date) which includes but is not limited to schools, faith communities, city blocks, prisons, nursing homes, and hospitals (Draper & Freedman, 2010). These gardens were introduced in the US as “relief” gardens to help with food shortages during the 1890s recession (McKelvey, 2015; Smithsonian Gardens, 2016, Lawson, 2005) and came back as “victory” gardens, which were considered a reflection of civic duty (Smithsonian Gardens, 2016; von Hassell 2002, 39) during the world wars. Yet it was not until the early 1970s that community gardens started to receive recognition for their myriad social, educational, environmental, and economical benefits.

Today, community gardens have regained their popularity and are appealing to diverse groups of people, especially millennials (NGA, 2014). By recognizing the connection between growing their own food and healthy lifestyles, young adults are a primary reason why trends like farm-to-table and personal gardens are becoming more popular (NGA, 2014). According to the National Gardening Association (2014), “millennials have spent $3.5 billion on food gardening in 2013, which is a 40% increase from 2008.”

Also, increased engagement in gardens by community organizations, faith groups, schools, politicians, and families have played a significant role. These influences led a rapid
increase in the number of registered community gardens. Within five years the number of gardens in the US went from one million to three million (Sinnes, 2014). With increasing popularity, the high demand for community gardens has impacted their design to suit the lifestyles of diverse communities, especially in urban areas where time and space are limited.

Dense cities like New York, Portland, Cleveland, and Detroit are seen as successful examples of sustainable land development in limited space. Influenced by food insecurity (Semananda, Ward & Myers, 2016) and lack of interest in chemicals or treatments used in commercial farming, community gardens in urban areas are a great option for the surrounding community to reliably access healthy, safe food (MacNair, 2002; Hale et al., 2011). In addition, community gardens contribute to aesthetically pleasing and inviting places to live through green infrastructure (Hale et al., 2011; Lin, Philpottb, & Jhac, 2015; Andersson., E., Barthel, S., & Ahrné, K., 2007).

Community gardens can provide a connection to nature and different ecosystem services for those who have limited access to green space (Lin et al., 2015; Andersson et al., 2007; Gittleman, Jordan, & Brelsford, 2012; Meyers et al., 2014). The most evident ecosystem service that gardens offer is the production of food. Community gardens often alleviate or reduce grocery expenses for users, depending on the lot size they are renting (MacKelvey, 2015). This represents a valuable resource for families with limited access to fresh produce.

Also, community gardens support an ecosystem service for the development of oxygen (Lin et al., 2015; Andersson et al., 2007). In tight spaces where pollution is abundant, repurposed lots that are developed into community gardens help lessen toxins and strong fumes in the air (Lin et al., 2015; Andersson et al., 2007). Thus, attracting locals to reconnect with nature and
host diverse insect communities and wildlife that have been forced out of the area (Andersson et al., 2007).

In most cases community gardens offer a park-like environment. Serving recreational and even spiritual benefits to its users (Gittleman et al., 2012; Meyers et al., 2014). Studies have shown that when gardens are used as parks, it allows people who reside nearby to have higher physical activity and better mental health (Armstrong, 2000; Dickinson et al., 2003; McAleese & Rankin, 2007). Additionally, they allow the local population to become more aware and learn about their surroundings.

Studies have analyzed these benefits among different age groups and different communities (Dickinson et al., 2003; Heim et al., 2009; Koch, Waliczek, & Zajicek, 2006). Community gardens often target a younger audience to teach how a garden is built and managed (Robinson-O'Brien, Story, & Heim, 2009). Heim et al. (2009) found that there are better development outcomes for children that participate in, or have been exposed to, a community garden. They often eat healthier and have a better environmental conscience (Heim et al., 2009, Koch et al., 2006; McAleese & Rankin, 2007; Robinson-O'Brien et al., 2009), which can positively impact our society and the economy for generations to come.

Gardens can help reduce grocery expenses by granting easier access to produce in places where convenience stores are popular (MacKelvey, 2015). According to the University of Missouri Extension website, limiting the cost invested in a garden while maximizing the crop yield can help save money in accessing fresh produce (MacKelvey, 2015; Trinklein, 2014). By knowing the basic principles of gardening and engaging with others to share and exchange produce, these spaces open the opportunity for gardeners to have place of gathering and create a sense of community (Kingsley & Townsend, 2006; Koch et al., 2006).
Therefore, gardens do not only provide environmental, economic, and educational benefits; they are also a place where a diverse group of people can gather to engage in a shared activity with a common goal (Kingsley & Townsend, 2006; Koch et al., 2006). Community gardens have become places where diversity and community thrive. Many Americans have unique, complex cultural backgrounds and in many cases seclude themselves from the local community due to a lack of shared culture or communication with their neighbors (Kingsley & Townsend, 2006). However, studies have shown that community gardens combat this situation by bringing people from different backgrounds together. A study by Saldivar-tanaka & Krasny (2004) explored the importance of community gardens within the Latino culture. The study reveals the positive impact that many immigrants have just by being part of the community garden. Moreover, the study shows how they interact more and become a greater part of society through gardening. In addition, crime rates significantly decrease when a community has the green space of a community garden. Yet for these benefits to thrive, a community garden must be designed in a way that influences people to find it inviting and functional.

Design/Use

When designing a garden, there are many elements that help shape the scale and design, depending on program and location (MacKelvey, 2015). In an urban context, there are many different places in which users can find optimal spaces to develop a community garden, including vacant lots, backyards, church lawns, and school playgrounds (Lin et al., 2015; Andersson et al., 2007). Among others, these sites offer common ground to the users that live in the area (Turner, Henryks, & Pearson, 2011). Flexible spaces and a short walking distance to homes and workplaces increase accessibility to diverse users and help them look forward to participating in the garden (Turner, 2011). Participation equals management and results in a successful garden (MacNair,
There is no standard size for a community garden (MacKelvey, 2015). A garden can either be large as the 14.5 acres in Shiloh Field in Danton, Texas, or small as a school garden like the ~0.4-acre BUGS in Baltimore, Maryland. Regardless of size, community gardens seem to share similar benefits and barriers. Lack of time and organization are two of the common obstacles that users encounter when volunteering in community gardens (MacKelvey, 2015). These elements can create a negative perception of the garden to the extent that many have opted to allow governmental groups, such as parks and recreation departments, to manage them instead (MacKelvey, 2015). It does not mean that gardens managed by a community group or school are not successful, but the idea of someone having the job to constantly check the garden’s performance helps minimize garden abandonment and failure (MacNair, 2002; Milburn & Vail, 2010).

