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Analyzing Spinach Growth Using Vertical Garden Techniques and Local Water Sources for Urban Gardens

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ANALYZING SPINACH GROWTH USING VERTICAL GARDEN TECHNIQUES AND LOCAL WATER SOURCES FOR URBAN GARDENS

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ANALYZING SPINACH GROWTH USING VERTICAL GARDEN TECHNIQUES AND LOCAL WATER SOURCES FOR URBAN GARDENS

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CIVIL, CONSTRUCTION, AND ENVIRONMENTAL ENGINEERING

ABSTRACT

The University of Alabama at Birmingham undergraduate and graduate programs' continued involvement in the Birmingham-Jefferson County community have identified food insecure areas, known as food deserts, and associated health issues negatively impacting the community due to poor diets and lack of access to healthy foods. Farm stands and community gardens around the Birmingham-metropolitan area have increased healthy food availability during the past several years to encourage healthier eating habits. To combat food insecurity, sustainable alternative growing techniques for urban agriculture need to be implemented and incorporated into local community gardens. Alternative gardening techniques such as vertical gardens maximize yield in limited space. This research seeks to analyze various vertical growth methods (Tower Garden®, Pyramid, and Vertical-Pallet), water quality (city and lake), and overall yield. Biomass, chlorophyll content, and amount of water required for irrigation were assessed to determine the growth mechanism providing the most efficient system as measured by vegetable production. The collected waters were analyzed for the impact of the water source on production. The goal of this study was to determine conditions and techniques for vertical gardening in urban areas located in the Southeastern United States with limited resources such as space, water, and soil.

Biomass was used to identify overall yield of spinach grown in the three vertical growth methods with different water sources. Spinach was selected based on its crop suitability for the regional climate conditions of Birmingham, Alabama. The resulting spinach leaves from each mechanism were dried and weighed for biomass analysis (dry versus wet weight). Aldridge Gardens, located in Hoover, Alabama, provided land space and resources for this research. The data were analyzed to estimate optimal growing practices for communities in climate zones similar to those of Birmingham, Alabama, in growing spinach and similar leafy greens. The research determined the most cost-effective mechanism by plant survivability was the pallet gardens and overall most successful water type was lake water. The Tower Gardens® were successful in plant yield, but the unit cost outweighs the success of this mechanism when compared to the pallet gardens.

Keywords: Food security, growth mechanism, vertical garden, urban agriculture

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INTRODUCTION

1.1 Dissertation Organization

The report is organized into the following sections:

I. Introduction

II. Literature Review

III. Methodology: Vertical Techniques, Water Sources, and Plants

IV. Data Collection and Analysis Methods

V. Results and Analysis

VI. Conclusions

The first chapter introduces the topics and objectives. Chapter II provides a comprehensive literature review supporting the positive outcomes associated with community and urban gardens, various garden techniques, and an explanation of data analysis. Chapter III outlines the overall experiment, and Chapter IV defines the data collection and data analysis process. Chapter V provides results and discussion. Chapter VI provides conclusions and future recommendations.

1.2 Introduction

As the world's population continues to rise, researchers have identified the need to create healthy, equitable, and sustainable communities, especially in terms of food security, to support the growing population and changing environment. The importance of food security has permeated several disciplinary fields, such as environmental science and engineering, public health, sociology, nutrition science, etc. An interdisciplinary approach to further the study of food security includes the analysis of the relationship between socioeconomic status and food security, climate and environmental health, and big picture plant science and biology.

Food security and ways to ensure food security for people living in areas with limited resources have been on the forefront of research throughout the world, especially in the United States as "17.4 million U.S. households are food insecure" in 2014 which is approximately 14% of the total population (Food Insecurity, 2014). In 2018, food insecurity had declined to affect 11.1% (14.3 million) of U.S. households. The United States Department of Agriculture (USDA) states food insecurity has continued to decline since 2011 and is approaching food insecurity rates similar to those of the pre-recession era (early 2000); however, Alabama's insecurity is above the U.S. average (USDA Economic Research Service, 2019). An initiative by Healthy People 2020 Food Insecurity (Office of Disease Prevention and Health Promotion, 2018), identified food insecurity as "the disruption of food intake or eating patterns because of lack of money and other resources." Food insecurity is related to multiple factors ranging from financial to geographic, and those affected by food insecurity incur a higher risk for experiencing negative health outcomes, such as cardiovascular disease and diabetes. Food deserts, as defined by the USDA, are both urban (1 mile) and rural (10 miles) areas that have limited access to affordable fresh and healthy foods by distance (Food Deserts, undated). Per the USDA definition, Birmingham, Alabama, was identified to be impacted by food desert conditions, and the associated risk factors have disproportionately impacted communities of color.

Birmingham, Alabama was analyzed for food desert conditions in the 2015 non-thesis report, *Use of GIS Spatial Analysis to Identify Food Deserts in Birmingham, Alabama*, by J. Ashlyn Manzella (2015). The data provided by the United States Census Bureau was converted from census tracts to ZIP Codes to further identify food desert areas in the Birmingham-metropolitan area. The report identified that twenty of the twenty-eight Birmingham-metropolitan ZIP Codes were described as low-income, low-access (to fresh fruits and vegetables) based upon USDA definitions. The report identified 65% of the residents of these ZIP Codes defined as low-income, low-access were African-American, corroborating previous research conducted by Jefferson County PLACE MATTERS (The Jefferson County PLACE MATTERS Team, 2013) and the Mari Gallagher Research and Consulting Group (2010). This data has further been corroborated by 2018 "Jefferson County Community Health Equity Report" (Health Action Partnership, 2018).

As identified by the 2018 Health Action Partnership report, negative health outcomes result from food insecurity and environmentally deteriorated areas. A correlation exists between poor diets low in fresh fruit and vegetable intake and cardiovascular disease and diabetes. Further, a correlation between a greater likelihood of disease, higher mortality rates, and reduced life expectancies have been linked to low-income residents and those who live in food insecure areas (Health Action Partnership, 2018).

The overall history and city planning of Birmingham, Alabama negatively impacted its residents' food security (Manzella, 2015). The research performed by The Jefferson County PLACE MATTERS team (2013), Mari Gallagher Research Consulting Group (2010), and J. Ashlyn Manzella (2015) recommended community, public, and home gardens to provide access to fresh foods representing a social and holistic approach to offset the health risks associated with food insecurity (Manzella, 2015). In response to food insecurity, the United States Department of Agriculture National Resources Conservation Service (NRCS) published the "Community Garden Guide: Vegetable Garden Planning and Development" to assist communities in the development of community gardens and was used in the development of this project (United States Department of Agriculture: National Resources Conservation Service, 2009a).

Another issue impacting the health of Birmingham, Alabama is the physical environment. The United States Environmental Protection Agency (USEPA) identified North Birmingham, located within the city of Birmingham, as an area in need of environmental cleanup and remediation due to years of industrial activities negatively impacting the environment and, ultimately, placing the public's health at risk. In conjunction with the Alabama Department of Environmental Management (ADEM) and the Jefferson County Department of Health, the North Birmingham project (sponsored by the USEPA) is addressing environmental issues and enforcing environmental regulations related to air, water, and environmental justice, etc. The soil cleanup process addressed residential homes, schools, and other properties where soil contaminant concentrations exceeded established concentration values. The City of Birmingham is collaborating with the USEPA to establish a watershed management plan to address water concerns (United

States Environmental Protection Agency, undated). Due to the stigma associated with the negative environmental impacts of brownfield sites to soils in Birmingham, Alabama, this research chose to not use the site's soil. Rather, this research focused on vertical gardening techniques using organic soil purchased from a local hardware store. A secondary research focus of this project was to provide a low-cost option for obtaining spinach and leafy greens rather than purchasing these items from a local or chain store, or farmer's market, if these options are available. In consideration of a low-income community, the lowest cost organic soil mixture was chosen. It should also be noted that the city of Birmingham, located in Jefferson County, Alabama, consists of two soil areas, the Appalachian Plateau and Limestone Valleys and the Uplands as established by Charles C. Mitchell, Jr., Auburn University Professor of Agronomy and Soils (Mitchell, 2008). Appalachian Plateau soils are sandstone or shale, where Limestone Valleys and Uplands are predominately limestone (Mitchell, 2008). Therefore, these soils are not well-suited for farming needs.

Besides the fact that some of the soils are contaminated and/or not ideal soils for farming, like many urban areas, Birmingham has limited space available for large-scale community gardens; however, numerous communities have started gardens in the Birmingham area. Bham Now's Sharron Swain (2019) identified that Birmingham offers ten large-scale community gardens throughout its various communities, which provide healthy food, education, and community engagement, and include the following gardens: Birmingham Eastside Eco-Gardens: Roebuck; East Lake Community Garden: South East Lake; Jones Valley Teaching Farm Community: Central City; Fountain Heights Farms: Fountain Heights; Tuxedo Community Garden: Ensley; Bush Hills Community Garden at

Woodrow Wilson: Bush Hills; Grace House Community Garden: Fairfield; Jonesboro Community Garden: Bessemer; Great Shiloh Community Garden: Jones Valley; and WE Garden: West End (Swain, 2019). Several other community gardens were excluded from Swain's list, likely due to garden size; however, smaller community gardens should be further encouraged throughout Birmingham to provide healthy food while inspiring community engagement and education. To further encourage Birmingham political and community leaders to invest in community gardens, there are grant opportunities available at the local and federal level, as well as other economic gains for the impacted areas.

Voicu and Been (2008) performed an analysis to establish the impact of community gardens on neighborhood property values in the publication, "The Effect of Community Gardens on Neighboring Property Values". The research begins by identifying the controversies associated with using vacant lots for community gardens including, impact to the overall community, how the land is selected and for specific uses by local governments, and the associated funding for community gardens and parks. Voicu and Been (2008) sought to identify reliable data on community garden impacts, particularly data related to economic impacts. The findings suggest "significant positive effects on surrounding property values, and that those effects are driven by the poorest of host neighborhoods" in areas hosting community gardens (Voicu & Been, 2008). Voicu and Been (2008) claim community gardens can potentially increase tax revenues "about half a million dollars per garden over a 20-year period" as an incentive for local governments to justify investment in community gardens.

As the demand for food production is expected to increase significantly with the world's population projected to be greater than nine billion by 2050 and two-thirds of the population living in urban areas, vertical and indoor farming practices are being evaluated as means to provide sustainable food production in urban areas (Federman, 2018). Several studies of larger urban areas have indicated that space is not always available for "conventional, ground-based agriculture production," and Specht et al. (2014) recommend using "ZFarming" (zero-acreage farming) to create innovative green urban agriculture systems using existing roofs and buildings. While Specht et al. (2014) specifically considered rooftop gardens, rooftop greenhouses, and indoor farms as part of their study of "ZFarming", the research indicated vertical greenhouses and vertical farms are also considered promising "ZFarming" methodologies. "ZFarming" methodologies offer numerous benefits such as the following: reducing food miles to combat food desert conditions by incorporating "ZFarming" in areas considered to be food insecure; reusing and recycling resources, such as water; reducing building energy consumption by providing additional insulation, and furthering sustainability (Specht et al., 2014). Basdogan and Cig (2016) discuss the benefits of vertical gardens in urban environments where green space is lacking. The primary benefits of vertical gardening are the availability of alternative green space that vertical gardens provide and the positive environmental impacts, such as the reduction of the heat island effect, air quality improvement, and building energy efficiency (Basdogan & Cig, 2016). From Basdogan and Cig's (2016) research, it was further stated vertical gardens provide fresh food though agricultural production as an economic advantage.

As numerous research studies have focused on the health, economic, and societal impacts of food insecurity, those concepts were explored in the literature review section. This research seeks to define ways to increase the availability of fresh fruits and vegetables via community gardens. Specifically, this research seeks to grow sustainable vertical gardens in climates and locations similar to Birmingham, Alabama with limited resources, such as soil, space, and water. Three different water sources (city, lake, and rain water) and three different vertical growth techniques were originally utilized to grow three different types of plants (kale, squash, and tomatoes). However, due to failures in the collection and maintenance of rainwater, the project was limited to two water sources (city and lake water). Attempts were made to grow multiple plants, but due to limited space only one plant (spinach) was selected to be grown in this study using three different vertical growth techniques (pallet garden, pyramid garden, and Tower Garden®) utilizing the two water sources, city-provided water and lake water.

Two different water sources, municipal city provided water and on-site lake water, were studied for impact on overall plant health and yield. An on-site lake at Aldridge Gardens provides a lower-cost water source in comparison to the Birmingham Water Works Board-provided water and the associated Jefferson County sewer costs. The vertical growth techniques selected were the Tower Garden®, pallet garden, and pyramid garden as shown in Figure 1. Tower Garden® can accommodate twenty plants in five tower sections in approximately three-square feet of horizontal space, the assembled pallet gardens can accommodate between eight to twelve plants in approximately 1.5 square feet of horizontal space, and the pyramid style garden selected can accommodate eighteen plants in approximately four-square feet of horizontal space. Kale, tomato, and yellow squash (squash) were originally selected and tested because each is a plant species known to grow in Birmingham's climatic conditions. Aldridge Gardens has successfully grown kale, yellow squash, and tomatoes in Tower Gardens® and raised-bed gardens per discussions with Aldridge Gardens' Executive Director, Rip Weaver (2017). However, due to initial failures and the need for replicability, kale, yellow squash, and tomatoes were not used for the next two planting cycles. Spinach was chosen ultimately for fall and spring seasons because of spinach's ability to grow in multiple seasons within Birmingham. The water sources, growth techniques, and plants are further described in Chapter III.

Figure 1: Tower Garden® (left), Pallet Gardens (middle), and Pyramid Gardens (right).

The research study was conducted at Aldridge Gardens in Hoover, Alabama. Aldridge Gardens is a 30-acre facility of the City of Hoover and has been operational since 2002. Aldridge Gardens offers walking trails, an event venue, a six-acre lake, art exhibits, and plant sales to the public (Welcome to the Gardens, 2018). Aldridge

Gardens' Rip Weaver, Executive Director; Debbie McDonald, Education Director; and Robert Wolff, Custodial and Building Maintenance; provided support and guidance for the research activity. Aldridge Gardens provided the water sources on-site: pond/lake water and City of Birmingham municipal water. This research was performed in Aldridge Gardens' Education Garden, which has a south/southeast orientation and where each garden type received equal amounts of rainfall and similar amounts of sunlight. Appendix A includes a map of Aldridge Gardens.

1.3 Objectives

This research seeks to define guidelines for producing high-nutrient valued plants using urban and vertical farming techniques in the metropolitan Birmingham, Alabama, area to enhance the community's food security. It is postulated that if local water sources, such as a small pond or lake water, were used without the addition of pre-treatment water chemicals, spinach can be grown sustainably in urban community-based gardens using commercially available organic soils and fertilizers. This research also seeks to reduce soil, water, and energy requirements for growing healthy foods for consumption while increasing the viability of these techniques in meeting population-based nutritional needs. The two growth techniques requiring soil were monitored for the volume of soil initially used in the growing system (approximately 2 cubic feet, which is equivalent to one large bag of commercially purchased garden soil) and added throughout the project to address erosion issues. The soils were monitored for pH as spinach grows best generally in a pH range of 6.0 to 7.5 per Cornell's *Growing Guide* (Growing Guide: Spinach, 2006). The amount of additional water and rainfall data were tabulated to monitor water demands. It is hypothesized that similarly sized spinach can be grown in the most cost-effective manner per square foot using both local city provided water and local lake water, commercially purchased organic soil and fertilizer, and upcycled pallets as compared to the Tower Garden®.

1.4 Methodology: Research and Analyze

The overall methodology involves the analysis of various growing techniques and water sources for each methodologies' ability to produce spinach. The 2009 NRCS "Community Garden Guide" provided insight for location and orientation of garden techniques; however, the land space was previously allocated by Aldridge Gardens and could not be addressed to reflect the NRCS recommendations (United States Department of Agriculture: National Resources Conservation Service, 2009a). Water quality analyses were performed in accordance with *Standard Methods for the Examination of Water and Wastewater, 20th Edition* (1999). The methodology is further discussed in the following sections.

Chapter II

LITERATURE REVIEW

For this study, food insecurity and socioeconomic status, community garden health and environmental impacts, water sources and conservation, community garden vegetable yields, and various analysis techniques of plant health were explored. Community gardens play an important role in health of both the community and the environment. Urban low-income communities are especially in need of these techniques as part of an ongoing sustainable health intervention plan to promote healthy and sustainable communities. Further, literature review subsections investigate health disparities in the United States for the future development of community engagements plans for encouraging community and individual gardening. This section is subdivided into multiple case study analyses.

2.1 Food Insecurity, Health Disparities, and Socioeconomic Status

Through this review, socioeconomic status and education were analyzed for impact on food security and health disparities. The reviews below suggest a correlation exists between income, race, and health, with people of color in lower income areas more negatively impacted by their social and economic statuses.

Economic Inequality and Food Insecurity (2018)

Michael Elmes (2018) discussed the effects of low-income and food insecurity on an individual's ability to live a full and healthy life in the article, "Economic Inequality, Food Insecurity, and the Erosion of Equality of Capabilities in the United States". Elmes postulates eating unhealthy foods devoid of necessary nutrients prevents individuals from living and participating fully in their lives and in the workplace. This incapacity to perform to the individual's optimal ability ultimately prevents the individual from growth and promotion; thereby, resulting in lower wages.

Elmes (2018) further presented how industrial food systems exploit workers, consumers, and the ecosystem for profit. The United States government and agricultural policies provide subsidies to discourage food production of certain crops to increase the demand for those crops and/or to encourage the production of crops with higher trade values. This perceived exploitation of the farmer has resulted in the need for the United States to receive foreign grown crops to subsidize the consumers' need at a much higher cost (monetary and quality). Elmes (2018) further defined a connection between the increased Farm Bill subsidies and the decreased allocation of funds for federal food programs by five percent in 2014 and 2015. Food access in the United States has become a privilege and not a right. Food gaps are supported by the failing infrastructure (Elmes, 2018).

The industrialization and commercialization of agriculture provides consumers with little choice in food production and selection, especially for those that are low-income with limited access to fresh foods and grocery stores. It has been noted numerous times that large grocery chains do not build in low-income areas because of the potential for reduced profit margins and high theft rates. Social innovations and the establishment of fresh food access as a right, not as a privilege, are ways to combat the industrialization of agriculture and the negative impacts developed (Elmes, 2018).

U.S. Disparities in Health (2008)

The United States government and other institutions collect data based primarily upon biological differences (race and sex); however, this is a systematic problem as social disparities impact all people as identified from the research of Adler and Rehkopf (2008). Research conducted by other countries, such as Great Britain, measure by social class rather than by race and sex. Researchers in the U.S. are now approaching research from a socioeconomic status (SES) perspective independently and as a function of race. It is important to assess data by socioeconomic status or social class as it is well-known that "those with fewer resources have worse health outcomes for a number of different causes" (Adler and Rehkopf, 2008).

Adler and Rehkopf (2008) identify that SES does not directly affect health, but it does influence health due to the availability of resources and access. It is important for future research to compare data in regard to "health, education, income, labor force participation, and wealth measures" to develop causation of health impacts (Adler and Rehkopf, 2008).

Stress, Life, Socioeconomic Disparities: Americans (2005)

The data collected by Lantz *et al.* (2005) indicated that lower income relates to higher life stress and the experience of stressful events resulting in poorer health outcomes, including mortality. Stress results in negative biologic responses especially when exposure to stress is chronic. There is an association between socioeconomic position and stressful life events and response to said events. Lantz *et al.* (2005) found lower income and educational attainment are predictors of health status. Income is a more accurate predictor of mortality than educational status per their findings, although the reasoning for this conclusion was not clear. Further, it was concluded social inequalities and life stressors impact those of lower social positions (Lantz et al., 2005).

Fundamental Causes, 2004

Phelan et al. (2004) described the relationship between socioeconomic status and mortality and the fact that minimal previous studies exist correlating the two factors. Socioeconomic status is inversely related to mortality, especially in relation to preventable mortality. Phelan and Link in 1995 coined the term “fundamental causes” to posit that socioeconomic status impacts mortality rates. Those of higher socioeconomic status have greater resources available to enhance health. Those living in lower socioeconomic areas are typically exposed to more pollution (i.e., noise, social conditions, and environmental pollutants) (Phelan et al., 2004). Phelan et al. (2004) further stated that those living in lower socioeconomic conditions are also exposed to more dangerous and stressful situations with inferior health benefits. Phelan et al. (2004) summarized these results are due to a theory of fundamental causes, which Phelan and Link had previously termed in 1995.

Food Insecurity, Chicago (2019)

According to Hunt et al. (2019), 12% of American households in 2016 experienced food insecurity with the Hispanic (19%) and non-Hispanic black (22%) subpopulations being disproportionally impacted. Some of the predictors for food insecurity include exposure to violence in the community and behavioral factors including substance abuse. The study by Hunt et al. (2019) examined demographic data, socioeconomics, and social risk, etc. to identify further predictors for food insecurity among the most disadvantaged subpopulations in Chicago, Illinois.

Hunt et al. (2019) identified that 33.1% of respondents in the Chicago study reported food insecurity, a percentage of the population is significantly higher than the national average of 12% food insecurity. Of the 33.1% of food insecure respondents, 65.2% received food stamps. Sex was not found to be a predictor of food security, but race was a predictor. African Americans were four times more likely than whites to be food insecure; Mexicans and Puerto Ricans were found to be 2.5 and 2.7 times more likely to be food insecure than their white counterparts. Those with a college degree were less likely than those with less than a high school education to be food insecure. Food security is also related to social risk factors such as safety, loneliness, and marital status (Hunt et al., 2018).

One of the most interesting results by Hunt et al. (2020) and other similar studies is the argument that those receiving food assistance continue to have higher levels of food insecurity than those not receiving such benefits. This is an indicator that the current system of food distribution is not working optimally and provides support for the use of community and individual gardens for increasing food sufficiency.

Food Pantry Diet Quality, Eastern Alabama (2009)

Researchers sought to examine the quality of diets consumed by female clients of a food pantry in Lee County, Alabama. Duffy et al. (2009) found female food pantry clients were at a higher risk of malnutrition as compared to those not using food pantries as a main food source. The clients were found to have higher levels of food insecurity and obesity due to the lower quality of diet. These individuals also had higher incident rates of smoking, and it theorized that smoking cessation methods could potentially positively impact these women's overall health and diet. The largest impact on the participants Health Eating Index-2005 (HEI-2005) was education level. Those with less than a high school degree had the lowest HEI-2005 score. More interesting was the fact that those who participated in federal food security programs (Food Stamps and Women, Infants, and Children) did not experience higher diet quality (Duffy et al., 2009).

2.2 Health Benefits of Community Gardens and Food Pantries

This research explored studies analyzing various races and socioeconomic groups within the population impacted by community gardens. Numerous studies reviewed below have corroborated the positive physical and mental health impacts of community gardening on participants. Summaries of each study are provided below.

The environment in which one lives, learns, works, worships, and plays also impact overall physical and mental health. Further educational attainment and socioeconomic status are prime predictors of mental and physical health. Previous studies have discussed the negative impacts of living in high stress social environments, including exposure to drug and alcohol abuse and domestic violence. Individuals seek comfort from tobacco, illicit drugs, and alcohol as a means to deal with life stressors. The use and availability of community gardens could potentially provide a healthy intervention (Lantz et al., 2005).

Garden of Hope, Ohio (2015)

As incident rates of various cancers and cancer survival increases, researchers have found plant-based diets and increased physical activity are strategies to improve long-term survival outcomes. The Garden of Hope in central Ohio provides a complimentary garden for cancer survivors, and the garden was utilized in a study focusing on the impact of harvesting garden produce on cancer survivors (Spees et al., 2015). The research studied diet, perceived mental and physical health, sense of community, and health maintenance of participants.

The results of the study using the Garden of Hope found participants consumed more fresh produce, and subjects had an enhanced opportunity to consume a more plant-based diet, as is recommended for a post-cancer lifestyle, than prior to the subjects' involvement in the study. The study participants self-assessed overall mental health improved as the gardens provided a means for stress-relief, as well as, increased access to fresh produce. The gardening activities increased the subjects' perception of social networking and support. However, many of the participants reported perceived challenges in continuing the intake of fresh produce during times when the Garden of Hope had no gardening needs or produce for harvesting (Spees et al., 2015).

Frenchtown, Florida (2017)

Frenchtown, Florida, a predominately a low-income, African-American community located just outside of Tallahassee, was selected for inclusion as part of a National Science Foundation (NSF) ethnographic field school. The purpose of the NSF project was to demonstrate that participation in community gardens "transcend race, culture, income, and neighborhoods, while also promoting health, heritage, place-making, and economic opportunities" (Hite et al., 2017). Hite et al. (2017) explains that Frenchtown's poverty and food desert conditions are due to decreased development and economic conditions which led to further violence in the municipality. The research stated reclaiming space, such as through community gardens, provides a means to enhance community cohesion and health. The research concluded that community gardens promote community engagement, food security, and provide economic advantages.

