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EVALUATING THE POTENTIAL FOR PASSIVE GREYWATER IRRIGATION IN NORTHERN GHANA

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EVALUATING THE POTENTIAL FOR PASSIVE GREYWATER IRRIGATION IN NORTHERN GHANA

By

Chelsea L. Fagan

A THESIS

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This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Civil Engineering.

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Abstract

Water scarcity, malaria, and malnutrition are all concerns facing the people of Chirifoyili and the Northern Region of Ghana. Greywater pooling outside of homes increases human exposure to pathogens and provides breeding grounds for disease carrying insects, especially malaria spreading mosquitoes. This project looks at draining this water away from the home and using it to irrigate vegetables, fruit trees and other beneficial plants.

The purpose of this study is to estimate the effects of greywater irrigation on the growth of plants commonly found in village home gardens. The field project consisted of constructing and managing household greywater irrigation systems for valuable trees. These greywater pools were modeled in a campus laboratory to determine the effect greywater would have on the growth of tomato plants. The results of the study showed the tomato plants' health and growth rate were improved by the extra water and nutrients.

This system will benefit those who implement it in northern Ghana by decreasing the available mosquito breeding grounds and providing additional sources of nutrients from fruits and vegetables, which are often absent from the local diet.

SECTION 1: GENERAL INTRODUCTION

1.1 Peace Corps Service

My Peace Corps job assignment in my village was to educate residents about health, water and sanitation. I taught lessons at the schools and in the community about malaria and HIV/AIDS prevention, malnutrition risks, hygiene and clean water practices, and worked to construct a water distribution system for the community.

I would spend time with my friends and their families at their farms, helping where I could, and observing their farming practices. Walking the narrow networks of paths to each of my destinations, I would see the small garden plots that were squeezed into any available space between neighboring homes and existing paths. Tobacco was very common to see, as it would fetch a high price at the market and the roaming livestock would not be tempted to eat it. I would also see small patches of tomato plants, hot peppers called *pepa*, garden eggs (similar to eggplant), okra, and occasionally millet and corn.

Traveling the well tread path between my own home and my counterpart's house, I would regularly pass by a large compound with a particularly healthy tobacco crop. This was the home of one of the respected elders of the community who had a large household. I watched this home and its tobacco closely as the seasons changed and as all the farmers were preparing the harvest. The tobacco plants here were three times as big as all the other plots in the village. When I asked the elder if I could look at his plants, he showed me where I would normally find a pool of stagnant water outside the bath house, there was a small trench in the ground directing this stream of water into the patch of tobacco plants. The plants closest to the stream were well over six feet tall, but even those plants at the edge of the garden, furthest from the water, were twice as tall as the neighbors'. I was excited to see this elder had used the potential of this alternative irrigation resource and would spend the remainder of my service working to determine if others would also pick up the practice.

This particular compound was unique because no other households in my village of Chirifoyilli had adopted the practice on their own. At least in Chirifoyilli, it seemed the reason for placing any crop near the house was not to be closer to the discarded water, but to use any small piece of land available. It was also beneficial to have these vegetable plots close to the home because it was more likely someone would be sitting outside the house or passing by to chase away any wandering goats and sheep who would eat the plants. I would occasionally see fruit trees such as banana planted in an older bathing enclosure once a new enclosure had been built. Usually enough of a wall still remains to protect a young tree from livestock.

When visiting the sites of other Peace Corps Volunteers who also lived in the Northern Region, I found that in some of these other villages it was more common to see trees or other plants intentionally grown near the bath area drains, as seen in Figure 1. Small

banana groves were common, as shown in Figure 2, as well as some mango trees. Some households had even planted papaya, which as a tropical plant can be found in the southern areas of Ghana but is not easily grown in the dry north without irrigation. This indicates that people in these other communities were aware of the potential this constant water source has for growing a wider variety of plants than normally found in the arid savannah grassland climate. These trees were planted a distance away from the house, downhill when possible, and often with a trench leading to the tree, all of which shows the intent of planting to utilize the water source while giving the tree enough space away from the structure to grow.

Figure 1: Home in eastern part of Northern Region near Togo border where planting near bath drain is more common (Photo by Chelsea Fagan)

Figure 2: Banana grove planted near bathing drain in the village of Voɤue, Northern Region (Photo by Chelsea Fagan)

I would travel for projects to some of the other tiny villages and settlements in the vicinity of Chirifoyilli. I found that in some of these places, people were also planting trees near the bath drains of their homes. As I traveled and explored more, it seemed that if the practice had been picked up by one home in a settlement, others would follow. But there were some communities, such as my own where the practice was not popular.

The students of the community and I did several projects together throughout my service. I presented the idea to them of planting trees near the bathing area pools at their homes as a continuation of a different gardening project on which we had been working. A project at individual homes has a greater chance of success as there is a smaller group of people to take responsibility, and a smaller group would be able to witness and benefit if successful. The goals for this project were to reduce the amount of pooling water found outside the homes and utilize this water source for planting.

I would plan out each of these individual planting schemes with the students. We would meet with their parents or the heads of the household to discuss the project and gain permission. The families and I would decide where to plant the trees depending on the land available and the amount of water to which the tree would have access. In exchange for the seedlings I provided, the students were required to build a fence to protect the valuable trees from roaming livestock. Students also needed to dig a trench so that water would not pool outside the compound wall but would drain toward the tree. This way, the trees would serve more as an exchange of goods for services, rather than a handout requiring neither ownership nor follow-up. Depending on the families' preference, we

planted mango, papaya, banana and moringa trees. Figures 3-6 show the different stages of this project.

Figure 3: Young banana seedling planted near a bath drain surrounded by homemade fence (Photo by Chelsea Fagan)

Figure 4: Initial frame for a fence around a papaya seedling near a bath drain (Photo by Chelsea Fagan)

Figure 5: Student weaving the fence surrounding his moringa tree (Photo by Chelsea Fagan)

Figure 6: Trench directing water from the bathing area drain outside the compound wall (Photo by Chelsea Fagan)

Fruit Trees
Fruit trees are valuable in Ghana, especially in the arid northern part of the country. Banana trees are common in the tropical south, but in the drier north, banana trees are only distributed by the Ministry of Agriculture (MOFA) to certain government sponsored banana farmers. These banana farms need to be close to a water source because banana trees require steady watering (Tropical Permaculture: Bananas, 2014).

Banana plants are actually perennial herbs and in the order *Zingiberales* (Tropical Permaculture: Bananas, 2014). A plant produces one bushel of bananas from a single flower in its lifetime of about 9 months to 1 year, and dies soon after. Banana trees reproduce by new seedlings, or suckers, sprouting from the rhizome at the base of the parent plant called the corm (Newley, Akehurst, & Campbell, 2008). Most of these suckers must be uprooted and replanted elsewhere or they will all compete with the parent plant and each other for resources (Newley et al., 2008). One or two can be left to replace the dying parent plant after it produces fruit.

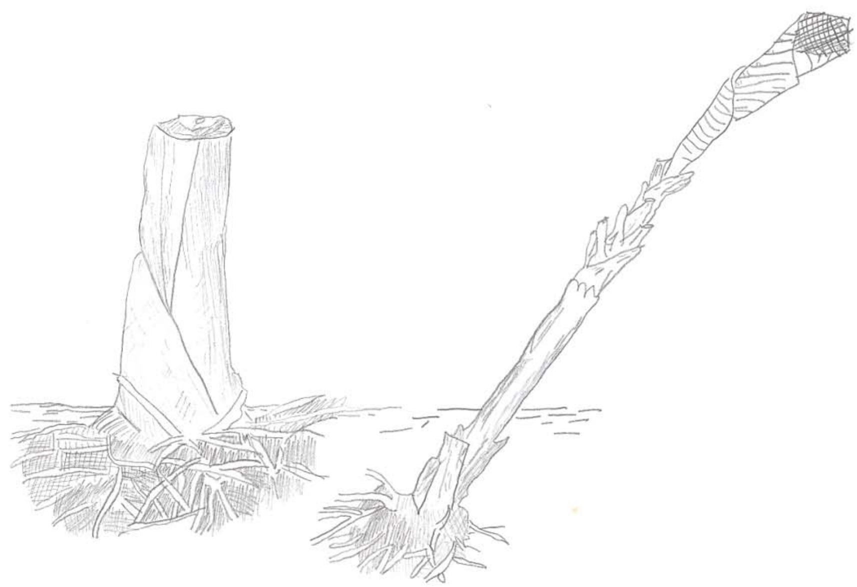


Figure 7: New banana seedlings growing around base of parent plant - Adapted from (Tropical Permaculture: Bananas, 2014)

Banana plants are ideal for planting near the bathing area drains because they require a steady supply of water and nutrients delivered close to the base of the plant due to the banana's small root system. Because bananas are surculose plants (plants which produce suckers), they produce offspring independently (Koeppel, 2008), so there is no extra expense of buying seeds. Community members could give their neighbors one of the sucker plants to start their own grove. The potential negative aspect of these surculose plants is that each offspring is essentially a clone of the parent plant; therefore each sucker would have the same disease resistance of the parent plant. If a disease struck the

area it would most likely effect all the banana trees in that area. Also, if a parent plant was already contaminated with a disease, it might pass that on to its sucker and if planted elsewhere in the community, that disease might continue to spread. However, due to the small number of banana trees growing in the community, even an infected sucker would not have many trees available to further infect.

Bananas prefer to grow in groves where they protect each other and their flowers from wind and extreme heat (Newley et al., 2008). They were therefore ideal for planting several around drains and between family compounds where walls provided protection. With enough water, nitrogen, and potassium provided by the wastewater, banana plants require little maintenance (Newley et al., 2008). The bananas can be consumed by the family, and any surplus can be sold at the market.

Figure 8: A banana sucker collected from a MOFA banana farmer to be planted at a student's house (Photo by Chelsea Fagan)

Bananas are a valuable and dependable fruit throughout Africa. Originating in Asia, it is believed that banana and plantain breeds first arrived on the continent in eastern Africa, and then different cultivars migrated throughout Africa to thrive in locations most suited for their breed (Koeppel, 2008). The bananas grown throughout Africa are different from the Cavendish cultivar, the breed found in supermarkets throughout Europe and North America (Koeppel, 2008). Bananas in Africa are typically sold and consumed within 50 miles of where they are grown (Koeppel, 2008).

Many African populations depend on bananas for the majority of their food. In Uganda, the average person consumes 500 pounds of bananas each year; and this number increases in more rural communities without alternative crops to 970 pounds per person per year (Koeppel, 2008). In many of these rural Ugandan communities, there will be a

tree planted outside every home. Bananas are credited for the lack of famine in Uganda that is common to other nations in the region (Koeppel, 2008).

Mangos are also a valuable fruit in arid northern Ghana. Mangos originated from Mexico, Central and South America but are now mass produced in Ghana. Small mangoes, known as “local mangos” are approximately 5 inches long with the pit occupying most of the fruit leaving little space for consumable flesh. These are often juiced and the flesh is eaten along with the fruit skin. It is common to see these local mangoes in rural communities planted near a school or in front of households. Far more valuable are the larger “grafted mangos”, which are grown on plantations in the Northern Region managed by the Integrated Tamale Fruit Company (ITFC) and exported internationally. Due to the near monopoly of ITFC, grafted mango trees are viewed as valuable by northern Ghanaians, and it is prestigious to have one of these trees planted near the home. The “grafted mango” cannot be grown from seed but requires a skilled grower to graft a branch from an existing tree to the stem of a local mango seedling.

Papaya trees are even rarer in the north than mango and banana. Papaya fruits (referred to locally as *pawpaw*) are only sold in the city and are expensive. Papaya trees require a steady water supply so would only grow in the north with diligent irrigation.

Moringa trees are growing in popularity and praised as the “miracle tree” by the Peace Corps and other aid organizations. Moringa leaves are particularly high in protein, as well as vitamins and minerals and are promoted as a soup additive to help combat childhood malnutrition. The trees are easy to plant and grow quickly. The leaves provide valuable nutrition, the seeds can be used as a coagulant in water treatment, the flowers are used to make tea, and the roots are used for medicinal purposes (Peace Corps Mali, 2011). Branches can also be used for nutritionally dense animal fodder, and as natural fertilizer for other crops.

Trees are valued in northern Ghana not just for the food they provide but also for shade. Most northern rural Ghanaian homes have a permanent or portable bench, or some arrangement of stones, tree stumps and roots outside the front door to the compound. This seating area is where visitors are greeted, meetings are held, business conducted and where men of the household spend most of their time when at home. The men of the house will receive their meals in this area. Elderly men of the household will spend nearly their entire day here, reclining in a locally made chair as if to keep an eye on their household and the neighborhood. A vital addition to this seating area is a large shade tree. Compound sites are often chosen to be near a large, older tree. Neem trees were often seen shading this area, but it was common for the men of the household to want one of the grafted mango trees. The water from the bath drain could provide the necessary irrigation to grow these culturally valuable home additions.

Figure 9: People gathering under a neem tree in Bagurugu, Northern Region (Photo by Chelsea Fagan)

1.2 Country Background

Ghana is located along the coast of West Africa, Figure 10, sharing borders with Ivory Coast to the West, Burkina Faso to the North, and Togo to the East. The country is divided into 10 regions with a large portion of the population concentrated in the southern regions, Figures 11 and 12. Ghana is a diverse country made up of more than 100 ethnolinguistic groups, many of which are further divided by sub-dialects and cultures (Berry, 1995). The country occupies 238,533 km^2, approximately the size of the US state of Oregon (Central Intelligence Agency, 2014). The capital city is Accra.

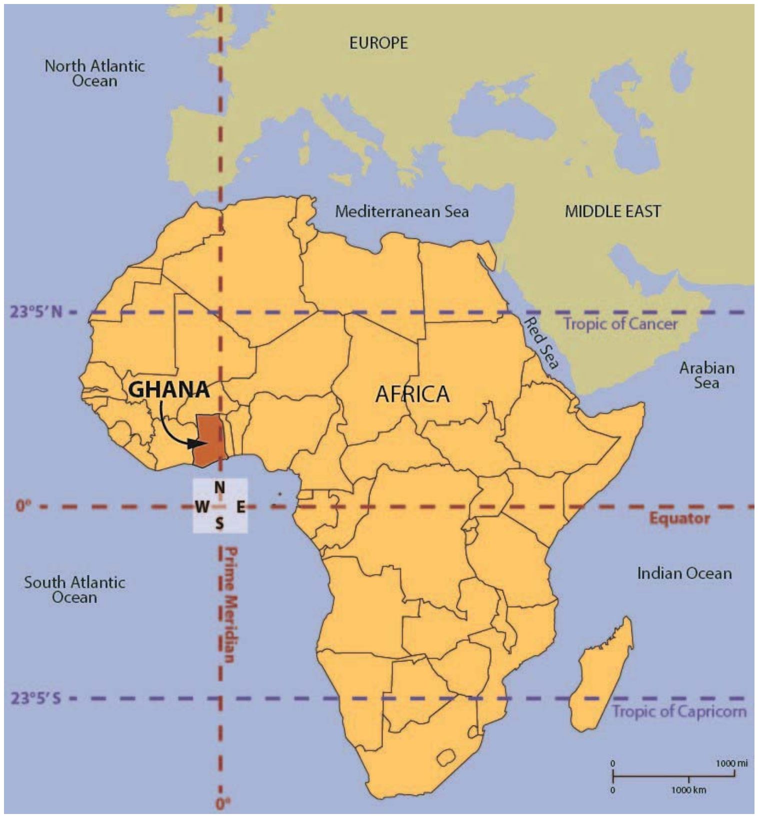


Figure 10: Ghana's location in Africa - Adapted from (Atlas, 2014)

Figure 11: Map of Ghana by Regions - Adapted from (Ghana Statistical Service, 2010)

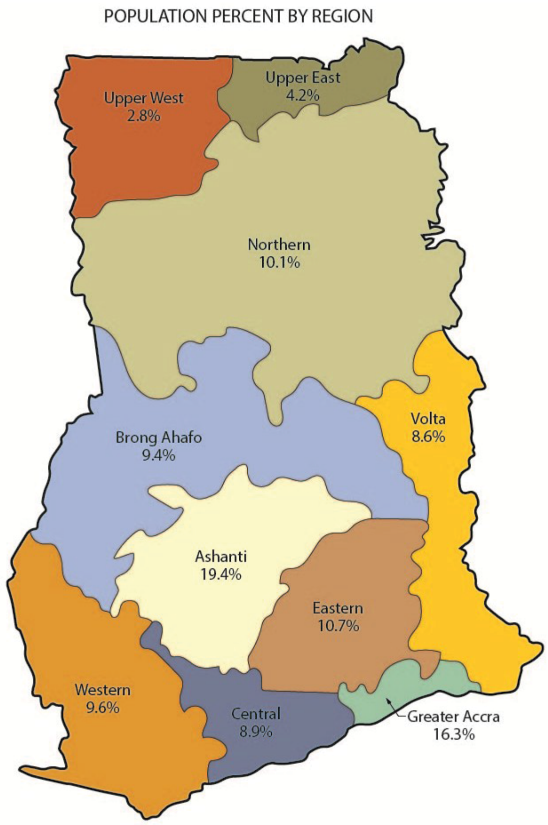


Figure 12: Percentage of population by Ghana Region - Adapted from (Ghana Statistical Service, 2012)

History

The Portuguese were the first Europeans to begin trading on the Ghanaian coast in 1471 followed by Danish then Dutch merchants (Gocking, 2005). These European traders initially arrived in the area seeking gold, but as the demand for slaves rapidly increased, human trafficking far outpaced other trade (Berry, 1995). The English arrived in the area in 1665 and control seesawed between the English, Dutch and different local tribes. The British established the Gold Coast colony in 1874, the name indicating its primary mineral export (Berry, 1995). Ghana gained independence in 1957, the first sub-Saharan African country to do so, after a decade of political moves from locally founded and locally controlled political parties (Gocking, 2005). The new country was created by combining the two lone British colonies in the region, the Gold Coast and Togoland (Central Intelligence Agency, 2014).