For example, in Portland most people lease a 22 square meter plot or bed from the Parks and Recreation Department. Leases help ensure that land used for the community garden is restricted to those involved in it, which in turn demonstrates land value of the site (Hou, Johnson, & Lawson, 2009; Milburn & Vail, 2010). If users fail to comply, the bed or space is taken over by someone else. Management by the city allows the garden beds to be maintained by community volunteers that are seriously involved (Hou, et al., 2009; MacKelvey, 2015). Among many benefits, volunteers in community gardens not only add a democratic element to the management of the garden, but they also influence the space’s layout and design as well (Hou, et al., 2009).

As previously stated, the design of a garden varies according to the unique needs of the users and growing conditions of the crops, which means that there is not a defined design standard of how a community garden should be physically developed (MacKelvey, 2015). However, there are some popular design methods that one can find in a community garden. For example, bed
orientation is suggested to be oriented in a north-south direction to maximize crop production (Berle & Westerfield, 2019). Proper orientation allows a higher possibility of 6-7 hours of sunlight that a crop needs in a day (Bradley, 2019; Berle & Westerfield, 2019).

Similar to bed orientation, garden bed design can influence crop yield. Some of the most popular designs are simple plots or raised planters. A plot is generally referred to as a small more naturalistic gardening area using just ground soil. They tend to mix in with the surrounding landscape and can easily be shaped in various designs. Yet, even though plots are more flexible in size and placement, many gardeners prefer raised planters instead (Sinnes, 2014). Raised beds are typically smaller than plots and are elevated a few inches or feet above the ground (MacKelvey, 2015). Furthermore, planters offer a variance of height in order to accommodate all type of gardeners. Promoting ADA accessibility allows children to older audiences to enjoy and participate in the act of gardening and still have the proper soil depth for designated crops (Sinnes, 2014). Planters tend to range from 60.96 to 91.44 centimeters (cm) in height. MSU (University of Missouri) Extension website recommends that beds should be no longer than 3.66 meters (m) (Trinklein, 2014). Lumber boards commonly have a length of 3.66 m; anything longer than that size is subject to create conflict in the building process. In addition, it is suggested that the size should be *multiples of 4* for ease of construction. Even though they are commonly built with lumber, other mediums such as brick, stone, are also used. And in comparison, to plots, raised beds are designed in much simpler shapes such as: squares or rectangles. Additionally, raised planters allows greater control of the soil and less chance of soil loss or compaction by pedestrians (Trinklein, 2014; Berle & Westerfield, 2019).

Raised planters can also help reduce the amount of water used when gardening (Berle & Westerfield, 2019). Fruits and vegetables are 75 to 95 percent water. Therefore, for a healthy
plant to grow, it needs to be well irrigated. Having a fixed dimension to water, raised planters allow users to calculate the exact amount of water that a bed needs in order to maintain a healthy crop (Berle & Westerfield, 2019). For example, an average of 333 liters (L) of overhead water is required for a 4.88 m by 1.22 m raised bed to fully hydrate crops for 3 weeks (Berle & Westerfield, 2019).

**Water**

As mentioned before, most community gardens are located in urban settings where the demand and cost of water is usually higher than in rural areas. Studies have shown that irrigation in urban areas is significantly higher in cost compared to a commercial agricultural land ([FAO], 2016). Also, urban areas are prone to water scarcity due to population increase, aging infrastructure and climate change ([FAO], 2016).

Water scarcity has become a growing reality in the US. Studies have shown, that having the major Ogallala Aquifer feeding nearly 27 percent of the irrigated land in the US would not be alarmed if it were not for the increasing impervious surface coverage from development ([FAO], 2016). Impervious surface slows down or can even block water to filter into the surface to recharge our any subsurface, in this case the aquifer. Meaning that the supply does not match the demand (Wichelns, 2011). In addition, water quality is constantly threatened due to agricultural and industrial practices (Wichelns, 2011). As water sources keep shrinking and water quality keeps decreasing, the demand for and cost of water increases.

According to Wichelns (2010), these factors have led farmers to rethink their water management. Alternative methods of irrigation are being considered to replace current practices “with more costly center-pivot and low-pressure sprinklers, and subsurface drip irrigation” (Wichelns, 2010) in order to reduce water, use and application of traditional surface irrigation treatments. Lack of sufficient water can promote crop diseases and decrease food production in a
community garden. High demand to keep gardens running while water supply declines has forced garden designers to find other means to water community gardens.

There are two forms in which water makes its way to a garden: either through rain or a human application (Dupriez et. al, 2002). Rain can be beneficial to plants, but too much rain contributes to urban flooding. Mara Gittleman (2012) studied storm water mitigation in community gardens in New York City. The results showed that community gardens helped alleviate the amount of storm water runoff in the city. Also, Gittleman’s research helped quantify the amount of water that is affected by the number of beds in the city; such information has not had enough research. Though gardens can help mitigate storm water, the primary benefit of rain to a garden is to offset irrigation. Many people struggle to set aside the necessary time and labor that watering a garden requires. Yet because of limited research, most community gardens still prefer to hand water because of the significant amount of water that is saved compared to other systems such as dripping irrigation.

**Irrigation Treatments**

Hand watering treatments came about thanks to the invention of the garden hose. Initially, hoses were made using ox intestines; the hose became common when B. F. Goodrich used rubber to create this irrigation gadget in the late 1800s. Even though the hose’s demographic target was firefighters, continuous improvements included lighter and more manageable materials which sparked interest among horticulturists and gardeners to use them for gardening. Nowadays, the gardening hose is a standard tool when it comes to hand watering treatments. Its versatility allows different attachments to regulate water pressure and application (Hashagen, 1998).
Hand watering has been the most practical and traditional option for small-scale gardens. A single faucet can serve many garden plots and beds. Although it is more time consuming, hand watering assures gardeners check on their harvest (Bradley, 2019; Berle & Westerfield, 2019). Even though it is flexible, hand watering is ultimately easier to manage if garden layout is linear (Berle & Westerfield, 2019). It avoids getting tangled in an odd-patterned path. Additionally, when hand watering, the faucet needs to be ideally no further than 15.24 m from nearest bed (Bradley, 2019).

When done properly, hand watering can be efficient. The user has control over the quantity of water put in a single plant, which can reduce the possibility of overwatering. Still, hand watering is a method that can become time-consuming and therefore uncomfortable if time is a limited resource. It is also the most physically driven watering method, requiring gardeners’ active labor. Nevertheless, the garden hose offers endless possibilities through extensions and attachments that can help create a better watering treatment for gardeners.