This community-based participatory research project identified six community gardens in either Frenchtown or the Tallahassee metropolitan area for analysis. It highlighted the various communities' involvement in community gardens based on socioeconomic class and use. The predominately white, middle-class sponsored gardens were unharvested and primarily ornamental, whereas the predominately minority, lower class sponsored gardens contained primarily fruits, vegetables, and herbs that were maintained and harvested. The white, middle-class gardens were also noted to be less welcoming of guests with their signs regarding restriction of entrance to the garden and the harvesting of the gardens restricted to individuals participating in the care of gardens. The minority-sponsored, predominately African American, gardens were more welcoming and offered anyone the opportunity to harvest the garden as part of an effort to enhance food security and community engagement (Hite et al., 2017). Although the article does not explicitly identify the cause in the variance in the garden usage by class and race, it can be inferred that the difference is based on real and perceived needs for garden production by community members.

The minority-sponsored gardens included gardens specifically managed by local youth who provided food baskets to community members in need of food assistance. These gardens provided education and fresh foods to the community, as well as a strategy for connecting various generations of residents (Hite et al., *2017*). In connecting the younger and older community members, social and cultural community capital, was enhanced. Thus, the transmission of group norms and values for healthy diets is encouraged throughout all ages of community residents.

The gardens supported by the more affluent sponsors did not create a sense of community per the researchers. The Frenchtown community garden participants agreed that the gardens provide a sense of restoration and community engagement by reclaiming the area as “their own” and the removal of blight to establish the gardens. An interesting feature of the community gardens was the monthly joint meetings between the gardens in the Tallahassee areas. “Collards and Cornbread” intersected race and generations to commune and network over their gardens and harvests. These networks and gardens provided a positive impact on social and political change as described in the research (Hite et al., 2017). From this research, it can be noted that the achievement of a common goal (community garden) can be used to unite various generations and races for the betterment of society and population health.

Prague, Czechia (2017)

In the research conducted by Jana Spilková (2017), the focus involved determining the impacts of community gardens in a post-Communist areas such as Prague, Czechia. Most of the current research described by Spilková (2017) focused on non-Communist countries (North America). A major finding from this survey of gardeners, which significantly contrasts with existing data, is the fact most gardeners stated the main purpose of the gardens was to create better spaces for the community. Most other research concludes that the gardens are created to enhance food security and sovereignty (Spilková, 2017). Although Spilková's (2017) finding was contrary to most research, the interviewed gardeners similarly concluded that the gardens provided a means to produce food and enhance physical activity.

Twin Cities, Minnesota (2016)

The Twin Cities of Minnesota are home to many refugees and immigrants. Community gardens have been instituted to provide additional food security to those requiring it in the Twin Cities. Kari A. Hartwig and Meghan Mason (2016) of St. Paul University studied the impacts of community gardens on health on Karen and Bhutanese refugees and immigrants living in the Twin Cities. Eighty-six percent of the study's participants were receiving some amount of food support. The study focused on the perceived increase in fresh fruit and vegetable intake and the mental health impacts associated with participating in community gardens (Hartwig and Mason, 2016).

The study found that the participants in the community gardens study increased vegetable intake and that ninety percent of the participants would recommend community gardening in the future. Participants estimated food cost savings from using the produce from the gardens to be as much as twenty-five dollars over the course of the gardening season. Most of the participants believed the gardens improved both personal mental health and community involvement (Hartwig and Mason, 2016).

2.3 Environmental Impacts of Community Gardens

Research studies have also focused on the environmental impacts of community gardens ranging from stormwater management to soil contamination. Water sources and conservation of water sources have also been addressed.

New York City (2016)

The absorption of stormwater by community gardens' soil was empirically studied in New York City. Gittleman et al. (2016) described the environmental impacts of impervious surfaces on the urban environment and sought to define the impact of community gardens in reducing stormwater runoff. Five hundred twenty-nine community gardens cover approximately 120 acres of land space in New York City. The study found the community gardens mitigated stormwater runoff, and that the community gardens retained approximately 12 million gallons of stormwater per year in New York City (Gittleman et al., 2016). This impact was created by the raised-bed gardens' soil absorption of the water and evapotranspiration. The research supports the use of community gardens as a method for stormwater runoff mitigation and as more beneficial to the community and stormwater runoff mitigation than utilizing residential and empty lots as mitigation techniques (Gittleman et al., 2016).

Cleveland Heights, Ohio

In Cleveland Heights, Ohio, a case study was performed to determine the effects of rain barrel collection of urban stormwater runoff. The urban area studied has poor soil for draining due to the shale-derived clays from glaciation. Building codes in Cleveland Heights require roof runoff be piped directly into the water systems as a result of the poor absorptive properties of the soil. Jennings et al. (2013) recommended that using urban gardens and rain barrel systems would reduce accelerated stormwater runoff by diversion to the rain barrel systems for urban gardens. Secondarily, Jennings et al. (2013) stated that the recovered rainwater could be used to provide an additional water source for urban gardens. According to the study, connecting "a 50-gal. (189-L) rain barrel connected to 25% of a 2000-ft^2 (186-m^2) residential roof and serving a 150-ft^2 (14-m^2) garden in Cleveland Heights, Ohio, would reduce total growing-season runoff by 2.4-5.4%" and that increasing the barrel and garden size would decrease the impact of stormwater runoff to the overall water system (Jennings et al., 2013).

Kawaala, Kampala, Uganda (2011)

Kulabako et al. (2011) designed a tower garden (not the same as the Tower Garden® used for this dissertation) to be used within homes in Kawaala and Kampala, Uganda, using greywater as the water source. The areas included in this study are extremely impoverished and had limited access to a fresh water supply due to demand. Water used for general cleaning and laundry was typically discharged near the homes; but for this study, this water was collected by participants for use in food production. Participants successfully grew tomatoes, collard greens, and buga using the same soil which consisted of a mixture of soil, cow manure, and ash (unspecified). A control system using tap water was also evaluated (the research did not define the tap water characteristics); however, the participants began using greywater independently after seeing the success of the other participants growing food using greywater. The greywater used for the tower gardens was analyzed for physio-chemical characteristics. It was found that the pH of the greywater was suitable for irrigation (pH <10). The total dissolved solids (TDS) and other characteristics of the greywater were within national standards for irrigation proving the use of greywater would be acceptable for future use. Although *E.coli* were detected in the greywater, the researchers believe proper handling of the greywater does not present any negative health impacts associated with *E. coli* (Kulabako et al., 2011). The researchers stated continuing the study to assess crop yield and other impacts on participants' lives. It should be noted that in accordance with Funk et al. (2012), the United States Geological Survey found that yearly rainfall totals of 500 mm (approximately 19.7 inches) or more are sufficient to support crops in Uganda; however, the USDS has found that as environmental temperatures continue to rise, the rainfall in Uganda decreases significantly (Funk et al., 2012); hence, the need for alternative watering sources for crops such as greywater.

2.4 Community Garden Vegetable Yields

Current community garden research has analyzed crop yields from raised-bed community gardens. However, current data does not specifically exist for crop yields from vertical gardens. It was originally hoped that the case studies listed below would provide some data from which to compare this research's data; however, due to variances in data collection methods, the data could not be compared.

Farming Concrete, NYC

Farming Concrete's mission is to measure and analyze food production and techniques from urban farms to backyard gardens (Farming Concrete, 2010). Through Farming Concrete Tool, individuals can document and share farming practices, techniques, and yields as a process to provide empirical evidence of the success of gardening specifically within urban and community gardens (Farming Concrete, 2010). In 2010, the Farming Concrete Report published harvested data collected from sixty-seven of the over five-hundred New York City community gardens, primarily involving raised-bed gardens. The data included date, yield (number of plants or crop area), and weight, and the data were imported into a database for analysis (Farming Concrete, 2010). The 2010 Farming Concrete Report estimated that over 39,000 plants with a total of 97,690 pounds harvested edible plants for an estimated harvest value exceeding $200,000. Tomatoes were the highest yielding plant with spinach, summer squash, and kale within the top 25 highest yielding plants (Farming Concrete, 2010). Although the plant weights were based on the total plants (versus individual leaves or fruits), the data was some of the first to be published at such a large scale. The Farming Concrete Organization actively allows users to publish collected data ranging from plant harvesting to rainwater harvesting, participation, and environmental impacts, and the data are available for public use (Farming Concrete, 2010).

Although the concept of Farming Concrete is a great resource for collecting and sharing data, there is no explicit instructions nor calibrated means for collecting the data. This is an open source website, and anyone can add data. The Mill section houses the Farming Concrete data that has been added by users. The Mill data were downloaded from April 1 through June 1, the course of this project, to use as a comparison (Farming Concrete, 2019). Unfortunately, The Mill data does not explicitly define the type of garden or square footage of garden space used to collect the spinach; however, there were 12 separate user added data points included in The Mill report (Farming Concrete, 2019). The users' data were reported from three different uses from Arizona, Nebraska, and New York (state). The New York (state) users provided the variety of spinach used, Avon. The collected weights range from 0.125 lbs. to 6 lbs. Unfortunately, there is not enough information provided to use this data for comparison to the results of this research.

San Jose, California

Algert et al. (2014) analyzed community gardens participation and produce output in San Jose, California. This study collected data on the participants, crops, and harvest to clarify the conflicting data regarding crop yields as published in the technical literature available at the time of this study. Algert et al. (2014) indicate a city of Philadelphia project and the Farming Concrete Project in New York City grew 1.4 and 1.2 lbs./sq. ft. of produce, respectively, in community gardens versus 0.5 lbs./sq. ft. of produce grown in small-scale gardens per the National Garden Association (Algert et al., 2014). The San Jose, California, community garden study found yields average 0.75 lbs./sq. ft. of produce (Algert et al., 2014). Unfortunately, the provided data does not correspond with this project for comparison.

2.5 Visual Analysis of Plant Health

One of the simplest ways to analyze plant health is visually inspecting the plant. The color of the plants' foliage provides insight into overall plant health. Brie Dyas (2015) interviewed plant health experts regarding the health of plants. Dyas' article, "6 Things Your Plant's Leaves are Trying to Tell You", points out brown leaves require water, discolored or yellow leaves indicate the plant is overwatered, pale leaves may indicated inadequate nutrients, and leaning plants could signal excessive sun exposure. (Dyas, 2015). Beyond the visible-eye inspection, satellites and digital cameras can be used to study plant health using near infrared (NIR) and the normalized difference vegetation index (NDVI).

The imagery provided by satellites and digital cameras detects diseased and distressed plants in large scale crops and small crops. This information allows farmers to adjust water and nutrients to increase the production of crops. NDVI specifically "expresses the ratio of red and near-infrared light absorbed and reflected by vegetation" and describes phenological changes (Anderson et al., 2016). Research by Anderson et al. (2016) proved digital cameras provided equivalent NDVI results as more advanced techniques and can be used for monitoring vegetation changes, specifically in the High Arctic. However, due to the complexity of NDVI, this method was not selected for use in this research.

The University of Alabama at Birmingham (UAB) Department of Biology conducts visual analysis of numerous plants as part of research studies. After discussions with Dr. Karolina Mukhtar, it was determined to use a non-destructive method to analyze the spinach leaves for this research. Chlorophyll fluorescence is a non-destructive method for visualizing plant health. This method utilizes light to measure the F_v/F_M using a fluorometer. The methodology is further discussed in Chapter III.

Evaluation Technologies for Food Quality (2019)

Evaluation Technologies for Food Quality (2019) edited by Zhong and Wang provides numerous techniques for evaluating food quality at both the micro and macro level. This book provides summaries of food quality evaluation methods. One of the methodologies discussed involves fluorescence. This method provides a non-destructive method of analyzing plant health. The "Fluorescence spectroscopy and imaging instruments for food quality evaluation" chapter discussion is provided by Sikorska, Khmelinskii, and Sikorski, which supplemented the decision to use fluorescence imaging as means to study the overall health of the spinach leaves for this research.

Seeing is Believing (2001)

Chaerle and Van Der Straeten (2001) describe image analysis techniques for analysis of physiological changes in plants. The discussion includes how plant leaves can be excited with light to induce red chlorophyll *a* fluorescence. This imaging technique can identify patterns and gradients associated with photosynthesis and metabolism of the plant. Fluorescence imaging techniques can also identify potential pathogens and other microorganisms. The article further describes additional imaging techniques, such as bioluminescence and thermal imaging. The fluorescence techniques are unique in that these can be performed on-site without the introduction of foreign bodies found in laboratory environments (Chaerle and Van Der Straeten, 2001).

Chlorophyll Fluorescence Imaging for Plant Health (2009)

Takayama and Nishina (2009) established and identified from a research analysis of non-destructive methods for measuring plant health and two chlorophyll fluorescence methodologies for comparison (saturation pulse and induction). Takayama and Nishina (2009) define chlorophyll fluorescence as the unused energy from photosynthesis that is emitted as red light and state the measurement of the red light can be utilized to assess plant health. The red light measurement provides information on the production of photosynthesis and its effectiveness. Additionally, Takayama and Nishina (2009) recommended chlorophyll fluorescence should become a common methodology for analyzing commercial plant health.

Profiles of Light Absorption and Chlorophyll within Spinach (2002)

Vogelmann and Evans (2002) measured the chlorophyll fluorescence of spinach leaves to compare the light absorption of the adaxial (facing toward the stem of the plant) and abaxial (facing away from the stem of the plant) surfaces another optical parameter. The results indicated that spongy mesophyll and columnar palisade cells both facilitate light absorption and provide similar data.

CHAPTER III: METHODOLOGY

Current community and urban gardening research primarily focuses on the health impacts on humans associated with community gardens and not necessarily on the techniques and methods for growing sustainable community and urban gardens (Algert et al., 2014 and Farming Concrete, undated). Tennessee State University's Department of Agriculture and Environmental Sciences has performed an analysis of organic vertical gardening specifically for urban communities using a soilless based system (Nwosisi et al., 2017). Nwosisi et al. (2017) corroborated there is limited research regarding vertical gardens and the resources necessary to develop and maintain sustainable community gardens. Major urban areas typically do not offer large plots of land for gardening because available free space is typically allotted for public parks or future land development.

This research focuses on cost-effectively growing produce vertically for urban areas with limited access to horizontal land space and desirable soils. The other primary focus of this research is to establish the impact on the garden's production using city water versus lake water without pre-treatment chemicals. Organic fertilizers were used to provide the soil with nutrients required for successful plant growth. All vertical growth mechanisms were originally to be planted with plants purchased from a single vendor and placed in a consistent orientation, as described below. However, it was learned during the fall planting season that it was not successful to use plants from the hydroponic vendor in the soil-based systems (pallet and pyramid gardens). The hydroponic plants were shocked when planted in soil without the use of the Tower Garden® nutrient blend. Also, due to the predefined landscape, the Tower Garden® systems were located in a different orientation. The goal of the research was to identify the most productive vertical growth mechanism and water source.

Due to the limited budget and space, the most feasible approach to designing a cost-effective vertical garden experiment was selecting three vertical growth mechanisms (Tower Garden®, pallet garden, and pyramid garden) due to each mechanisms' unique attributes (described below). This limitation was reflected in the minimization of alternative water sources to only comparing city provided water and lake water as there was not enough available space and mechanisms to perform equitable growth in each mechanism and water type. Due to the overall space, each mechanism and water type was minimized to growing less than an ideal number of plants or plants of the same variety. Based on the water analysis laboratory limitations, the type of water analysis was limited to indicators of water quality health and did not include testing that would identify contaminants. With the overall uniqueness of this project, there was not significant data to compare the results and analysis; therefore, the analysis was simplified to using analysis of variance (ANOVA) to provide consistency in the analysis performed. The methodology is further defined below.

3.1 Vertical Growth

Three vertical growth mechanisms were chosen for analysis and are described below (Figure 2). Vertical growth techniques were chosen for this research due to the limited horizontal space in the Birmingham-metropolitan area, especially in low-income neighborhoods and public housing communities. Vertical gardens potentially provide the opportunity to grow more plants in less horizontal space as compared to traditional gardening techniques. The collected yield per square foot data were compared between the Tower Garden®, pallet gardens, and pyramid gardens as a measure of effectiveness. These were then compared in terms of overall costs to provide measures of cost per yield per square foot.

Figure 2: Experimental Layout at Aldridge Gardens.

A key part of this research was identifying vertical gardening systems since the research is trying to attract those with limited space for gardening. Vertical gardening mechanisms, in theory, should require less horizontal land space than traditional gardens and raised-bed gardens. Several vertical gardening systems exist with large variance in cost. Many of the suggested vertical gardening systems are ideal for decorative plants but are not necessarily ideal for vegetable growth. This research project attempted to look at various types of gardening systems as well as their costs. Tower Gardens® were selected because they are an aeroponic/hydroponic system used previously in several research projects at UAB. These systems are costly, more than $600 in initial cost, but were borrowed from UAB and Aldridge Gardens for this research. The pallet gardens were and are currently used at Aldridge Gardens with success, so pallet gardens were selected based upon this prior success and acceptability for various vegetable plants. The pallets were donated by Aldridge Gardens and the supplies to create the pockets were purchased for a total cost of less than $100 for all of the pallets. The pallets can be manipulated to create "soil pockets" for each plant to grow in individually. The pyramid gardens were selected because they can either be commercially purchased or constructed from purchased materials around $100 each depending on size. Pyramid gardens are similar to raised-bed gardens in that the system is off the ground and each level offers a soil-based system for growth. A breakdown of the costs is provided in Appendix B. Some of the additionally types of vertical gardens considered are described below.

Living walls have been used throughout the world for aesthetic decoration and sustainability while also providing economic benefits in terms of environmental benefits (Sheweka & Magdy, 2011). Sheweka and Magdy (2011) indicate living walls can be used beyond aesthetic decoration by providing air pollution control and temperature control, including urban gardens and urban agriculture. The three types of green walls identified by Sheweka and Magdy (2011) are wall-climbing, hanging-down, and modules and are described as follows: wall-climbing green walls are ideal for climbing plants requiring minimal supporting structure and use ground soil; hanging-down green walls are ideal for long-stemmed plants which can be planted in box structures affixed to the building's different stories; and the modular green wall is ideal for short plants and is supported by panels affixed to a building façade. Very little information is available regarding the success of living walls for growing vegetables; however, Sheweka and Magdy (2011) identified the Chilean Consortia Building in Santiago, Chile as an example of a living wall for growing vegetables. The Chilean Consortia Building provides almost 3,000 square meters of vertical space for a vegetable garden in a modular green wall method (Sheweka & Magdy, 2011). *Note:* The success of the vegetable garden was not discussed by Sheweka and Magdy (2011).

One of the least expensive living wall module methods to create vertical gardens involves using felt pockets attached to a vertical surface, such as the side of a house or barn (5 Vertical Vegetable Garden Ideas for Beginners, 2017). Living wall methods were not ideal for this project because there was no free vertical surface for use at Aldridge Gardens in the Educational Garden. Aldridge Gardens does affix pallets to exterior walls of the Aldridge House, which act as living walls. These pallets are for decorative use rather than for vegetable growth. This method is also not ideal for those who live in rental spaces where renters are typically not allowed to affix items to the structure or for those using community gardens which often only offer horizontal space.

Other growing systems beyond living walls also exist. There are several options for using vertical, stackable pots while offering a slow drip method for watering; however, many of these systems require composting soil to be used (5 Vertical Vegetable

Garden Ideas for Beginners, 2017). Composting soil was not available for this project. Another growing method uses a frame to create a growing frame, but this method is more suitable for vine plants. Vertical growth frames can be purchased from hardware stores (5 Vertical Vegetable Garden Ideas for Beginners, 2017). Each of these methods could have been selected, but due to previous interests, the pallet garden, pyramid garden, and Tower Gardens® were selected.

Four Tower Gardens®, four raised-bed pyramid gardens, and four pallet gardens were assembled and utilized (Figure 2). Figure 3 identifies the initial layout. An additional pyramid was added between the far left pallet and pyramid for the final layout. Half of the garden systems received city water supplied by the Birmingham Water Works Board and half received on-site lake water. The Tower Gardens® utilized the Tower Garden® nutrient supply as prescribed by the Tower Garden® instructions. The soil-based gardens were fertilized with an organic fertilizer defined in following sections.

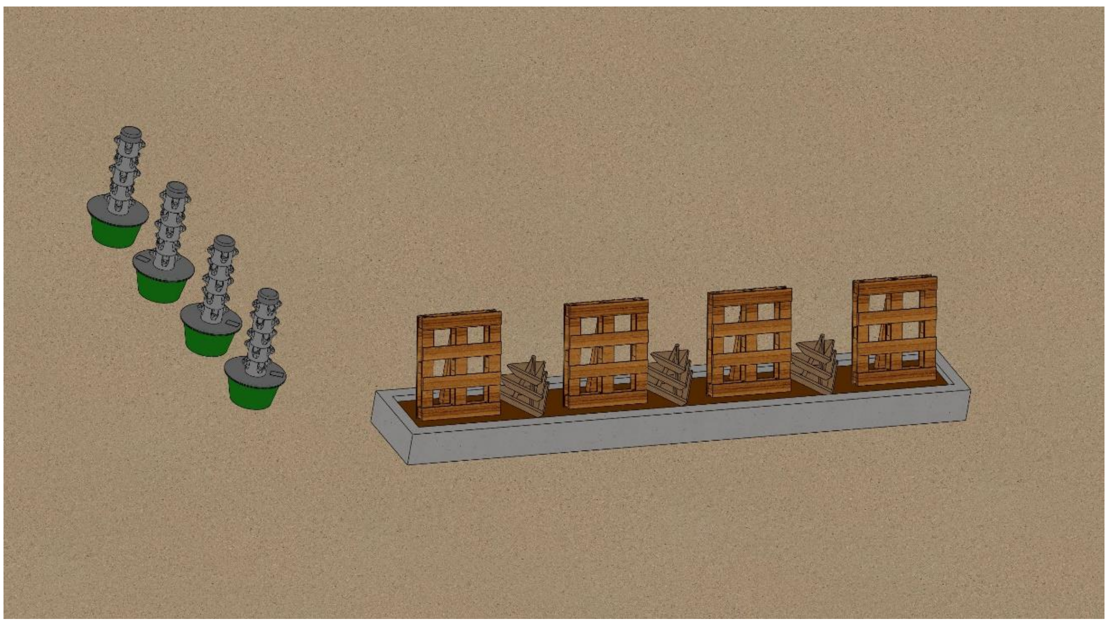

Figure 3: Initial Layout.

The initial costs of the garden systems varied, and each system was selected due to the uniqueness each one offers. The Tower Gardens® is the most expensive of the selected techniques starting at $525 each initially and is an aeroponic/hydroponic system. The three-tiered, unassembled raised-bed pyramid gardens are $99.99 each and constructed from natural materials. The pallets for the pallet gardens were donated by Aldridge Gardens, offering an upcycled option, and the cost of pallet garden assembly was less than $100 total for all four pallets. This lower cost associated with the pallet gardens is one of several advantages for advocating for use of pallet gardens in low-income communities.

To date, no research has explained how the utilization of vertical gardens for growing produce at the individual or community level is cost effective in food insecure communities. There also have been no explicit results to identify the multiple social benefits associated with self-sufficiency in communities fostering vertical community gardens in regard to social engagement, intergenerational connections, networking, and social capital. These topics would be ideal for future research endeavors.

Tower Gardens®

The Tower Garden® is a vertical, aeroponic system (a form of hydroponics) that can hold four plants per growth pod (five pods) for a total of 20 plants. The Tower Garden® includes a basin (water tank), pump, timer, drain tube, and growth pods (Figure 4). From the Tower Garden® Discover (undated) website, as compared to traditional growing methods, aeroponics can increase plant yields by 30%, triple growth rates by reducing the growth time, and use significantly less water than traditional gardening

(~98%). The claims in regard to plant yields and watering were not found to be true for this research and is discussed in Chapter V. Growth time was not assessed because seeding was not the same between the plants purchased from WNC Urban Farms and Lowe's®. Note, it was not the aim of this study to prove or disprove the claims made by Tower Garden®.

Aeroponic and hydroponic systems do not utilize soil, but rather use liquid nutrients and soilless growth mediums. The Tower Garden® system also includes a specially formulated nutrient supply, the Tower Garden Mineral Blend® (Tower Garden Discover, undated). The Tower Garden® systems claims it can grow 20 plants in less than three square feet of horizontal space. The Tower Garden® is 62 inches tall and 30 inches wide at its base (What are Tower Garden's® Dimensions?, undated).

Figure 4: Tower Gardens® Initial Experimental Setup.