Government

Kwame Nkruma was the first president of the newly formed nation, continuing the leadership role of Prime Minister he held under the transitional period after the British left Ghana in 1951 but before independence was officially declared in 1957 (Berry, 1995). A series of military coupes and instability followed independence for decades. Lt. Jerry Rawlings placed himself as President in 1981 beginning a time of stability, though

not an era of political freedom and democracy as Rawlings banned all political parties (Central Intelligence Agency, 2014). Under Rawlings, a new constitution was instated in 1992, and he was reelected in 1992 and 1996 (Central Intelligence Agency, 2014). The government has remained stable and relatively peaceful since. The current major political parties are the National Democratic Congress (NDC) and the New Patriotic Party (NPP).

People

The current population of Ghana is over 25 million, and the population growth rate is 2.19%, compared to 0.77% in the US (Central Intelligence Agency, 2014). The population is young, with a median age of 20.8 years, whereas the US median age is 37.6 years (Central Intelligence Agency, 2014). The annual birthrate in Ghana is 31.4 births for every 1,000 people (Central Intelligence Agency, 2014), and 51.9% of the population lives in urban areas, with a 3.5% urbanization rate. For comparison, in the US 82.4% live in cities (Central Intelligence Agency, 2014). The percentage of Ghanaians living below the international poverty line is 28.5% (Central Intelligence Agency, 2014).

English is the official language of Ghana, spoken in the government and taught in schools, but most of the population speaks their local tribal dialect (Berry, 1995). Table 1 lists the population divisions of the major language groups, although these groups are further divided into the over 70 unique languages spoken in the country. The nation's different ethnic groups have a similar population breakdown, as each ethnic group often speaks its own language.

Table 1: Percent of Ghana population speaking major language groups (Central Intelligence Agency, 2014)

Asante	14.8 %
Ewe	12.7%
Fante	9.9%
Boron (Brong)	4.6%
Dagomba	4.3%
Dangme	4.3%
Dagare	3.7%
Akyem	3.4%
Ga	3.4%
Akuapem	2.9%
Other (smaller language groups)	36%

Christianity dominates in the southern parts of Ghana, while Islam is primarily practiced in the north. Islam was brought to northern Ghana over the centuries by traders and migrants from the Sahara region (Berry, 1995). Traditional beliefs and practices are typically mixed with Christian and Muslim rituals, which are especially apparent during

life cycle events such as births, marriages, and funerals. Overall in Ghana, 71.2% identify as Christian, 17.6% as Muslim, and 5.2% as purely traditionalist practicing a form of animism (Central Intelligence Agency, 2014).

The Ghanaian people face many tropical endemic diseases such as malaria, hepatitis, cholera, typhoid, trachoma and dysentery (Berry, 1995). The population of people living with HIV/AIDS is relatively low - 1.4%, compared to the rest of Africa. Comparatively, the US has 0.6% of the population living with the disease. While the world's highest prevalence rate of the disease is in Swaziland - 27.4% (Central Intelligence Agency, 2014; Kaiser Family Foundation, 2015). Hospitals are found in major cities, with health clinics found in some smaller towns. The physician density of the nation is 0.09 doctors for every 1000 people (Central Intelligence Agency, 2014). Life expectancy is 65.75 years (Central Intelligence Agency, 2014).

Economy

Ghana's natural resources include gold, timber, industrial diamonds, bauxite, manganese, fish, rubber, silver, salt and limestone (Central Intelligence Agency, 2014). Oil was recently discovered off the coast and production began in 2010 (Central Intelligence Agency, 2014).

Permanent cropland occupies 11.74% of the nation's land (Central Intelligence Agency, 2014). Cocoa was introduced to Ghana in 1878 (Berry, 1995) and is a major cash crop in the southern, tropical part of the country. In addition to cocoa, the country's major agriculture products include rice, cassava, peanuts, corn, shea, bananas, mangoes and cashews (Central Intelligence Agency, 2014).

The country's GDP is $90.41 billion, and ranked 74th in the world (Central Intelligence Agency, 2014). The current inflation rate is 11% (Central Intelligence Agency, 2014).

Geography and Climate

Ghana falls within the Intertropical Convergence Zone, due to its location near the equator, where the Northeast and Southeast Trade Winds meet (Furman & Guertin, 2014). Traveling the approximate 900 km from the coast to the northern border, the geography quickly changes from the tropical, warm rainforest of the south to highland forests, and then to the hot, dry grassland savannah in the north, as shown in Figure 13 (Central Intelligence Agency, 2014).

Ghana as a whole has 53.2 cubic kilometers of renewable water resource available (Central Intelligence Agency, 2014). Of this, 0.98 cubic kilometers of freshwater are drawn from the cycle each year, 66% of which is used for agriculture (Central Intelligence Agency, 2014).

Some of the environmental issues Ghana faces include drought in the northern part of the country, deforestation, overgrazing, soil erosion, water pollution, and an insufficient supply of potable water (Central Intelligence Agency, 2014).

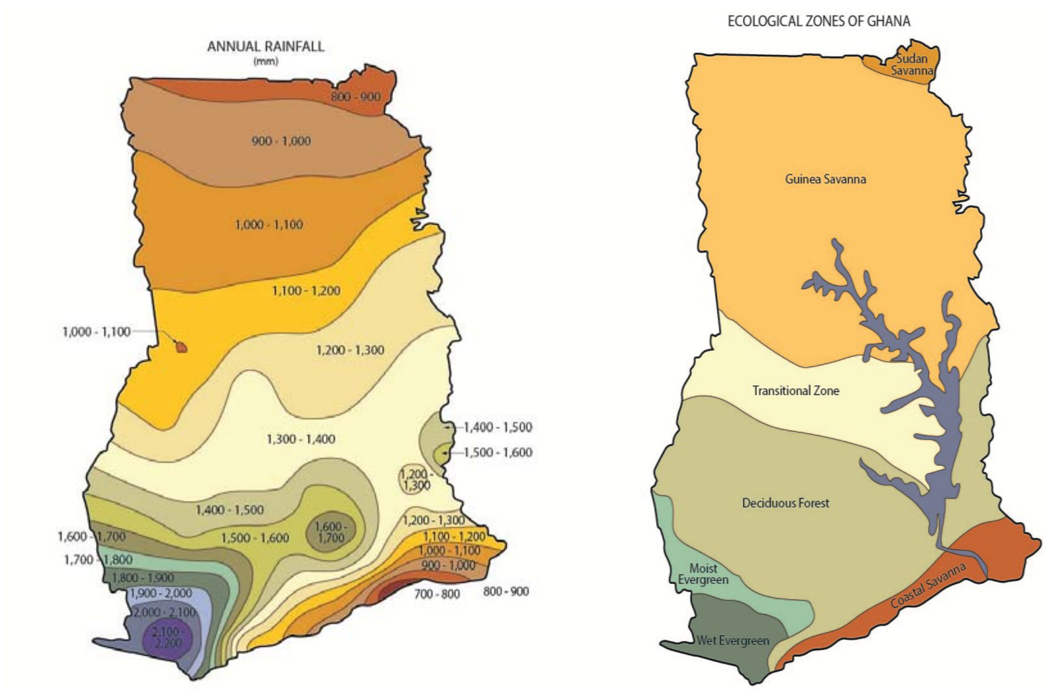


Figure 13: Annual Rainfall (mm) and Ecological maps of Ghana - Adapted from (Food and Agriculture Organization, 2004)

1.3 Northern Region

The Northern Region of Ghana occupies 70,384 km^2 and, as of the 2010 National Census, had a population of 2,479,461 and a population density of 35.2 people per square kilometer (Ghana Statistical Service, 2012). Of the Northern Region population, 69.7% live in rural areas (Ghana Statistical Service, 2012). The Northern Region is the only region in Ghana where Islam is the dominant religion, representing 60% of the population (Ghana Statistical Service, 2012).

The Mole-Dagbon ethnic group represents 16.6% of the population of Ghana. The Dagomba tribe falls within this group, and primarily resides within the Northern Region. Dagbani is the language of the Dagomba tribe and is spoken by 4.3% of the nation's population (Central Intelligence Agency, 2014). Historical writings and archeological evidence show that the Dagomba have lived in the area since approximately 1450 (Gocking, 2005).

1.4 Chirifoyilli

The village of Chirifoyilli is located in the Tolon District of the Northern Region. According the most recent census, the village has a population of approximately 5000. Nearly all members of the community are of the Dagomba tribe and speak Dagbani exclusively. The majority of people in the community identify as Muslim, though traditionalist customs are widely practiced, and the beliefs of Islam and traditional

animism coexist peacefully. There is a central mosque with a few other smaller mosques throughout the community which host the traditional Muslim daily prayers. There is a primary school and junior high school in the village, as well as a Muslim school. The primary occupation of most residents in the village is farming.

Overhead electric wires run along the main road through town, and some houses are connected and have access to somewhat reliable electricity. Of those houses with electric power, some have a television. Most often the household will have a single light bulb within the compound and one outside the compound walls. Occasionally a few of the sleeping rooms in the compound have an indoor light.

During the rainy season, the village relies on hand dug cisterns located throughout the community to collect rainwater as the water supply. These cisterns are uncovered and unlined, and debris from the area is often washed into them. After the rains stop for the season, a small reservoir located approximately one mile away along the main road north of the village is used as a water source by several surrounding communities. Once this reservoir dries up, another reservoir located approximately 2.5 miles northwest of the village is used until the rains return. Boreholes were constructed along the top of the dam but are rarely used for drinking water by the local population. The water from these boreholes has a somewhat metallic taste, and therefore it is only used for washing clothing, bicycles and motorcycles, while the open surface water is preferred for drinking and cooking.

Chirifoyilli does not have its own market because the village population attends the Katandaa market located in the nearby village of Tali. This is the second largest market in the region, after the market in the regional capital, Tamale. Katandaa market is held every six days.

1.5 Purpose of study

The purpose of this study is to determine if simple greywater irrigation systems, similar to those established during Peace Corps service outside northern Ghanaian homes, would improve plant health and increase plant growth due to the increased water and nutrients provided by the system. A laboratory experiment is conducted to measure the potential effects of a greywater irrigation scheme on the growth rate of tomato plants. Planting beds are assembled to simulate the greywater gardens at the bath-area drains with pooling water surrounded by tomato plants. Beds are irrigated with either high volumes of secondary effluent from a municipal wastewater treatment plant, high volumes of clean water, or low volumes of clean water. Plant growth is measured over a period of two and a half months. Growth indicators are analyzed and compared by irrigation variable.

In the following sections, background information specific to this project is provided. The study methods are then presented, followed by results and discussion. Finally study conclusions are highlighted and the future potential of greywater irrigation gardens in rural African communities is outlined.

SECTION 2: STUDY BACKGROUND

2.1 Houses in Rural Northern Ghana

Rural houses in the Northern Region of Ghana are typically extended family compounds made up of several circular and sometimes rectangular structures. Each structure serves a particular purpose, such as living quarters, receiving halls, kitchen, storage, or bathing area. An external wall usually connects all of these structures, which surround a central courtyard where household activities take place. It is common for the women and young children of the house to spend much of their time within the central compound with their work and household chores, while the men sit outside the compound walls under a shade tree.

The compounds are made from local materials, and designed and built with local knowledge. In this way, low income families are able to build for themselves, often consulting a local mason (Afram, 2007). The majority of homes in the village of Chirifoyilli, and in many surrounding communities, are composed of mud walls with cement stucco and a woven grass roof. These mud compounds are always changing. As one mud structure starts to fall down over many seasons, a new structure will be built in another part of the compound to replace it. When a room is first built, it will typically be used as sleeping quarters. As the floor starts to wear away, if it is not repaired, the room will then be used as an indoor kitchen or storage area. Its purpose will continue to downgrade: as the walls wear away or the roof starts to fall in, it may be used for storage of less valuable possessions; for example, instead of bags of grain, it may now house older bicycles. This repurposing continues until it is no longer a room and repairs are made to close in the compound wall around it.

The compound grows as the family grows. Large, extended families live together; therefore households may range from 6 people to over 90. When the sons of the household reach adulthood, they will get their own room. As a new bride marries into the family, she would also get her own hut. As the compound radius expands, trees which were once outside the compound are incorporated within the walls. Tradition is to leave these trees in place and build around them rather than to cut them down in order to expand.

As a household gains wealth, the upgrades to the home are typically first to add a corrugated metal roof to the patriarch's room, then moving down the household rankings to add metal roofs to additional rooms. Only the wealthiest of the community have a house made from concrete blocks and rooms solely covered with metal roofs. These households still maintain the traditional floor plan of rooms surrounding a central courtyard.

The bathing area in each household is a circular enclosure with no roof and a small hole in the mud wall at floor level to serve as a drain. This drain may include a short piece of plastic pipe, and excess concrete from a previous project may be used to create a spout at

the base of the drain to direct wash water away from the structure. Drains like this are also often included in the living quarters, used for draining water during the colder harmattan season when bathing takes place in-doors or when a room is cleaned. The bath water leaving these drains is left to pool outside the house. There may be several bathing areas in one compound depending on the size of the household.

2.2 Farming in Rural Northern Ghana

Family farms are typically located around the outskirts of the community with different traditional and family laws dictating who can farm a particular piece of land. Some family farms are near the community, but others may be many miles away. Staple crops planted at the family farm plots are maize, rice, yams, and groundnuts. Land ownership, as well as the ownership of the crops harvested from the land, varies depending on the size of the plot and the type of crop grown there. Often, areas of land are broken up by an inheritance system. However, rarely is there a sole owner to a piece of land (Obeng, 2000).

In addition to the larger plots reserved for cash crops, many families will maintain a smaller garden in the area outside the home in any available space between other compounds and paths. This practice is also common in the cities throughout the country where a household will hold a few animals and a small garden in the yard (Drechsel, Graefe, Sonou, & Cofie, 2006). This is more often practiced by migrants who originated in the rural areas of the country but moved to the city. The size of the plot that can be maintained by the family in the city is not only dependent on the land available, but more so on the availability of irrigation or the labor to fetch water for the plants (Drechsel et al., 2006).