Drip irrigation goes back thousands of years in the form of clay pots that “wept water” onto the soil in Asia (White, 2016). In the 1920s this concept was modified in Germany by perforating clay pipes by the to distribute water throughout a field or garden (White, 2016). However, it was not until World War II that the use of plastic allowed for the development of plastic emitters and, consequently, Dr. Daniel Hillel’s development of micro-irrigation and drip irrigation studies from 1950s to present day (White, 2016). Today a variety of drip irrigation systems are available: drippers, drip emitters, and micro-sprayers, to name a few. In addition, there are several tools that have been invented to help install and maintain an irrigation system, such as timers, pressure regulators, specific tools, and more.
With these improvements, drip irrigation systems have developed multiple benefits making them a widely used watering option in agriculture. According to landscape designer Robert Kourik (2009), drip irrigation is much easier to install when beds are in an orderly pattern, such as a straight line. Yet, components of the system can be placed and adjusted to cover almost any garden layout. Drip irrigation uses water more efficiently and prevents plant disease by using emitters, which minimize direct water contact to leaves.

Research indicates that once installed, drip irrigation is more time-efficient since it has the capacity to add a timer (Bradley, 2019; Berle & Westerfield, 2019), allowing each plant to receive the amount of water needed. Although automated irrigation systems are more time-efficient, depending on the timer used, it can become a pricey first purchase that will be paid off throughout the growth of crops. In small-scale gardens, David Berle and Robert Westerfield, 2019 from the University of Georgia Extension points out the possible physical tripping hazards created by a dripping line in a communal setting. In addition, pipes are often susceptible to become a habitat for insects, which can interrupt the system.

In 2013, a Michigan State University short-term study by Benjamin Byl found that using overhead and subsurface drip irrigation treatments on asparagus resulted in higher crop yields. The asparagus industry is known to grow their crops by three irrigation treatments: trickle, furrow, and center pivot sprinkler; still, it leaves a gap to explore other watering treatments in commercial asparagus farming. Even during the humid climate and Michigan summer rains, the study showed a significant increase in yield: about 6-21% throughout the experiment. Results were then compared to the average cost that commercial asparagus farmers would benefit for the increased yield. It was calculated that, in order to justify the initial irrigation installation cost, yield improvements should happen two to ten times during the anticipated 15-year life of the
asparagus (Byl, 2013). The study not only explored gaps in watering management in the asparagus industry, but following similar studies, it also opens the opportunity of exploring more subsurface irrigation treatments and their respective impacts on crop production.

Subsurface watering treatments have become a popular method of agricultural irrigation throughout the US (Semananda et al., 2016). The idea of a more controlled watering system can aid the growth of the crop with less manual labor. A subsurface irrigation treatment is more commonly used with raised planters. Irrigation is done through a capillary rise from a self-contained, rough material-filled subsoil reservoir (Semananda et al., 2016). Saturated water from the reservoir permits the soil to keep moisture, allowing plants to take in the water needed and not be overwatered.

A study by Niranjani P. K. Semananda et al. (2016) showed the water use efficiency by testing relatively newer subsurface irrigation treatments called “wicking beds” and their effects on small scale agriculture. Semananda found that wicking beds were more labor-efficient, requiring significantly less frequent watering to achieve the same or better water use efficiency: “[w]icking beds are inherently low-tech and scalable and appear well-suited to a variety of urban agriculture settings” (Semananda et al., 2016). Yet, there is a gap that requires further study: cost comparison to other methods of irrigation treatments. A series of cost comparison analysis could have helped understand the overall performance of planters compared to other irrigation treatments. Additionally, Semananda tested this treatment on tomatoes; testing other crops with the same high demand of water, such as strawberries, could possibly open the discussion of whether the treatment is compatible to other crops.
Figure 2.1  Sequence of subsurface irrigation system construction including pond liner, perforated pipe distribution, washed gravel, filter fabric, and soil.

Strawberries

Strawberries, Fragaria x ananassa, are one of the most demanded berries around America (Boriss, Bunke & Kreith, 2006; Hummer & Hancock, 2009; Trinklein, 2012), and play an important part for many people as a nutritional source (Maas, Wang, & Ialletta, 1996; Paparozzi et al., 2018). Strawberries possess a high content of Vitamin C, making them a great source to
build up a strong immune system (Maas et al., 1996). Their pleasant fragrance and vibrant color allow strawberries to be very appealing, thus generating a high demand once they were reintroduced to the US during the 1700s (Boriss et al., 2006; Paparozzi et al., 2018).

Today, strawberries can be grown essentially anywhere around the country (Paparozzi et al., 2018) and are classified in three types: June bearing, everbearing, or day-neutral. Thus, fruit production is visible within the first year of planting (Trinklein, 2012). Strawberries can produce large yields with full sunlight, which is considered 6 to 10 hours of direct sunlight each day (Strawberry, no date). The most common time of the year for peak harvest is in May.

Even though strawberries are known to adapt and grow in almost any type of environment, they require to be planted in well-drained soil. Strawberries need constant moisture and should be watered regularly, but the crop will rot if left in standing water. The most optimal situation is to plant in raised planters (Strawberry, no date); strawberries have a shallow root system that averages 25 cm in depth ([FAO], 2016), so a planter with an elevation of 25 to 30 cm would allow water to be drained properly (Strawberry, no date).

For proper hydration, day-neutral cultivars respond better when planted in a staggered pattern. Spacing 30.48 cm from each plant prevents crops from competing with each other, or with runners, for nutrients and water (Strawberry, no date). Runners are replica plants that do not produce fruit yet are capable of establishing root systems and stealing water and nutrients from the mother plant.