There are four total Tower Gardens® included as part of the research. Two Tower Garden® tanks were initially filled with 20 gallons of Birmingham city water as recommended by the user's manual, "Tower Garden® Growing Guide" (undated). The remaining two Tower Garden® tanks were filled with 20 gallons of on-site lake water from Aldridge Gardens to meet the required recommendation for 20 gallons of water. All waters were replaced with fresh water from the respective water source prior to the new growing season. The Tower Garden® user's manual recommends dechlorinating the water by allowing the water to sit in five-gallon buckets in the sun for at least 24-hours prior to filling the Tower Garden® tank. Timers were set to provide water for 15 minutes, break for 15 minutes, water for 15 minutes, etc., as prescribed by the user's manual for each Tower Garden® (Tower Garden® Growing Guide, undated).

Initially, all Tower Gardens® began with the Tower Garden Mineral Blend® at the recommended dosage as described in the user's manual, which is 200 mL for the 20-gallon tank. The reservoirs were refilled with either city water plus mineral blend or lake water plus mineral blend, as identified on the system after the initial fill-up and as needed during watering sessions to maintain the 20 gallons of water in the tanks. City and lake water were dechlorinated by a minimum of a 24-hour solar dechlorination process, then the mineral blend was added to the refill water buckets in increments of 10 mL per one gallon. It should be noted that the mineral blend was added to five-gallon buckets of refill water prior to adding additional water to the Tower Gardens®.

Each of the four Tower Garden® systems were initially planted with twenty spinach seedlings. The seedlings received were planted in rock wool, as received from the WNC Urban Farms, which is ideal for maintaining the seedlings per the *Tower Garden® Growing Guide* (undated). The seedlings were all obtained from the same supplier.

There are many pros and cons associated with the Tower Garden® systems from the research experience. One of the advantages is the ability of the system to continuously water plants; however, the con is related to the power requirement to run the system; thus, increasing the cost of production due to the need for supplied electricity. Any power loss can result in the loss of plant life, which was the case for the spring planting season (described in section 5.1: Results and Limitations). The requirement for power is also a limitation in where the Tower Garden® systems can be used. Rip Weaver (2017) explained Aldridge Gardens had invested in a solar panel and power converter to use with the Tower Garden® systems, and it was a successful option from his research. Future investigations could study the success rate of using solar panels in multiple growing seasons. This research used a traditional power source supplied by Aldridge Gardens instead of a solar panel.

To maintain the required 20 gallons of water in the Tower Garden® system, it requires weekly to biweekly refills, which is not much less time and effort than water requirements for the soil-based systems. The Tower Garden® system will continue to provide water to the plants if there is less than 20 gallons of water so long as the pump has enough water to support the system. Water refilling could be limited if the user is willing to allow the volume of water to be less than the required 20 gallons and greater than the number of gallons to maintain the pump. The practice of running the Tower Garden® with sub-optimal volume of water was avoided to prevent damage to the pump.

Another advantage of the Tower Garden® systems is that the system can provide the needed nutrients required via the nutrient blend; however, this may also be a disadvantage. The nutrient blend costs $60.00 and lasted about one growing season for the four Tower Garden® systems as compared to approximately $12-15 for eight-pound bags of organic fertilizers for the soil-based systems. One eight-pound bag of organic fertilizer lasted through three growing seasons. Additionally, the nutrient blend must also be added each time water is added, whereas the fertilizers was only required to be added to the soil-based systems every 30 days.

The most significant disadvantage of the Tower Garden® system is the overall cost of purchase and maintenance (power cost, nutrient blend, pH Kit, netted pots for holding the seedlings). For one season alone, the operational cost, not including power, is over $800 based upon the 2020 prices (Tower Garden® Growing Systems, 2020). The Tower Garden® systems are typically very successful in terms of play yield, but the costs require multiple seasons of use for successful plant yields to be affordable. Due to the costs associated with the Tower Garden® systems, the Tower Garden® systems are more of a novelty or hobbyist item.

Raised-Bed Pyramid Gardens

A cedar, three-tiered raised-bed pyramid garden system was chosen after researching unique vertical gardening systems (Figure 5). The planter product description describes the system as providing “over 3 times more plants per square foot” than traditional raised-bed systems and suggests it only utilizes “4 sq. ft. of ground space, but offers 15 sq. ft. of space for planting” (Raised cedar planter 3-level triolife plant pyramid, undated). The system holds 21 gallons of soil and aapproximately16 plants. The largest layer holds seven plants, the middle layer holds five plants, and the top holds three plants (Figure 5-Right). However, it was realized through this research that the system cannot support 16 plants because there was not enough room for root growth; thus, during the spring growing season, the plant load was reduced to a total of 9 plants (3 per tier). The overall dimensions of the pyramid gardens are 26-inches high and 43-inches wide.

Figure 5: Pyramid Garden (L) and Plant Orientation (R).

Four pyramid gardens were utilized for the spring growing season. Two utilized Birmingham Water Works Board provided water and two utilized Aldridge Gardens supplied lake water. Each pyramid garden in the spring growing season held 9 total plants.

From this research project, there was limited success with the pyramid gardens. Overall, there were not any advantage associated with pyramid gardens, and it would not be recommended for urban food growth. The pyramid gardens had significant plant death after two to three weeks of growth after planting. The overall design of the pyramid gardens does not provide for favorable root growth and access to water and nutrients. The design also shades the lower-tiered plants based on the position of the sun. The design of the pyramid systems allows for soil erosion due to the designed height and angles of the side walls. Soil was added multiple times throughout the project to keep plants roots covered. The cost of the pyramid gardens unassembled was $99.99 plus tax and shipping. This system would not be recommended for growing vegetables because the system failed to adequately grow kale, spinach, squash, and tomatoes due to its suboptimal yields.

Pallet Gardens

Pallet gardens upcycle pallets typically discarded by industries. Pallet gardens can be mounted vertically to existing buildings and require little horizontal land space. However, for this research, legs were added to the pallets to allow the pallets to stand vertically and independently (Figure 6). After growing kale, squash, and tomatoes, it was realized the pallets needed to be set-up at an angle to increase sunlight availability. The pallets were mounted to 95-100˚ angles. This is an area of future research as well as this may be based on the direction of the pallet in relation to the sun.

Heat-treated pallets were locally sourced and disinfected with a two-to-one ratio of bleach to water to prevent any potential chemicals from reaching the plants as suggested by the University of Illinois Extension (2013). Due to the various sizes of the pallets, the number of plants per pallet varied. The pallets use approximately 1.5 square feet of horizontal space, not including the legs. The legs are approximately forty-two inches long and two inches wide and made of leftover 2-inch by 4-inch lumber from a prior Aldridge Gardens project. The horizontal space in front of the pallet and between the legs was used to plant additional plants. Pallets ranged from holding nine to twelve plants based on the size of the pallet chosen. Two of the pallets are approximately 48 inches high and 40 inches wide with a six-inch pocket depth. The remaining two pallets are approximately 48 inches high and 48 inches wide with a six-inch pocket depth (Figure 6).

Figure 6: Pallet Garden.

The pallets were lined with landscape fabric (similar to burlap) to create an approximately six to eight-inch-deep pocket affixed to the pallet structure using a staple gun. Leftover lumber from an Aldridge Gardens' project was used to create the legs. Approximately one bag of soil (1.5 cubic feet) was used to fill each pallet. It was not necessary to add additional soil throughout the season to the pallet gardens as was required by the pyramid gardens.

Generally, the pallet gardens were very successful. The advantages of the pallet gardens are the low cost of assembly and maintenance and the sustainability of reusing the pallets. The total cost to assemble six pallets was less than $100 for the landscape fabric, staple gun, and staples (supplies are still available to build more pallet gardens). There was minimal soil erosion, another advantage to the pallets. Plant watering was challenging using the one-liter measuring cup (to collect accurate data on water use), but watering would not be an issue using a garden hose. Because of the landscape fabric, water was able to drip to lower plants if too much water was applied to the plants. A disadvantage for the pallet garden is its inability to stand alone. Pallet gardens need to be mounted or leaned against a solid surface or need to have “legs” added for support. The addition of legs to the pallets was critical for the project because there was a not a free vertical surface from which to mount or lean the pallets on. Pallets can also be lined and used horizontally similar to traditional raised-bed gardens, if space allows. Another disadvantage of the pallet gardens is identifying heat-treated versus chemically-treated pallets. It is ideal to use heat -treated pallets to avoid contamination from chemicals used during the chemical treating process for producing and distributing the pallets (University of Illinois Extension, 2013). Based solely on cost and plant survival rates, pallet gardens are the least expensive and most successful option in terms of plant survival and production by cost.

3.2: Water Sources

This project sought to determine the impact of various water sources on overall plant growth and production. Aldridge Gardens has access to Birmingham Water Works Board water and on-site lake water. As part of the research, the water sources were analyzed for alkalinity, specific conductance, hydrogen ion (pH), and turbidity. This is further discussed in Section 4.3.1 Water Analysis. The water sources are briefly described below. The amount of water utilized between mechanisms were approximately the same indicating the type of water did not impact the amount of water needed, this is further discussed in Chapter IV.

Birmingham Water

Potable city water has become an increasingly expensive commodity in Jefferson County, Alabama, and other areas in the United States of America due to poor infrastructure and requirements to sequester heavy metals and other toxic chemicals from water supplies, as these toxins comprise a major public health threat (Daniel, 2017). The Birmingham Water Works Board provides potable water to over 600,000 people in Jefferson County and to residents of four adjacent Alabama counties (Daniel, 2017). As described by Daniel (2017), many water treatment facilities and infrastructure, water lines, and sewer lines are in dire need of updates or replacement, but the costs for these improvements are extremely high and would be passed along to the consumer. Additional increases to water costs in the Birmingham, Alabama region are expected to address the improvements to the water system infrastructure per the Birmingham Water Works Board (Daniel, 2017). However, the Birmingham Water Works Board (BWWB) states the water provided to its customers is one of the highest quality waters in the United States (Birmingham Water Works Board, undated). Due to increasing costs for potable water, it is advisable to seek other sustainable ways to irrigate the gardens, especially for low-income communities. For this project, BWWB water was used as the control since city water is a more readily available source for community and home gardens.

Per conversations with Jaquice Boyd, an engineer with the Birmingham Water Works Board, the Shades Mountain Filter Plant services Aldridge Gardens. The Shades Mountain Filter Plant receives water from the Cahaba River and Lake Purdy (Emergency Storage) (Boyd, 2018).

Lake Water

Aldridge Gardens has a six-acre lake on-site for water retrieval. Aldridge Gardens' Executive Director, Rip Weaver (2017), explained that a unique aspect of Aldridge Gardens is its lack of off-site water contribution due to the "bowl" shaped topography of the thirty-acre property; approximately 85% of the water that falls on the property stays on the property, flowing into the six-acre lake. The lake has no outside or additional water source beyond rain runoff. A small amount of offsite water contribution comes from the adjoining property's playground and parking lot, Birmingham First Church, SDA. There is minimal water contribution that flows over any concrete surface and none that flows directly into the lake without first going through a landscaped area. Additionally, Aldridge Gardens uses very little in the way of herbicides, fungicides, or insecticides (Weaver, 2017).

3.3: Soil and Fertilizers

The raised-bed systems soil was not able to be provided by Aldridge Gardens due to site limitations, so an organic garden soil was selected from a local commercial store. During discussions with staff members of Aldridge Gardens, the use of either a garden soil or a top soil was recommended by Rip Weaver (2017). As this project seeks to make gardening a realistic option in low-income communities, the lowest priced per cubic foot garden soil was selected in an effort to lower cost. Kellogg Garden® Organics All Natural Garden Soil for Flowers and Vegetables was originally selected because of its lower cost of $6.77 for two cubic feet of soil. The All Natural Garden Soil is a mixture of wood fines that provide the benefits of moisture retention and organic matter (Kellogg Garden® Organics, undated). During the fall and spring planting of spinach, Miracle-Gro® 1.5-cubic foot Organic Raised Bed Soil® was selected because the 100% organic mix is designed for used in raised-bed systems and does not require the addition of further fertilizers until 30 days after initial planting (Miracle-Gro®, 2020). At most retailers, the cost of the Miracle-Gro® 1.5-cubic foot Organic Raised Bed Soil is $8.98, but Lowe's® hardware store provided this product at a discounted rate of $8.00 and excluded tax because this was a school research project.

During the summer planting of kale, squash, and tomatoes, no additional fertilizer was initially added to any of the growing systems. As the plants struggled to survive, an organic general vegetable fertilizer (Espoma Organic Garden-tone: Herb and Vegetable Food) was added approximately one month after the initial planting. The Espoma Organic Garden-tone was selected based upon reviews of the various types of soil provided by Lowe's®. From this experience, it was realized that the soil for the pyramid gardens and pallet gardens would require addition of fertilizer despite the concept of not using additional fertilizers.

The summer planting resulted in less than satisfactory results. There was not enough surviving plants in the soil-based systems to perform any type of weight measurement or chlorophyll analysis. Through discussions with the doctoral committee members and Aldridge Gardens mentors, it was decided to select a singular plant species that could grow both in fall and spring. There are very few plants which have two growing seasons in Alabama because of the state's climate. Spinach was selected and agreed upon to use for the fall and spring planting seasons.

Once it was decided to plant spinach, it was immediately known that a specific fertilizer would be needed to supply the spinach with the added nutrients. The North Carolina Cooperative Extension suggested home gardeners use a 10-10-10 fertilizer for spinach (Sanders, 2001). Using a local commercial store and North Carolina Cooperative Extension information (Sanders, 2001), Pennington UltraGreen All Purpose Plant Food 10-10-10 was selected. This all purpose, 10% Nitrogen-10% Phosphorus-10% Potassium fertilizer boasts the ability to use less water and grow more vegetables, and it was one of the few 10-10-10 options available at the commercial store (Pennington UltraGreen 5-lb All Purpose Food, 2018). The fertilizer was applied 30 days after initial planting as prescribed by Miracle-Gro®(Miracle-Gro Raised Bed Soil, 2020).

3.4: Plants

The plants originally selected for this project represented fruits, leafy greens, and vegetables that are typically grown in the Southeastern United States. Tomatoes, kale, and squash were chosen due to their successful, historical growth in Tower Gardens® and raised-bed gardens at Aldridge Gardens (Weaver, 2017). Each garden system was planted with each plant in the same order. Squash was planted on the bottom, kale in the middle, and tomatoes on top due to the sunlight and growth requirements discussed below. All seedlings were procured from the same farm for consistent species. However, throughout the growing season, numerous problems were encountered, and the project was halted. The numerous variables in terms of plant health, water conditions, and fertilization needed to be addressed. There also needed to be a replicability factor that was not available due to plant selection.

Therefore, the project shifted in a different direction. The Alabama Cooperative Extension System through Alabama A&M and Auburn Universities' ANR-0063 "Planting Guide for Home Gardening in Alabama" (Musgrove et al., 2013) was consulted for vegetables that had both a fall and spring harvesting guideline in Alabama. Due to time constraints with the project, spinach was selected due to planting dates in September and February to March (Musgrove et al., 2013).

Spinach

Spinach is a cool season crop that can grow in both full sun and partial shade and requires moist soil (Growing Guide: Spinach, 2006). Cornell University's Growing Guide (2006) describes the germination temperature range for spinach as 40˚F to 75˚F with failure to germinate at warmer temperatures and drier soil. Spinach prefers a soil pH range of 6.4-6.8, and a high pH may be indicated by slow growth and yellowing of leaves (Sanders, 2001). However, the Cornell University's Growing Guide (2006) indicates spinach can be sustained in soils with a pH range of 6.0-7.5 (Old Farmer's Almanac, 2018). The recorded pH of the soils in the pallet and pyramid gardens ranged from 6.8 to 7.2.

From this information and in consultation with Gary Hughes from Tower Farms and WNC Urban Farms, it was decided to delay the planting of the spinach seedlings until late September when the Birmingham area’s temperatures are typically cooler. Mr. Hughes recommended purchasing Emperor Spinach as it is an option known to grow successfully in the Birmingham area climate (Hughes, 2018). For the spring planting, late March or early April were indicated as the ideal time for planting.

For the fall season, WNC Urban Farms grew 210 Emperor Spinach seedlings on September 8, 2018 and the resulting seedlings were shipped to Hoover, Alabama on September 24, 2018. The plants arrived late in the afternoon of September 26, 2018 and were transplanted to their respective gardening technique at Aldridge Gardens on September 27, 2018. There were 18 additional plants that were not allocated to the alternative growth techniques. Those plants were planted in the raised garden bed upon which the pallets and pyramids stand. These plants were not assessed for this research because they were not originally in the plan and the soil in the raised bed system was inconsistent with the other soil-based systems.

For the spring season, it was established soil-based plants needed to be purchased in soil rather than from WNC Urban Farms. The seedlings from WNC Urban Farms were “shocked” by the introduction of soil and did not adapt well to the change in environment; thus, spring spinach seedlings for the soil-based systems were purchased from Bonnie Plants® from Lowe’s® hardware store. The spinach seedlings were purchased April 3, 2019 and planted on April 4, 2019 for the Tower Gardens®, 100 spinach seedlings were ordered on March 20, 2019 and arrived April 3, 2019. These seedlings were also planted April 4, 2019 at Aldridge Gardens.

3.5: Location

Aldridge Gardens, located in Hoover, Alabama, was selected for this project because of the unique relationship previously established between UAB and Aldridge Gardens. The Executive Director of Aldridge Gardens, Rip Weaver, and Dr. Robert W. Peters, of UAB have previously researched and executed testing of solar panels and Tower Gardens® at Aldridge Gardens. Aldridge Gardens has an education garden for K-12 students to learn about the benefits of gardening and the natural environment. The Education Garden was selected as the site for this research because of its availability of space and existence of previous gardens. This unique relationship and location led to the establishment of this study and location selection.

As this research is focused primarily on the benefits of community gardens in the Birmingham, Alabama area, it was necessary to use a site that represents the climate of Birmingham and the southeastern United States. Applying these gardening techniques in a cost-effective manner also provides an opportunity of natural prevention intervention strategy for encouraging healthier lifestyles and community engagement.

3.6 Objectives, Goals, and Hypotheses

The objectives for the project were to analyze three different vertical gardening techniques using two different water sources to determine if equitable spinach plants could be grown in the various setups. The objective was to also determine whether an alternative water source, lake water, could be utilized instead of potable water due to increasing potable water costs. From this information, the objective was to define guidelines for producing high-nutrient valued spinach using vertical farming techniques and alternative water sources. Guidelines were based on the most effective vertical garden mechanism (Tower Garden®, Pyramid Garden, or Pallet Garden) in terms of plant production.

From the objectives, the goal is to establish a user-friendly and cost-effective guideline for growing spinach. Based on known initial costs and previous experiences, the goal is to be able to suggest setting up pallet gardens in community gardens and other shared spaces in Birmingham, Alabama. It is further hoped these spaces can provide lake water to grow spinach or other leafy greens based on the guidelines defined from this project.

There are multiple hypotheses to be explored using Analysis of Variance to compare mean values in terms of plant weight, percent moisture content, and overall survival rate. The null hypothesis, H_0, is that the technique and/or water type will not have an impact on plant weight, percent moisture content, and/or survival rate. The alternative hypothesis, $H_{A,}$ is that the technique and/or water type will have an impact on plant weight, percent moisture content, and/or survival rate. The hypotheses are further discussed in Chapter IV. The assumptions are listed below:

- H_0: $\mu_A = \mu_B$
- H_A: $\mu_A > \mu_B$

H represents the hypothesis being tested and μ represents the mean values.

CHAPTER IV

DATA COLLECTION AND ANALYSIS METHODS

This chapter describes the project timeline, data collection and analysis, and anticipated results. This data provides preliminary conclusions on the overall production of each growth technique and water type.

In terms of quality control, identical watering instruments (a one-liter measuring cup) was used to water each system. Two commercially purchased soil meters were used to analyze pH and water content for the soil-based systems at the site. For wet and dry weight analysis for biomass, UAB's Biology Department provided facilities and support. The Biology Department also provided the facilities and support for the chlorophyll analysis. The UAB's Department of Civil, Construction, and Environmental Engineering labs provided support for the water analyses. A rainwater meter was installed on a pallet garden to provide rainfall measurements.

4.1 Timeline and Tasks

This project was conceptualized in November 2017, but actual work began in April 2018. Various meetings were held with Aldridge Gardens between November 2017 and May 2018 to solidify commitment to the project to select plants and gardening techniques. The Tower Gardens®, pallet gardens, and pyramid gardens were setup May 23-25, 2018. Seedlings were planted on June 7, 2018, and the first harvest (squash) occurred July 14, 2018. Watering occurred two to three times per week depending on the amount of rainfall. However, after the initial project scoping meeting on July 27, 2018, the project was immediately halted due to the concern for the inclusion of too many variables being addressed, including plants, water sources, and soil requirements. During the scoping meeting, the doctoral committee agreed to simplify the project to one plant and two water sources. Spinach was selected because spinach has two growing seasons in the Birmingham-Metropolitan area. The Birmingham city water remained as the control, and lake water was chosen as a dependent variable to assess because it was considered to be less variable in terms of contaminants than the collected rainwater.

The spinach seedlings were ordered from the supplier, WNC Urban Farms, and seeded September 8, 2018, with the intent of a later season planting due to the warmer temperatures in the Birmingham Metropolitan Area that are less acceptable for spinach. The soil was fertilized with Pennington UltraGreen 10-10-10 (NPK) on October 12, 2018. The seedlings were transplanted within the various growing systems at Aldridge Gardens on September 27, 2018. The first harvest occurred on November 6, 2018, and the harvested spinach leaves were weighed and dried. The second harvest occurred November 9, 2018 to perform chlorophyll analysis. During this time, plants were watered eight times and soil pH was measured four times. No water testing occurred during this time because of the lack of lab availability.

The spring planting began April 4, 2019 (Figure 7) with the first harvest being May 1, 2019 (Figure 8). Tower Garden® plants were ordered March 15 from WNC Urban Farms, LLC, and the soil-based plants were purchased April 3, 2019. Between April 4 and May 1, 2019, there were nine watering sessions. Harvests occurred May 1, 2019, May 13, 2019 and May 20, 2019. Between the watering session on April 24 and April 28, 2019, the power was inadvertently turned off to the Tower Gardens®. This led to the partial demise of several plants. Birmingham Water Works Board watered Tower Gardens® resulted in the loss of 15 plants out of the 40 total plants. The lake water Tower Gardens® resulted in the loss of six plants out of the 40 plants. The loss of supplied water and nutrients can be visualized in Figure 8.

Figure 7: Tower Gardens®, Pallet Gardens, and Pyramid Gardens Day 1 Spring Planting.

Figure 8: Tower Gardens®, Pallet Gardens, and Pyramid Gardens Spring Harvest Day 1.

Plants were transported to UAB for weight analysis after harvesting occurred. Chlorophyll analysis occurred May 2, 2019. Data analysis began in June 2019. Water testing was conducted the weeks of May 6, 2019, May 13, 2019, May 20. 2019, and May 27, 2019. Data analysis and termination of the project was completed in February 2020 and described in subsequent sections. Graduation is anticipated to be May 2020. A project schedule can be found in Appendix C.

4.2 Data Collection

The data collection begins with the amount and type of each water source used for the various vertical growth techniques. Once harvesting begins, the harvested spinach will be measured for overall yield, wet weight, dry weight, and chlorophyll content. This data indicates which growing technique provides the highest yield. Further, visual analysis was provided during the course of the study as an indicator of plant health.

4.3 Analysis

Statistical analysis of the data collected was used to identify the best gardening technique and water source combination. One-way analysis of variance (ANOVA) was determined if any growth technique provided better plant yield and size, and ANOVA also determines if one water source provides better or equivalent plant yield and size. Based on the data currently collected, the water source impacts the yield more than the plant technique. The data collection is further described below.

4.3.1 Water Analysis

The collected lake water was analyzed for alkalinity, specific conductance, hydrogen ion (pH), and turbidity in accordance with the United States Environmental Protection Agency 40 CFR 136 Table 1B-List of Approved Inorganic Test Procedures (Clean Water Act Analytical Methods, 2019). From this table, Standard Methods Test 2320, Test 2510, Test 4500-H^+, Test 2130 (1998) were performed in the Civil, Construction, and Environmental Engineering Laboratory under the oversight of Lab Manager, Richard Hawkins. These tests were selected because they were the most feasible and appropriate tests to be performed given the limited budget and timeframe of this project.

The collected data were used to identify the water influence on plant growth or hinderance. Testing began once the supplies necessary were available. It was hoped that water analysis testing could be performed twice per month to establish any potential trends in the water supply that affect the growth of the spinach. The testing was not able to commence during the fall season due to the lack of materials, but did occur during the spring season.

The lake water and Birmingham Water Works Board water were collected in a sanitized glass jar with a lid, and then transferred to the Environmental Engineering Laboratory for testing. All test procedures are provided in Appendix D. A summary of the analyses follows.

Alkalinity and Hydrogen Ion (pH).