In the village goats, sheep and chickens are free to wander throughout the community, and herds of cattle are often led through the village between their grazing fields and the owner's compound. Planting near the house comes with the risk of roaming livestock eating the plants. It is common to see tobacco grown near the house because the animals will not be tempted to eat the tobacco plants. The tobacco is harvested, dried and prepared, then sold at the market for extra income, typically by the men in the household. Families may also have a small plot of tomatoes, peppers, okra, egg plant, traditional leafy vegetables and occasionally fruit trees growing near the home. These vegetable plots are typically planted and maintained by the women of the house. These gender differentials are cultural; throughout most of West Africa there are certain crops more likely associated with one gender over the other (Drechsel et al., 2006). For example, women tend to grow and sell tomatoes, peppers, and okra, while men are usually in charge of the tobacco crop. Urban household gardens are more likely to grow new or exotic vegetables such as lettuce, spring onion, cabbage, carrots, green bean and cucumber.

Tomatoes are common in local cuisine and will be consumed by the farmer's family. If there is a surplus for the season they will be sold at market. Those producing a large

tomato crop may sell to a domestic processor for 0.12-0.49 Ghcedi/kg ($0.03-$0.14 US Dollars/kg), depending on the region where they are grown. Growing and selling tomatoes is more lucrative than many of the staple crops grown in the area, including rice, maize, groundnuts, yams, and peppers (Jaiteh, 2010). Of the total amount a family will spend on vegetables, 38% will go towards fresh tomatoes or tomato products (Jaiteh, 2010). Tomatoes are common in much of West Africa due to their versatile ability to grow in different climates, and different uses in meals (Jaiteh, 2010). From 1996 to 2000, documented land used for tomato production grew by 30% (Jaiteh, 2010). Ninety percent of the population of the northern-most regions of Ghana grow tomatoes (Jaiteh, 2010). Even with this rapid increase, tomato growers in Ghana cannot keep up with domestic demand, so tomatoes are often imported from Burkina Faso (Jaiteh, 2010). Farmers will likely only grow tomatoes if an irrigation source is available because of the higher water requirements for the plant (Robinson & Kolavalli, 2010).

Fertilizers and pesticides are available for sale to farmers even in the remote, rural villages. However both are often used improperly, especially as directions for use and possible risks are communicated by word of mouth and cannot be read on labels by the mostly illiterate population. This overuse of chemicals puts the farmer, consumer and the environment at risk (Drechsel et al., 2006).

2.3 Dry Season Farming

In the Northern Region of Ghana, the rain season lasts from May to October with monsoon like rains occurring in August (World Bank, 2014). The northern half of Ghana receives, on average, 1,000 mm of rain annually which is concentrated in the rainy season (Berry, 1995). Farmers plan around this cycle with planting during the initial light rains of the season so that plants have established roots prior to the heavier monsoon rains. The harmattan season occurs around December, when the wind currents change from a moist southwest equatorial system (from the ocean) to a dry, dusty continental system (from the Sahara desert) (Berry, 1995). As a result, November to April is the peak dry season when no farming can occur without irrigation.

As of 2003, only 309 km^2 of land in Ghana was formally irrigated by a system established and maintained under the government or an NGO (Central Intelligence Agency, 2014; Drechsel et al., 2006). A few villages throughout the northern part of the country have irrigation systems which were established by an NGO, Figure 14. These systems draw water from a reservoir so that a small amount of crops can be grown in the dry season. Many large irrigation schemes have failed in Ghana. Dams are expensive to build, in many areas the groundwater is too deep to support irrigation, and there are often complex local customs surrounding land ownership that hinder large irrigation projects (Obeng, 2000).

Smaller irrigation schemes have been more successful in parts of West Africa including Mali and Burkina Faso, which due to their higher latitude, are drier environments than Ghana (Obeng, 2000). Smaller projects, especially those built and maintained at an

individual household are easier to manage because the responsibility falls to a smaller group of beneficiaries (Obeng, 2000). Some farmers choose to grow during the dry season, providing their own informal irrigation. Watering by hand is labor intensive, requiring farming plots without a pump-powered irrigation system to be close to the water source. However, there may be strong financial incentives to growing crops during the dry season. Farmers depending on rains are vulnerable to weather and climate changes. They are locked into a poverty cycle: when the rains are good, all farmers produce more driving down crop prices. When there is drought, no one can grow enough to sell (Obeng, 2000).

With a higher demand for the less available product during the dry season, those who can sustain a crop can increase their annual harvests (Scheierling, Bartone, Mara, & Drechsel, 2010) and are more likely to overcome the international poverty standard of one US dollar per day (Drechsel et al., 2006).

Figure 14: Dry Season farming scheme with hand-dug irrigation trenches near Tumu, Upper East Region, Ghana (Photo by Chelsea Fagan)

2.4 Nutrition

The standard diet throughout Ghana consists of meals of a large ball of starch served with an oily soup. Variations will depend on the types of crops common to the area. In the

southern parts of the country, the starch may be yams, plantains, cassava, rice or maize with a palm oil soup. The standard meal for most rural northern homes is called T-Zette, which is ground maize cooked into a thick porridge and served with a groundnut soup. The soup will contain small portions of tree leaves, a tomato or an onion, and often okra. However, due to the comparative expense of these vegetables, what is considered a standard serving of vegetables for one person will be added to the large pot of soup and shared between the entire family which averages 15 people. Of the total amount of money a family in Ghana will spend on food, only 9.6% is spent on vegetables (Jaiteh, 2010).

Malnutrition rates are high in Ghana. There are three different categories of malnutrition: stunted, wasted, and underweight. Overall in Ghana, 28% of children under the age of 5 are stunted, which means they are far below the average height for their age (Ghana Statistical Service, 2010). Stunting is a sign of chronic malnutrition, a long term issue of food insecurity or poor feeding practices. Stunting in children in the Northern Region (Figure 15) occurs at higher rates of than the national average. Wasting is when a child is too thin for their height, and this affects 10% of Ghanaian children under the age of 5 (Ghana Statistical Service, 2010). Wasting is typically a short term problem indicating a drought or poor growing season. An underweight child is too thin for their age, and this effects 14% of Ghanaian children under 5 (Central Intelligence Agency, 2014; Ghana Statistical Service, 2010). Underweight children suffer from both chronic and acute malnutrition (Ghana Statistical Service, 2010).

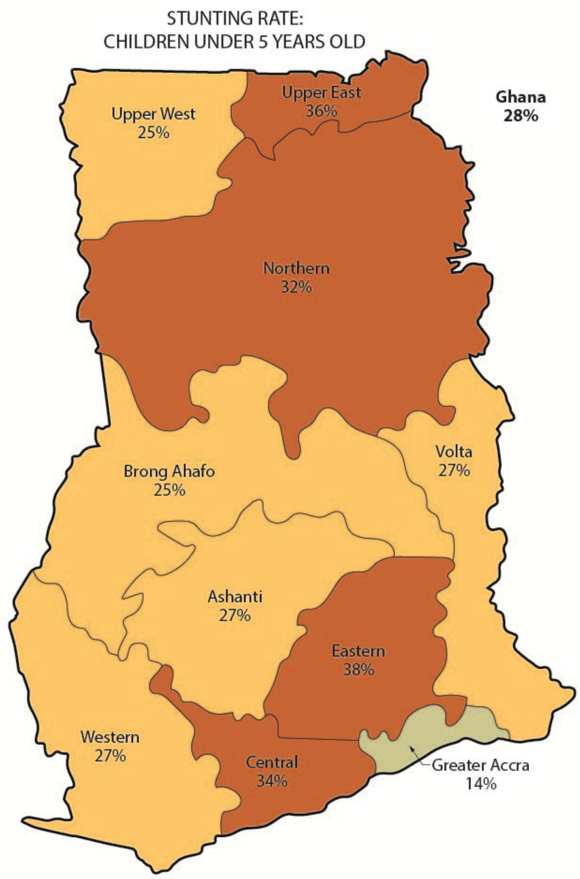


Figure 15: Rate of stunting in children under the age of 5 in Ghana by region - Adapted from (Ghana Statistical Service, 2010)

Children in Ghana are at risk from disease and hindered growth development from many insufficiencies in their diets. Vitamin A deficiency can lead to eye damage, and it puts a child at risk for increased severity of common infectious diseases such as malaria, measles and diarrhea (Ghana Statistical Service, 2010). The Ghanaian health care system is attempting to combat this issue with health care workers giving out Vitamin A drops at child welfare days. Iron deficiency slows mental development and physical growth, and it increases risk of death from infectious diseases (Ghana Statistical Service, 2010).

Many of these severe malnutrition cases could be reduced with a more complete diet that includes a greater variety of food than may be typical in rural Ghana. Growing small gardens around the home would allow families to be more self-reliant for their complete diet and less dependent on the market for valuable fruits and vegetables (Thornton, 2009).

Bananas have high levels of potassium, and some local African breeds are high in beta-carotene, a pigment that converts to vitamin A in the body and is an antioxidant (Koeppel, 2008). Tomatoes are high in lycopene, an antioxidant, and they contain

vitamins A, B, and C as well as potassium, iron and phosphorous (Jaiteh, 2010). Key nutrients needed by malnourished children and their amounts in the fruits and vegetables discussed in this project are shown in table 2.

Table 2: Amounts of key nutrients found in the fruits and vegetables grown in the project (Thornton, 2009)

	Protein (g/100g serving)	**Vitamin A** (mcg RAE#)	**Vitamin C** (mg/100g serving)	**Calcium** (mg/100g serving)	**Iron** (mg/100g serving)
Banana	1.3	3.2	17.3	11	0.6
Mango	1.3	38.3	39	20	0.3
Papaya	0.5	47.5	73	24	0.7
Sweet Peppers	2	156.5	140	29	2.6
Tomatoes	0.5	41.7	28	11	0.5
USDA RDA*	19 g/day	400 mcg RAE#	25 mg	1,000 mg	10 mg

*USDA Recommended Dietary Allowance for children 8 years of age and under (Otten, Hellwig, & Meyers, 2006)
#microgram RAE – Retinol Activity Equivalents

Moringa is considered a “miracle tree” for its ability to grow in difficult climates, its many potential uses, and high levels of nutrients. Peace Corps training materials state that, “Moringa is to malnutrition as the mosquito net is to malaria” (Peace Corps Mali, 2011). Moringa has high levels of calcium, iron, vitamin A, vitamin C, potassium and protein. The leaves of the moringa tree can be eaten fresh or dried and ground into a powder. Eight grams of moringa powder has 14% of a child’s daily protein, the equivalent of 1 egg; 40% daily calcium, the equivalent of 4 glasses of milk; 100% of daily vitamin A, the equivalent of 4 carrots; 23% daily iron; 7 times the vitamin C in an orange; and 3 times the potassium of a banana (Peace Corps Mali, 2011).

2.5 Greywater

On average worldwide, 75-85% of water used in urban settings is either collected as wastewater or disposed to the environment (Qadir et al., 2010). Greywater is the disposed water from cleaning activities such as bathing, washing dishes, and laundry. Greywater makes up between 50% to 80% of total wastewater produced (World Health Organization, 2006c). It does not include water from a toilet which is considered black water (Pinto, Maheshwari, & Grewal, 2010). In developed nations, greywater is included with sewage, and in some cases storm water, and pumped to wastewater treatment

facilities. In the cities of many developing countries, however, the population has grown faster than the poorly constructed and poorly managed wastewater infrastructure (Scheierling et al., 2010). Some developing urban centers initially lacked the space or funding to construct adequate sewage or waste removal systems even before their recent population booms (Mihelcic, Fry, Myre, Phillips, & Barkdoll, 2009).

In most West African cities, less than 10% of wastewater is collected and treated (Drechsel et al., 2006). Smaller, decentralized treatment facilities were promoted in the past as being more flexible and able to adapt to a growing and changing population in African urban centers. Ghana has 70 of these plants (Scheierling et al., 2010), 44 of which are in major cities (Drechsel et al., 2006). However, as of 2010, only 10 of these treatment facilities are functional and these few only service large hotels (Scheierling et al., 2010). Less than 10% of households in Ghana are connected to a sewage system (Drechsel et al., 2006). This illustrates the shortcomings of current sanitation infrastructure in more developed West African cities.

Some governments have tried to work towards western standards but are unable to keep up with the needs of the rapidly growing population or the management, repairs and maintenance of the existing infrastructure. As a population's standard of living increases, the volume of wastewater produced also increases (Qadir et al., 2010). Of Ghana's urban population, 19.9% have access to some type of improved sanitation, this drops to 8.4% of the rural population (Central Intelligence Agency, 2014). Improved sanitation is defined as a hygienic facility which separates human excreta from human contact (World Health Organization, 2015). Although this lack of sanitation infrastructure affects both urban and rural communities, rural communities may have the ability to improve their own sanitation situation because there is more land available near their homes and they have more freedom to alter and improve their houses.

Poorly draining soils and oversaturation from constant flooding often lead to water pooling outside the home where it is disposed rather than infiltrating into the ground (Mihelcic et al., 2009). The red clay common in northern Ghana contributes to this slow infiltration. The greywater pooling outside of northern Ghanaian homes will contain soap or detergent, dirt, skin particles, small traces of fecal matter, and urine because these bathing areas are also used as the primary urinal in the home for both men and women. Urine is normally sterile and exposure will not spread disease. However, there is risk of transmission of certain rare infections that are carried in urine of an infected person, including urinary schistosomiasis, typhoid, and leptospirosis (Feachem et al., 1980).

The make-up of greywater will be effected by the original water supply (Eriksson, Auffarth, Henze, & Ledin, 2002), which varies seasonally in this area between hand-dug cisterns to larger reservoirs collecting runoff from the surrounding watershed. The cisterns within the community are often contaminated by garbage and other wastes washed from neighboring compounds. The reservoirs likely contain fertilizer residue as well as animal and human waste from neighboring fields. Both sources will also contain greywater washed from the overflowing pools outside of homes.

In addition to the greywater from the bathing area, wastewater from washing clothing, dishes and other food preparation is often thrown on the ground outside the home and may also accumulate and start to pool. Table 3 shows the parameters which the WHO reports are typical for greywater worldwide compared to a sample from a northern Ghanaian village. These are typical values for greywater produced, while WHO standards recommended for greywater to be reused will be discussed in following sections. As the table shows, the water from the bath drain in Chirifoyilli falls within the WHO-reported typical range for many of the parameters. The Biochemical Oxygen Demand (BOD) of the bath drain sample is very low, which may be an indication that there is less organic matter in this water than in average greywater worldwide. The nitrate level of this sample is much higher than the WHO range because of the high urine content in this wastewater. Nitrification would convert the ammonia from urine in the stagnant wastewater to nitrite then to nitrate while the sample sat for an undetermined amount of time in the laboratory prior to testing, leading to the high measured nitrate. The sulfate level in the sample may have been high due to dish water containing salt and food preservatives contributing to the greywater pool. Greywater from the village would not have heavy metals or many of the chemicals found in the greywater of wealthier nations. The population from the village will often use locally made soap rather than mass produced soaps with additives and scents. However, due to small amounts of water used when bathing, washing dishes, and washing clothing, concentrations of contaminants will be much higher in this greywater than the wastewater of wealthier areas with running water to dilute soap and other particles.

Table 3: Comparing typical greywater parameters to sample from northern Ghana (World Health Organization, 2006c)

Parameter	Unit	Average Greywater Range (WHO)	Bath drain sample from Chirifoyilli
BOD	mg /L	90-290	14
Nitrate (NO_3-N)	mg/L	<0.1-0.8	13.73
Phosphate (PO_4-P)	mg/L	0.6-27.3	10.63
Sodium	mg/L	29-230	160
Turbidity	NTU	22-200	66
pH	------	6.6-8.7	7.95
Sulfate	mg/L	7.9-110	274

The stagnant water left outside the home, as shown in Figure 16, presents health risks to the people living in the household and the entire community. The polluted water cuts

across walking paths, small children are found playing near the pools, and livestock drink the water. Water used for bathing will contain small amounts of human excreta which may contain pathogens, bacteria, protozoa and helminths. Due to the micro-organisms in the water, there is a risk of spreading diseases when humans are exposed (Eriksson et al., 2002).