A study made by Renquist (1980) suggest that more precise watering methods do have a significant impact in strawberry crowns and leaves. By utilizing a drip irrigation treatment, strawberries responded positively throughout the three experiments made. In addition, Renquist tested the use of black polyethylene mulch, which resulted in the same positive results. The
mulch kept soil moist for strawberries and, similarly to the dripping system, the strawberry plants produced fruit.
CHAPTER III

METHODOLOGIES

Experimental Condition

The experiment was conducted at the Mississippi State University Community Garden. Located in USDA Hardiness Zone 8a, the garden provides real-world conditions in which plants are exposed to rainfall and temperature variation. The project utilized nine raised planters, each measuring 4.88 m by 1.22 m (Figure 3.6). Planters are oriented east to west along their long axis and placed 91.44 cm apart. All nine planters are located in a row and are adjacent to an existing building on the east side of the beds (Figure 3.1), which cast shade on the beds during morning hours. Each bed is constructed of 10.16 cm by 38.48 cm cedar timbers, and three of the nine beds have an existing subsurface irrigation system. The costs of materials for each treatment, above the standard planter costs, was collected from receipts including tax and delivery where appropriate.
The experiment was set up in early February and was executed over a 100-day period between March and June 2018, with temperatures ranging from 10 to 29.44 degrees Celsius. Two day-neutral cultivars of strawberries, *Evie 2* and *Seascape*, were selected for the experiment. The cultivars were selected for their popularity, hardiness, ease of growing, and high yields (Rowley et al., 2011). One hundred and thirty-five, six-week-old plugs of each cultivar were obtained from Nourse Berry Farm in Minnesota. Nourse Berry Farm says that *Evie 2* is a popular berry among commercial growers. Released by the Peter Vinson breeding program in Kent, England, the berry is less sensitive to the warm summer temperatures that shut down day-neutral production in the eastern and midwestern US (Strawberry, no date). *Seascape* was released by the University of California breeding program in 1992. This day-neutral has been highly successful for northeastern growers for summer and fall production, according to Nourse Berry Farm berry catalog.
Each plug was transplanted on February 28, 2018. At that time, each plug was fertilized with the slow-release fertilizer, Osmocote® 14-14-14 (14N-6.1P-11.6K, 4-5 months, Scotts Miracle-Grow Co., Marysville, OH), to encourage growth and reduce stress from transplanting (see figure 3.1). Between 50 to 76 mm of pine straw was added to each bed to control weeds, reduce evaporation, and help protect plugs from potential late-season frost. No other alteration or substance was added to the plants for the rest of the experiment. All plants were hand watered for an establishment period from February 28 to March 20, 2018, at which point the experiment began. The experiment ended 100 days later on June 28, 2018.

Figure 3.2 Images of strawberry planting for automated (left) and hand (right) watering treatments.

**Experimental Design and Treatments**

Each bed hosted 15 plugs from each cultivar, yielding a total of 270 strawberry plants. Plugs were transplanted in two rows. *Evie 2* plugs were transplanted to the north side and
Seascape were transplanted to the south side of each bed in order to keep track of each cultivar’s location. The plugs were evenly spaced at 30.48 cm on center.

With three pre-existing beds already constructed with a subsurface irrigation system, the rest of the six beds were equally distributed with automated or hand watering treatments. Each treatment was watered based on the amount of water that a strawberry needed. Using Smith et al.’s 2016 study, the amount of water required for a strawberry to prosperously grow was calculated by running an analysis with the FAO CROPWAT model. Soil moisture and composition were measured and averaged 7 ml of water transpiration. A strawberry has an average root length of 25 cm and an average water consumption of 0.6+/−-liters. Therefore, it was concluded that the plants should be watered every two days based on the moisture retention of the growing substrate and the water consumption of the strawberry.

Each irrigation treatment conducted in the experiment had different characteristics. The first irrigation treatment was hand watering (Figure 3.3). This treatment was composed of a 30.48 m gardening hose, a 25-psi water regulator, and an extended watering wand. All plants that were hand watered were placed in raised beds filled with 30.48 cm of soil and were labeled as planter numbers 1, 5, and 8 (see Figure 3.6). Based on rainfall and visually observed plant health, the plants were hand watered during 15 watering sessions over the 100-day experiment.
The drip irrigation treatment (Figure 3.4) was designed with individual emitters that produced 3.79 L of water per hour. Planters using this system were labeled as numbers 2, 4, and 6. Emitters were connected to a 1.6 cm drip irrigation tube using 0.64 cm drip irrigation distribution tubing. Each emitter was placed roughly at the center of each plant to drip directly on top of the plant’s roots. All planters using drip irrigation were connected to an automated irrigation timer that, for this study, was manually operated at 15 watering sessions over the 100-day experiment. The setup time of 30 minutes per planter was used to calculate labor time needed for this system. To determine how an automated timer and a timer with a rain sensor would impact water use, a post study analysis was executed to determine water use if they system was automatically activated every other day and every other day less days with rain events.
The subsurface irrigation treatments (Figure 3.5) had a reservoir or retention area below the soil that helped maintain a consistent soil moisture. The wicking planters’ main features are the vertical water insertion pipe, the underground washed gravel water storage, and the overflow pipe. All planters were lined with a 0.37 ml PVC liner with nylon mesh reinforcement. The liner holds 30.48 cm deep of washed gravel that allows for 578 liters of water in the 40% average void space created by the gravel.

Non-woven geotextile filter fabric was used as a barrier over the gravel to support the soil above and to all vertical moisture movement. To quickly distribute water through the gravel layer, a 10.16 cm perforated pipe goes around the bed and connects to both the vertical fill and horizontal outfall pipe. These planters were labeled as numbers 3, 5 and 9.
Irrigation Application

Hand watering was applied to each plant’s base using a watering wand. Water pressure and duration were calculated by filling up an 18.93 L bucket with a fixed, gentle setting on the watering wand and timing the process. It took an average of 7.01 min over three tests to fill the 18.93 L bucket which determined a flow rate of 2.7 l/min. Based on the strawberry plant irrigation demand of 0.6 l of water, each plant would need 13.33 seconds of watering. To account for movement between plants and inaccuracies in the process, each plant was watered as close to 15 seconds as possible using a stopwatch. The total time in labor and water use to water each bed was averaged after testing the process three times to 9 minutes per planter or 27 minutes for all three hand watering replicates. Plants were watered every other day skipping observed rain days.

To calculate the amount of time that the drip irrigation system would need to operate, the strawberry plant demand of 0.6 l was divided by the individual emitter flow rate of 0.063 l/min to determine a run time of 9.5 minutes. Responding to rain patterns and by following the same
schedule as the hand watering treatment, the drip system was turned on when the hand watering was executed.

Also on hand watering days, the reservoirs of the subsurface planters were filled until water came out of the overflow pipe. This process averaged two to seven minutes per planter. To determine volume added to each planter when filling, an 18.93 l bucket was filled using a fixed flow setting on the garden hose. The process took an average of 5 min to fill the 18.93 L bucket over three attempts, resulting in a flow rate of 3.8 l/min. This flow rate was multiplied by the watering time recorded for each planter and session to determine total water use over the experiment, and the watering time to fill the planters was used to calculate labor time for the treatment.