Standard Methods Test 2320: Alkalinity describes alkalinity as "a measure of an aggregate property of water" and is "primarily a function of carbonate, bicarbonate, and hydroxide content" (American Public Health Association, American Water Works Association, & Water Environment Federation, 1998). Alkalinity is measured as $CaCO_3$ mg/L and indicates the "water's ability to neutralize acidity" (Cox, 1995). Further, high alkalinity "effects fertility and plant nutrition" (Cox, 1995). The analysis of alkalinity and pH were used to determine potential effects on the spinach quality. As discussed earlier, spinach requires a soil pH between 6.4 and 6.8.

Alkalinity testing was conducted in accordance with the Standard Methods Test 2320 Titration Method using the color change procedure 2310B.4b (1998). The test states there is precision due to sample variations. Test 4500 H+ Colorimetric was used for determining the pH of the water.

Conductance.

Standard Methods Test 2510 Conductivity tests the water's ability to carry an electric current, and organic compounds have poor conductivity in aqueous solutions (American Public Health Association, American Water Works Association, & Water Environment Federation, 1998). The U.S. Environmental Protection Agency (2012) further explains inorganic dissolved solids also impact conductance. Changes in conductance can indicate potential discharges or pollution (U.S. Environmental Protection Agency, 2012). If the conductivity measurements are inconsistent, chemical oxygen demand (COD) or biochemical oxygen demand (BOD) testing may be required. However, the need for COD and BOD testing was not necessary for this research.

Turbidity.

Standard Methods Test 2130 was employed to assess for turbidity, or water clarity (American Public Health Association, American Water Works Association, & Water Environment Federation, 1998). Turbidity measures the amount of suspended solids and other matter in the water, and can present health issues if it is excessive by encouraging pathogens in the water and ultimately growing systems (United States Geological Survey, 2016). According to the National Primary Drinking Water Regulations, turbidity must be less than or equal to 0.3 NTU (U.S. Environmental Protection Agency, 2009). If values are greater than 0.3 NTU, COD or BOD testing may be required to determine the cause of the higher turbidity results.

4.3.2 Plant Analysis

Plant samples will be analyzed for weight, water content, and chlorophyll content. UAB’s Department of Biology has graciously provided their laboratory facilities to assist in this research effort.

Biomass Analysis.

Data from the wet and dry weight of the samples was collected as part of the biomass analysis. The biomass procedure was derived from the Hames et al.’s “Preparation of Samples for Compositional Analysis” (2008) Method B Convection

Drying and the National Resources Conservation Services "Above-Ground Biomass (Plant) Determinations" (Franks & Goings, undated). The data collected provides the moisture content of the spinach.

The procedure is as follows: cut the plants at ground level; place samples in a sealable container with added moisture to transfer to UAB; weigh the wet sample at UAB; place the sample in the oven for a minimum of 48 hours at 45 ± 3 ˚C; remove the sample from the oven, and weigh the dry sample. The full procedure is provided in Appendix D.

Using the wet and dry weights, the percent moisture content can be determined. Weights were rounded to the nearest 0.1 gram (g). The calculation for percent moisture is indicated below:

$$\% \, Moisture\ Content = \frac{(Wet\ Weight - Dry\ Weight)}{(Dry\ Weight)} \times 100$$

Reference: (Franks, undated)

Lefsrud et al. (2008) studied the dry matter (DM) content of spinach and kale using various techniques and temperatures in the report "Dry Matter Content and Stability of Carotenoids in Kale and Spinach During Drying". The research involved oven drying at +50 ˚C with influences from nitrogen (low and high) and found spinach dry matter was 6.9±2 % DM for high nitrogen plants and 9.6±0.7 % DM for low nitrogen plants (Lefsrud et al., 2008. Although this is not directly related to the methods of this study and utilized higher temperatures, it can be used for reference; thereby, suggesting the percent moisture content should range from 89.7% to 91.1% for low nitrogen plants.

Chlorophyll Content Analysis.

A common methodology for understanding plant physiology is chlorophyll fluorescence, a non-invasive measurement of the photosystem II (PSII) (Murchie & Lawson, 2013). Murchie and Lawson (2013) explain that chlorophyll fluorescence is used as an indicator of plant response to changes in the environment by measuring the efficiency of photosynthesis. An Opti-Sciences Chlorophyll Fluorometer (OS30p) measures the maximum possible fluorescence, F_m, and the variable fluorescence, F_v, and provides the indicator for quantum yield of fluorescence (PSII), F_v/F_m. As described by Murchie and Lawson (2013), an unstressed plant should have a F_v/F_m value of approximately 0.83. However, Gary A. Ritchie (2006) explains in “Chlorophyll Fluorescence: What is it and What do the Numbers Means,” that the normal optimal range for quantum yield is 0.7 to 0.8. The data collected were within the 0.7 to 0.8 range.

4.3.3 Soil Analysis

Due to soil analysis constraints, the soil was analyzed using two commercially purchased soil pH, moisture and temperature meters. A Dr. Meter 4-in-1 Soil Water Monitor (Model #: DSMM600) was selected based on the product’s positive reviews. Since there was no way to calibrate the data, a Hydro Crunch Soil Moisture 3-in-1 Soil Tester (model number not provided) was also purchased to compare readings. The two devices were used to collect soil pH and moisture data. The pH measurement can indicate potential issues with the soil, although the soil was not amended to correct any observed issues. The moisture data was used for the determination of the amount of water to be added to the soil.

CHAPTER V

RESULTS AND ANALYSIS

This chapter describes the collected data and results of both the fall 2018 and spring 2019 planting seasons. The data and results from the fall planting were preliminary and statistically insignificant; however, several lessons were learned from the fall planting. The lessons were then implemented in the spring planting, which resulted in a more successful growing season. The fall data were analyzed using descriptive statistics because there was not enough data to analyze. The spring data were analyzed using both descriptive statistics and comparison of means for hypothesis testing.

Several assumptions were made in regard to data analysis. These assumptions are listed below unless otherwise specified:

- Data was analyzed with IBM SPSS Statistics 25
- Analysis of Variance (ANOVA) was primarily used unless otherwise stated
    - One-tailed testing was performed
- Data was fitted with a normal curve and data appears to be adequate
- Outliers were not removed in data sets because of the volume of data available

5.1 Results and Limitations

There were two separate growing seasons, fall and spring. There was no statistically significant data collected during the fall season due to limitations of the study that have been briefly discussed in previous sections. The data collected for each season is discussed below.

There were numerous limitations to this study. The main limitation was the location and space available within the Birmingham-metropolitan area. It was imperative to have access to waters provided by a lake and a municipal system. The space also needed to have a power source for the Tower Gardens®. Aldridge Gardens was an excellent fit in terms of the required access needs of water types and power availability; however, Aldridge Gardens is a public space with year-round visitors. The Educational Garden used is located away from the main walking trail, but the area is still visible from the trail. Visitors of the Gardens were able to potentially harvest spinach without the knowledge of the researcher. This area is also frequented by children as part of the education program, so there was also the potential for misuse. Also, this area has domesticated and undomesticated animals roaming the site. These limitations were also benefitting because the limitations offered a more realistic setting for community gardens; however, for research, it would have been more ideal to be in a controlled environment.

Since this was an uncontrolled environment, the plants were subjected to the natural elements, such as extreme heat and severe thunderstorms. One thunderstorm had strong enough winds to blow over one of the pallet gardens, but no damage was noticed to the plants. The extreme heat was one of the major factors in the demise of the spinach plants during the fall planting season. The uncontrolled environment also resulted in leaf-eating pests, such as aphids, eating plant leaves. The aphids luckily did small amounts of damage to leaves, so the leaves were still able to be evaluated for mass and water content.

Another limitation of the research was the limited funding. The limited funding resulted in the use of fewer mechanisms. The results would be stronger had there been more than two of each mechanism with water type. The space availability was also a limiting factor in the expansion of the mechanisms.

Due to scheduling conflicts with the UAB Environmental Lab, the water analysis was not completed during the fall planting season. The water analysis for the spring planting season was also delayed due to schedules. Also, supplies for the testing required for testing had to be ordered which also led to the delay in water analysis.

The type of plant to study was also a limitation to this study. Initially, it was hoped to use three different types of plants for diversity: flowering plant and fruit (tomato), leafy green (kale), and flowering gourd (yellow squash). However, this proved to create too much variability in the research. Based on input from the doctoral committee, it was then decided to select one plant to harvest, but the plant needed to have multiple growing seasons. There are very limited plants that have multiple seasons and can grow in Tower Gardens®; thus, spinach was selected because it can grow in both spring and fall in Alabama and can grow in Tower Gardens®. Due to the heat of Alabama falls, it was learned that spinach needed to be planted in late October and early November when the temperatures begin to have highs in the low 70s. Further, due to cost and timing, the project was limited to purchasing seedlings. It would be more conducive and relevant to compare identically seeded plants. By seeding at the same time of the same strain, the data would be more comparable throughout the growing season during the different developmental stages. Optimally, future test design would include a minimum of three growing seasons and standardized harvesting.

Due to the limited sample sizes, one-tailed Analysis of Variance (ANOVA) with a 95% confidence level (significant at $p<0.05$) was performed. Unless specifically noted, outliers were not removed from data sets also because of the sample sizes. To increase sample sizes for comparison, data needs to be collected during three or more growth seasons. Again, due to the limitations of the time and resources, this project was limited to the two seasons which limited the available data.

5.1.1 Fall Results: Plant Health

Of the 200 spinach plants planted, only 26 plants survived until harvesting. Of those 26 plants, only 11 plants were healthy enough for harvesting and testing. Only three plants were harvested from all of the pyramid gardens, and all three of those plants were from the top level of the same city water pyramid garden, City-1 (C1). One plant was harvested from each of the city water Tower Gardens®, C1 and C2. Each of these came from a C location, meaning the pod had a western orientation. The lake water Tower Gardens® proved to be slightly more successful with three plants from L1 and two plants from L2. These plants were a mixture of orientations; however, none of the Tower Gardens® had success in the eastern orientation. It is assumed this failure was due to limited sunlight associated with an awning. The data from the planting are presented in Figure 9 and Table 1.

Of the 11 plants, the average wet weight of a single leaf was 0.58 mg and dry weight of 0.04 mg. The average percent moisture content was found to be 94.13%. Interestingly, the lake water Tower Gardens® leaves were typically significantly larger in terms of weight than those from the other systems. This fact is contrary to the previous study growing kale, squash, and tomatoes where nothing grew in the lake water.

Further, the chlorophyll fluorescent measurement average was 0.752, well within the range of a healthy plant. All 11 leaves tested were within the range of 0.720 and 0.773, indicating the plants were not stressed.

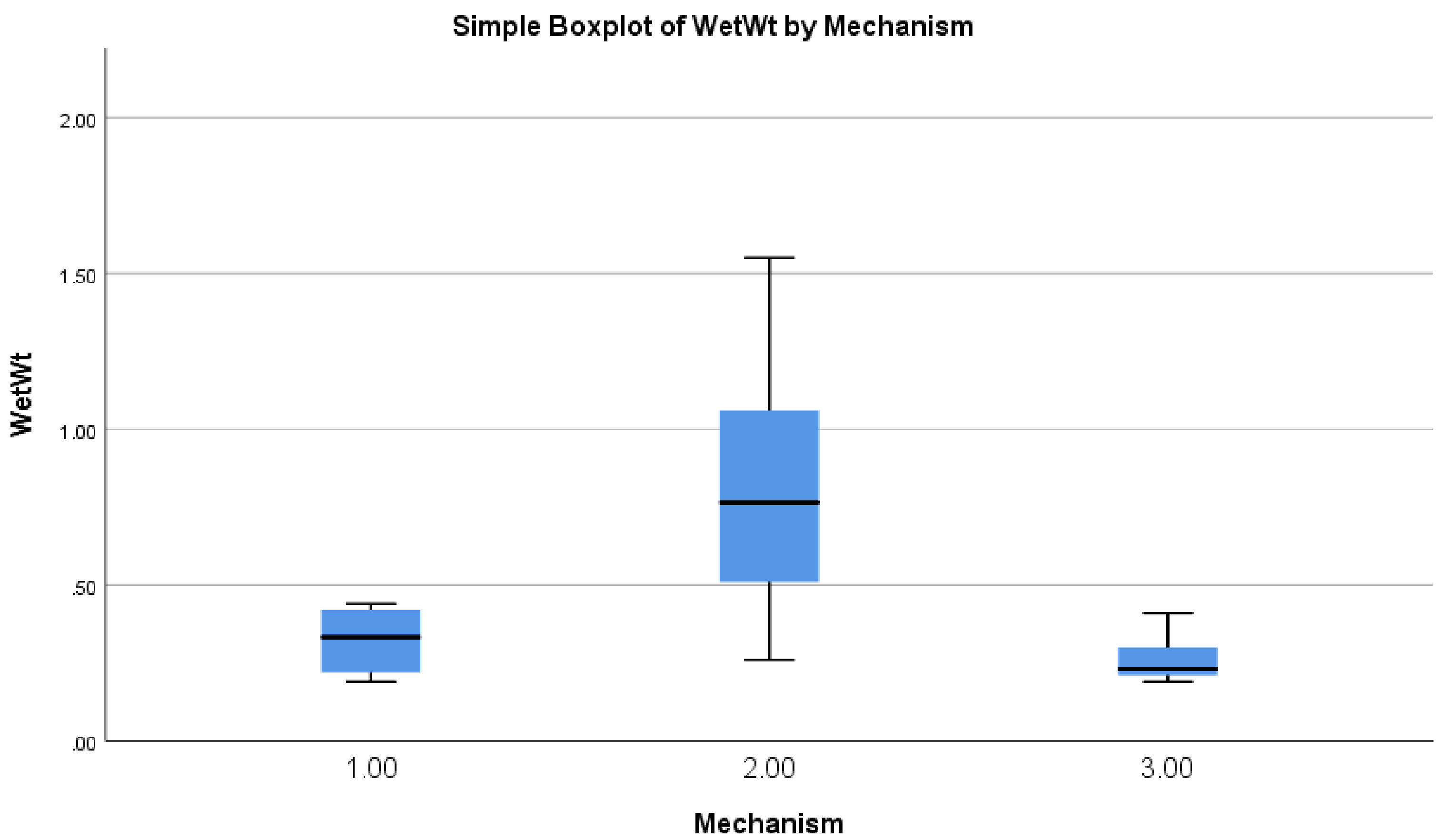

Figure 9: Fall 2018 Wet Weight (mg) by Mechanism and Water Type.

(Coding for Figure 9: 1.00: Tower Garden® BWWB, 2.00: Tower Garden® Lake, 3.00: Pyramid Garden

Table 1

Fall Planting Weights, Percent Moisture Content, and Chlorophyll Content

Location	Total No. Leaves Per Plant	Wet Weight (mg)	Dry Weight (mg)	Percent Moisture Content	Chlorophyll (F_v/F_m)
		0.21	0.01	95.24	
	7	0.41	0.02	95.12	0.751
		0.22	0.01	95.45	
		0.23	0.01	95.65	
Pyramid BWWB	5	0.24	0.01	95.83	0.749
		0.30	0.02	93.33	
		0.31	0.02	93.55	
	4	0.21	0.01	95.24	0.752
		0.19	0.01	94.74	
		0.34	0.02	94.12	
	8	0.44	0.02	95.45	0.762
Tower Garden® BWWB		0.32	0.02	93.75	
		0.22	0.01	95.45	
	9	0.19	0.01	94.74	0.732
		0.42	0.03	92.86	
		0.46	0.02	95.65	
	17	0.30	0.02	93.33	0.758
		0.26	0.02	92.31	
		0.68	0.05	92.65	
Tower Garden® Lake	20	0.96	0.02	97.92	0.773
		0.67	0.05	92.54	
		0.96	0.06	93.75	0.720
		1.01	0.06	94.06	

Location	Total No. Leaves Per Plant	Wet Weight (mg)	Dry Weight (mg)	Percent Moisture Content	Chlorophyll (F_v/F_m)
	19	1.51	0.10	93.38	
		0.78	0.05	93.59	
	13	0.51	0.04	92.16	0.763
		1.06	0.07	93.40	
		0.40	0.03	92.50	
Tower Garden® Lake	11	0.75	0.02	97.33	0.766
		0.68	0.05	92.65	
		1.14	0.09	92.11	
	12	1.55	0.11	92.90	0.750
		1.24	0.08	93.55	

5.1.2: Fall Results: Soil

The pH of the soil-based systems was monitored weekly from October 7th, 2018 through November 4th, 2018. The average soil pH was 6.96 with a range of 6.8 to 7.2. The soil pH was within the Old Farmer's Almanac (2018) range of 6-7.5 but slightly higher than suggested by Sanders (2001), 6.4-6.8. The descriptives data are presented in Table 2. The mean pH values were all very close (Pallet BWWB was 6.9, Pallet Lake was 6.99, Pyramid BWWB was 7.01, and Pyramid Lake was 6.94).

Table 2

Descriptives for Fall Soil pH

	n	Min.	Max.	Mean	Std. Deviation
Pallet Garden BWWB	10	6.80	7.00	6.900	.0667
Pallet Garden Lake	10	6.80	7.20	6.990	.1287
Pyramid Garden BWWB	10	7.00	7.10	7.010	.0316
Pyramid Garden Lake	7	6.80	7.10	6.943	.0976

5.1.3: Fall Results: Conclusions

As previously mentioned, there were numerous limitations to this study during the fall of 2018. These factors affected the health of the spinach resulted in valuable lessons learned. The major issue for the spinach health was the *unusually hot* temperatures in the Birmingham area after the initial planting date. The temperatures for the first three weeks after the plants were planted averaged highs in the mid to upper 80s ˚F. As previously discussed, spinach is sensitive to warm temperatures and should not be exposed to temperatures above the mid-70s for extended periods of time (Growing Guide: Spinach, 2006). While the temperatures were in the higher ranges, the plants were watered three times per week; however, there were as a combined loss of 24 out of 80 plants in the Tower Gardens®, a combined loss of 56 out of 64 plants in the pyramid gardens, and a combined loss of 25 out of 48 plants in the pallet gardens during this time. Presumably, there are other factors to be considered as well, such as the need for fertilizer, soil selection, etc., but overall testing was extremely limited.

Water quality analysis was not available during the fall planting season due to reasons outside of the control of the researcher. Those factors were mitigated, and water quality testing commenced in April 2019. Further, Aldridge Gardens is an uncontrolled site open to the public for use and education. It is impossible to patrol the site to prevent patrons and pests from disrupting the experiment. Although this is a nuisance, it provides a more realistic study for those implementing vertical gardening techniques into community areas.

In terms of water quantity analysis, the pallet and pyramid gardens, on average required, two to three times more water per liter during watering than the Tower Gardens®. For example, if one liter was added to each Tower Gardens®, then 3 liters were added to each pallet and pyramid garden. However, once the initial 75 liters of the Tower Garden® were included in the quantification of water used it was realized that the Tower Garden® required twice as much water as the pallet and pyramid gardens. There was not a significant difference between the type of water and amount of water (liter) used during watering within mechanisms. The mean water used by Tower Gardens® was 8.68 L, pallet gardens was 4.59 L, and pyramid gardens was 3.74 L. The descriptives data are provided in Table 3. ANOVA and multiple comparisons were run on the data. There was no significant difference in the means for the water types per mechanism at the 95% confidence level.

Based on the descriptives data and plant health, it was established that the amount of water used needed to be based on the soil moisture content for the soil-based systems. For the spring planting, a soil moisture monitor was used to ensure the plants were being watered similarly.

Table 3

Descriptives of Water Quantity in Liter

	n	Minimum	Maximum	Sum	Mean	Std. Deviation
Tower Garden® BWWB	22	.0	75.0	186.0	8.455	21.558
Tower Garden® Lake	22	.0	75.0	196.0	8.909	21.421
Pallet BWWB	22	1.0	7.0	100.0	4.545	1.595
Pallet Lake	22	1.0	8.0	102.0	4.636	1.706
Pyramid BWWB	22	2.0	5.0	87.0	3.955	1.090
Pyramid Lake	22	.0	5.0	77.5	3.523	1.776

Note: Data presented in liters

5.2: Spring Results

From the lessons learned, several aspects of the study were amended including the season, water data collection, orientation of the Tower Garden®, and spinach purchase. The most significant difference was the season of planting since temperatures are typically cooler and more consistent in the spring in Alabama. Water quantities for the soil-based systems were based on soil moisture measurements to ensure the soil was considered to be "wet". Soil pH continued to be measured and monitored as a plant health indicator. The Tower Garden® units were moved away from the awning of the shed to better ensure similar sunlight opportunities for the plants as the soil-based gardens. As noted, soil-based spinach was purchased from Lowe's® hardware store because it was assumed the seedlings grown in the Tower Garden® nutrient blend were shocked when planted in soil systems not using the same nutrient blend during the fall planting.

5.2.1: Spring Results: Plant Health and Success

The health and success of plants were analyzed by assessing wet weight, dry weight, and chlorophyll content. The wet weight and dry weight were used to determine the percent moisture content. The data were compared across techniques and water sources to determine if the techniques and overall systems are as successful as the Tower Garden®. The chlorophyll content data were compared to standard estimates for healthy plants to determine success or failure.

The overall plant survival rates were also used to determine overall success of each mechanism and water type during the spring 2019 season. Survival was based on whether the individual plant had five remaining spinach leaves during each week's evaluation. Survival rates based on mechanism and water type are presented in Figure 10. The Birmingham Water Works Board Tower Garden® had 25 out of 40 (62.5%) plants survive the entire growing season. The lake water Tower Garden® had 34 out of 40 (85%) plants survive the entire growing season. As previously discussed, the power was lost from the Tower Gardens® resulting in the unexpected loss of plants. It is assumed one of the Aldridge Garden's employees turned off power to the main power supply; thus, removing power to the Tower Gardens®. Approximately 40% of the seedlings were assumed lost after the power loss; however, there was some regrowth after four days. Note: No one was willing to accept responsibility for turning off the power, but an additional sign was added to remind the workers to not shut down the power.

The Birmingham Water Works Board pallet gardens had a survival rate of 83.3% (15 of 18), and the lake water pallet gardens had a survival rate of 94.4% (17 of 18). The plant deaths predominately occurred after the first harvest. The pyramid gardens had extremely low survival rates. The Birmingham Water Works Board pyramid gardens had a 33.3% (6 of 18) survival rate, and the lake water pyramid gardens had a 50% (9 of 18) survival rate. From lessons learned previously with the pyramid gardens, only 9 plants were planted in each mechanism. After the first two weeks of watering and prior to harvesting, plant loss began.

The survivability was also assessed individually by water type and mechanism. Based on combined water results, plants grown in BWWB water had a success rate of 60.5% while plants grown in lake water had survival rate of 78.9% (Figure 11). Based on the combined mechanism data the following survival rates were found: 73.6% survival rate for Tower Gardens®; 88.9% survival rate for pallet gardens; and 41.7% for pyramid gardens (Figure 12).

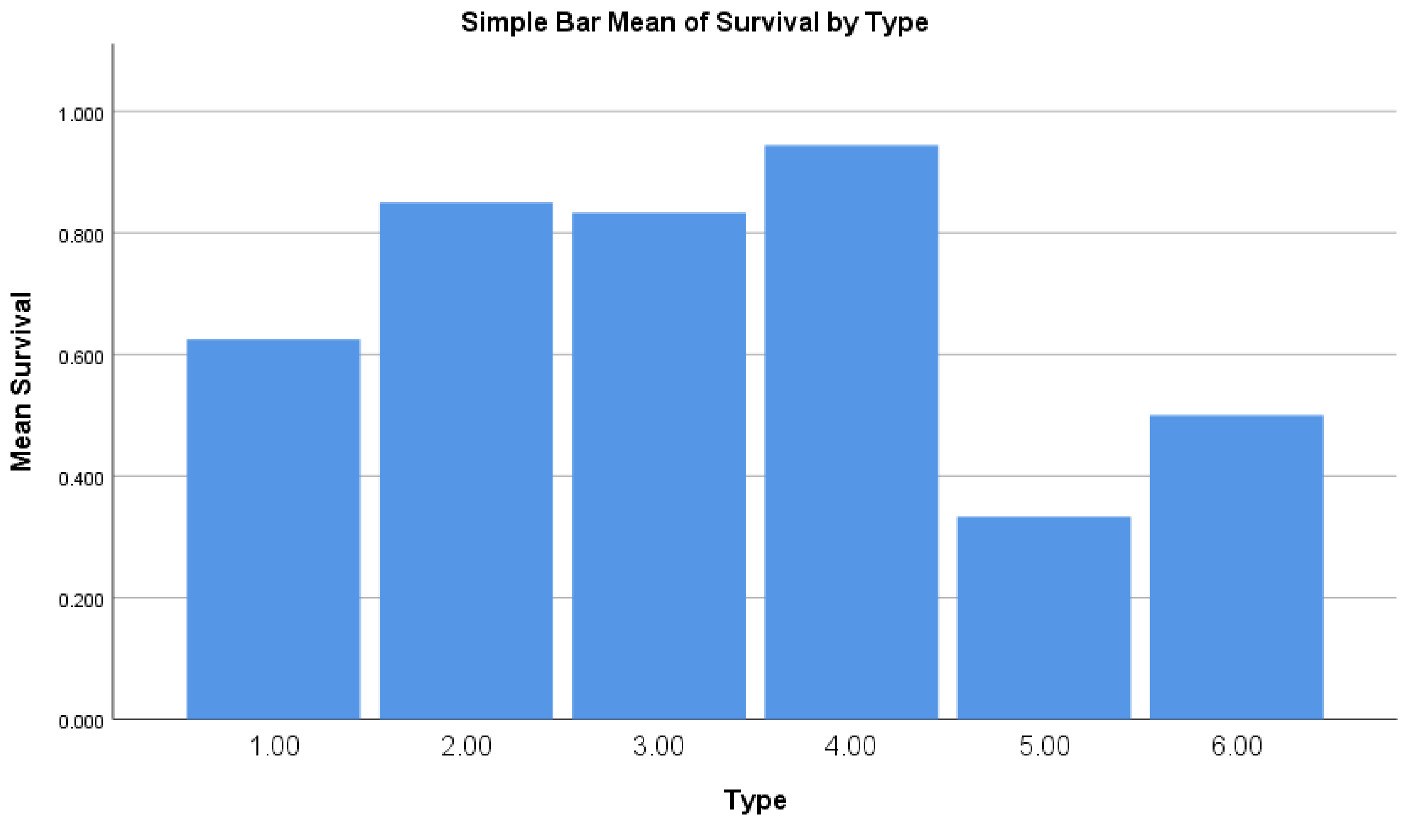

Figure 10: Bar Chart of Survival Fraction Rate by Garden Type.