Figure 16: Water pooling outside a compound in Chirifoyilli (Photo by Chelsea Fagan)

These stagnant pools are also breeding grounds for disease carrying insects (Mihelcic et al., 2009). Although the malaria carrying mosquito, the female *Anopheles gambiae* mosquito, prefers clear and clean water for breeding (Drechsel et al., 2006), *Anopheles gambiae* larvae have been found in polluted water containing detergents and human waste (Kasili et al., 2009). Malaria claims 1-3 million lives each year worldwide (Kasili et al., 2009). The disease is considered hyper-endemic in Ghana, responsible for 22% of deaths of children under 5 years old and 9% of deaths of pregnant women (Ghana Statistical Service, 2010).

Other insects such as the *Culex quinquefasciatus* mosquito, the carrier of lymphatic filariasis; the *Aedes* mosquito, transmitter of dengue fever, yellow fever, and West Nile

fever; and other vectors such as blowflies have been found to breed in standing, polluted water (World Health Organization, 2006a).

2.6 Shortcomings of current greywater solutions

Many development organizations, including the Peace Corps, promote the construction of "soak-pits" or "soak-away pits" to remove these pools of contaminated water. Soak pits are constructed by digging a large pit at the location of the drain and filling it with large rocks, ideally with a layer of sand and gravel lining the bottom, as shown in Figure 17. The intent is to create more surface area where the water is draining to allow the water to evaporate or soak into the ground and eliminate pooling. Similar to soakage trenches and beds that lead to septic tank systems in rural areas of wealthier nations (Gunn, 1988) . It is advised that pits should be between 1.5 to 3 meters deep and 1 to 2 meters in diameter depending on the number of people using the bath area and the type of soil in which the water is draining (Mihelcic et al., 2009). Some variations of soak pits include: lining some portion of the drain or the rim of the pit with concrete, or covering the pit with tarp, wood plank, or concrete slab (Mihelcic et al., 2009).

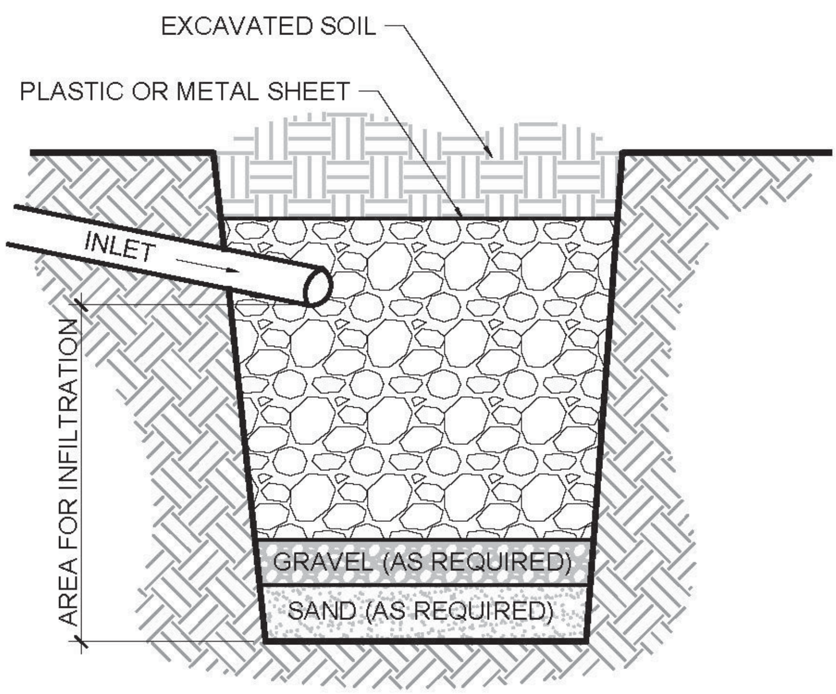


Figure 17: Soak pit design for greywater infiltration - Adapted from (Mihelcic et al., 2009)

Unfortunately, these soak pits rarely work in Ghana for more than a few weeks after they are constructed, as wastewater and rainwater fill the pit quickly. If uncovered, mud and

trash fill the pit, clogging any openings created by the large rocks, resulting in the same problem faced initially. Literature provided by the Peace Corps on instructions for these pits advises owners to re-dig the pit, clean all the rocks and replace them every 6-8 months. The drain of the bathing area needs to be cleaned of solids daily to prevent clogging (Mihelcic et al., 2009). From community observations, this frequency of labor, involving an unpleasant task, when soak-pit owners may not fully understand the need or purpose, is not well received and rarely performed. Similar issues are common in developed-world septic tank systems where a significant level of operation restrictions and maintenance are required for a fully functional system. These systems often face "total neglect" until a serious failure occurs, as consumers expect to install a system and have it run without additional attention (Gunn, 1988).

2.7 Greywater Irrigation Potential

Greywater irrigation is ideal for fruit trees and crops grown for animal fodder. It is best to start irrigating with greywater on well established, mature plants, as they can tolerate the higher levels of salinity and sodium compounds found in greywater as well as the varying levels of pH (World Health Organization, 2006c). It is also best for greywater to be used in furrow irrigation rather than by spray system or manual watering to avoid applying the greywater to foliage or the stem of a plant (World Health Organization, 2006c). Gravity-driven furrow systems are preferred so that greywater is not left standing and allowed to pool, and it is important to provide enough plants that will take up all the greywater draining from the system (World Health Organization, 2006c).

Various societies throughout history have intentionally used wastewater for irrigation and fertilizer. Ancient Greeks had established reuse irrigation systems, as did ancient cities in East Asia (Scheierling et al., 2010). Prior to modern biological wastewater treatment methods, much of Europe used "sewage farms" to dispose of wastewater and improve soil quality (Scheierling et al., 2010). These sewage farms were first used in Germany and Scotland in the sixteenth century and spread to other fast-growing Western cities until 1913, when modern wastewater treatment methods were introduced (Scheierling et al., 2010). Today, 20 million hectares of agriculture land worldwide are irrigated with some form of wastewater, approximately one tenth of all crops (Scheierling et al., 2010).

Wastewater irrigation is increasing around the world because reusing wastewater conserves potable water (World Health Organization, 2006c). The nations where the practice is growing include wealthier, advanced countries in arid climates, such as Israel, Jordan and Australia, which recognize the potential of reusing their valuable water resources in their water conservation programs; as well as poorer countries that lack water and wastewater infrastructure. Table 4 lists the twenty countries worldwide with the highest documented volume of wastewater used for irrigation. These values only represent areas with established data collection systems in place and likely ignore areas with higher rates of unofficial wastewater irrigation practices.

Table 4: Top 20 countries with highest volume wastewater irrigation (Scheierling et al., 2010)

Country	Wastewater used for Irrigation (m^3/day)
Mexico	4,493,000
Egypt	1,918,000
China	1,239,000
Syria	1,182,000
Spain	932,000
USA (California & Florida)	911,000
Israel	767,000
Italy	741,000
Saudi Arabia	595,000
Kuwait	432,000
Iran	422,000
Chile	380,000
Jordan	225,000
United Arab Emirates	200,000
Turkey	137,000
Argentina	130,000
Tunisia	118,000
Libya	110,000
Qatar	80,000
Cyprus	68,000

As the volume of wastewater generated increases with increasing population, the use of wastewater as an irrigation source has also increased in developing countries. This is often because there is no alternative source of water available for irrigation, especially in drier regions (Qadir et al., 2010; Scheierling et al., 2010). Some farmers in developing areas use wastewater for irrigation intentionally knowing the valuable nutrients found in the water will fertilize plants (Drechsel et al., 2006).

Due to the current substandard sanitation systems in these areas, most surface water is contaminated by untreated waste discharge and storm water runoff containing solid waste and fertilizers from the watershed (Scheierling et al., 2010). Any irrigation systems in place are most likely drawing from this polluted water source already (Drechsel et al., 2006). Reusing greywater closer to the source can reduce the pollution of surface water systems which are used as the primary source for drinking water. Even where groundwater sources are available, reusing wash water for some farming would preserve

the clean groundwater source for higher valued uses such as drinking, cooking and personal hygiene.

When properly managed, greywater and wastewater irrigation is “integrated resource management” since it considers discarded water a renewable resource rather than a waste product (Drechsel et al., 2006). Under safe conditions the practice can save money by reducing cost of wastewater collection, processing, and disposal, as well as by providing a free nutrient source for crops, either adding value or reducing the need for fertilizer (Qadir et al., 2010). Wastewater provides the valuable organic matter, nitrogen and phosphorous that is expensive for fertilizer manufacturers to produce and ship. A study in Dakar, Senegal showed a crop of lettuce irrigated with greywater grew larger, faster and with higher insect resistance than lettuce without greywater irrigation. Farmers in this study were able to produce 8-12 harvests each year using greywater irrigation versus 5-6 harvests per year without (Drechsel et al., 2006). According to recent World Bank policy on wastewater in agriculture, “properly managed, wastewater irrigation contributes significantly to sustaining livelihoods, food security, and the quality of the environment” (Scheierling et al., 2010).

Clay soil, like that found in northern Ghana, is a good choice for greywater irrigation as clay helps to remove viruses found in water (World Health Organization, 2006c). Parasitic protozoa and helminthes are also filtered by the soil particles (Eriksson et al., 2002). However, the clay soil also leads to slower infiltration. Most wastewater used in irrigation is coming from the household so it is free of industrial heavy metals which might harm crops (Drechsel et al., 2006).

Farmers throughout West Africa are resourceful and are already accustomed to using any organic waste as a readily accessible and alternative fertilizer. It is common to see solid waste, compost, and latrine sludge applied to fields of staple crops (Drechsel et al., 2006). In Nigerian cities, families will often apply to their fields an organic mix consisting of manure, household waste, sweepings from the compound and ashes from the cooking fires (Drechsel et al., 2006).

SECTION 3: METHODS

Planting beds were assembled to simulate the greywater garden schemes from the Peace Corps project. Secondary effluent from a local wastewater treatment plant was used as a greywater substitute. Beds were planted with tomato cultivars with similar characteristics to those found in Ghana. Silty clay was used as a growth medium to simulate the clay soil found in Northern Ghana. Tomato plants were grown under similar conditions in a greenhouse, irrigated with high volumes of the greywater substitute, high volumes of fresh water, or low volumes of fresh water. Height and leaf count were measured throughout the two month growth process. At the end of the growth process, root lengths, root mass, total fresh mass and total dry mass were measured. These measurements were then analyzed to determine how the different watering variables affected plant growth.

3.1 Greywater for Irrigation

A sample of greywater was collected using a 2 liter soda bottle from a household in the village of Chirifoyilli in July of 2013 and tested for water quality parameters at the Savanna Agriculture Research Institute (SARI) and Council for Scientific and Industrial Research (CSIR) Water Quality Laboratory in Tamale, Northern Region, in Ghana. The sample was carried on the public transportation system from Chirifoyilli to Tamale, and delivered to the CSIR lab the same day it was collected. Due to the high cost of the test, only one sample could be taken. Therefore the values from this sample should be taken as a guideline for the type of wastewater found outside Ghanaian homes rather than exact values to be recreated.

These values are compared to guidelines from the United States Environmental Protection Agency (EPA) for greywater irrigation in Table 5. The values listed are for food crops which are likely to be consumed raw. The EPA guidelines allow higher levels of these parameters, typically by a degree of 10, for livestock fodder crops and foods that are be processed, such as canned foods (Environmental Protection Agency, 2012). Although tomatoes grown in this study are classified under food crops, they are almost never served raw in rural Ghanaian villages but are cooked in a soup or stew.

Table 5 also lists the recommended World Health Organization (WHO) standards for greywater irrigation of food crops. Similar to the EPA, the WHO also has more strict standards for vegetables likely to be consumed uncooked and higher allowable levels for animal fodder, fruit trees and ornamental use. Many nations have adopted their own set of standards varying from these recommended guidelines. For example, Mexico sets a standard of fecal coliforms $\leq$ 2,000 cfu/100 ml for greywater irrigation, more lenient than the WHO standards. Germany requires fecal coliform $\leq$ 10 cfu/100 ml, more strict than the WHO standards of $\leq$ 200 cfu/100 ml for vegetables eaten uncooked and the WHO standard of $\leq$ 1,000 cfu/100 ml for animal fodder and fruit trees (World Health Organization, 2006c).

Also shown are the average values used in the laboratory irrigation experiment. These parameters are measured regularly by the wastewater treatment plant staff. The values fluctuate slightly from day to day. Averages of each value over the length of the irrigation experiment are shown.

Table 5: Water quality of greywater sample from bath area drain

Parameter	**Unit**	Ghana Bath-area waste water	EPA guidelines (food crop irrigation)	WHO standards	Average lab irrigation
Nitrate (NO_3-N)	mg/l	13.73	< 5		4.6 (NH_3-
Phosphate (PO_4-	mg/l	10.63	2		0.9 (Total
Potassium	mg/l	64			
Fecal coliform	CFU/100	$28x10^4$	0	≤ 200	63
BOD	mg/l	14.0	≤ 10	≤ 20	3.5
pH	pH-unit	7.95	6 - 9		
TDS	mg/l	774.9		≤ 20 (TSS)	2.6 (VSS)
Dissolved Oxygen	mg/l	14.5			
COD	mg/l	1915			
Total coliform	CFU/100	$482x10^4$			
E. coli	CFU/100	$11x10^4$			

The key greywater parameters are listed in bold in Table 5. These indicators are the most important because they are most prevalent in the greywater used, and will have significant effects on plant growth and human health. Nitrogen, phosphorous and potassium are important because these are the key elements of fertilizer. Higher levels in the wastewater would likely increase the growth of the plant. Any of these elements in excess or non-optimal ratios may divert energy to other growth phases, such as increased foliage growth rather than fruit development. The fecal coliform levels in the bath water sample were surprisingly high. This may have been a result of chicken, sheep, and goat manure near the home being washed into the stagnate greywater.

According to an FAO fertilizer report, too much nitrogen increases chlorophyll production, increasing the number and size of leaves but reducing flower and fruit development. This also leaves less energy available for root production. Excess phosphorus reduces the level of micronutrients a plant can take up from the soil, especially zinc and iron. This insufficiency leads to yellowing or bleaching of leaf tissue. Excess potassium would also affect micronutrient absorption (Food and Agriculture Organization, 2005). It is the goal of this study to determine if wastewater with similar parameters to the greywater found outside rural Ghanaian homes would affect plant growth.

3.2 Greywater Irrigation of Tomato Plants Experiment

3.2.1 Overview of Tomato Growth Experiment

Although fruit trees were most often used in the bath area gardens during the Peace Corps project, it would have been difficult to acquire and grow them in the laboratory. Tomatoes were chosen as a substitute because tomato seeds and plants are easy to acquire, they grow to maturation quickly, they require less space to grow than a fruit tree, and they can grow in the climate of the laboratory greenhouse. It is argued that tomatoes are a reasonable substitute in the experiment because they are often grown in northern Ghana household gardens and could also be planted strategically near bath drains. Due to a tomato plant's structure, elements found in the irrigation water would more likely be taken up by the roots and make it to the foliage and fruit than in more complex fruit trees (Scheierling et al., 2010).

Tomatoes were grown in three different variable groups. The first group was irrigated under advised tomato growth conditions as recommended by tomato growers (Buff, 1999). The second group was irrigated under similar timing and volume as would occur when planted around the bathing area drain, but with clean water. The third group was irrigated to simulate conditions around the bathing drain. The different variable groups are described in more detail below. These variables were chosen to determine whether the effect on plant growth was caused by a higher volume of water alone or by the combination of high volume and added nutrients. The plants were measured throughout the growth process, and a final measurement after harvest was taken to determine the effect of these variables on the growth rate.