Figure 3.6  Experiment design with planters 1, 5, and 8 as hand watering; 2, 4, and 6 as drip irrigation; and 3, 7, and 9 as subsurface irrigation systems.
Plant and Fruit Performance

Day-neutral cultivars were used for the experiment since the length of day or night does not affect their growth (Strawberry, no date). Fruit were hand harvested and weighed every, one to two days from April 24, 2018 to June 26, 2018, 56 Days After Transplanting (DAT). Fruit was considered to be ready for harvest when more than 90% of the fruit body were red in color as seen in Figure 3.7. Culled fruit was recorded unless severe damage to fruit was made by sunburn, insects, or birds. Fruit were measured based only on fruit weight. At each harvest weight (g) total number, planter number and cultivar were recorded. The quality variables that were analyzed consisted of: fruit yield, size, acidity, soluble solids content (SSC), and plant growth index (PGI).

![Figure 3.7 Image example of fruit ready for harvesting.](image)

(PGI) was measured at the end of the study period once all fruit was harvested. First site condition was studied and was determined that because most of the plants that were adjacent to a building, sun exposure varied throughout beds 1-7 (Figure 3.6). In addition, it was also revealed that not all plants received the same amount of water due to their location. Plants that are
exposed longer to sunlight tend to require different amount of water than plants that are partially shaded. Meaning that there would not be an equal physical growth on each plant.

So, to test each bed as equal as possible, all plants that were analyzed came from the far left, middle and far right of each bed. In the next part this process, strawberry plants were destructively harvested, separating the crowns and roots, cleaned and then weighted. Once calculated the fresh weight, all crowns and roots went through a drying process and were oven dried at 60 °C. After the drying process was completed, dry weights of crowns and roots of each plant were weighed. Total dry weight of a given plant was calculated by adding dry weight of crowns and roots and compared to a fresh plant.

Figure 3.8  ATAGO PR-101 32a; Atago U.S.A. Inc., (Bellwvue, WA) apparatus used to measure the soluble sugars found in fruits (Image from https://www.novatech-usa.com/3442-PR-101a)

Sucrose (sugar) is found when fruit is in the middle of ripening and is one of the major soluble sugars found in strawberries (Hummer & Hancock, 2009). These soluble sugars help with the enjoyable flavor of the fruit (Hummer & Hancock, 2009). The SSC of the fruit was determined by extracting 0.3 mL of juice from fruit on the surface of a digital refractometer
(ATAGO PR-101 32α; Atago U.S.A. Inc., Bellvue, WA), which calculated the natural sugar content of the fruit.

For this process 15 strawberries from each cultivar and bed were used, a total of 270 fruit. To gather enough samples, two picking sessions were made with one day in-between. Once all samples were gathered, juice was extracted by slicing each strawberry and manually extracting the juice using a cheesecloth to prevent pulp or seed interference in the results. The refractometer was calibrated using deionized water after each testing.

![Image of FR-5120 apparatus](https://www.carousell.ph/p/fruit-hardness-tester-fruit-penetrometer-fruit-sclerometer-lutron-fr-5120-238609296/)

Figure 3.9 The FR-5120, Lutron Electronic Enterprise CO., LTD, Taipei, Taiwan apparatus used to measure fruit firmness. (Image from [https://www.carousell.ph/p/fruit-hardness-tester-fruit-penetrometer-fruit-sclerometer-lutron-fr-5120-238609296/](https://www.carousell.ph/p/fruit-hardness-tester-fruit-penetrometer-fruit-sclerometer-lutron-fr-5120-238609296/))

To test the firmness, the same strawberries used to calculate SSC, were used prior to the slicing process. This data was gathered by perforating each strawberry with a digital fruit firmness tester (FR-5120, Lutron Electronic Enterprise CO., LTD, Taipei, Taiwan). The fruit firmness tester measures the hardness of the fruit by the pressure applied on each perforation.
The device was cleaned every other test to avoid any alteration in the result that may be caused by excess pulp residue. Each test was manually and digitally recorded.

![Figure 3.10 Image of EasyPlus METTLER TOLEDO, Columbus, OH apparatus used to measure the Titratable acidity (TA)](/image)

The acidity data gathered from fruit was done at the end of the season. Thus, collection of fruit was limited, and strawberry fruits were frozen until a sample of 10 strawberries were collected from each cultivar and bed (total of 180 strawberries). The thawing process consisted of setting the containers that held the frozen fruit on top of warm water. The process took 10-15 min depending on the size of the fruit. After thawing, three aliquots (5 ml) of the fruit’s juice were diluted with 50 ml of distilled water and titrated with 0.1 N NaOH to an endpoint of pH = 8.2 using an automatic titrator (EasyPlus METTLER TOLEDO, Columbus, OH). To reach the endpoint, the NaOH (ml) requirement was recorded. The titratable acidity of strawberry fruits was expressed as percentages of citric acid equivalent.
Similar to Edward Gbur et al.’s 2012 data analysis, the Statistical Analysis software SAS (version SAS (r) Proprietary Software 9.4 (TS1M5) for Windows by SAS Institute Inc., Cary, NC, US), was used to make an analysis of variance (ANOVA) of the data gathered. General box models were developed by analyzing the interaction of the previous variables mentioned and the three watering treatments. When the fruit harvest variables were significantly different (P < 0.05), cultivar and watering treatment data were analyzed. All P-values below 0.05 are included in the result tables.
CHAPTER IV

RESULTS

Effect of irrigation treatments on the cost of irrigation systems

The total price for each system was calculated based on costs generated to outfit three planters for the experiment. This number was extrapolated to comprehend how cost would relate to one, three, and nine planters so it could be understood in various contexts from a homeowner to larger, public garden.

Hand watering treatment was the most affordable out of the three (Table 5.1). The overall cost included a 30.48 m garden hose and an eighteen-dollar extension wand, which helped set up the gentle spray that was used for each watering application. This cost remains the same across multiple planters since the same resources are shared throughout a garden, making this system the most economical in terms of material cost.

Table 4.1 Materials costs for hand irrigation system on 1, 5, and 8, 4.88 m by 1.22 m planters.