(Coding for Figure 10: 1:00, Tower Garden® BWWB, 2.00: Tower Garden® Lake, 3.00: Pallet Garden BWWB, 4.00: Pallet Garden Lake, 5.00: Pyramid Garden BWWB, 6.00: Pyramid Garden Lake)

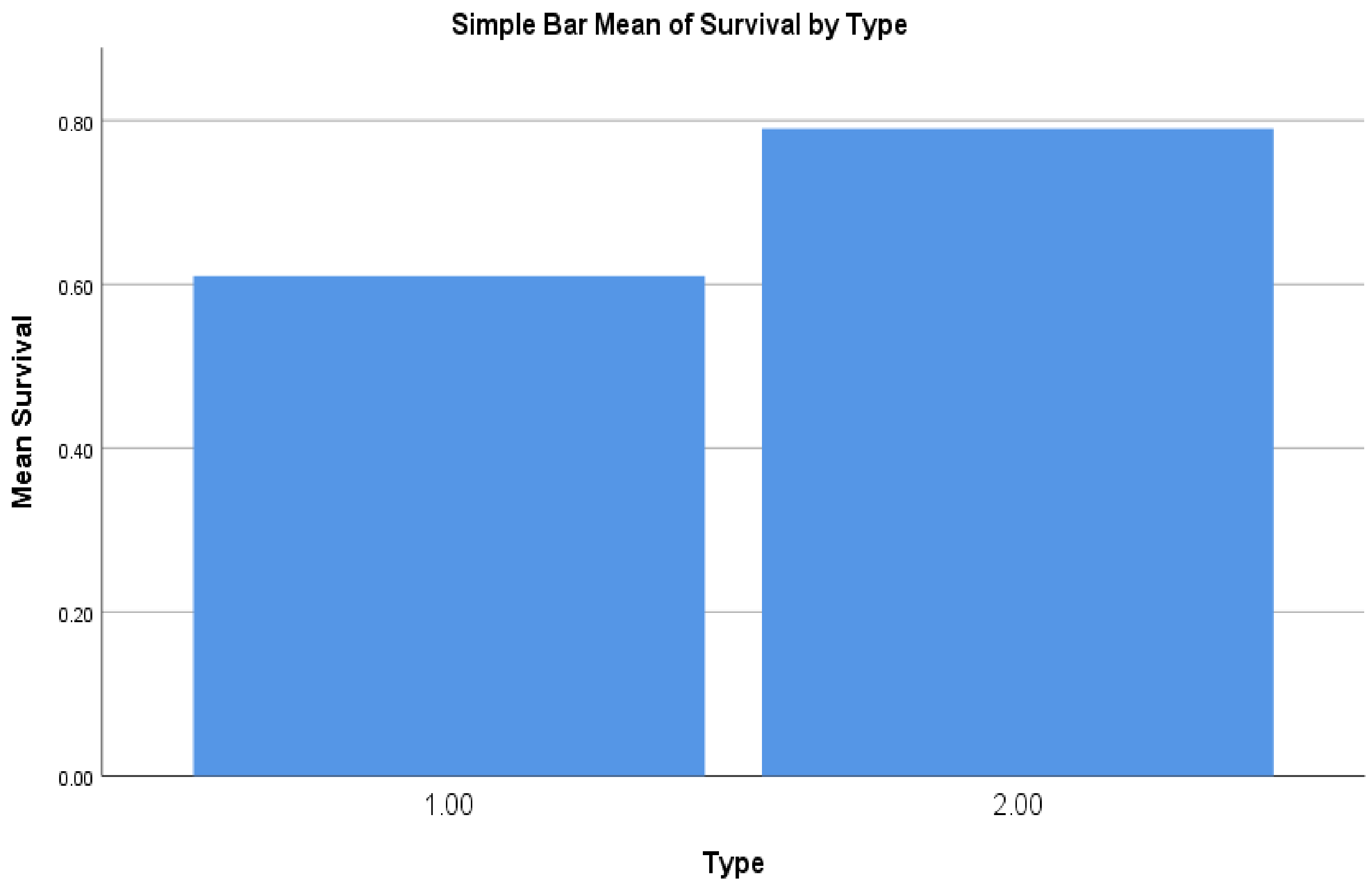

Figure 11: Bar Chart of Survival Fraction Rate by Water Type.

(Coding for Figure 11: 1.00: BWWB Water; 2.00: Lake Water)

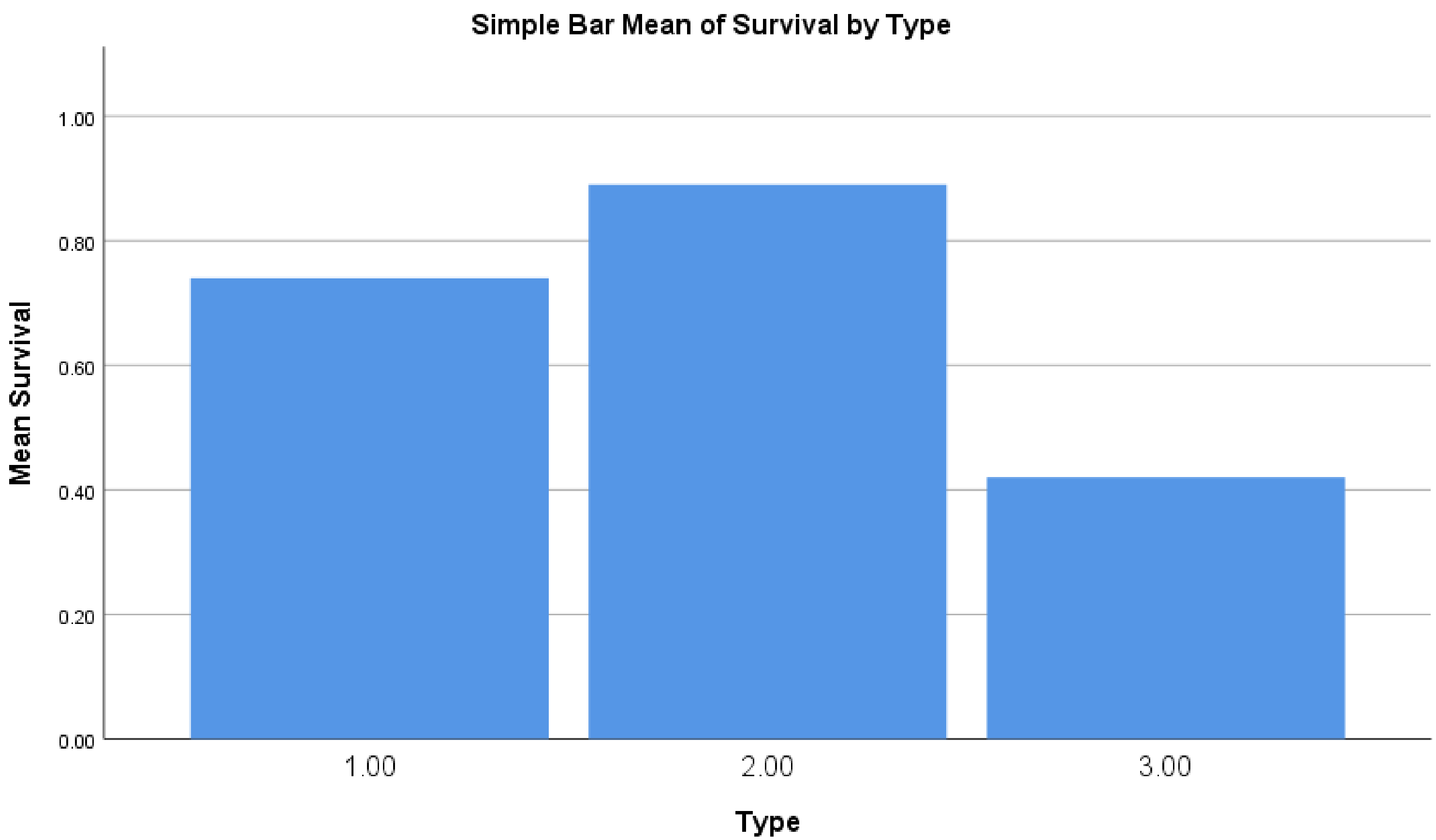

Figure 12: Bar Chart of Survival Fraction Rate by Mechanism.

(Coding for Figure 12: 1.00: Tower Garden®; 2.00: Pallet Garden; 3: Pyramid Garden)

5.2.2: Spring Results: Wet Weight Analysis

Overall, there were 382 spinach leaves collected and analyzed with a mean weight of 1.413 grams and a standard deviation of 0.786. The minimum weight was 0.366 g and the maximum weight was 5.603 g. A histogram of the weights is provided in Figure 13.

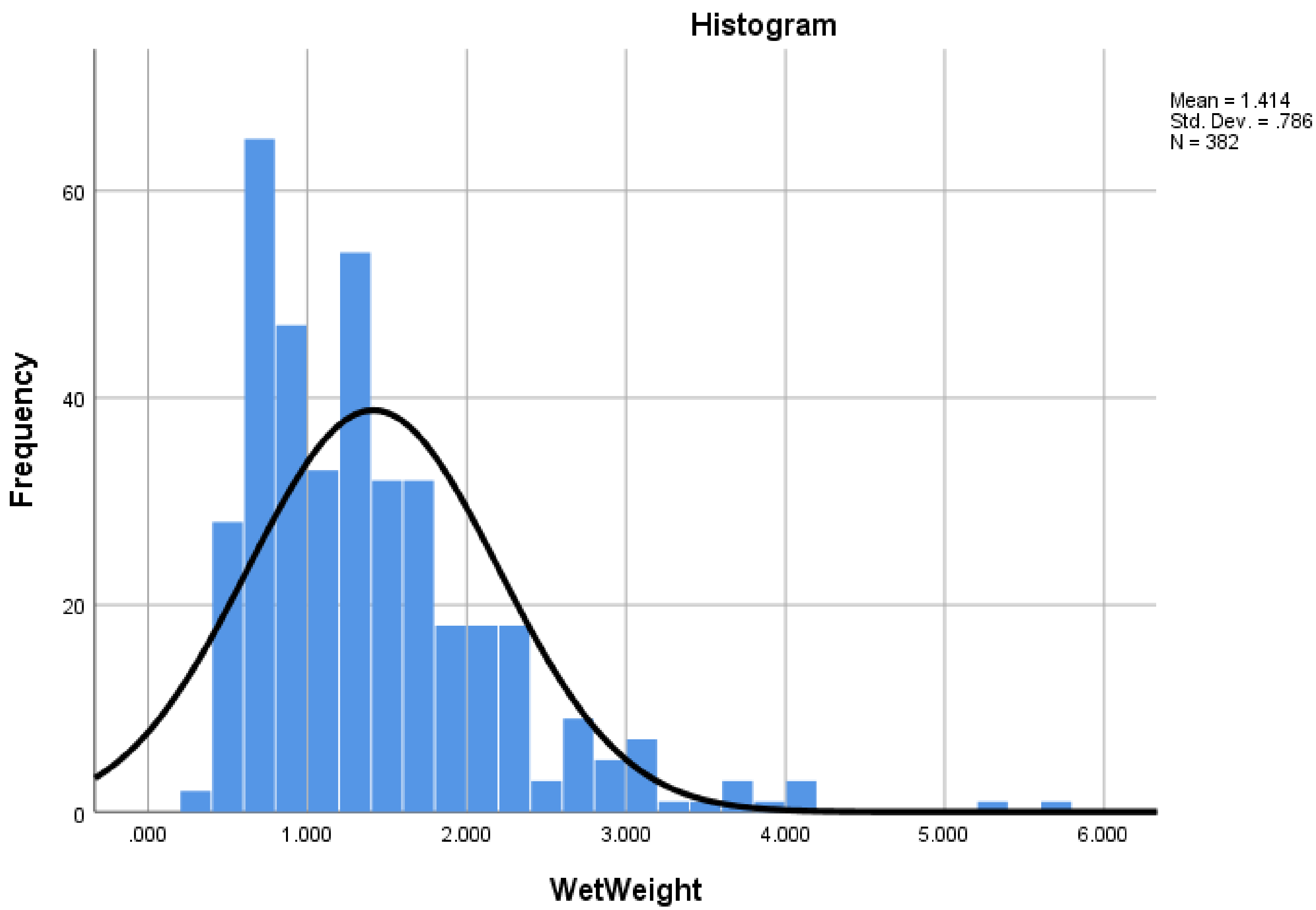

Figure 13: Histogram of All Wet Weights (Wet Weight presented in mg and Frequency in percentage).

For the first analysis, the null hypothesis, H_0, was water type (Birmingham Water Works Board or BWWB, and Lake provided) has no effect on wet weight for the same technique type (Tower Garden®, pallet, or pyramid garden). The alternate hypothesis, H_A, was the water type has an effect on wet weight for the same technique type. The total weight of spinach per technique collected indicates lake water was more productive which was also indicated by the number of spinach leaves that were collected for testing. The Tower Garden® with lake water had a n=91 and sum weight of 137.412 mg; thus producing the largest volume and weight of spinach. The data suggests the techniques using lake water produced more spinach (Tower Garden® n= 91, Pallet n=77, and Pyramid n=43). The minimum and mean weights for both pallet and pyramid lake water were larger than their BWWB counterparts. The pyramid garden with BWWB water produced the least number of spinach leaves, n=35, and smallest combined weight, 39.965 mg. The data are further presented in the Descriptive Statistics Table, Table 4.

Table 4

Wet Weight Descriptive Data

Technique-Water Type	n	Min.	Max.	Mean	Median	Std. Deviation	Sum
Tower Garden® BWWB	74	0.425	5.303	1.77	1.620	0.876	131.011
Tower Garden® Lake	91	0.366	5.603	1.510	1.308	0.916	137.412
Tower Garden® Combined	165	0.366	5.603	1.627	-	0.905	268.423
Pallet BWWB	62	0.370	2.106	1.036	0..868	0.443	64.234
Pallet Lake	77	0.552	3.912	1.390	1.223	0.706	107.016
Pallet Combined	139	0.370	3.912	1.232	-	0.626	171.25
Pyramid BWWB	35	0.466	2.833	1.142	0.987	0.606	39.965
Pyramid Lake	43	0.437	3.463	1.404	1.312	0.685	60.383
Pyramid Combined	78	0.437	3.463	1.287	-	0.660	100.348

Note: Data are presented in mg for weight. H_0: water does not affect weight mean. H_A: water type does effect weight mean.

Analysis of Variance (ANOVA) with a 95% confidence level was used (significant at $p<0.05$). During the analysis, an assumption was made in regard to outliers based on *Performing Data Analysis Using IBM SPSS*, Meyers (2013). Weights that were greater than the mean plus 2.5 times the standard deviation were removed to normalize the data (Meyers, 2013). For the first analysis, the null hypothesis, H_0, was water type (Birmingham Water Works Board or BWWB, and Lake provided) has no effect on wet weight for the same technique type (Tower Garden®, pallet, or pyramid garden). The alternate hypothesis, H_A, was the water type has an effect on wet weight for the same technique type. For the Tower Gardens®, $p=0.066$ indicated the null hypothesis was true. Results from both pallet and pyramid gardens ($p=0.002$ and 0.049, respectively), indicated the null hypothesis is false and water type has an effect on the soil-based systems. The data are presented in Table 5. Box plots of the data are presented in Figure 14.

Table 5

Wet Weight Analysis by Water Type (ANOVA)

	Sum of Squares	Degrees of Freedom (Df)	Mean Square	F	Significance (Sig.)
		Tower Garden® Wet Weight			
Between Groups	2.767	1	2.767	3.432	0.066
Within Groups	131.446	163			
Total	134.213	164			
		Pallet Garden Wet Weight			
Between Groups	3.049	1	3.049	10.064	0.002*
Within Groups	40.901	135	0.303		
Total	43.950	113637			
		Pyramid Garden Wet Weights			
Between Groups	1.494	1	1.494	4.003	0.049*
Within Groups	27.616	74	0.3.73		
Total	29.110	75			

Note: *Significant at the $p<0.05$.

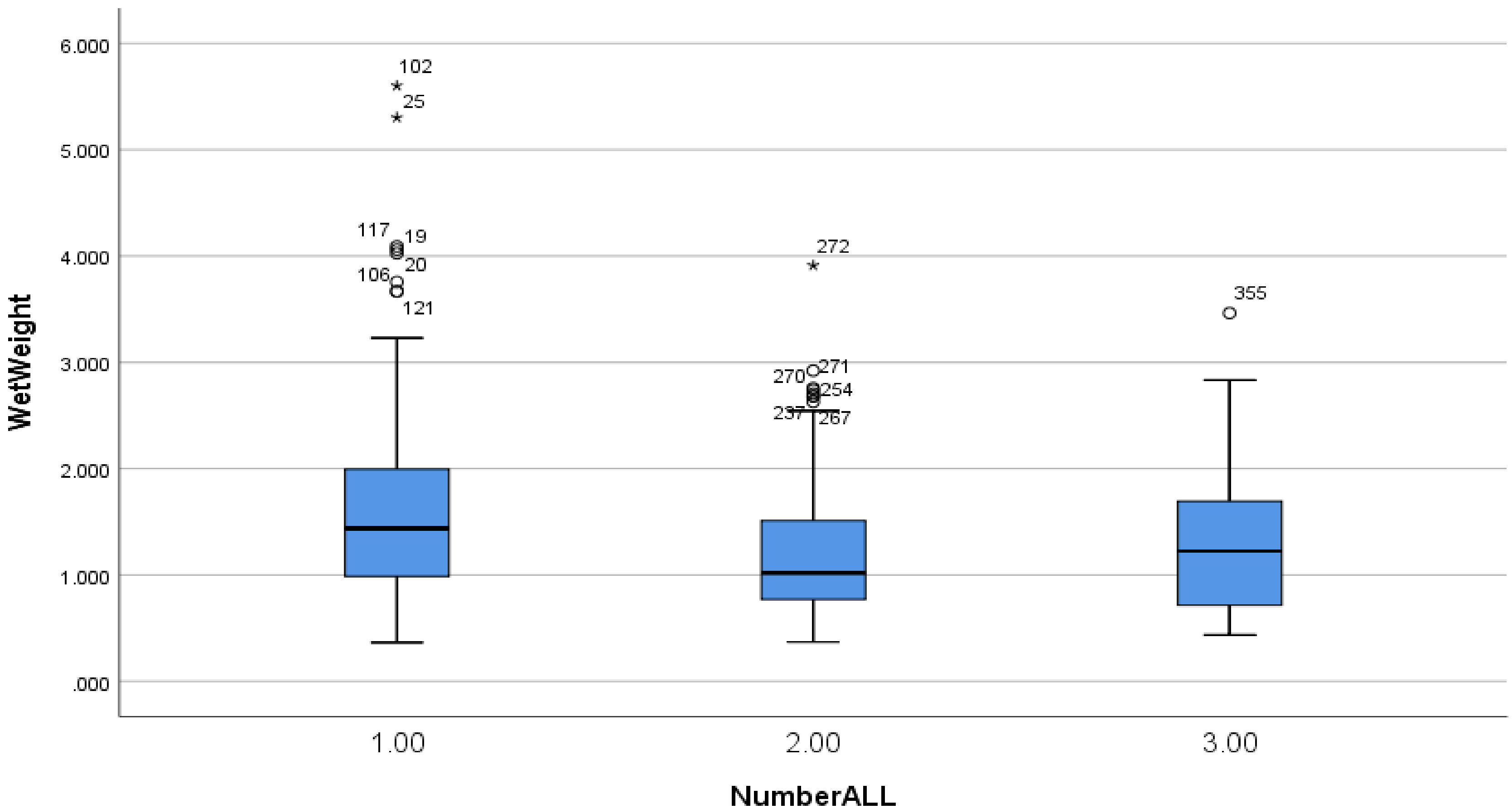

Figure 14: Boxplots of Wet Weights (mg)

(Coding for Figure 14: 1.00: Tower Gardens®, 2.00: Pallet Gardens, 3.00: Pyramid Gardens)

The data were further analyzed using a one-tailed multiple comparisons test to compare the means of the combined wet weight data of each technique. The data compared all of the Tower Garden® wet weights to the pallet garden wet weights, pyramid garden wet weights, and vice versa. The null hypothesis, H_0, is the mechanism does not affect the overall wet weight, and the alternate hypothesis, H_A, is the mechanism does affect the overall wet weight. Per Levene's Test/Test of Homogeneity of Variance, it was assumed the variances are equal, significance is $p<0.05$, however, the significance was $p=0.000$ indicating Games-Howell was to be used. The data indicated the null hypothesis is false and differences exists between Tower Garden® and pallet garden (p=0.002) and pallet garden and Tower Garden® (p=0.002). However, the null hypothesis is true when comparing Tower Garden® and pyramid garden (vice versa) and comparing pallet garden and pyramid garden (vice versa). The data are presented in Table 6. The mean wet weights for each mechanism are as follows: Tower Garden® was 1.6237 mg, pallet garden was 1.23, and pyramid garden was 1.287. Assessing the boxplot, it was observed the pallet gardens had smaller wet weights and a smaller range. This could imply the pallet garden plants did not grow as large as the Tower Garden® plants when considering the null hypothesis is false.

Table 6

Multiple Comparisons of Wet Weights by Mechanism

(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Level of Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tower Garden®	Pallet Garden	0.260*	0.076	0.002*	0.082	0.438
	Pyramid Garden	0.206	0.092	0.069	-0.012	0.423
Pallet Garden	Tower Garden®	-0.260*	0.076	0.002*	-0.438	-0.082
	Pyramid Garden	-0.054	0.092	0.823	-0.271	0.163
Pyramid Garden	Tower Garden®	-0.206	0.092	0.069	-0.423	0.013
	Pyramid Garden	0.054	0.092	0.823	-0.163	0.271

*. The mean difference is significant at the 0.05 level.

The wet weight analysis using Multiple Comparisons (Table 6) indicated that differences do exist between the different techniques and different water types as described previously. It was anticipated the Tower Garden® would outperform the soil-based systems due to the added nutrients the Tower Garden® requires. It was also not surprising that the lake water outperformed the Birmingham Water Works Board water because the lake water has added nutrients from fertilizer run-off and aquatic life.

5.2.3: Spring Results: Percent Moisture Content

Percent moisture content is a measurement of the spinach leaves in relation to the dry content. This information indicates the amount of water content of the spinach and how much mass is actually consumed by the consumer.

The percent moisture content descriptive statistics are presented in Table 7. The values are presented as a percentage, such that 81.73 is 81.73%. The percent moisture content means ranged from 89.18 (pyramid lake) to 91.69 (Tower Garden® BWWB). From Lefsrud et al. (2008), the means are within the range identified in their study.

Table 7

Descriptive Statistics for Mechanism by Water Type in terms of Percent Moisture Content

	n	Minimum	Maximum	Mean	Std. Deviation
Tower Garden® BWWB	74	81.73	94.95	91.69	1.87
Tower Garden® Lake	91	89.16	95.12	91.65	1.10
Tower Garden® Total	165	81.73	95.12	91.66	1.49
Pallet BWWB	62	84.40	98.74	90.06	2.27
Pallet Lake	77	80.47	95.96	90.29	2.33
Pallet Total	139	80.47	98.74	90.19	2.30
Pyramid BWWB	35	74.98	95.69	89.81	3.64
Pyramid Lake	43	74.87	94.37	89.18	3.334
Pyramid Total	78	74.87	95.69	89.46	3.47

Note: Data are presented in percentages.