3.2.2 Tomatoes

Tomato cultivars were chosen for this study because of their similarity to the tomato cultivars grown in Northern Ghana. It was difficult to find the exact type of tomatoes grown because the cultivar names in Ghana are often unknown or they are referred to by a local name. The International Food Policy Research Institute (IFPRI) has been conducting studies in Ghana regarding farming and food market processes. In a recent IFPRI study, tomato breeds grown in the Brong Ahafo Region, southern neighbor to the Northern Region, are referred to as Power Rano and Pectomech (Robinson & Kolavalli, 2010). The breeds common to the Upper Eastern Region, northern neighbor to the Northern Region, are called Pectomech and Techiman (Robinson & Kolavalli, 2010). Studies have also been conducted at Kwame Nkruma University of Science and Technology (KNUST) in Kumasi, Ghana on tomato plants. These KNUST studies cite the most available tomato breeds for sale as Burkina, Ashanti, Caterpillar, Power, Cocoaba, and Rando (Jaiteh, 2010). In general, growers select seeds for plants which grow quickly and produce fruits that are spherical, often with crevices or flutes, high water and low soluble content, and an acidic or "biting" taste (Robinson & Kolavalli, 2010). The number of local tomato processing plants has been increasing to meet the demand for canned tomato products in West Africa. Therefore quality canning tomatoes are also valuable cultivars.

Using the tomato descriptions that could be found, and observations of tomatoes growing in gardens and for sale in the local market, several US tomato breeds were chosen because of their similar qualities and appearances. Some of these cultivars are shown in Figure 18.

First, Large Red Tomato was selected for its size and fluted fruit common for Ghana tomatoes. The breed produces 2-4 inch diameter fruits, weighing up to 12 oz. The cultivar was common in New England during the mid 1800s, but the plants grow well under high heat, full sunlight and can withstand some drought areas (Baker Creek Heirloom Seed Co, 2014).

Second, Amish Paste Tomatoes are similar to Roma tomatoes and are preferred in making tomato paste (Baker Creek Heirloom Seed Co, 2014). Amish Paste fruits are acorn shaped and weigh 8-12oz. Although originating in Wisconsin, Amish Paste tomatoes are a heat tolerant plant (Harland & Larrinua-Craxton, 2009) and would be successful in the Ghanaian climate.

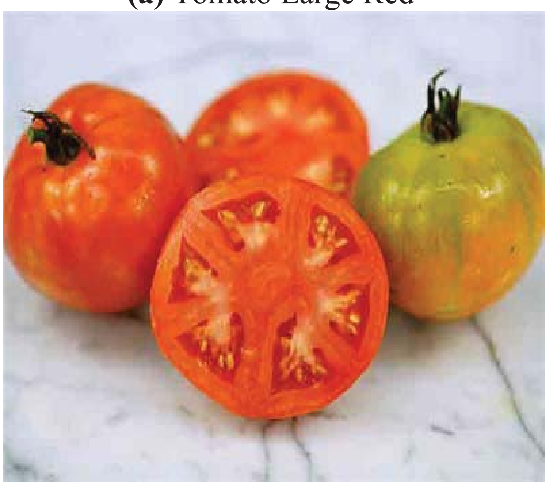
Third, Bison Tomatoes are a smaller cultivar, approximately 2-3 inches in diameter. These plants can withstand drier climates such as the semiarid climate of northern Ghana. Bison tomatoes have a slightly acidic taste that is common among the locally grown Ghanaian cultivars.

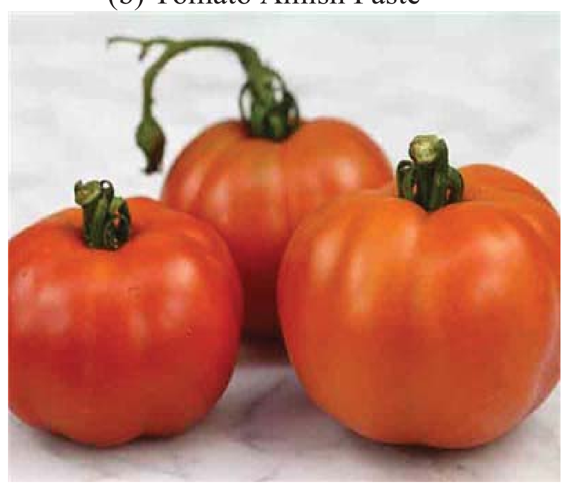
Fourth, the Tomato Rouge d'Irak originated in Iraq, which has a similar semiarid climate as northern Ghana. These tomatoes range from 8-16 oz. The tomatoes often crack during maturation, especially when a heavy rain follows a long dry stint, which is common trait seen on many of the tomatoes sold in northern Ghanaian markets.

Fifth, Boy-oh-Boy hybrid (not pictured) produce a larger fruit, approximately 16 oz. Fruits are slightly fluted and are similar to a beefsteak tomato.

Finally, the Rutgers cultivar (not pictured) produces a medium-sized fruit, 5-8 oz. They were bred as a "general use" tomato at the Rutgers University Agriculture Experiment Station in 1934 for processed tomato products or fresh consumption (Station, 2013).

(a) Tomato Large Red (b) Tomato Amish Paste





(c) Tomato Bison **(d)** Tomato Rouge D'Irak

Figure 18: Some of the tomato breeds used in experiment (Photos courtesy of Baker Creek Heirloom Seed Co, 2014)

Each tomato plant was started from seed. Seeds were planted in egg shells with drainage holes placed in cardboard egg cartons with Miracle-Gro® Seed Starting Potting Mix. The mix contains 0.03% total nitrogen, 0.03% phosphate, and 0.03% soluble potash. Seeds were planted in egg shell pots because the egg shells control the moisture in the soil and encourage faster germination. Seeds were planted ¼ inch deep, and the soil was kept moist during the germination process. Each egg carton was planted with 12 seeds of the same cultivar. Trays were placed in a sunroom exposed to natural sunlight and kept at an average 85° F.

Seedlings that reached a height of 5-10 inches were transplanted to larger 6-inch plastic pots. These pots were moved to a constructed greenhouse and grown under 3200-lumen

fluorescent lights. Each of these seedlings was watered with a total of one gallon per week.

The experiment used both plants expected to reach full-grown height by the end of the experiment as well as young seedlings. This way it was possible to determine the effects of the watering variables on established plants as well as the effects on seedlings.

3.2.3 Soil

The soil found in the north of Ghana is typically reddish, fine clay. The United Nations Food and Agriculture Organization (FAO) classifies the soil found around the village of Chirifoyilli as plinthic luvisol, a light colored clay layer with high cation exchange capacity (Food and Agriculture Organization, 2005). To achieve a similar quality of clay as the growing medium for the experiment, a sample of silty clay was collected from a local till-floored lake plain formation. This is a soil with fine particles which settled when the area was under a glacial lake (Jerome, 2006).

3.2.4 Planting Beds

The 60 tomato plants were arranged in 12 different planting beds, with five plants per bed. The beds were Viagrow® Tomato Planter Raised Bed Gardens as seen in Figure 19. These are flexible polyethylene containers with large holes for drainage at the base. Each bed is 39 inches long by 22 inches wide by 10 inches deep and can hold 4.35 cubic feet of soil (Viagrow, 2014).

Figure 19: Viagrow Tomato Planter Raised Bed (Photo courtesy of Viagrow, 2014)

Each bed was set up to simulate bath-drain gardens in Ghana. A small trench directed the water toward the center of the bed where it was allowed to pool as it does near Ghanaian homes. The five tomato plants were planted around the perimeter of this center pool as shown in Figures 20, 21 and 22. Four of the beds were watered with high volumes of greywater, four beds were watered with high volumes of fresh water, and four beds were watered with smaller volumes of fresh water. Plants were arranged so that each group of

beds was planted with an identical planting scheme across the watering variables. For example, a full-grown Large Red plant from the same batch was planted in position 1 for the greywater bed, position 1 in the fresh water high volume bed, and position 1 in the freshwater bed, as illustrated by the highlighted plants in Figure 22. This helped to eliminate variability between initial planting height, breed and proximity to the center pooling water. Also, the plants were grown under identical conditions prior to being planted in their different watering variable beds. Due to the compact size of the growing bed with the center pool, position 3 as shown in Figure 20 was always planted with a seedling.

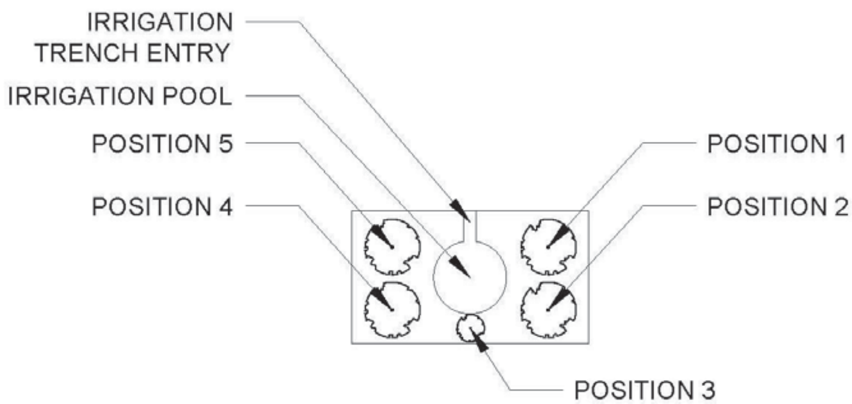


Figure 20: Placement of tomato plants and irrigation trench in planting beds

Figure 21: Greywater Bed 1. Example of planter layout (Photo by Chelsea Fagan)

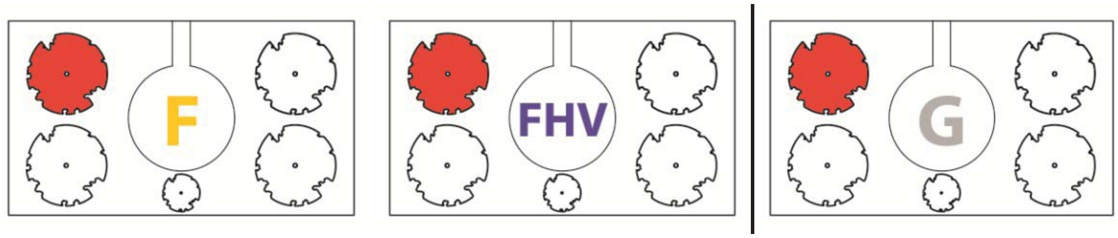


Figure 22: One set of tomato plants highlighted within each different watering variable bed

3.2.5 Greywater Used

In order to use water similar to the greywater used in the field, this experiment used samples of secondary effluent-wastewater that has already been through a settling tank where most solids have been removed and through biological treatment, but prior to chemical disinfection. The goal was to achieve similar levels of nitrogen, phosphorus and BOD to those found in the Ghana wastewater sample. Due to the different laboratories performing tests for different indicators, the parameters tested do not match exactly between the Portage Lake Wastewater Treatment Plant in Houghton, Michigan and the Savannah Agriculture Research Institute in Tamale, Ghana. The water quality parameters for the different water sources are shown in Table 6.

Table 6: Water quality of sample from wastewater treatment plant and field greywater sample (NA=not available)

Parameters	Influent Wastewater WWTP	Secondary Effluent WWTP	Ghana bathing area Greywater
Temperature (°F)	55	NA	77.7
pH	7.6	NA	7.95
Nitrogen (mg/l)	20.1 (NH_3-N)	4.6 (NH_3-N)	13.73 (NO_3-N)
Total Phosphate (mg/l)	2.9	0.9	10.63 (PO_4-P)
BOD (mg/l)	154	3.5 (CBOD)	14.0
VSS (mg/l)	136	2.6	774.9 (TDS)
Fecal Coliform (CFU/100ml)	NA	63	$28x10^4$

Since the wastewater treatment plant measures ammonia rather than nitrate, or total nitrogen, it is difficult to determine the levels of nitrate in the secondary effluent sample used. Ammonia (NH_3-N) oxidizes to nitrate (NO_3-N) during the treatment process as part

of the nitrification cycle (Tchobanoglous, Burton, & Stensel, 2003), as shown by the drop in ammonia from influent to secondary effluent in Table 6. Ammonia levels decrease over time as nitrate levels increase. Thus, ammonia levels will serve as an indication of the presence of nitrogen in the wastewater assuming it will oxidize to nitrate, the form of nitrogen most readily taken up by plant roots in soil (Campbell & Reece, 2002).

Phosphates, specifically polyphosphates, are sometimes used as an ingredient in detergents. Lower levels of phosphates were measured in the secondary effluent from the wastewater treatment plant because polyphosphates have been banned as a detergent builder in the US, but are likely still present in some soap found in Ghana. In addition, phosphates would have precipitated in the aeration basin in a treatment step prior to collection at the wastewater treatment plant.

3.2.6 Greenhouse

A 10-ft x 9-ft x 6-ft tall greenhouse was constructed in the laboratory as shown in Figure 23 and Figure 24. Two particle boards 10 ft x 4 ft were each elevated each by six supports, each 6-ft long 4-in x 4-in columns, and placed side by side. Six shop lights were hung from the particle boards, each with two 4-ft long, 3200-lumen fluorescent light bulbs. The lights were connected to a timer, turning the lights on for 12 hours each day (Figure 25). A tarp was placed over the structure to contain moisture and heat. The twelve planting beds were placed over a tarp on the floor, next to each other, and grouped by watering variable.

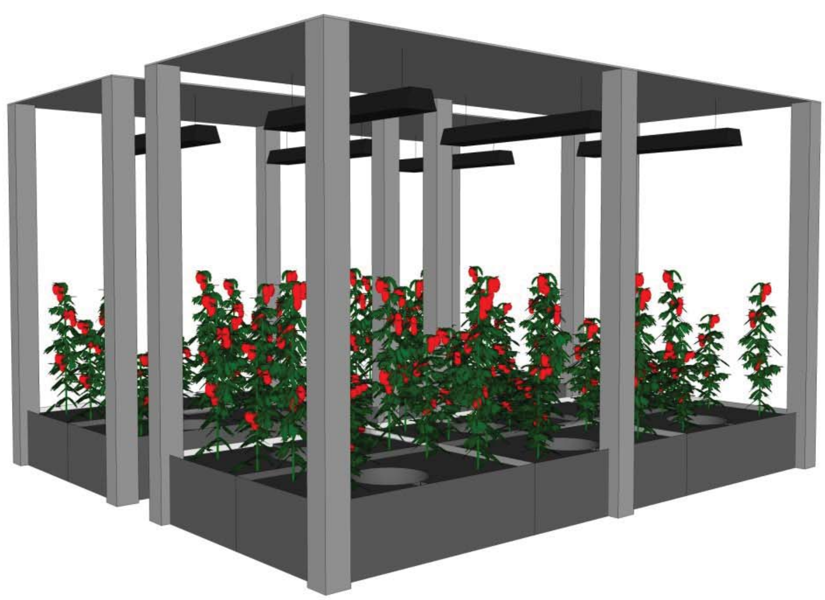


Figure 23: Three dimensional diagram of greenhouse

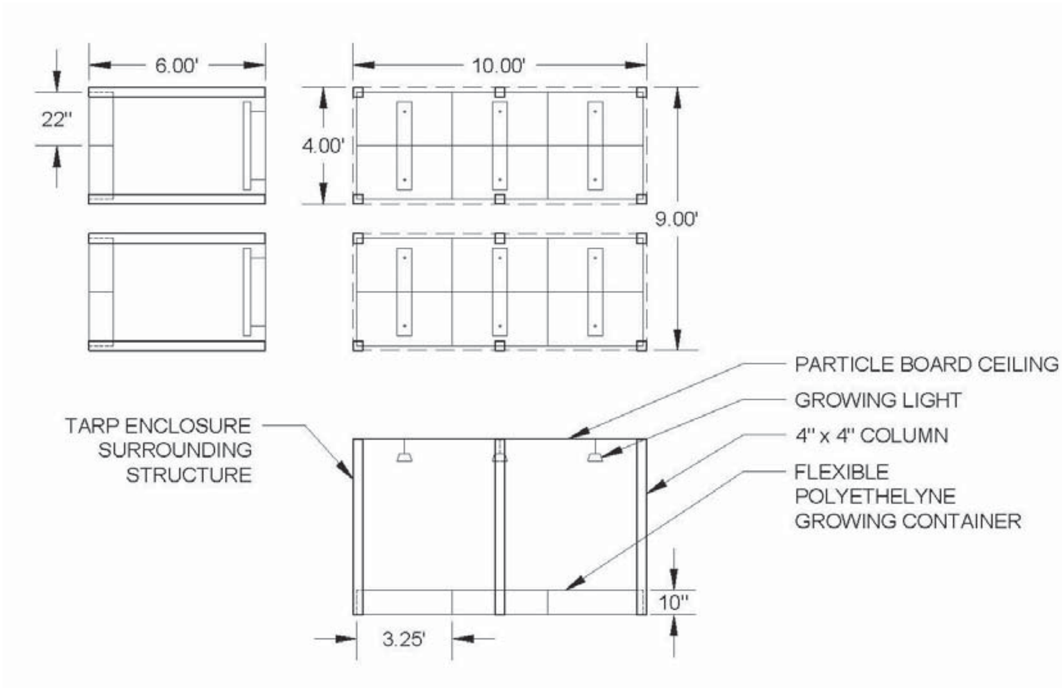


Figure 24: Section, Plan, and Elevation view of greenhouse structure

Figure 25: Picture of lit greenhouse with tomato plants (Photo by Chelsea Fagan)

3.2.7 Watering Variables

The planting beds were divided into three watering variables. The first group of four beds received the secondary effluent from the wastewater treatment plant following the greywater simulation as described above. Watering began with a total of 1 liter per day when the tomatoes were first placed and increased to a total of 3 liters per day. At the volume of 3 liters per day, the soil in the beds reached a saturation point and any additional volume above 3 liters immediately drained from the beds. The beds were irrigated with half their daily volume in the morning, at 7:00 AM, and half in the evening, at 7:00 PM, to simulate the bathing schedule of a typical Ghanaian household.