<table>
<thead>
<tr>
<th>Element</th>
<th>Materials Used on 3 Planters</th>
<th>Materials Shared on up to 9 Planters</th>
<th>Cost for 1 Planter</th>
<th>Cost for 3 Planters</th>
<th>Cost for 9 Planters</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>$0.00</td>
<td></td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>1 - 100' Garden Hose</td>
<td>$36.38</td>
<td></td>
<td>$36.38</td>
<td>$36.38</td>
<td>$36.38</td>
</tr>
<tr>
<td>1 - Watering Wand</td>
<td>$18.56</td>
<td></td>
<td>$18.56</td>
<td>$18.56</td>
<td>$18.56</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td>$54.94</td>
<td>$54.94</td>
<td>$54.94</td>
</tr>
</tbody>
</table>

*Prices include tax and shipping were applicable.
The cost of the drip irrigation treatment included a basic timer, garden hose, tubing, stakes, and emitters, see Table 5.2. Each individual plant had their own emitter that was elevated above grade by a plastic stake. The stakes prevented all the emitters from contacting the ground and avoiding any potential clogs. The system’s cost is cheaper on a per planter basis when applying it to 9 planters due to multiple shared elements resulting in a roughly one-hundred- and eighty-one-dollar cost per planter.

Table 4.2  Materials costs for drip irrigation system on 2, 4, and 6, 4.88 m by 1.22 m planters.

<table>
<thead>
<tr>
<th>Element</th>
<th>Materials Used on 3 Planters</th>
<th>Cost for 1 Planter</th>
<th>Cost for 3 Planters</th>
<th>Cost for 9 Planters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Roll 1/4&quot; Drip Tubing</td>
<td>$19.26</td>
<td>$6.42</td>
<td>$19.26</td>
<td>$57.78</td>
</tr>
<tr>
<td>1 - Roll 1/2&quot; Drip Tubing</td>
<td>$14.98</td>
<td>$4.99</td>
<td>$14.98</td>
<td>$44.94</td>
</tr>
<tr>
<td>6 - Emitter Packs (15)</td>
<td>$64.20</td>
<td>$21.40</td>
<td>$64.20</td>
<td>$192.60</td>
</tr>
<tr>
<td>9 - Stake Packs (10)</td>
<td>$19.26</td>
<td>$6.42</td>
<td>$19.26</td>
<td>$57.78</td>
</tr>
<tr>
<td>2 - T Connectors</td>
<td>$6.81</td>
<td>$2.27</td>
<td>$6.81</td>
<td>$20.42</td>
</tr>
<tr>
<td>1 - End Cap Pack (5)</td>
<td>$2.14</td>
<td>$0.71</td>
<td>$2.14</td>
<td>$6.42</td>
</tr>
<tr>
<td>3 - Elbows</td>
<td>$8.19</td>
<td>$2.73</td>
<td>$8.19</td>
<td>$24.57</td>
</tr>
<tr>
<td>1 - Hose Valve</td>
<td>$10.70</td>
<td>$10.70</td>
<td>$10.70</td>
<td>$10.70</td>
</tr>
<tr>
<td>1 - Back Flow Preventer</td>
<td>$7.49</td>
<td>$7.49</td>
<td>$7.49</td>
<td>$7.49</td>
</tr>
<tr>
<td>1 - Pressure Regulator</td>
<td>$10.70</td>
<td>$10.70</td>
<td>$10.70</td>
<td>$10.70</td>
</tr>
<tr>
<td>1 - In-line Filter</td>
<td>$10.70</td>
<td>$10.70</td>
<td>$10.70</td>
<td>$10.70</td>
</tr>
<tr>
<td>1 - Timer with Moisture Sensor</td>
<td>$54.99</td>
<td>$54.99</td>
<td>$54.99</td>
<td>$54.99</td>
</tr>
<tr>
<td>1 - Adapter</td>
<td>$5.35</td>
<td>$5.35</td>
<td>$5.35</td>
<td>$5.35</td>
</tr>
<tr>
<td>1 - 100’ Garden Hose</td>
<td>$36.38</td>
<td>$36.38</td>
<td>$36.38</td>
<td>$36.38</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$181.26</strong></td>
<td><strong>$271.15</strong></td>
<td><strong>$540.82</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Prices include tax and shipping were applicable.

In comparison to the previous systems, the subsurface irrigation treatment was the most expensive of the three, see Table 5.3. The additive cost of the treatment included gravel, piping, filter fabric, and pond liner. Generally, the cost for these types of systems are around two-
hundred dollars, regardless of scale and unlike the other two systems, there are very few similar
design components. However, if structurally sound, a wicking bed has a higher probability of
lasting much longer in comparison to the temporary and exposed materials used in the drip
system.

Table 4.3  Materials costs for subsurface irrigation system on 3, 7, and 9, 4.88 m by 1.22 m
planters.

<table>
<thead>
<tr>
<th>Element</th>
<th>Materials Used on 3 Planters</th>
<th>Materials Shared on up to 9 Planters</th>
<th>Cost for 1 Planter</th>
<th>Cost for 3 Planters</th>
<th>Cost for 9 Planters</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 -2&quot; Street Elbows</td>
<td>$9.63</td>
<td></td>
<td>$3.21</td>
<td>$9.63</td>
<td>$28.89</td>
</tr>
<tr>
<td>6 - 2&quot; Elbows</td>
<td>$9.63</td>
<td></td>
<td>$3.21</td>
<td>$9.63</td>
<td>$28.89</td>
</tr>
<tr>
<td>6 - 4&quot; Couplings</td>
<td>$28.89</td>
<td></td>
<td>$9.63</td>
<td>$28.89</td>
<td>$86.67</td>
</tr>
<tr>
<td>6 - 2&quot;x3&quot; Bushings</td>
<td>$5.91</td>
<td></td>
<td>$1.97</td>
<td>$5.91</td>
<td>$17.72</td>
</tr>
<tr>
<td>3 - 4&quot; Perf. Pipe Elbow</td>
<td>$20.48</td>
<td></td>
<td>$6.83</td>
<td>$20.48</td>
<td>$61.44</td>
</tr>
<tr>
<td>3 - 2&quot;x5&quot; PVC Pipe</td>
<td>$25.65</td>
<td></td>
<td>$8.55</td>
<td>$25.65</td>
<td>$76.94</td>
</tr>
<tr>
<td>6 - 2&quot; Brackets</td>
<td>$4.43</td>
<td></td>
<td>$1.48</td>
<td>$4.43</td>
<td>$13.29</td>
</tr>
<tr>
<td>2 - Cu.Yd. Washed Gravel</td>
<td>$153.00</td>
<td></td>
<td>$51.00</td>
<td>$153.00</td>
<td>$459.00</td>
</tr>
<tr>
<td>1 - 4&quot;x100' Perf. Pipe</td>
<td>$84.53</td>
<td></td>
<td>$28.18</td>
<td>$84.53</td>
<td>$253.59</td>
</tr>
<tr>
<td>1 - PVC Cement</td>
<td>$10.70</td>
<td></td>
<td>$3.57</td>
<td>$10.70</td>
<td>$32.10</td>
</tr>
<tr>
<td>1 - Silicone Calk</td>
<td>$9.61</td>
<td></td>
<td>$3.20</td>
<td>$9.61</td>
<td>$28.83</td>
</tr>
<tr>
<td>1 - 16&quot;x20' Pond Liner</td>
<td>$107.00</td>
<td></td>
<td>$35.67</td>
<td>$107.00</td>
<td>$321.00</td>
</tr>
<tr>
<td>1 - 10&quot;x50' Filter Fabric</td>
<td>$55.00</td>
<td></td>
<td>$18.33</td>
<td>$55.00</td>
<td>$165.00</td>
</tr>
<tr>
<td>1 - 100' Garden Hose</td>
<td>$36.38</td>
<td></td>
<td>$36.38</td>
<td>$36.38</td>
<td>$36.38</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$211.20</strong></td>
<td></td>
<td><strong>$560.83</strong></td>
<td><strong>$1,609.74</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Prices include tax and shipping were applicable.