The null hypothesis, H_0, is that water type for the same technique does not affect percent moisture content. The null hypothesis was true for each technique. The alternate hypothesis is that water type for the same technique affects percent moisture content. The ANOVA table is presented in Table 8 for each technique and water type. Wet versus dried spinach leaves are shown in Figure 15.

Figure 15: Wet Spinach and Dried Spinach.

Table 8

ANOVA Mechanism by Water Type in terms of Percent Moisture Content

	Sum of Squares	*Df*	*Mean Square*	*F*	*Sig.*
		Tower Garden® Percent Moisture Content			
Between Groups	0.713	2	0.356	0.159	0.854
Within Groups	364.304	162	2.249		
Total	365.017	164			
		Pallet Garden Percent Moisture Content			
Between Groups	1.743	1	1.743	0.328	0.568
Within Groups	729.028	137	5.321		
Total	730.771	138			
		Pyramid Garden Percent Moisture Content			
Between Groups	7.746	1	7.746	0.641	0.426
Within Groups	918.609	76	12.087		
Total	926.355	77			

Note: Significant at the $p<0.05$

The data were further analyzed using multiple comparisons using a one-tailed test (Table 9). The null hypothesis, H_0, is the percent moisture content means are the same across the technique at the 95% confidence level. The alternate hypothesis, H_A, percent moisture content means are not the same across the technique at the 95% confidence level. Based on Levene's Test, our *p*=0.000, meaning the variances are not equal and to use data from the "equal variances not assumed" row. Since the homogeneity of variances assumption failed and sample sizes were unequal, Brown-Forsythe methodology was used for this analysis. The data are listed below and indicate there is no significant difference in means between the Pallet and Pyramid Gardens, but a difference in means exists between Tower Gardens® and Pyramid Gardens, and Tower Gardens® and Pallet Gardens. The pallet and pyramid gardens had greater standard deviations than the Tower Gardens®, which could explain that a significant difference exists between the Tower Gardens® and the pyramid and pallet gardens (exclusively). The percent moisture content was more consistent and less widespread for the Tower Gardens®.

Table 9

Multiple Comparisons using Brown-Forsythe for Percent Moisture Content

(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Tower Garden®	Pallet Garden	1.486*	0.219	0.000*	0.968	2.004
	Pyramid Garden	2.210*	0.405	0.000*	1.243	3.177
Pallet Garden	Tower Garden®	-1.486*	0.219	0.000*	-2.004	-0.968
	Pyramid Garden	0.724	0.439	0.229	-.317	1.765
Pyramid Garden	Tower Garden®	-2.210*	0.405	0.000*	-3.177	-1.243
	Pallet Garden	-.724	0.439	0.229	-1.765	0.317

Note: *. The mean difference is significant at the 0.05 level.

5.2.4: Spring Results: Chlorophyll Analysis

Chlorophyll content data were collected using the Opti-Sciences Chlorophyll Fluorometer (OS30p) which provided the indicator for quantum yield of fluorescence (PSII), F_v/F_m. The overall minimum F_v/F_m was 0.732 and the maximum F_v/F_m was 0.798, which are within the identified ideal range of 0.7 to 0.8 (Ritchie, 2006). There were 12 samples tested for each mechanism and water type. The descriptive statistics are represented in Figure 16 and provided in Table 10.

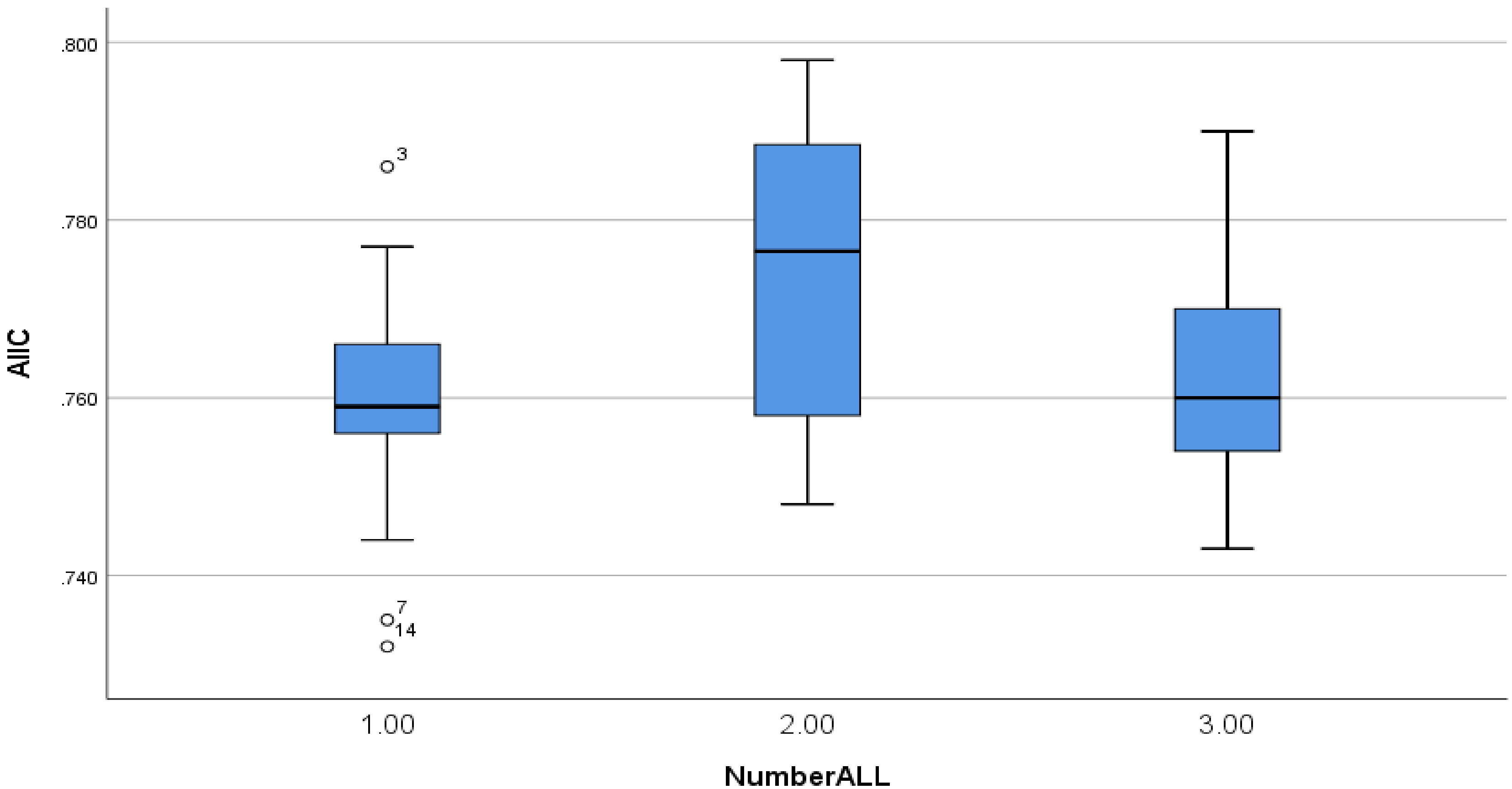

Figure 16: Chlorophyll Content Boxplot.

(Coding for Figure 16: 1.00: Tower Gardens®, 2.00: Pallet Gardens, 3.00: Pyramid Gardens, AllC is in F_v/F_m)

Table 10

Descriptive Statistics for Mechanisms by Water Type in Terms of Chlorophyll Content, F_v/F_m

	n	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Tower Garden® BWWB	12	0.735	0.786	0.758	0.013
Tower Garden® Lake	12	0.732	0.777	0.761	0.011
Tower Garden® Combined	24	0.732	0.786	0.760	0.12
Pallet BWWB	12	0.748	0.791	0.770	0.017
Pallet Lake	12	0.749	0.798	0.777	0.016
Pallet Combined	24	0.748	0.798	0.774	0.016
Pyramid BWWB	12	0.744	0.790	0.766	0.014
Pyramid Lake	12	0.743	0.776	0.756	0.010
Pyramid Combined	24	0.743	0.790	0.763	0.012

Note: Data presented in F_v/F_m.

The null hypothesis, H_0, was the mechanism by water type does not affect chlorophyll content. The alternate hypothesis, H_A, was the mechanism by water type does affect chlorophyll content. The data for the one-tailed ANOVA by water type suggests there was no significant difference between water type and mechanism in terms of chlorophyll content, especially since the chlorophyll content values are well within the range of 0.7-0.8. This is presented in Table 11.

Table 11

ANOVA Chlorophyll Content by Water Type

	Sum of Squares	*Df*	*Mean Square*	*F*	*Sig.*
		Tower Garden® Chlorophyll			
Between Groups	0.000	1	0.000	0.227	0.638
Within Groups	0.003	22	0.000		
Total	0.003	23			
		Pallet Chlorophyll			
Between Groups	0.000	1	.000	0.981	0.333
Within Groups	0.006	22	.000		
Total	0.006	23			
		Pyramid Chlorophyll			
Between Groups	0.000	1	0.000	2.414	0.135
Within Groups	0.003	22	0.000		
Total	0.003	23			

Note: Significant at the $p<0.05$

The null hypothesis, H_0, was no significant difference exists between each mechanism in terms of chlorophyll content at the 95% confidence level using a one-tailed test. The alternate hypothesis, H_A, was a difference exists between each mechanism in term of chlorophyll content. A multiple comparison of the data required the use of Games-Howell based on the Levene's Statistics Test of Homogeneity of Variance. Variance exists based on the mean $p<0.05$. The hypothesis is true that no statistical difference exists between the Tower Gardens® and the pyramid gardens in terms of chlorophyll content; however, significant differences exist between the Tower Gardens® and the pallet gardens, as well as between pallet gardens and pyramid gardens. The data are presented in Table 12. Since the data were within the specified range of 0.7-0.8 as described by Ritchie (2006), the differences are not significant to determining whether the chlorophyll content was necessarily affected by the mechanism.

Table 12

Multiple Comparisons of Chlorophyll Content between Mechanisms

	(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Games-Howell	Tower Garden®	Pallet Garden	-0.0139*	0.004	0.004*	-0.024	-0.004
		Pyramid Garden	-0.003	0.004	0.666	-0.012	0.005
	Pallet Garden	Tower Garden®	0.0139*	0.004	0.004*	0.004	0.024
		Pyramid Garden	0.011*	0.004	0.031	0.001	0.021
	Pyramid Garden	Tower Garden®	0.003	0.004	0.666	-0.005	0.012
		Pallet Garden	-0.011*	0.004	0.031*	-0.021	-0.001

Note: *. The mean difference is significant at the 0.05 level. Data presented in F_v/F_m.

5.3 Spring Results: Water Analysis

Water was analyzed for quantity and quality. Water quantity was measured to the nearest 0.5 L. Water quality testing was in accordance with *Standard Methods for the Examination of Water and Wastewater 20th Edition* (1998).

5.3.1 Spring Results: Water Quantity

There were 34 different watering sessions for a combined total of 1,238 liters of water used to maintain each mechanism. The combined mean watering was 6.00 liters. A boxplot representation is provided in Figure 17. The descriptive data for each mechanism by water type are provided in Table 13. The descriptive data suggests there were no significant differences between the mechanisms' sum use of water based on water type.

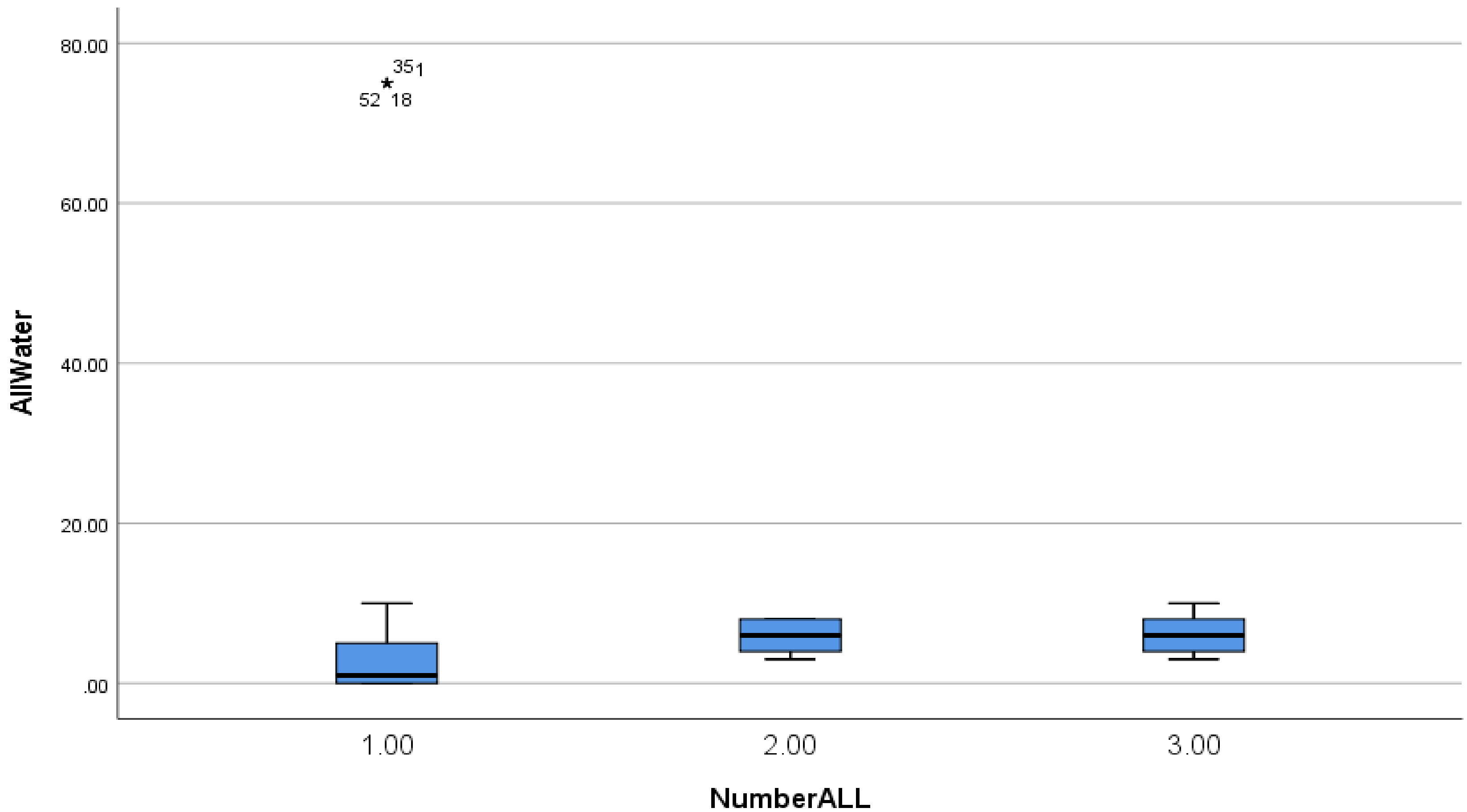

Figure 17: Water Volume (liters) Boxplot.

(Coding for Figure 13: 1.00: Tower Gardens®, 2.00: Pallet Gardens, 3.00: Pyramid Gardens)

Table 13

Descriptive Statistics for Water Quantity (liters)

	n	Minimum	Maximum	Sum	Mean	Std. Deviation
Tower Garden® BWWB	34	0.00	75.00	220.00	6.471	17.647
Tower Garden® Lake	34	0.00	75.00	218.00	6.412	17.624
Tower Garden® Combined	68	0.00	75.00	438.00	6.441	17.503
Pallet Garden BWWB	34	3.00	8.00	198.00	5.824	2.007
Pallet Garden Lake	34	3.00	8.00	198.00	5.824	2.007
Pallet Garden Combined	68	3.00	8.00	396.00	5.824	1.992
Pyramid Garden BWWB	34	3.00	10.00	206.00	6.059	2.348
Pyramid Garden Lake	34	3.00	8.00	198.00	5.824	2.007
Pyramid Garden Combined	68	3.00	10.00	404.00	5.941	2.171

Note: Data are presented in liters

The null hypothesis, H_0, was the mechanism would not affect water volume used. The alternate hypothesis, H_A, was the mechanism would affect water volume used. A one-tailed ANOVA presented the significance of p=0.933 indicating the mechanism does not affect the water volume used, which was also indicated by the descriptive data (Table 14). Additionally, the null hypothesis, H_0, was that the type of water in the mechanism would not affect the amount of water used. The alternative hypothesis, H_A, was the type of water in the mechanism would not affect the amount of water used. Data related to the hypothesis are presented in Table 15. The null hypothesis was correct for each mechanism and water type.

Table 14

ANOVA for Total Water Volume Used

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.627	2	7.314	0.070	0.933
Within Groups	21108.412	201	105.017		
Total	21123.039	203			

Note: Significant at the $p<0.05$

Table 15

ANOVA for Water Volume Used by Mechanism

	Sum of Squares	df	Mean Square	F	Sig.
Tower Garden® Volume Used by Water Type					
Between Groups	0.059	1	0.059	0.000	0.989
Within Groups	20526.706	66	311.011		
Total	20526.765	67			
Pallet Garden Volume Used by Water Type					
Between Groups	0.000	1	0.000	0.000	1.000
Within Groups	265.882	66	4.029		
Total	265.882	67			
Pyramid Garden Volume Used by Water Type					
Between Groups	.941	1	0.941	0.197	0.658
Within Groups	314.824	66	4.770		
Total	315.765	67			

Note: Significant at the $p<0.05$

From this analysis, it can be deduced that each mechanism and water type require a similar volume of water for plant survival. The data provided are based on assumptions made about the need for the soil moisture reading to be “wet”. Variability exists in the amount of moisture in the soil and the amount required by different plant species. The volumes of water represented here should not be seen as a standard, but rather as only what occurred to sustain the spinach plant’s life in this research.

5.3.2: Spring Results: Water Quality

An additional facet of this project was testing the water quality of the water used. These data were used as an indicator of plant growth success based on the overall coloration and health of the spinach. A comparison of the Birmingham Water Works Board 2018 reported data is compared to the values collected for this project in Table 16 (Birmingham Water Works Board, 2019). The Birmingham Water Works Board 2019 “Quality in Every Drop” provides a summary of the 2018 Chemical Analysis for each water source plant by providing a “highest value” and a “range” for numerous chemical parameters; however, data was not presented for hydrogen ion, pH in the referenced document.

The highest alkalinity value for both the Aldridge Gardens’ BWWB collected water (210 mg/L as $CaCO_3$) and lake water (150 mg/L as $CaCO_3$) were higher than the highest 2018 value measured (78 mg/L as $CaCO_3$) at the Shades Mountain Filter plant from which the water is provided. There are multiple ways to measure alkalinity, and it is unknown which method was used by the Birmingham Water Works Board.; therefore, no direct comparisons can be drawn.

The specific conductance for the Aldridge Gardens' BWWB collected water (258 µS/cm) and lake water (116 µS/cm) were less than the 2018 maximum value measured (360 µS/cm) at the Shades Mountain Filter plant. This test is also temperature dependent, and the conditions for Birmingham Water Works Board testing is unknown. Further, the turbidity of Aldridge Gardens' BWWB collected water (0.18 NTU) was less than highest 2018 recorded value (0.21 NTU) at the Shades Mountain Filter Plant; however, the lake water had a higher turbidity reading of 1.35 NTU. It is expected for the turbidity reading to be higher for the lake water because it is not filtered water.

Table 16

Comparison of Water Quality Characteristics

	Alkalinity due to Bicarbonates (mg/L as $CaCO_3$)	Conductance (µS/cm)	Hydrogen Ion, pH	Turbidity (NTU)
2019 BWWB Report Shades Mountain Plant	78	360	-	0.21
Aldridge BWWB	210	258	7.11	0.18
Aldridge Lake	150	116	7.4	1.35

Note: Data is presented in the highest recorded value.

It was assumed the lake water would provide similar plant outcomes (survival, weight, and chlorophyll content) to city water due to the natural and supplemented nutrients the lake water provided by the aquatic life and drainage of fertilizers to the lake. There was some concern that the run-off from the Aldridge Gardens' property could negatively impact the health of the spinach, so water monitoring was implemented in the study. Water quality testing was performed during the last four weeks of the spring planting season and the results are provided in the tables below. The state of Alabama does not maintain water quality standards for agricultural waters; therefore, the results do not have a state comparator. *Note: Distilled water was used as a control.*

Alkalinity.

Alkalinity measurements were taken four times during the spring growing season and each time two sets of water samples were analyzed for each water type. A boxplot of the data are provided in Figure 18. The descriptive data are provided in Table 17.

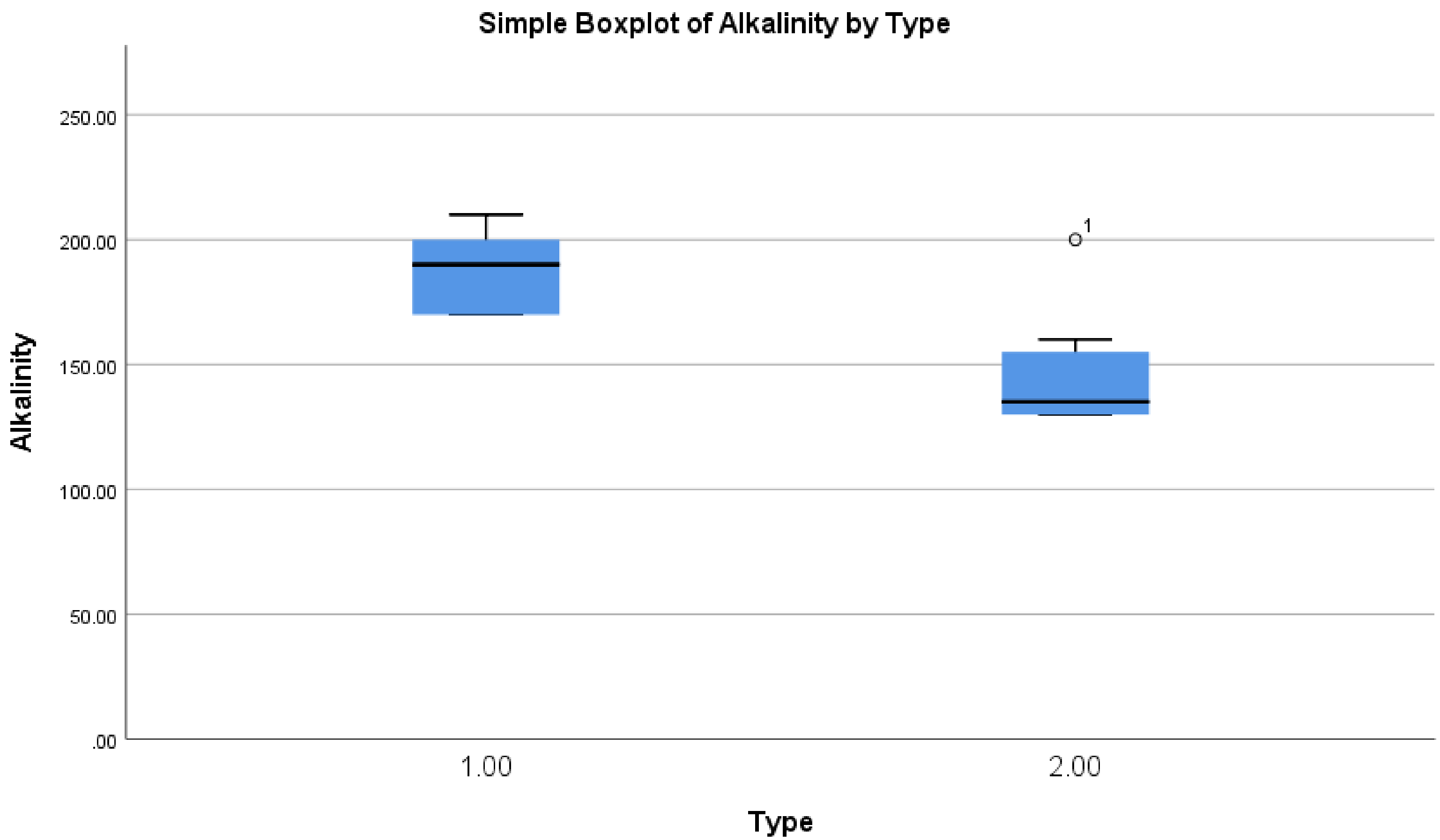

Figure 18: Alkalinity due to Bicarbonates (mg/L as $CaCO_3$) Boxplot.

(Coding for Figure 18: 1.00: BWWB Water and 2.00: Lake Water)

Table 17

Descriptives of Alkalinity due to Bicarbonates (mg/L $CaCO_3$)

	N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
BWWB	8	187.50	16.69	173.55	201.45	170.00	210.00
Lake	8	146.25	24.46	125.80	166.70	130.00	200.00
Total	16	166.88	29.375	151.22	182.53	130.00	210.00

Note: Data presented in $CaCO_3$ mg/L

Conductance.