The second group of four beds received tap water in the same high volume as the greywater beds. Watering for the high-volume freshwater beds mirrored the greywater beds by beginning with a total of 1 liter per day after initial planting and increasing to a total of 3 liters per day. The tap water was allowed to sit in a container, uncovered, for at least 24 hours after leaving the tap before application to planting beds to allow residual chlorine, and other municipal water additives that may be present to evaporate.

The third group of four beds received tap water at a lower volume than the other groups. Watering began with 0.5 liters every other day after initial planting and increased to 1 liter per day. This volume was based on recommendations from tomato growth guides recommending ½ -1 inch of water per week for tomato plants grown in containers (Buff, 1999; Harland & Larrinua-Craxton, 2009). For the size of planting beds used, this was approximately 7 liters per week. This tap water was treated the same as for the high-volume freshwater group, i.e., allowed to sit uncovered for 24 hours before watering.

3.2.8 Measurements

Throughout the growing period, the height of each plant was measured every 5 days and the number of leaves was counted. The time between the plants' initial placement in planters and when they were harvested for final measurements was 63 to 72 days, depending on the set. Each set of plants of the same breed, planted in the same position in their respective planting beds, was planted and harvested on the same day to maintain consistency within each set.

At the time of harvest, each plant was measured for height and leaves were counted a final time. The plant was carefully removed from the soil, keeping the root structure intact. The root was rinsed in a tub of water to remove soil still attached to the root. The root mass was measured for length. The plant was then weighed for its fresh mass, as shown in Figure 26. Each plant was then cut at its soil line, and the root and the top shoot were weighed separately. The root and shoot were then labeled and placed in an oven at 100°F for 12 hours. At the end of the oven cycle the plants were removed, and the dry root and dry shoot were weighed, as shown in Figure 27.

Figure 26: Tomato plant set before placed in oven (Photo by Chelsea Fagan)

Figure 27: Dry tomato set after dehydration for 12 hours as preparation for dry mass measurement (Photo by Chelsea Fagan)

3.2.9 Timeline

Seeds were planted in batches of 12 between July 14 and August 4, 2015. This gave the plants the recommended 8 to 10 week establishment and early development time as recommended by tomato growers (Buff, 1999). Healthier plants were transferred into 6-inch pots when they reached heights of 5 to 10 inches. Tomato plants were transplanted to the planting beds between October 6 and 9, 2015. Beds were watered according to their watering variable. Plants were measured when initially transplanted to beds and every 5 days after. Plants were harvested and final measurements taken between

December 10 and 19, 2015, which was 63-72 days after they were transplanted to the beds.

SECTION 4: RESULTS AND DISCUSSION

4.1 Results

Harvest Measurements
Each set of final harvest measurements shown in Tables 7.1-7.20 corresponds to the same breed, at the same stage of maturity, planted in the same batch and location in the planting beds, and harvested on the same day so that the only variable within each set is the type of irrigation each plant received. Shown are the full height of the shoot of the plant, the number of leaves, the length of the longest root, the total mass immediately after harvest, the dry mass (after dehydration for 12 hours), and the fresh root mass to shoot mass ratio.

Table 7: Set 1 - Tomato Large Red Batch A – full grown

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (LRA-1)	85	144	18	45.7	2.9	0.08
Freshwater High Volume (LRA-8)	58	90	24	23.9	2.1	0.12
Freshwater (LRA-7)	78	107	23	27.4	2.6	0.11

Table 8: Set 2 - Tomato Large Red Batch C – full grown

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (LRC-5)	120	501	34	112.7	44.6	0.01
Freshwater High Volume (LRC-7)	130	254	34	131	52.6	0.03
Freshwater (LRC-1)	97	151	35	61.9	25.5	0.03

Table 9: Set 3 - Tomato Amish Paste Batch C – full grown

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (APC-1)	160	154	32	127.1	14.8	0.03
Freshwater High Volume (APC-7)	150	165	41	110.1	11.6	0.03
Freshwater (APC-4)	121	107	21	56.6	5.2	0.04

Table 10: Set 4 - Tomato Bison Batch A – full grown

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (BA-1)	97	304	17	75.0	5.2	No data
Freshwater High Volume (BA-3)	94	156	25	38.7	2.9	No data
Freshwater (BA-7)	64	146	28	37.9	3.5	No data

Table 11: Set 5 - Tomato Rouge D’Irak Batch A – full grown

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (RD’IA-11)	150	199	35	118.5	9.9	0.04
Freshwater High Volume (RD’IA -4)	111	150	35	54.1	5.8	0.08
Freshwater (RD’IA -7)	112	121	41	44.2	5.7	0.10

Table 12: Set 6 - Tomato Amish Paste Batch B – full grown

	Height (cm)	Leaf count	Root Length (cm)	Fresh mass (g)	Dry mass (g)	Root : Shoot Ratio
Greywater (APB-11)	127	126	23	53.6	4.3	0.2
Freshwater High Volume (APB -10)	134	118	23	76.9	4.9	0.4
Freshwater (APB -8)	121	169	30	82.4	9.3	0.9

Table 13: Set 7 - Tomato Rutgers Batch A – full grown

	Height (cm)	Leaf count	Root Length (cm)	Fresh mass (g)	Dry mass (g)	Root : Shoot Ratio
Greywater (rutA-7)	120	147	21	70.2	26	0.05
Freshwater High Volume (rutA -1)	114	117	19	48.1	14.4	0.08
Freshwater (rutA -10)	89	90	23	28.4	7.8	0.21

Table 14: Set 8 - Tomato Boy-oh-boy Batch B – full grown

	Height (cm)	Leaf count	Root Length (cm)	Fresh mass (g)	Dry mass (g)	Root : Shoot Ratio
Greywater (BobB-8)	150	173	28	115	6.6	0.02
Freshwater High Volume (BobB -1)	169	126	33	86.3	6.9	0.04
Freshwater (BobB -7)	128	96	21	68.3	6.2	0.06

Table 15: Set 9 - Tomato Boy-oh-boy Batch A – full grown

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (BobA-4)	107	139	29	59	2.7	No data
Freshwater High Volume (BobA -3)	102	103	37	32.2	No data	No data
Freshwater (BobA -2)	78	80	26	21.9	No data	No data

Table 16: Set 10 - Tomato Large Red Batch C - seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (LRC-2)	25	57	10	4.8	0.3	0.20
Freshwater High Volume (LRC-11)	16	33	21	3.7	0.3	0.38
Freshwater (LRC-8)	12	37	10	1.2	0.2	0.30

Table 17: Set 11 - Tomato Large Red Batch C - seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (LRC-9)	36	60	31	7.9	0.5	0.36
Freshwater High Volume (LRC-12)	41	69	16	9.9	0.6	0.09
Freshwater (LRC-10)	33	59	25	5.8	0.5	0.09

Table 18: Set 12 - Tomato Large Red Batch D - seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (LRD-8)	45	79	17	12.8	0.9	0.11
Freshwater High Volume (LRD-12)	48	93	16	12.3	0.7	0.07
Freshwater (LRD-10)	21	47	10	3.4	0.3	0.10

Table 19: Set 13 - Tomato Amish Paste Batch C - seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (APC-11)	51	91	15	8.4	0.6	0.09
Freshwater High Volume (APC-8)	36	56	18	5.1	0.2	0.13
Freshwater (APC-12)	35	43	14	6.6	0.6	0.07

Table 20: Set 14 - Tomato Amish Paste Batch B - seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (APB-6)	42	59	22	5.2	0.3	0.09
Freshwater High Volume (APB-12)	45	51	17	4.8	0.3	0.15
Freshwater (APB-2)	9	6	12	0.6	0.01	0.50

Table 21: Set 15 - Tomato Amish Paste Batch C – seedling

	Height (cm)	Leaf count	Root Length (cm)	Fresh mass (g)	Dry mass (g)	Root : Shoot Ratio
Greywater (APC-3)	82	78	22	16.4	1.2	0.15
Freshwater High Volume (APC-5)	75	77	27	17.9	1.2	0.12
Freshwater (APC-2)	42	59	19	10.7	1.1	0.18

Table 22: Set 16 - Tomato Bison Batch B – seedling

	Height (cm)	Leaf count	Root Length (cm)	Fresh mass (g)	Dry mass (g)	Root : Shoot Ratio
Greywater (BB-6)	34	75	13	6.7	0.4	0.22
Freshwater High Volume (BB-10)	36	62	14	4.2	0.4	0.21
Freshwater (BB-12)	24	45	17	4.0	0.3	0.30

Table 23: Set 17 - Tomato Bison Batch B – seedling

	Height (cm)	Leaf count	Root Length (cm)	Fresh mass (g)	Dry mass (g)	Root : Shoot Ratio
Greywater (BB-3)	15	30	21	2.2	0.2	0.57
Freshwater High Volume (BB-9)	36	55	12	3.6	0.3	0.28
Freshwater (BB-11)	36	66	14	5.4	0.4	0.10

Table 24: Set 18 - Tomato Rouge D'Irak Batch B – seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (RD'IB-5)	26	41	16	3.8	0.1	0.19
Freshwater High Volume (RD'IB -6)	29	35	12	3.1	0.3	0.19
Freshwater (RD'IB -10)	18	33	20	2.4	0.3	0.32

Table 25: Set 19 - Tomato Rutgers Batch B – seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (rutB-6)	70	126	28	15.6	1.1	0.09
Freshwater High Volume (rutB -5)	27	33	10	2.6	0.3	0.19
Freshwater (rutB -8)	30	39	15	3.9	0.4	0.23

Table 26: Set 20 - Tomato Boy-oh-boy Batch B – seedling

	Height (cm)	**Leaf count**	**Root Length (cm)**	**Fresh mass (g)**	**Dry mass (g)**	**Root : Shoot Ratio**
Greywater (BobB-4)	52	56	11	7.1	0.5	0.11
Freshwater High Volume (BobB -3)	33	38	15	3.1	0.1	0.15
Freshwater (BobB -9)	15	26	12	1.1	0.0	0.22

Growth Measurements

The height of each plant over the growing period is shown in Figures 28 and 29 below.

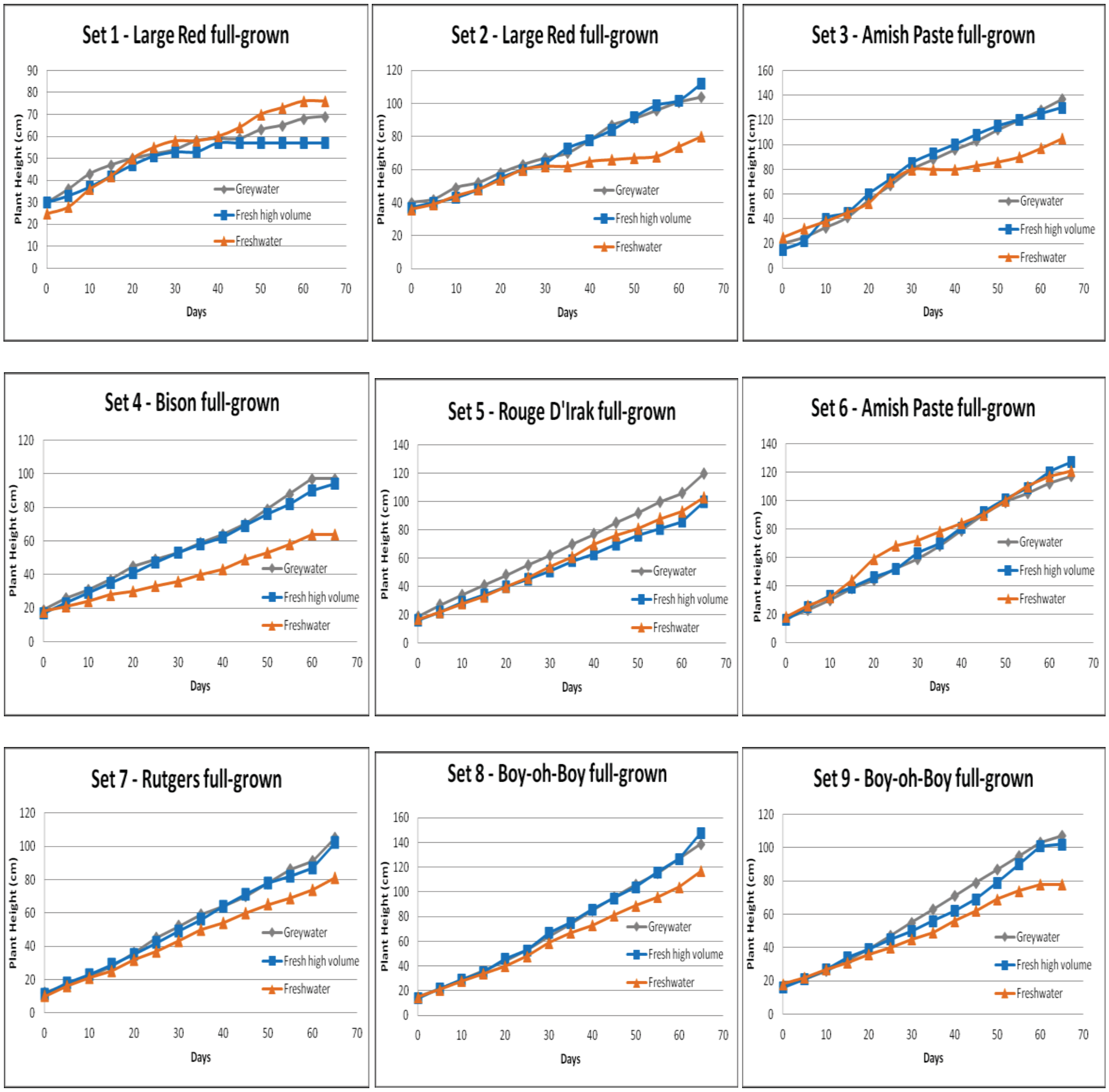


Figure 28: Height of full-grown tomato plants over growth period shown by set and labeled by cultivar