**Effect of irrigation treatments on labor**

The labor invested in each treatment was measured in minutes spent watering for the
hand and subsurface system and just set-up for the drip system since it would typically be on a
timer. Hand watering, as shown on Table 5.4, required more watering, in comparison to the other
two treatments. In addition, it was the treatment that required the most physical movement. The
hand watering treatments were watered a total of 15 times over the experiment resulting in 135 minutes watering each planter.

Even though there was no overhead watering in the beds with subsurface irrigation after the establishment period, each bed was refilled each time the beds using the hand irrigation treatments were watered, a total of 15 times. In contrast with the other systems, each bed that had a built-in subsurface irrigation treatment required the gardening hose to be placed inside a fill pipe and run water until the bed was filled; indicated by water coming out of the overflow pipe. Through this process a discrepancy in the construction of the beds was found, a leakage in bed number 9. This meant that the bed would require more water than the other two, see Table 5.4.

Unlike the subsurface treatment, the drip irrigation treatment, which for the purpose of this study, was activated and managed to water every time all the beds were watered. As seen on Table 5.4, total labor time for drip irrigation was 30 min. per bed. Time was determined that it took roughly 2-3 mins to set up each watering session in each 4.88 m by 1.22 m planter (replicate).

Table 4.4 Water use for hand, drip, and subsurface treatments over the course of the study.

<table>
<thead>
<tr>
<th>Planter Number</th>
<th>Irrigation System</th>
<th>Total Watering Time for each Replicate (min.)</th>
<th>Total Watering Time for 3 Replicates (min.)</th>
<th>Average Watering Time for each Replicate (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Hand</td>
<td>135.00</td>
<td>405.00</td>
<td>135.00</td>
</tr>
<tr>
<td>7</td>
<td>Hand</td>
<td>135.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Hand</td>
<td>135.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Drip</td>
<td>30.00</td>
<td>90.00</td>
<td>30.00</td>
</tr>
<tr>
<td>6</td>
<td>Drip</td>
<td>30.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Drip</td>
<td>30.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Subsurface</td>
<td>30.00</td>
<td>207.00</td>
<td>69.00</td>
</tr>
<tr>
<td>9</td>
<td>Subsurface</td>
<td>127.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Subsurface</td>
<td>50.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subsurface with Leaking Planter (#9) Removed</td>
<td>30.00</td>
<td>N/A</td>
<td>40.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Effect of Irrigation Treatments on Water Used

Hand watering system used the most water over the experiment with subsurface as the lowest and drip also relatively low (Table 5.5). However, several analyses illustrated different perspectives on potential water use in a public garden. When a drip system is activated with a timer and/or a timer with rain sensor, the water used in that system increases dramatically. Additionally, as mentioned previously, one of the subsurface planters had a leak caused during planter construction, which created a higher water demand. When this planter is removed from the analysis, the subsurface system become even more appealing.

Table 4.5 Total water used for irrigating 30 strawberry plants in each 4.88 m by 1.22 m planter (replicate) for hand, automated, and subsurface irrigation treatments over 100-day experiment.

<table>
<thead>
<tr>
<th>Planter Number</th>
<th>Irrigation System</th>
<th>Total Water used in Each Replicate (L)</th>
<th>Total Water Used for 3 Replicates (L)</th>
<th>Average Water Used for each Replicate (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Hand</td>
<td>364.50</td>
<td>1093.5</td>
<td>364.5</td>
</tr>
<tr>
<td>7, 10</td>
<td>Drip as Executed in Study</td>
<td>269.33</td>
<td>807.975</td>
<td>269.325</td>
</tr>
<tr>
<td>4</td>
<td>Drip with Automatic Timer and Rain Sensor Set to Every Other Day</td>
<td>628.43</td>
<td>1885.275</td>
<td>628.425</td>
</tr>
<tr>
<td>6</td>
<td>Drip with Automatic Timer Set to Every Other Day</td>
<td>897.75</td>
<td>2693.25</td>
<td>897.75</td>
</tr>
<tr>
<td>8</td>
<td>Subsurface</td>
<td>113.70</td>
<td>784.53</td>
<td>261.51</td>
</tr>
<tr>
<td>5, 9, 11</td>
<td>Subsurface with Leaking Planter (#9) Removed</td>
<td>113.70</td>
<td>N/A</td>
<td>151.6</td>
</tr>
</tbody>
</table>
Effect of Irrigation Treatments on Plant Size, Plant Yield, and Fruit Size

The mean plant size (MPG) in measured plants did not show significant differences between the three treatments (Table 5.6). Over the nine beds, a total of 2,969 strawberries weighing 24,804 g were harvested. When analyzed, the total fruit yield did not show any significant difference in quantity or weight among any of the treatments (Tables 5.7 and 5.8). The results indicate that the subsurface system performed at least as well as the other two treatments in terms of growth and fruit production.