Conductance was tested over Weeks 1, 3, and 4 of the spring 2019 season and each water type was tested twice during Weeks 3 and 4. The data are presented in Figure 19 and Table 18.

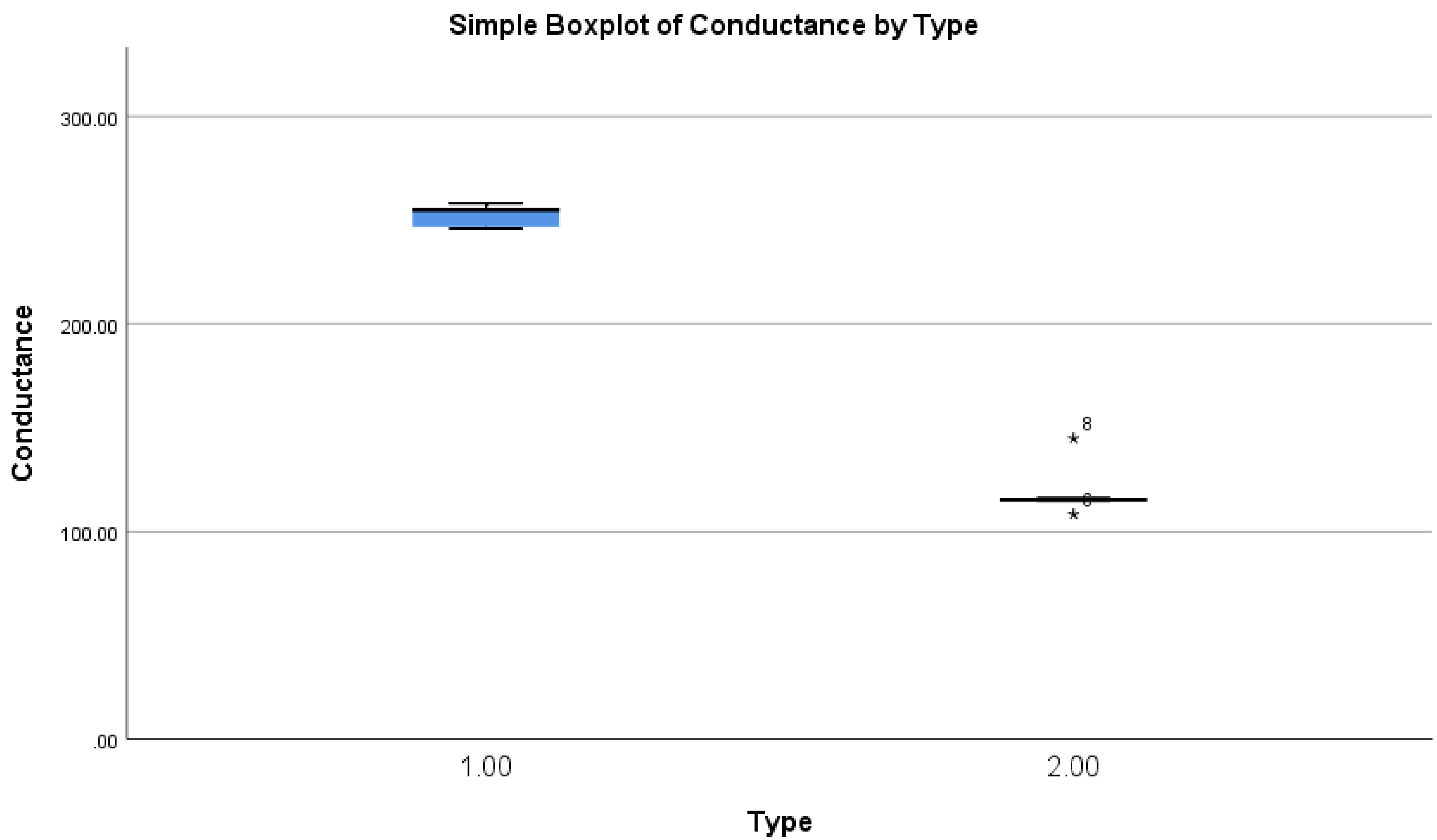

Figure 19: Conductance (µS/cm).

(Coding for Figure 19: 1.00: BWWB Water and 2.0: Lake Water)

Table 18

Descriptives of Conductance (μS/cm)

	N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
BWWB	5	252.40	5.51	245.60	259.23	246.00	258.00
Lake	5	119.8	14.29	102.10	137.58	108.30	144.80
Total	10	186.1	70.601	135.61	236.63	108.30	258.00

Note: Date presented as *μS/cm*.

Hydrogen Ion, pH

The Birmingham Water Works Board water and lake water pH was measured three times during Weeks 1-4. The mean pH for BWWB was 6.72 and mean pH for lake water was 6.90. Again, Alabama has no agricultural water guidelines from which to compare this data to. The overall maximum pH was 7.40 for the lake water. Had the pH of the water been greater than 8.0 or less than 6.0 for several days, it would be assumed the soil pH would have been impacted. The boxplot representation is presented in Figure 20 and descriptive data are presented in Table 19.

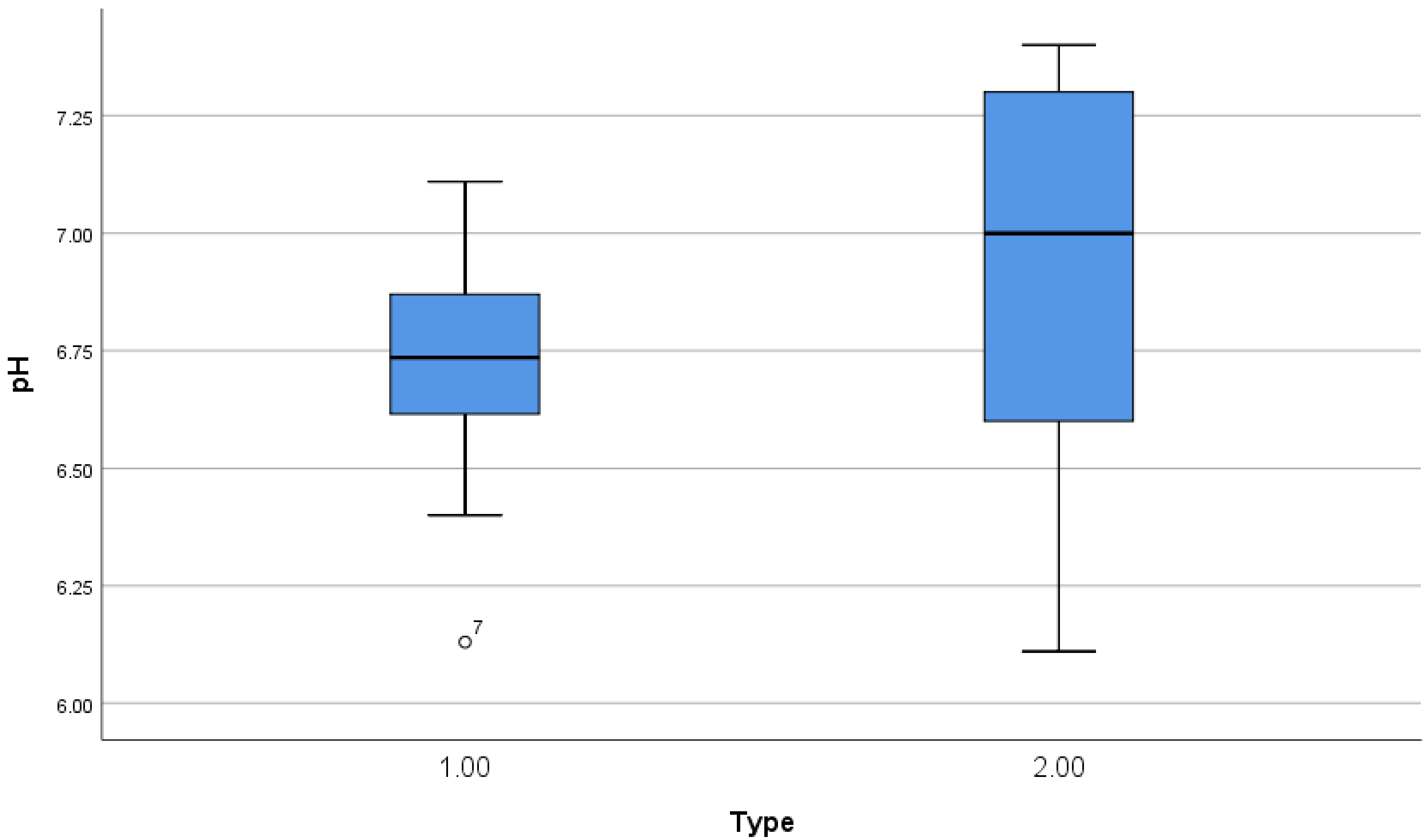

Figure 20: pH Boxplot.

(Coding for Figure 20: 1.00: BWWB Water and 2.0: Lake Water)

Table 19

Descriptives of pH

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
BWWB	12	6.72	.2755	.0795	6.5458	6.8959	6.13	7.11
Lake	12	6.8967	.4709	.1359	6.5975	7.1958	6.11	7.40
Total	24	6.8088	.3878	.0791	6.6450	6.9725	6.11	7.40

Turbidity

Turbidity measurements were taken two times during Weeks 1-4. As expected, due to the characteristics of lake water, the turbidity of the lake water was higher than that of the BWWB water. The lake water mean turbidity was 1.096 NTU as compared to 0.104 NTU for the lake water. The mean values are statistically significant when compared using ANOVA, but again, this was expected. The data are presented in Figure 21 and Table 20.

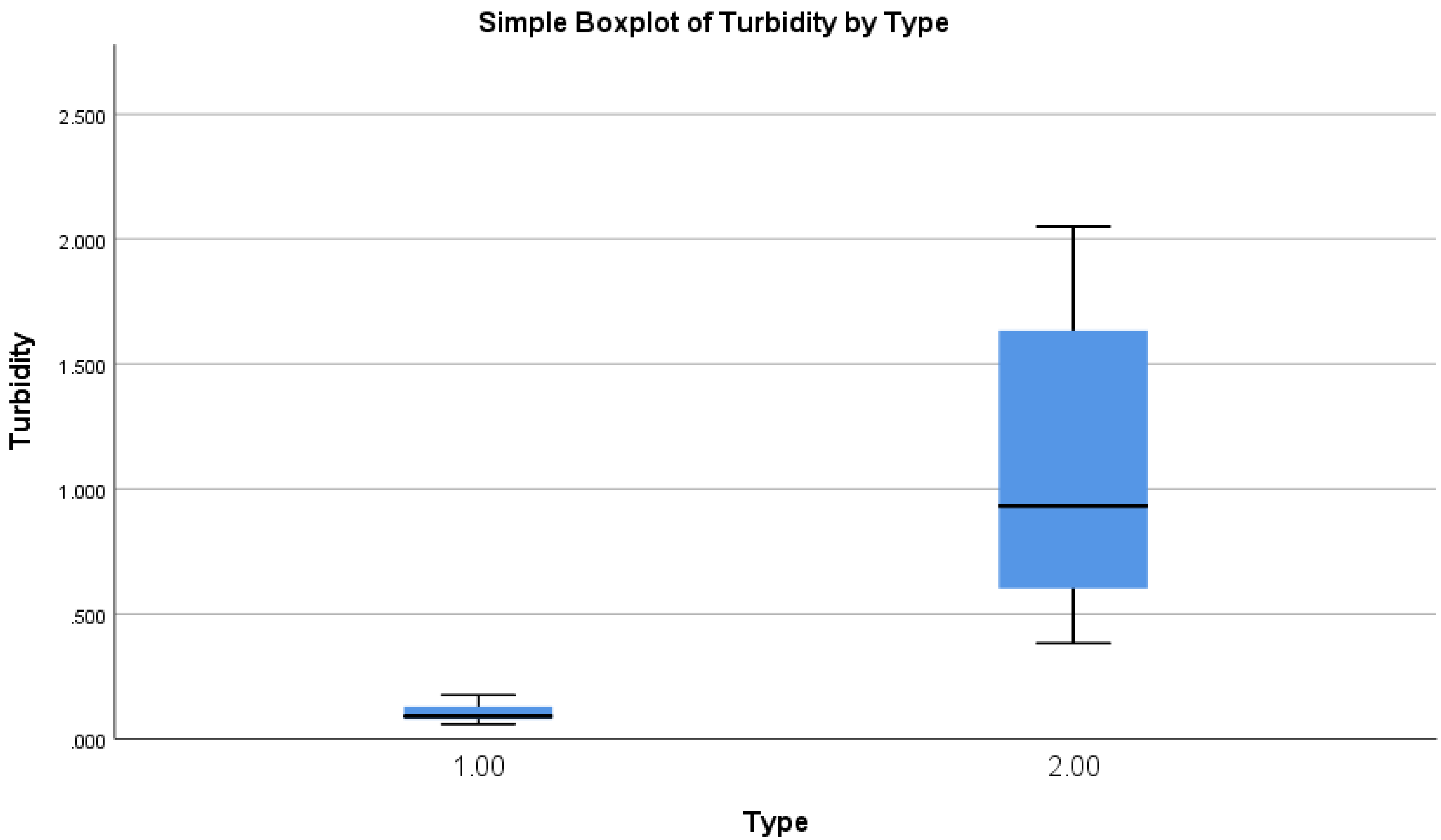

Figure 21: Turbidity (NTU) Boxplot.

(Coding for Figure 21: 1.00: BWWB Water and 2.0: Lake Water)

Table 20

Descriptives of Turbidity (NTU)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	8	0.104	0.0403	0.014	0.070	0.138	0.060	0.175
2.00	8	1.096	0.633	0.224	0.568	1.6252	0.383	2.050
Total	16	0.600	0.671	0.168	0.243	0.958	0.060	2.050

Note: Data presented in NTU.

5.4 Spring Results: Soil pH

The soil pH was measured 17 times using the Dr. Meter 4-in-1Soil Water Meter and the Hydro Crunch Soil Moisture 3-in-1 Soil Tester for the soil-based mechanisms between April 4, 2019 through May 19, 2019. The pH values were averaged between the two testers and used for the analysis. The highest measured soil pH was measured at 7.4 on April 30, 2019 for the BWWB Pallet, and the lowest pH was measured to be 6.9 for multiple mechanisms during the first two measuring sessions. The ideal soil range for spinach is 6.4-6.8 (Sanders, 2001). The soil pH was within the Old Farmer's Almanac (2018) range of 6-7.5. The pH of all the mechanisms ranged from 6.9 to 7.4 which was greater than the desired range per Sanders (2001); however, there was no indication of the pH of the soil affecting the spinach growth (no delayed growth) or coloration (no yellowing). The data are presented in Figure 22 and Table 21.

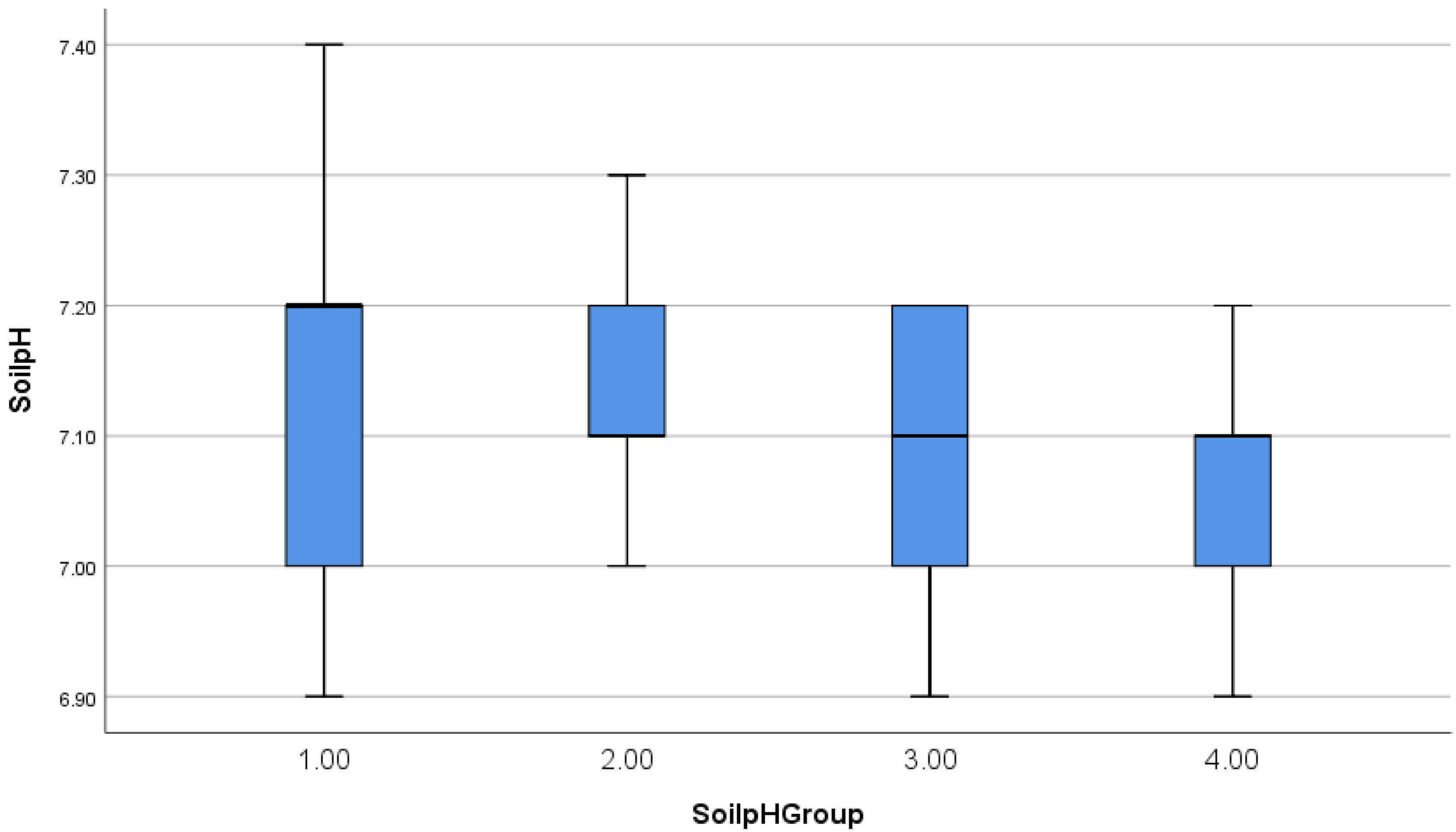

Figure 22: Spring Season Soil pH by Mechanism and Water Type.

(Coding for Figure 22: 1.00: Pallet BWWB, 2.00: Pallet Lake, 3.00 Pyramid BWWB, 4.00 Pyramid Lake)

Table 21

Descriptives of Spring Soil pH

	n	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Pallet BWWB	34	7.129	.119	7.088	7.171	6.90	7.40
Pallet Lake	34	7.121	.088	7.090	7.151	7.00	7.30
Pyramid BWWB	34	7.091	.090	7.060	7.123	6.90	7.20
Pyramid Lake	34	7.059	.070	7.034	7.083	6.90	7.20
Total	136	7.100	.096	7.084	7.116	6.90	7.40

CHAPTER VI

CONCLUSIONS

As previously discussed, food insecurity is the disturbance in normal and healthy eating habits due to the lack of resources, such as money, supplemental aid, and access to fresh fruits and vegetables (Office of Disease Prevention and Health Promotion, 2018). The 2019 USDA Economic Research Service further defines food insecurity as the uncertainty of sufficiently feeding all members of a household due to insufficient resources to acquire food. Food insecurity has declined in United States households from a peak of 14.7% in 2009 to 11.1% in 2018, and the decline in percentage of households defined as food insecure has been significant since 2011 due to an overall increasing economy (USDA Economic Research Service, 2019). However, the average food insecurity in Alabama was 14.7% for 2016-2018 per the USDA Economic Research Service (2019). The Health Action Partnership (2018) stated in 2016 that 19% of the Jefferson County, Alabama population was considered food insecure, a percentage significantly higher than the national food insecurity average of 12.3% in 2016 (USDA Economic Research Service, 2019). Even though food insecurity is currently declining in the United States, the projected increase in the world's population will continue to result in the need for sustainable food security measures to support the growing population and evolving environment (Federman, 2018).

Previous research by UAB, the Health Action Partnership, and numerous other groups indicate food insecurity affects a large percentage of residents residing in

Birmingham, Alabama. One of the suggested means to increase food security at the individual and local level is community gardens. To reduce food insecurity for faculty, staff, and students, UAB established a food bank, Blazer Kitchen. Blazer Kitchen established in 2017, provides non-perishable food, fresh foods, and other miscellaneous items from the Community Food Bank of Central Alabama and other local retailers (Gunter, 2017). In 2020, the UAB Green Thumb on-campus organization initiated a campaign, Green Thumb Gardening Days, to supplement Blazer Kitchen's food resources with fresh produce grown through UAB's community garden (Herfurth, 2020).

The historical air and soil pollution in Birmingham, Alabama, has resulted in residents fearing the impacts of years of pollution on health and the environment (Gould, 2018). Vertical gardening techniques can avoid the use of contaminated soils by using either commercially purchased soils or by using an aeroponic/hydroponic system. The purpose of this research was to identify cost-effective vertical gardening techniques for personal and community gardening to provide supplemental fresh food options to those living in food insecure conditions. Very limited research exists on the volume of edible produce harvested by vertical gardens, and this aspect was a priority of this research. Secondarily, this research sought to determine whether an alternative water source to city water with lower associated cost of use, i.e. lake water, could be used to reduce the overall cost of urban gardens. Again, research does not currently exist studying the impacts of lake water use on small community gardens; however, there are research findings regarding the use of rainwater and greywater for community gardening described in the literature review.

Prior research focused heavily on the causes of food insecurity and social determinants of health (race, socioeconomics, ethnicity, gender, and education status); the positive impacts of community gardens on food access, community engagement, and mental health; the environmental impacts of community gardens (water conservation and runoff), and plant yields from community gardens in various parts of the world. These research studies indicate the need for community gardens as a strategy to support healthier communities (physically and socially) but acknowledged community gardens are not alone sufficient to resolve the overall issue of food insecurity and health disparities. The current research analyzes using raised-bed gardens and rooftop gardens, especially in areas with limited green spaces. Very few research studies have been conducted on the impact of vertical gardening in community gardens and minimizing horizontal space requirements. The purpose of this research was to identify vertical gardening mechanisms and alternative water sources to sustain community gardens in areas with limited horizontal space and contaminated soils.

Once it was established to study vertical gardening mechanisms, three mechanisms were selected: Tower Gardens®, pallet gardens, and pyramid gardens. Each mechanism offered a unique opportunity to study. It was also imperative for the vertical gardening mechanisms to require limited amounts of horizontal space since land space is at a premium. Tower Gardens® are a type of hydroponics, aeroponics, which do not require the use of soil. Pallet gardens are an upcycled mechanism using shipping pallets that were destined for a landfill. Pyramid gardens are a raised-bed type growth system that increases the available square footage for plants by offering multiple levels for plants in one system. In terms of horizontal space and plant space, the following amount of space was required for each system: a Tower Garden® required approximately three square feet for 20 plants, a pallet garden required approximately 1.5 square feet for a range of 8-12 plants, and a pyramid garden required four square feet for 15 plants. The Tower Garden® purchase cost is approximately $600 for each device, but the Tower Garden® requires electricity and supplemental nutrients contributing to additional costs for the mechanism to operate. The cost to assemble six pallet gardens (only four were used for this project) with potential to assemble more units was less than $100. The pyramid garden prices varied based upon the number of levels desired and assembled. For this project, three-tiered pyramid gardens were purchased for $99.99 each.

The project desired to use multiple water sources, due to the universal increasing costs for potable water, with the multiple mechanisms. Originally, city-provided water, lake water, and collected rainwater were used. Due to the number of variables, three water sources, three mechanisms, and three varieties of plants, the use of collected rainwater as a water source was removed from the project because rainwater was determined to be excessively variable in terms of its contaminants and collection means. As previously discussed, spinach was selected to limit the variability in plant selection and to provide a plant with multiple growing seasons in Birmingham, Alabama. The final research resulted in fall and spring planting seasons using three mechanisms (Tower Garden®, pallet garden, and pyramid garden) with two water sources (Birmingham Water Works Board-provided and on-site lake water) growing spinach.

As there was a desire to avoid contaminated soils, commercially purchased soils were evaluated based on cost prior to selection. Originally, Kellogg Garden Organics® 2 cubic feet All Natural Garden Soil for Flowers and Vegetables was selected because of its lower price, but it was realized that this product did not provide adequate soil and nutrients as this product was composted mostly wood fines. Miracle Gro® Raised Bed Soil (1.5 cubic feet) was then selected as the soil because Miracle Gro® Raised Bed Soil did not require mixing with additional soil and was organic; however, Miracle Gro® Raised Bed Soil did cost more than the Kellogg Garden Organics®. The increased cost, approximately $1.50, of Miracle Gro® Raised Bed Soil was deemed to be reasonable due to the greater success in plant survival.