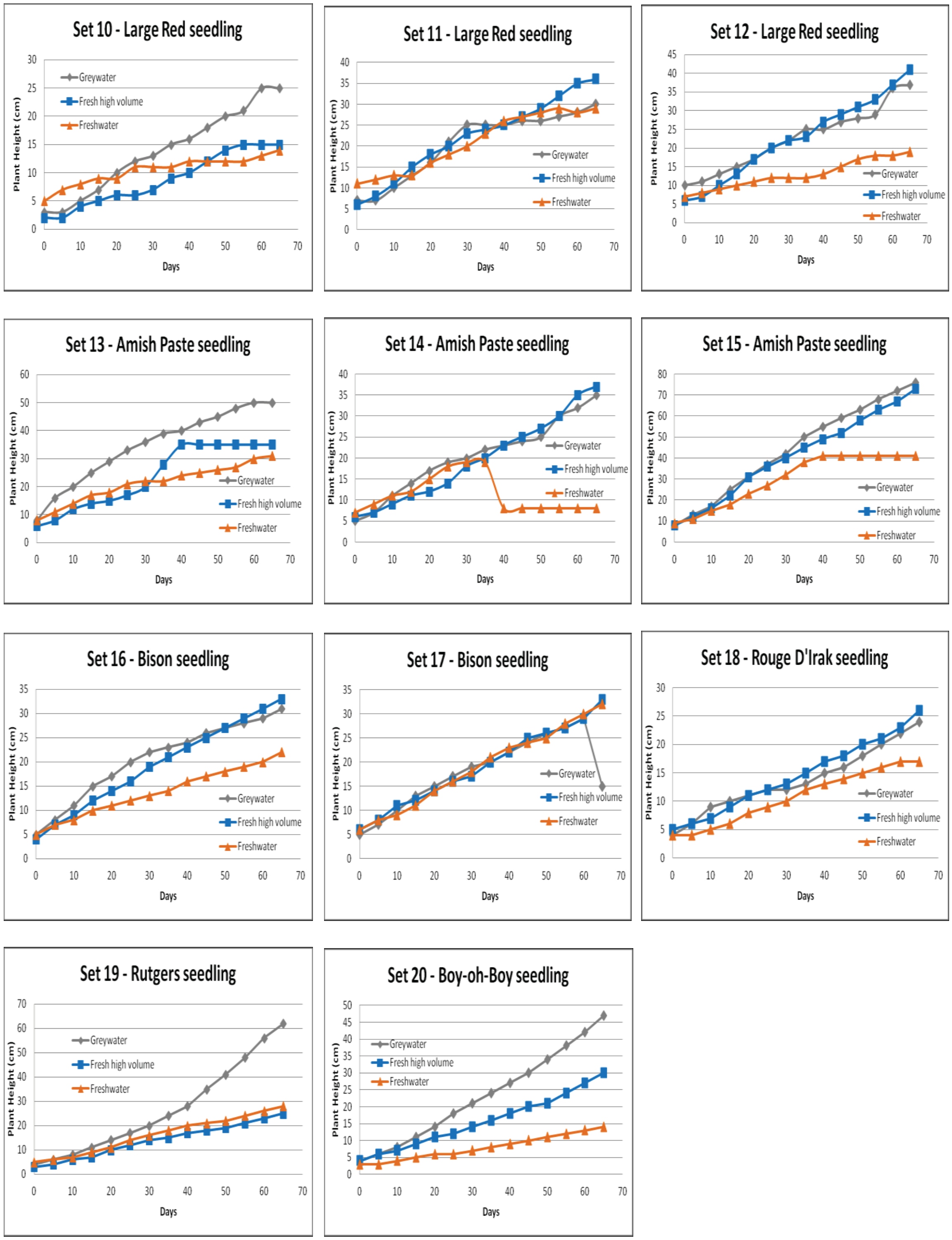


Figure 29: Height of seedling tomato plants over growth period shown by set and labeled by cultivar

4.2 Analysis

The growth graphs in Figures 28 and 29 show that in 7 of the 20 sets, the plant irrigated with greywater grew distinctly faster than the other plants, while in 4 of the sets plants receiving high volumes of fresh-water grew faster, and in only one set did the low-volume fresh-water irrigation result in plant growth greater than the others. The remaining 8 of the 20 sets show very similar growth rates between the two plants receiving the high-volume irrigation.

Figure 30 shows the average growth rate of the plants which reached full-grown height. This figure illustrates that the full-grown plants irrigated with high volumes of greywater grew slightly faster than the plants irrigated with high volumes of freshwater. Two tailed t-tests for paired samples were performed on final height measurements and the final leaf counts to account for the range of averaged values and determine the significance of differences between averages. The full grown plants' final heights for both the greywater-irrigated plants and freshwater high-volume irrigated plants were significantly greater ($p < 0.05$) than the freshwater plants. However, the greywater-irrigated plant heights were not significantly different from the heights of the freshwater high-volume irrigated plants.

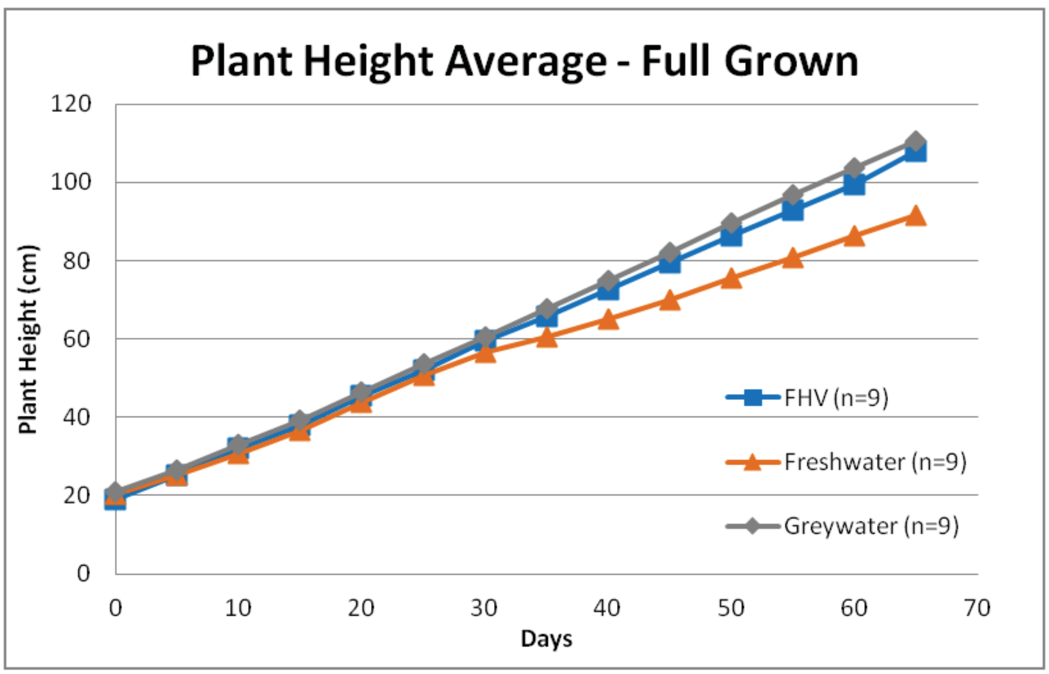


Figure 30: Average growth rate of plants reaching full grown height classified by watering variable (Greywater-Freshwater: $p = 0.0049$; FHV-Freshwater: $p = 0.0249$; Greywater-FHV: $p=0.471$; standard deviations and t-test tables found in Appendix 1)

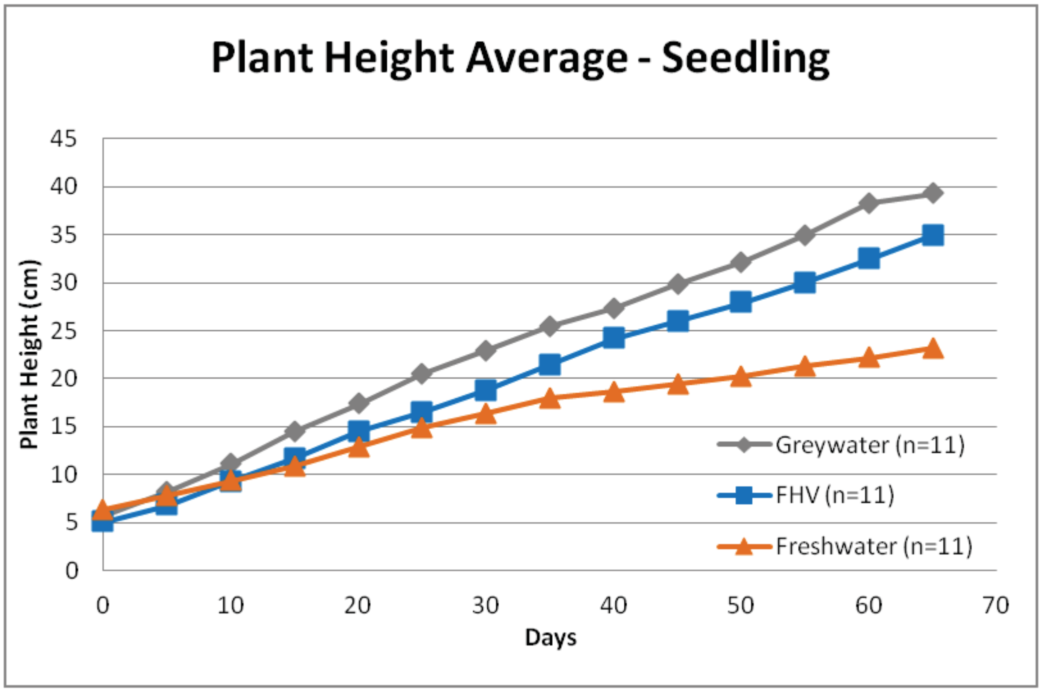


Figure 31: Average Growth rate of seedlings classified by watering variable (Greywater-Freshwater: p = 0.0077; FHV-Freshwater: p = 0.0077; Greywater-FHV: p=0.349; standard deviations and t-test tables found in Appendix 1)

The plants that were transplanted to the irrigation beds at a younger age were averaged separately from the mature plants. Figure 31 shows the seedlings in beds irrigated with high volumes of greywater grew faster than with the other watering schemes. Similar to the full grown plants, results for the seedlings' paired t-tests show that the high-volume irrigated plants had a significantly greater height than the freshwater plants, but there was a less significant difference between the final heights of the greywater irrigated and the freshwater high-volume irrigated plants. On average, both seedlings and mature plants grew slightly taller when irrigated with greywater, indicating they benefitted slightly from nutrients in the water; however, the close growth rate between the two high-volume watering plans indicates that the increased water volume had a more significant effect on the growth rate of the plants than did the extra nutrients.

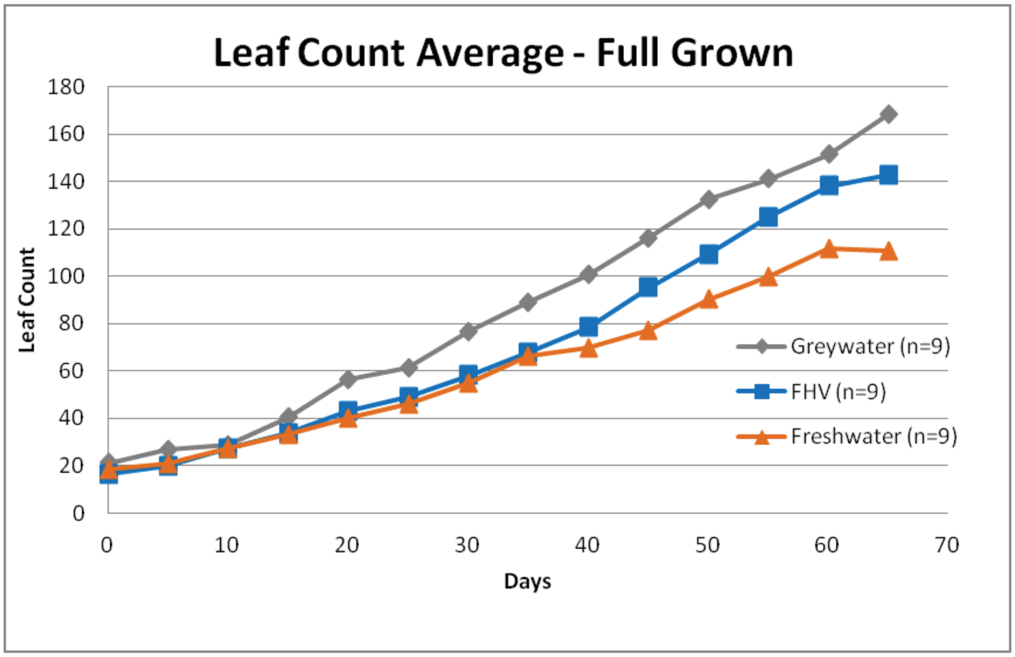


Figure 32: Average leaf count of plants reaching full grown height classified by watering variable (Greywater-Freshwater: p=0.0109; FHV-Freshwater: p=0.0668; Greywater-FHV: p=0.200; standard deviations and t-test tables found in Appendix 1)

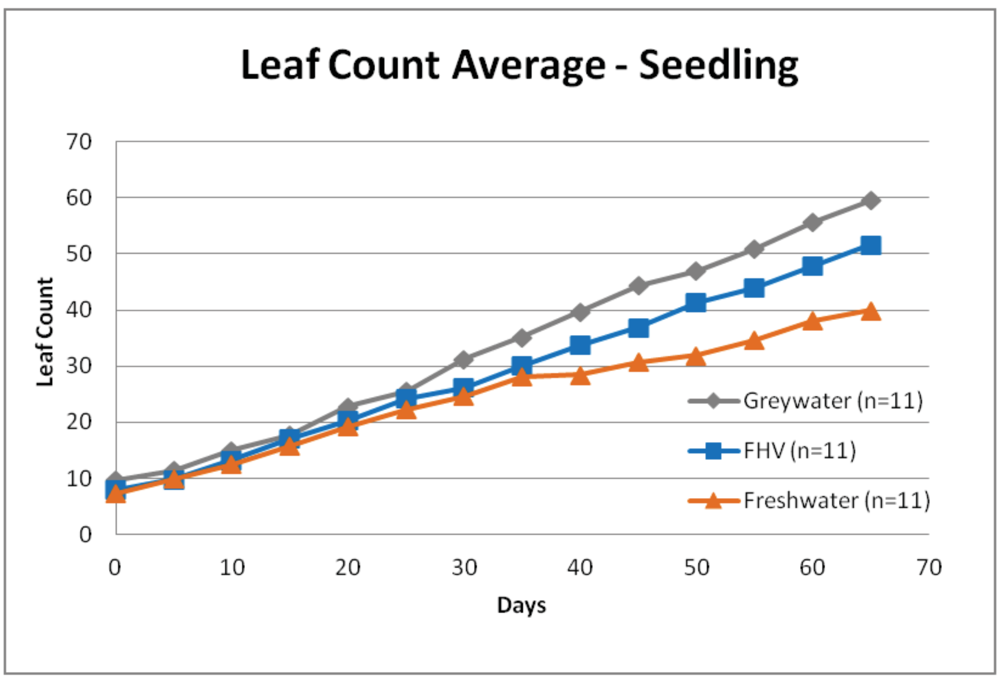


Figure 33: Average leaf count of seedlings classified by watering variable (Greywater-Freshwater: p=0.0216; FHV-Freshwater: p=0.0207; Greywater-FHV: p=0.263; standard deviations and t-test tables found in Appendix 1)

Figure 32 and Figure 33 show similar patterns in the average number of leaves during growth of mature plants and seedlings, respectively. Both seedlings and full grown plants grew new leaves faster when irrigated with greywater. This is reasonable, as the increased levels of nitrogen in water help plants in chlorophyll production, increasing the amount and health of foliage (Campbell & Reece, 2002). The paired t-tests for the leaf count show that the greywater-irrigated plants produced significantly more leaves in the case of both the full-grown plants and the seedlings. The greywater-irrigated plants did not show as significant of an increase in final leaf count when compared to the freshwater high-volume irrigated plants.