Table 4.6  Mean strawberry plant growth (MPG) for all plants in hand, automated, and subsurface irrigation treatments over 100-day experiment.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Mean Plant Growth Index (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>41.68 ± 3.60 (a)</td>
</tr>
<tr>
<td>Hand Watering</td>
<td>42.52 ± 3.83 (a)</td>
</tr>
<tr>
<td>Automated</td>
<td>42.65 ± 3.60 (a)</td>
</tr>
</tbody>
</table>

(2) Statistical relationships between groupings, F= 0.46, p = 0.64

Table 4.7  Mean yield of all strawberry fruit harvested in hand, automated, and subsurface irrigation treatments over 100-day experiment.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Mean Fruit Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>132.20 ± 27.36 (a)</td>
</tr>
<tr>
<td>Hand Watering</td>
<td>152.80 ± 23.19 (a)</td>
</tr>
<tr>
<td>Automated</td>
<td>151.00 ± 42.43 (a)</td>
</tr>
</tbody>
</table>

(2) Statistical relationships between groupings, F = 0.47, p = 0.48
Table 4.8  Mean weight of all strawberry fruit harvested in hand, automated, and subsurface irrigation treatments over 100-day experiment.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Mean Fruit Size (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>1,158.00 ± 192.30 (a)</td>
</tr>
<tr>
<td>Hand Watering</td>
<td>1,341.00 ± 94.17 (a)</td>
</tr>
<tr>
<td>Automated</td>
<td>1,428.00 ± 292.40 (a)</td>
</tr>
</tbody>
</table>

(2) Statistical relationships between groupings, F= 33.78, p < 0.001

**Effect of Irrigation treatments on Fruit Sugar Content, Acidity, and Firmness**

Table 5.9 shows that fruit had a positive response with a higher soluble solid content (SSC), on the subsurface system. Meaning that there was higher concentration of sweetness in the strawberries harvested in beds 3, 7, and 9. In Table 5.10, Tartaric acid (TA) calculations reveals that fruit harvested in beds 3, 7, and 9 also had a significant difference. Having a higher SSC and TA in a strawberry means that fruits harvested on beds using subsurface irrigation were more flavorful than the others. Additionally, beds using a subsurface irrigation system had the firmest of all the fruit harvested throughout the experiment, see Table 5.11.

Therefore, when analyzing the water treatments’ performance, the subsurface treatment recorded a significant difference affecting positively the acidity, sugar content, and firmness of the fruit. These results might indicate that because of the constant moisture that the strawberries received it allowed for the plant to never reach a moment of stress, compared to the other treatments.
Table 4.9  Mean Solid Soluble Content of strawberry fruit harvested in hand, automated, and subsurface irrigation treatments.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Mean Fruit Solid Soluble Content (Brix %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>8.89 ± 1.90 (a)</td>
</tr>
<tr>
<td>Hand Watering</td>
<td>8.21 ± 1.78 (b)</td>
</tr>
<tr>
<td>Automated</td>
<td>8.04 ± 1.62 (c)</td>
</tr>
</tbody>
</table>

(2) Statistical relationships between groupings, $F = 4.21$, $p = .02$

Table 4.10  Mean Tartaric Acid Content of strawberry fruit harvested in hand, automated, and subsurface irrigation treatments.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Mean Fruit Tartaric Acid (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>1.04 ± 0.03 (a)</td>
</tr>
<tr>
<td>Hand Watering</td>
<td>0.76 ± 0.15 (b)</td>
</tr>
<tr>
<td>Automated</td>
<td>0.68 ± 0.03 (b)</td>
</tr>
</tbody>
</table>

(2) Statistical relationships between groupings, $F = 5.85$, $p = 0.02$

Table 4.11  Mean Tartaric Acid Content of strawberry fruit harvested in hand, automated, and subsurface irrigation treatments.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Mean Fruit Firmness (kgf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>0.71 ± 0.23 (a)</td>
</tr>
<tr>
<td>Hand Watering</td>
<td>0.65 ± 0.18 (b)</td>
</tr>
<tr>
<td>Automated</td>
<td>0.64 ± 0.16 (b)</td>
</tr>
</tbody>
</table>

(2) Statistical relationships between groupings, $F = 3.29$, $p = .04$
CHAPTER V
DISCUSSION AND CONCLUSIONS

The results indicate that for this short-term experiment, subsurface irrigation (wick beds), while having the most expensive up-front cost, provided flexibility in time investment and reduced water volume compared to hand and drip watering. Additionally, the garden beds using the subsurface irrigation system yielded higher quality produce, measured by sugar content, acidity, and fruit firmness. And even though the beds using subsurface irrigation system had the most flavorful strawberries, all the treatments performed statistically the same in terms of plant growth and fruit production.

The cost of a subsurface system, above a hand watering or drip system, can be substantial. However, when considering reduction in time and water, the system becomes much more appealing. Adopting a subsurface system in a municipally funded community garden, where long-term maintenance costs are weighted more heavily than upfront costs, a subsurface system seems to be very appropriate compared to a drip system that requires easily lost or broken components. In short, the subsurface system is resilient and effective in a public setting where there are many users and variables to consider.

Water use in the subsurface system was marginally less in the subsurface system compared to the hand and automated systems as they were operated in the experiment. However, the analysis of potential water use with a timer and timer with a rain sensor indicate the potential of substantial water savings. In other words, an automated system would provide less labor but
would likely over water a bed, where a subsurface system would also reduce labor, but use much
less water for a similar amount of production.

The experiment also highlights the importance of proper design and construction of the
systems. Since the beds were recently built, an unforeseen leak caused the experiment to use
more water than was required. The leak was likely due to a tear in the PVC liner during
construction. Other examples of subsurface systems use metal containers that are much less
likely to leak and more durable in a public setting. These design considerations become critical
when evaluating a subsurface system for long-term performance potential. It is unclear if the leak
impacted results related to plant and fruit performance.

In accordance with Sullivan’s 2016 experiment, a further study with a longer time frame,
in other seasons, and with other crops is suggested in order to explore the maintenance of the
treatment, fruit production follow up and effect on different crops. Both experiments explored
efficiency of subsurface (wicking) beds including bed size, and different type of soils. Adding
these variables permits a more in-depth study that could help gardeners understand maintenance
demands and more accurately quantify crop value in urban agriculture.

Even though gardens provide many benefits to dense communities, scarce sources are a
challenge in the success of a garden. So, the research opens the discussion to test each value in a
real-life setting. Would it allow people to be more engaged in a community garden if there was
an initial high investment in beds, that will result in less labor and better fruit quality? Would it
be more appealing to them to have a moderate cost of bed design such as a hand treatment and
risk crop failure due to an unpredictable rain season?

For landscape architects, this study contributes to the design of public and private food or
community gardens which are a significant trend in landscape design. With more and more
communities opting to provide municipally managed community gardens, the design of the gardens becomes the purview of licensed practitioners who need to understand the short- and long-term impacts of planter watering. The study also illustrates the need for design standards for subsurface systems based on sound research to allow designers to confidently deploy subsurface systems in community gardens.
REFERENCE