Resulting from the requirement for electricity, the Tower Gardens® were located in a different orientation, southwest, than the pallet and pyramid gardens which were south-southwest oriented. The pallet and pyramid gardens were located adjacent to each other facing the same direction. An awning was added to the Educational Garden structure at Aldridge Gardens immediately behind the Tower Gardens® after the gardens were planted and ultimately added more shade than originally anticipated; thus, the Tower Gardens® were moved prior to the Spring 2019 season about one foot further away from the original location to reduce shading from the awning.

The Tower Gardens® were initially filled with 20 gallons of water plus the required amount of the Tower Gardens® Mineral Blend per the manufacturer's guidelines. Each pallet and pyramid garden required two to three bags of Miracle Gro® soil. Less than one bag of the fertilizer was used between the pallet gardens and pyramid gardens during the two growing seasons and was applied per the manufacturer's recommendations. The Tower Gardens® were planted with 20 spinach seedlings procured from WNC Urban Farms; the pallet gardens were planted with 8-12 spinach seedlings procured from WNC Urban Farms in the fall and from Lowe's® in the spring with the number of seedlings based on the size of the pallet, and the pyramid gardens were planted with 9-12 spinach seedlings from WNC Urban Farms (12 seedlings) in the fall and from Lowe's® (9 seedlings) in the spring. Watering occurred multiple times per week based on on-site measured rainfall amounts and soil moisture measurements. Each watering session was measured in liters of water per mechanism per water type. Rainfall amounts were recorded in inches. Water samples from both the Birmingham Water Works Board water and lake water were tested and analyzed for alkalinity, conductance, pH, and turbidity at UAB's Environmental Engineering Lab.

Spinach leaves were harvested and measured for wet and dry mass at UAB's Biology Lab. These data were used to calculate percent moisture content. The harvested spinach leaves' chlorophyll content was also measured at UAB's Biology Lab.

Very limited data was collected during the fall 2018 planting due to the higher than normal temperatures during September and October leading to the demise of many of the plants. The leaves from the surviving spinach plants were measured for wet weight, dry weight, and chlorophyll content. The leaves weights ranged from 0.21 mg to 1.55 mg with the percent moisture content ranging from 92% to 97%. The chlorophyll content measurements were within the acceptable range for spinach, as the data varied between 0.7 to 0.8 F_v/F_m. Due to the sample size, the fall 2018 planting data was not compared to the spring 2019 data. The fall 2018 growth season confirmed the fact that spinach plants do not grow well in sustained temperatures above 75 ˚F. Future Alabama fall seedings of spinach should be planted in late October or early November due to typically cooler temperatures at the time.

Based on findings in regard to ambient temperature, the spring 2019 season began in early April where temperatures are typically within the desirable range for spinach and generally more consistent. Of the 152 spinach seedlings planted in the three mechanisms, 106 survived the entire spring season for a survival rate of 69.7%. The pallet gardens had the greatest combined survival rate of 88.9% (plants grown in both city water and lake water), followed by the Tower Gardens® combined survival rate of 73.8% (plants grown in both city water and lake water). The pyramid gardens overall survival rate was 41.7%. The pallet garden with lake water had the highest individual survival rate of 94.4%. The Tower Garden® using lake water had the second highest survival rate at 85.0%, and the survival rate of the pallet garden with Birmingham Water Works Board (BWWB) water experienced a survival rate of 83.3%. The Tower Garden® using BWWB water had a survival rate of 62.5%. The pyramid garden using lake water experienced 50.0% survival, and the pyramid garden plants grown using BWWB water had a 33.3% survival rate. The data clearly indicated the pallet garden is a more successful mechanism based on plant survival than the other mechanisms. The data also indicated spinach growth with lake water produced greater survival rates (79.0%) than the spinach grown with BWWB water (60.5%). It should be noted that although the pallet gardens spinach survival rate was greater than that of the Tower Gardens®, this may be the result of the power failure to the Tower Gardens® for two to three days in April 2019.

The initial hypothesis was a follows: the null hypothesis, H_0, was water type (Birmingham Water Works Board or BWWB, and Lake provided) has no effect on wet weight for the same technique type (Tower Garden®, pallet garden, or pyramid garden). The alternate hypothesis, H_A, was the water type has an effect on wet weight for the same technique type. Analysis of Variance, ANOVA, with a 95% confidence level (significant at $p<0.05$) and one-tailed, indicated the following: H_0 was true for Tower Gardens® ($p=0.066$); H_0 was false for pallet gardens ($p=0.002$), and H_0 was false for pyramid gardens ($p=0.049$). The descriptives data of the pallet garden and pyramid garden with lake water produced greater mean and median wet weights than the pallet garden and pyramid garden with BWWB provided water.

The next hypothesis also tested the null hypothesis and alternate hypothesis using a one-tailed ANOVA and a 95% confidence level (significant at $p<0.005$). The second null hypothesis, H_0, is the mechanism does not affect the overall wet weight, and the alternate hypothesis, H_A, is the mechanism does affect the overall wet weight. The null hypothesis is true when comparing Tower Garden® and pyramid garden (vice versa) and comparing pallet garden and pyramid garden (vice versa). The data indicated the null hypothesis is false and differences exist between Tower Garden® and pallet garden (p=0.002) and pallet garden and Tower Garden®(p=0,002). Assessing the mean weights of spinach grown in Tower Gardens® (1.624 mg) and pallet garden (1.23 mg), it can be interpreted that the pallet garden spinach leaves did not grow as large as those grown in the Tower Gardens®.

The chlorophyll content data collected of the spinach leaves tested were within the ideal range of 0.7 to 0.8 (Ritchie, 2006). The null hypothesis, H_0, was the mechanism by water type does not affect chlorophyll content, and the alternate hypothesis, H_A, was the mechanism by water type does affect chlorophyll content. The data for the one-tailed ANOVA at $p<0.05$ by water type suggests there was no significant difference between water type and mechanism in terms of plant chlorophyll content.

The water analyses performed provided supplementary data related to plant health. The water quality was not demonstrated to have a negative impact on the health of the plants; however, it can be assumed the lake water's higher turbidity resulted in the higher plant survivability and larger mean wet weights due to of the additional natural (aquatic life) and supplemental fertilizers via runoff (fertilizers used by Aldridge Gardens) provided by the lake water. Water type did not affect the overall water quantity supplied to plants to maintain survival. The mechanism also did not affect the water quantity supplied to plants to maintain survival.

6.1 Future Recommendations

The limitations of this research should be considered in future decision-making based on the findings presented here. There were numerous limitations involved with this research, including budget, location, limitation of plant variety, and resource availability. With an increased budget and controlled location, the research could be more robust with more conclusive findings. This project was self-funded and thrived off of donations of space, equipment, and time. Aldridge Gardens served as an ideal location for growing due to its space and lake; however, it was an uncontrolled environment similar to those of typical community gardens. The uncontrolled environment allowed for weather and human interaction (power failure and unpredicted harvesting) that is suboptimal for research projects; however, these characteristics provided a more realistic environment for sharing these technologies with community gardens. The limitation of using one plant variety that required multiple growing seasons led to the selection of spinach. Due to limited funding and lab availability, water analysis was delayed, and assessments were reduced in scope. It would be ideal to repeat this research with additional funding dedicated to plant health and water analysis. Despite these limitations, for improving healthy food access in low-income communities, vertical gardening using pallet garden systems have distinct advantages over the pyramid gardens and Tower Gardens® growth mechanisms.

As demonstrated in this research, the spinach grown in the pallet gardens had an overall survival rate of 89%, a mean wet weight of 1.23 mg and total wet weight of 171.25 mg, a mean percent moisture content of 90.19%, and a chlorophyll content mean of 0.774 F_v/F_m. These results were similar to spinach grown in Tower Gardens® and superior to the of the spinach grown in pyramid gardens. The purchase cost of the Tower Gardens® and pyramid gardens is significantly higher than for the pallet gardens. Pallets can be upcycled and are easily obtained, often at no cost. The cost of pallet garden assembly is also minimal. The pallet garden construction is simple and can generally be accomplished with household tools and without the need for construction expertise. The soil and fertilizer for the pallet gardens can be purchased at local hardware stores. If lake water is available on-site, the operational cost of the pallet garden is further reduced, making such mechanisms more feasible for communities with limited resources.

The purpose of this research was to analyze alternative growth techniques that could be implemented on the individual and community-level cost-effectively, especially in areas of food insecurity and in urban settings where horizontal space for growing plants is limited. There are several mechanisms for alternative growth systems, but it was ideal to grow vertically to support the needs of the community in Birmingham, Alabama where horizontal green space is limited and potentially contaminated . Based upon the data analyzed for this research, it can be concluded that the most cost-effective and overall successful method for growing spinach in Birmingham, Alabama was via pallet gardens using lake water. The Tower Gardens® and pallet gardens were both successful overall, but purchase and operational cost are very important considering these garden concepts are to provide additional support for those with limited financial resources. The pallet gardens overall cost was less than $100 to assemble six individual pallet gardens including soil and fertilizer. Lake water is also a less expensive sourced water, but it is necessary for the lake water to have limited contaminants which may limit the viability of its use. Water testing is recommended to ensure the health and safety of the water being used for growing the plants, which is an additional cost to the user. Lake water is not always readily available for use, also lake water is not encouraged for use if it is not readily available due to the additional cost of transportation of the water from source to garden. As this was a small-scale study, it would be pertinent to conduct more in-depth analyses of the spinach grown with lake water to ensure quality for further implementation. Whichever water source is available, the data from this research concludes using pallet gardens for successful vertical gardening at the individual and community garden levels.

This research should be further analyzed for different climate regions and brownfields. The final conclusion of using a pallet garden can be replicated anywhere; however, adjustments would be necessary based on the climate. The vegetation grown, amount of water, and type of water would need to be analyzed specifically for each new region. Additionally, adding pallets to existing green roofs could be analyzed for successful vegetable growth. Furthering this research to various parts of the United States of America and worldwide could lead to the implementation of a dynamic model for universal access to guidelines and suggestions for a specific are similar to the resources currently provided by Farming Concrete.

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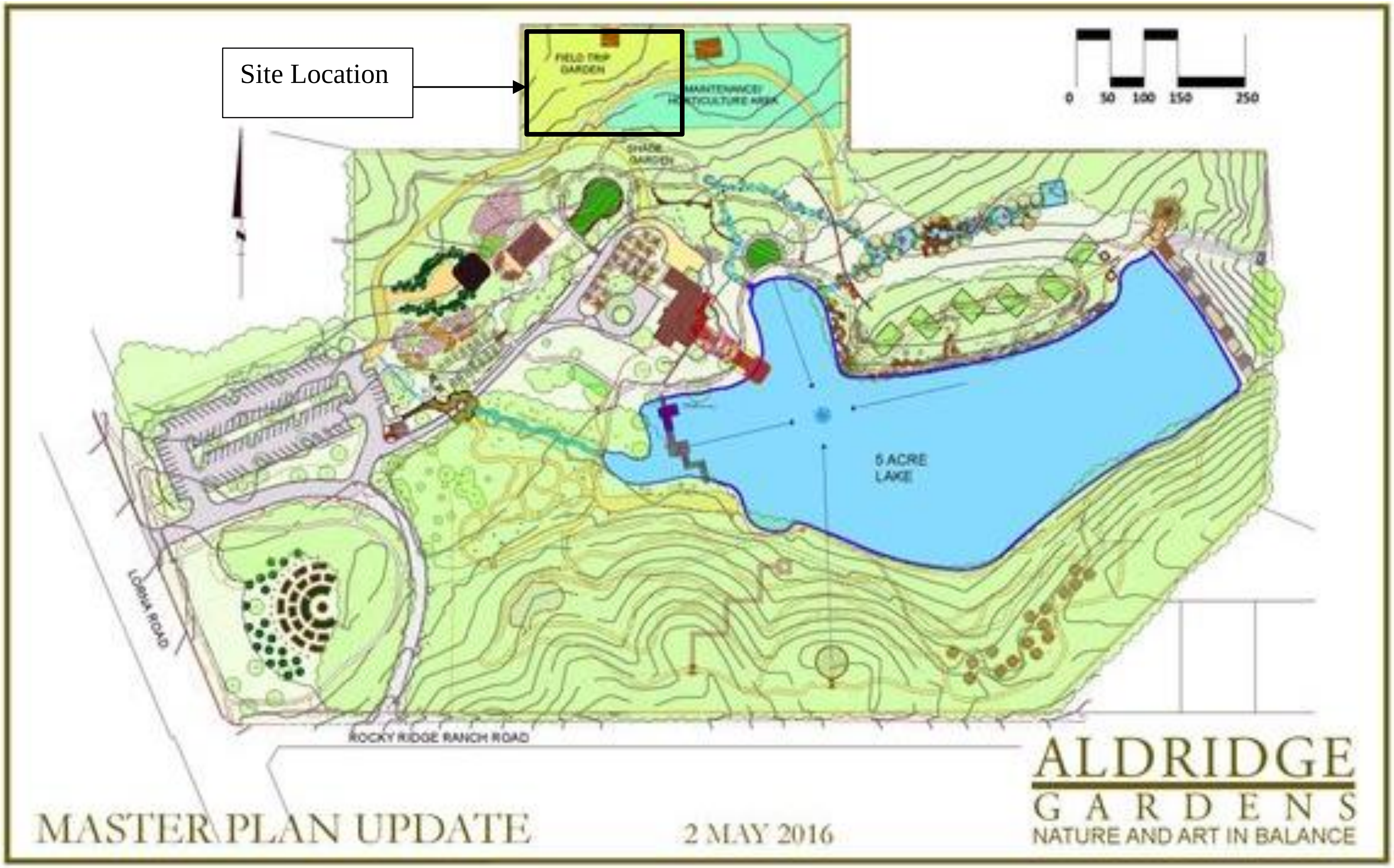
APPENDIX A

MAP OF ALDRIDGE GARDENS



Note: From “Master Plan Update” by Aldridge Gardens, 2016. Copyright 2016. Reprinted with permission.

APPENDIX B

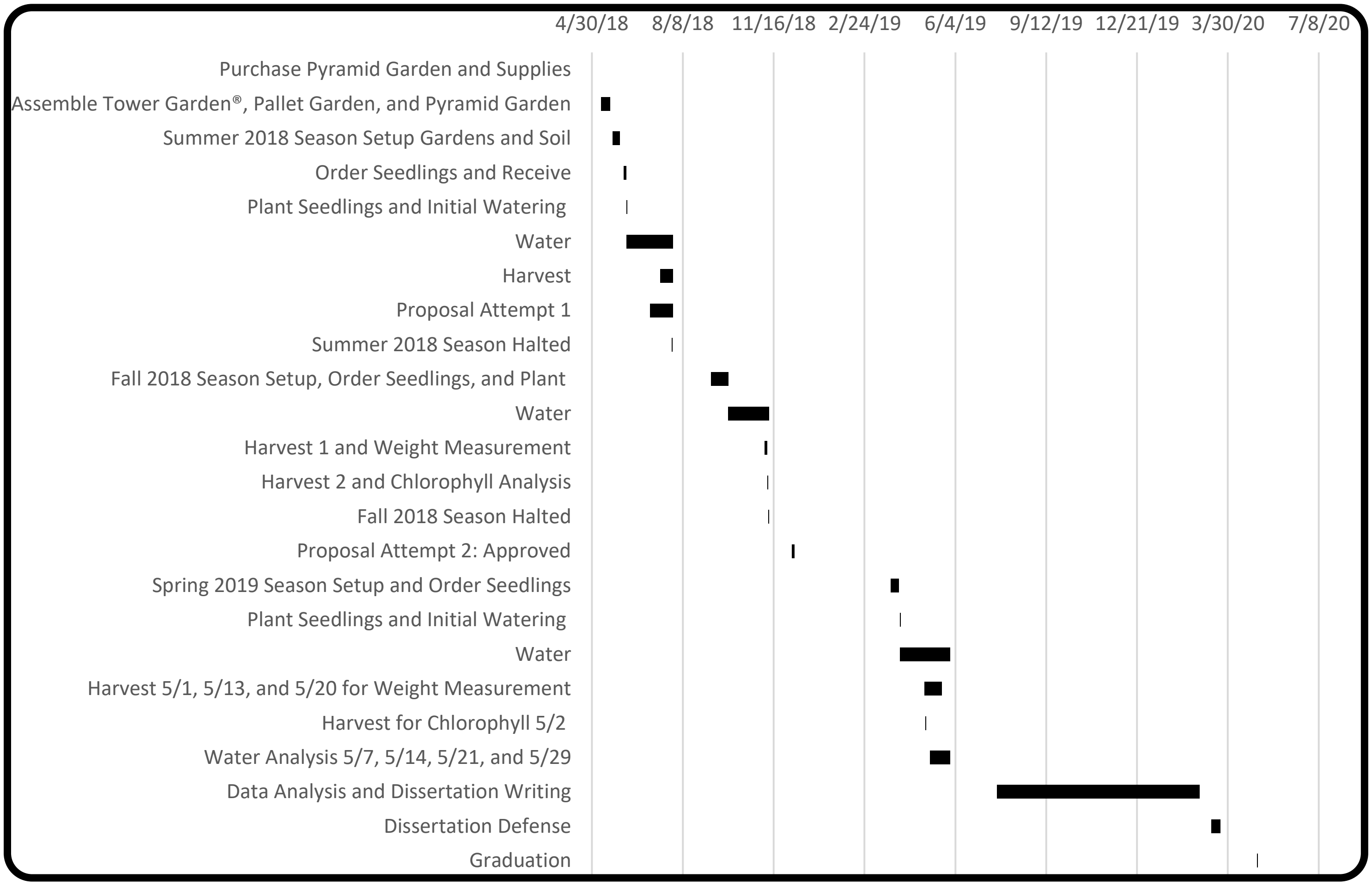
COST BREAKDOWN

	Tower Garden®	Pallet Garden	3-Tiered Pyramid Garden
Purchase/Initial Cost per Unit	$620.00*	$0.00	$99.99
Assembly Cost	$0.00	$65^	$0.00
Soil Requirement/Cost *Excludes tax and/or shipping	$0.00	2.5 bags of 1.5 cubic feet soil $8.98/bag	3.5 bags of 1.5 cubic feet soil $8.98/bag
Fertilizer/Nutrient Blend	$60.00	$7.98	$7.98
Miscellaneous	$29.00 (pH kit) $28.95 (timer)	$0.00	$0.00
Total Estimated Cost	$737.95	$98.43	$139.40

Note: Excludes tax and/or shipping. ^Assembled all 4 pallets

APPENDIX C

PROJECT SCHEDULE



APPENDIX D

PROCEDURES

1. Watering and Testing Guidelines

Note: All procedures were adapted from Harper, Jennifer and Kirby, Jason. (undated). *Laboratory Manual: CE – 326L.* Department of Civil, Construction, and Environmental Engineering at The University of Alabama at Birmingham.

Materials

- Birmingham Water Works Board Water (city water)
- Lake Water
- Distilled Water
- 1 L measuring cup
- Tower Garden® Mineral Blend
- 5-gallon Buckets
- Class A Burette
- 500 mL Beaker(s)
- 100 mL Beaker(s)
- Fisher Scientific Accumet AB15
- Orion Model 162
- Hach 2100 N
- Stir Plate and magnet stirrer

a. Plants shall be watered 1-3 times per week dependent on temperatures and rainfall.

    i. Temperatures greater than 75 ˚F require 3 days per week watering

ii. Temperatures below 75 ˚F require 2 days per week watering

iii. Rainfall greater than 0.5 inches between watering can result in less watering

b. Collected lake and city water shall undergo UV de-chlorination for a minimum of 24 hours

i. Collect water in the 5-gallon buckets

ii. The Mineral Blend shall be added to the city water while in the 5-gallon bucket to ensure equal mixing

c. Water application using the 1-L measuring cup

i. For Tower Gardens® use the provided inlet for watering

ii. For pallet and pyramid gardens, slowly pour the water around the plant and not directly on the leaves or exposed shoots

d. Record values to the nearest 0.5 L

2. <u>Alkalinity</u> *Performed in accordance to Standard Methods Test 2320*

a. Obtain a small, clean beaker of 50-100 mL of sample. Record the sample volume. 100 mL was used.

b. Obtain a stir plate and magnet and place beaker on top of beaker. Power on stir plate to a medium stir.

c. Add 4 drops of phenolphthalein to the sample. If the sample remains turns pink (pH > 8.3), continue all steps of the procedure. If the sample remains clear (pH < 8.3), skip step 3 and move on to step 4.

d. Titrate with 0.1 N hydrochloric acid until the sample turns colorless. Record the titrant volume. This titration finds alkalinity due to the carbonate ion.

e. Add 4 drops of bromocresol green to the sample.

f. Titrate with 0.1 N hydrochloric acid until a color change is noticed. Record the titrant volume. This titration finds alkalinity due to the bicarbonate ion.

g. Calculate the alkalinity due to bicarbonates using the below equation

$$\frac{(Titrant\ Volume * CaConcentration * CF)}{Volume\ Sample}$$

3. <u>Conductance</u> *Performed in accordance to Standard Methods Test 2510*

a. Allow water samples to equilibrate to room temperature.

b. Pour 500 mL of water sample into beaker.

- Turn on the conductivity meter, Orion Model 162, and let it warm up for 10 minutes.

c. Rinse the electrode with distilled water and wipe off with a Kimwipe.

d. Put electrode into the standardized solution and adjust calibration (if necessary).

e. Rinse the electrode with distilled water.

f. Place the electrode into the beaker of sample and record the conductance (in microsiemens).

4. <u>Hydrogen Ion (H+)</u> *Performed in accordance to Standard Methods Test 4500*

pH Calibration

a. Power on Fisher Scientific Accumet AB15. Check that the measurement mode is pH. If not, press the "MODE" button until "pH" mode appears on the LCD display.
b. Use pH buffers for calibration. Buffers should be at the same temperature as the testing solutions.
c. Rinse the pH electrode with distilled water and then with the buffer being used for calibration (i.e., pH 7.00).
d. Dip the pH electrode into a neutral pH buffer (i.e., pH 7.00).
e. Press the "CAL/MEAS" (calibration [or Standardization]/measurement) button to select the 'calibration (standardization)' function. Set the buffer pH value on the meter display to 7.00.
f. When the "reading" is stable, press the "ENTER" button to accept. The primary reading will flash briefly before the secondary display begins scrolling through the remaining available buffers.
g. Repeat for each buffer.

pH Measurements

h. Confirm that the meter is on the pH measurement mode.
i. Thoroughly rinse the pH electrode between measurements with distilled water to prevent contamination of the tested solutions. Gently blot the electrode on a laboratory cleaning tissue to remove the excess rinse water.
j. Dip the pH electrode into a testing solution or suspension.
k. Record value once pH reading is stable.

l. Repeat for each water type and each buffer.

5. Turbidity *Performed in accordance to Standard Methods Test 2130*

   a. Power on the turbidity meter, HACH 2100 N

   b. Clean the provided cuvette with distilled water.

   c. Carefully pour 3 mL of sample into the cuvette.

   d. Wipe the exterior of the glass bottle and ensure no bubbles are present.

   e. Place the cuvette into the turbidimeter and close the door.

   f. Record the NTU value.

6. Harvesting Guidelines

   Materials

   - Scissors
   - Sealed Container
   - Cooler
   - Ice-Water Bath
   - Paper Towels

   a. Prepare the sealed container for transfer of samples from Aldridge Gardens to UAB

      i. Prepare an ice-water bath in a sealed bag and place in cooler

      ii. Damp Paper towels and place inside sealed container to help retain moisture

   b. Cut the shoot as close to the ground as possible

      i. Ideally, cut 3-5 shoots from each plant

c. Immediately transfer the sample to a sealed container

d. Transfer samples to UAB

7. Wet and Dry Weight Analysis (Biomass)

Materials

- Denver Instrument SI-602
- Yamato DVS 600
- Weigh Boat

Sample Weight Procedure

a. Record weight of weigh boat

b. Tare the scale

c. Remove sample from sealed container or oven

d. Place sample in weigh boat and record weight

e. Label Sample based on growth location

f. Set sample and weigh boat to the side until ready to go in oven (if wet)

g. Repeat for all samples

Drying Procedure

h. Set oven to 45 ± 3 ˚C

i. Insert Samples

j. Allow samples to dry for a minimum of 48 hours

k. Remove Samples

l. Perform Sample Weight Procedure

8. Chlorophyll Analysis

Materials

- Opti-Sciences Chlorophyll Fluorometer OS30p
- Dark Adaptation Clips

Procedure

a. Attach the dark adaptation clips to samples
b. Allow samples to acclimate to the dark for a minimum of 20 minutes
c. Remove the slide and attach clip to the OS30p
d. Select Fv/Fm reading and begin
e. Record results