Measurements taken after the plants were harvested are shown in Figures 34-41. Figure 34 shows the average length of the longest root of full-grown plants. Both of the plant groups irrigated with freshwater developed longer roots than the average of the group irrigated with greywater. The plants irrigated with high volumes of freshwater grew the longest roots. Figure 35 comparing the average root mass shows that the plants irrigated with low volumes of freshwater developed a greater root mass than the other groups. This indicates these plants had to divert more energy to growing roots to seek out less available water. An extensive root system is important for the health of the plant, allowing it to anchor more securely in the soil and tolerate fluctuations in watering (Buff, 1999).

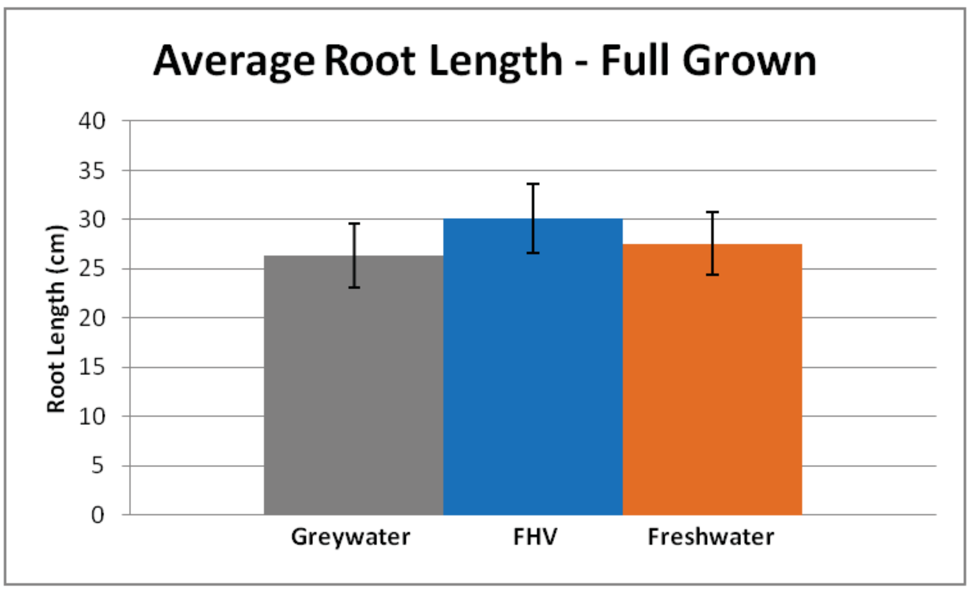


Figure 34: Average final root length of plants reaching full grown height (standard deviation shown by error bars)

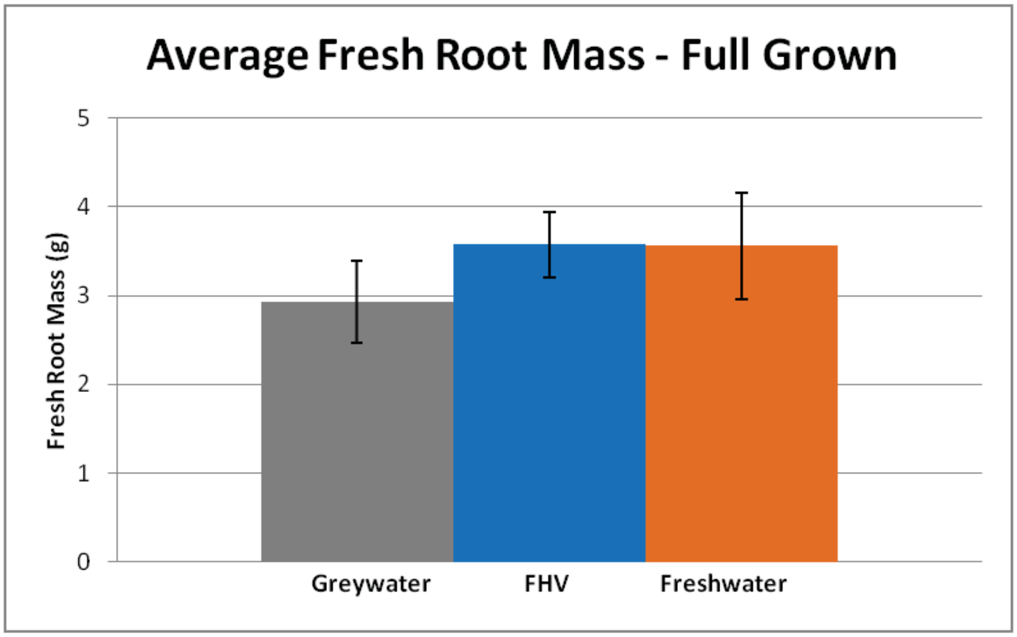


Figure 35: Average final fresh root mass of plants reaching full grown height (standard deviation shown by error bars)

The root measurements for the seedlings in Figures 36 and 37 show that the greywater plants had on average a slightly longer root than the other watering variables, yet distinctly outpaced the other variables in root mass. As the greywater encouraged these young plants to establish a strong root system early in development, they will most likely be healthier through maturation.

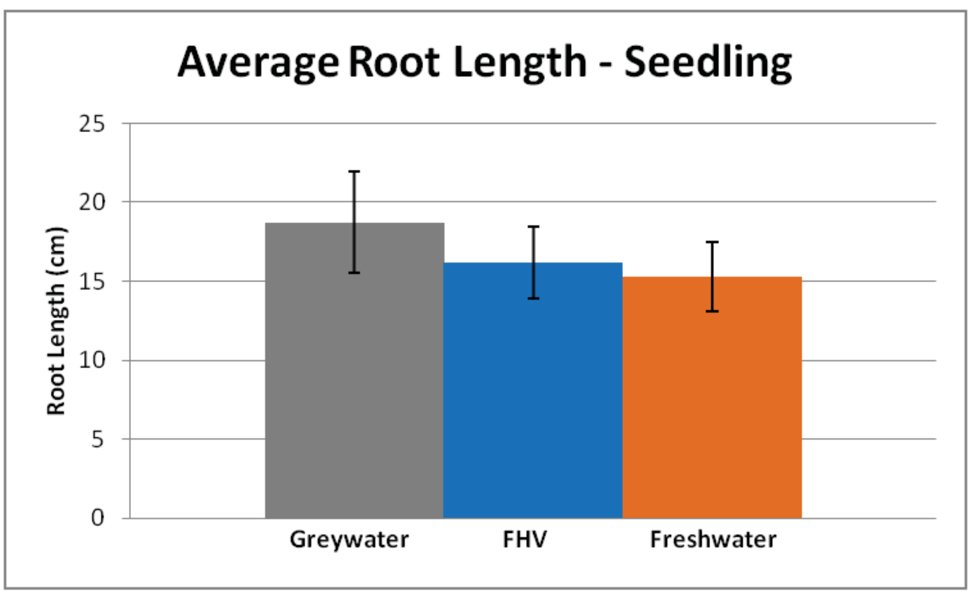


Figure 36: Average final root length of seedlings (standard deviation shown by error bars)

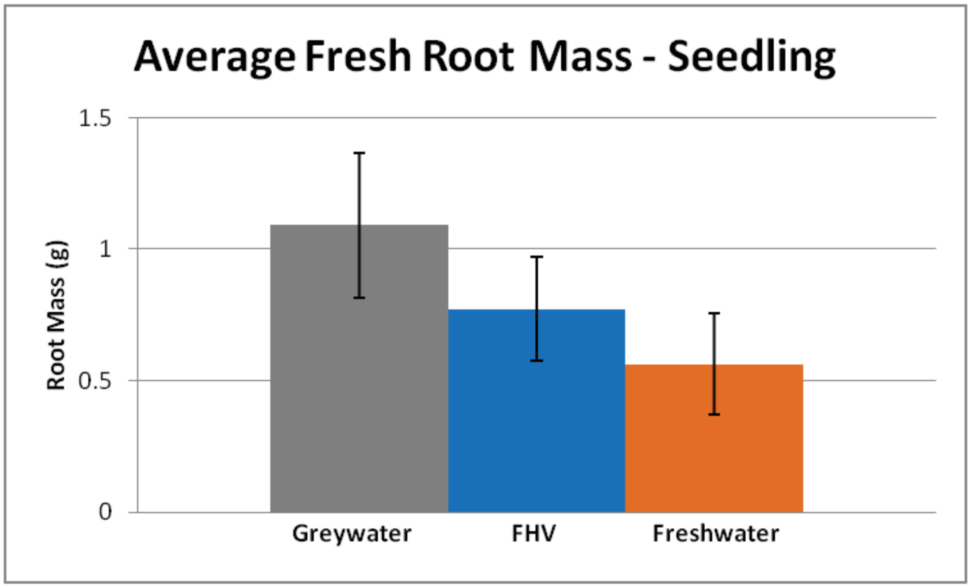


Figure 37: Average final fresh root mass of seedlings (standard deviation shown by error bars)

Figure 38 shows that the plants watered with greywater had a larger plant mass than the others. The plants grown with greywater had on average a greater fresh mass than those grown with the same volume of freshwater, indicating that the increased nutrients in the water helped the growth of the plant, and that the extra mass was not only from the increased water volume. Figure 39 shows the dry mass of the full grown plants irrigated with greywater was only slightly larger than the high volume freshwater irrigated plants.

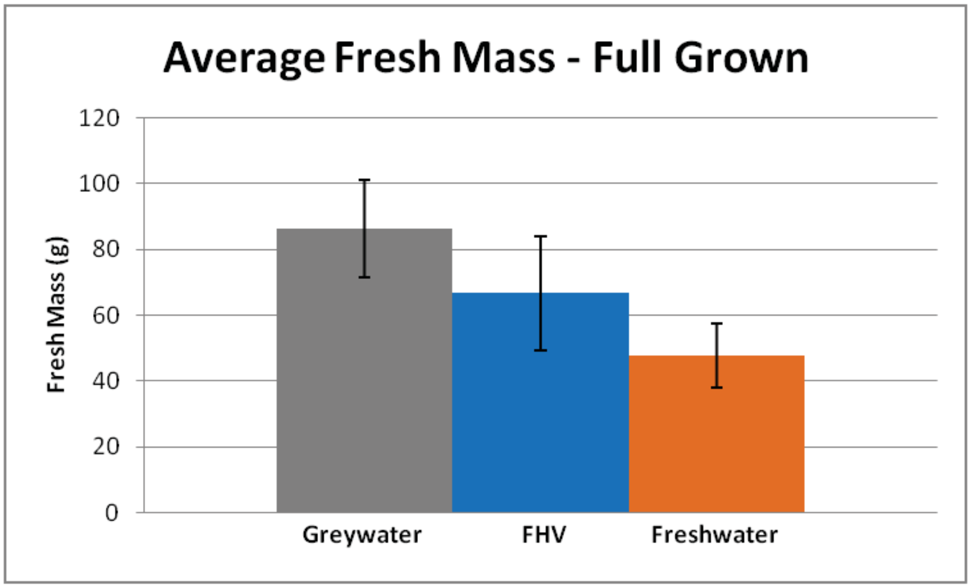


Figure 38: Average final fresh mass of plants reaching full grown height (standard deviation shown by error bars)

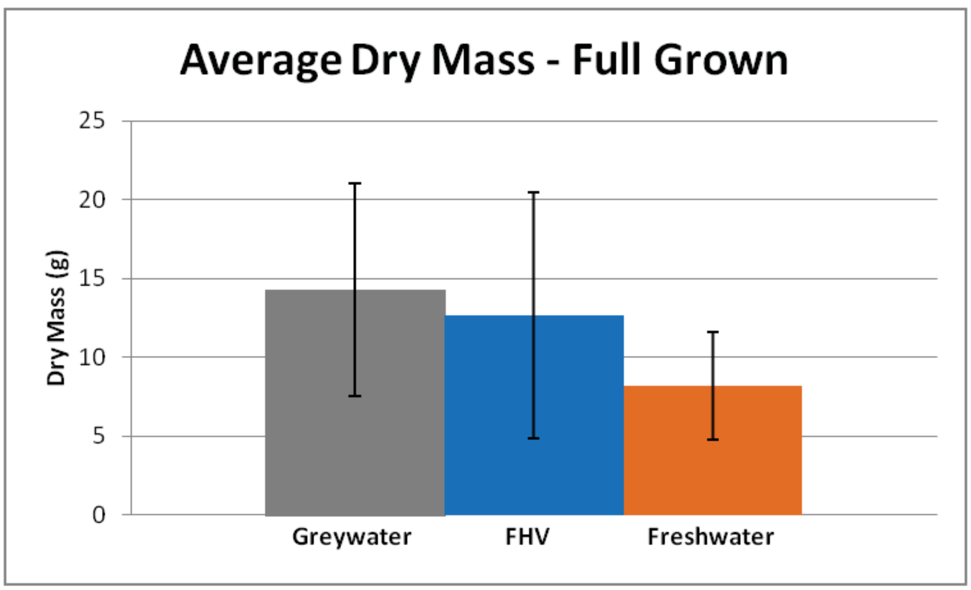


Figure 39: Average final dry mass of plants reaching full grown height (standard deviation shown by error bars)

Because the seedlings were still very young and small, the differing masses between variables were less distinct, as shown in Figure 40, than the full grown plants. However, the seedlings irrigated with greywater still had at least slightly greater masses than the others variables, with a larger margin of error. The dry mass measurements in Figure 41 show that both plants receiving higher volumes of water were beginning to outpace the

plants with low-volume irrigation, but the benefits of increased nutrients from the greywater had yet to show as much effect as in the more mature plants.

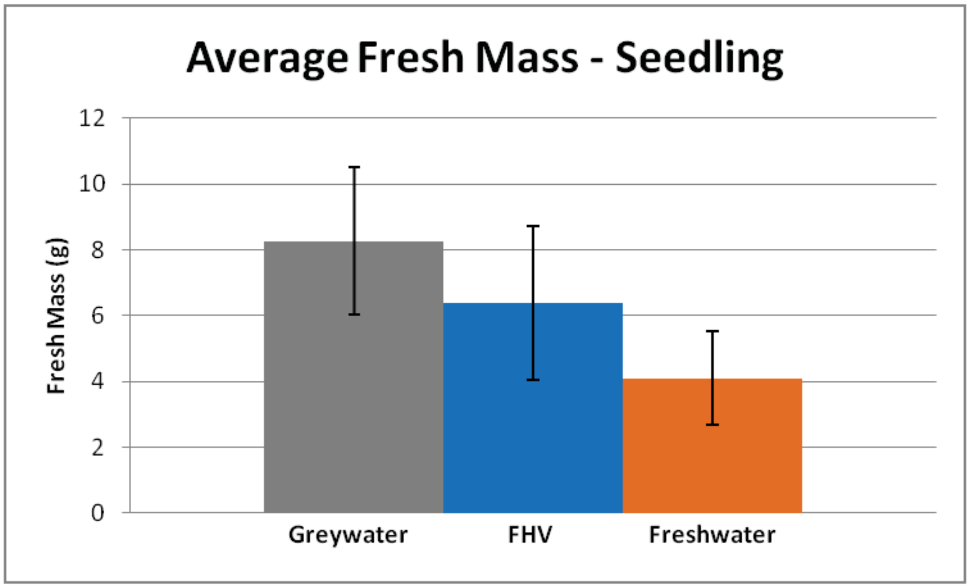


Figure 40: Average final fresh mass of seedlings (standard deviation shown by error bars)

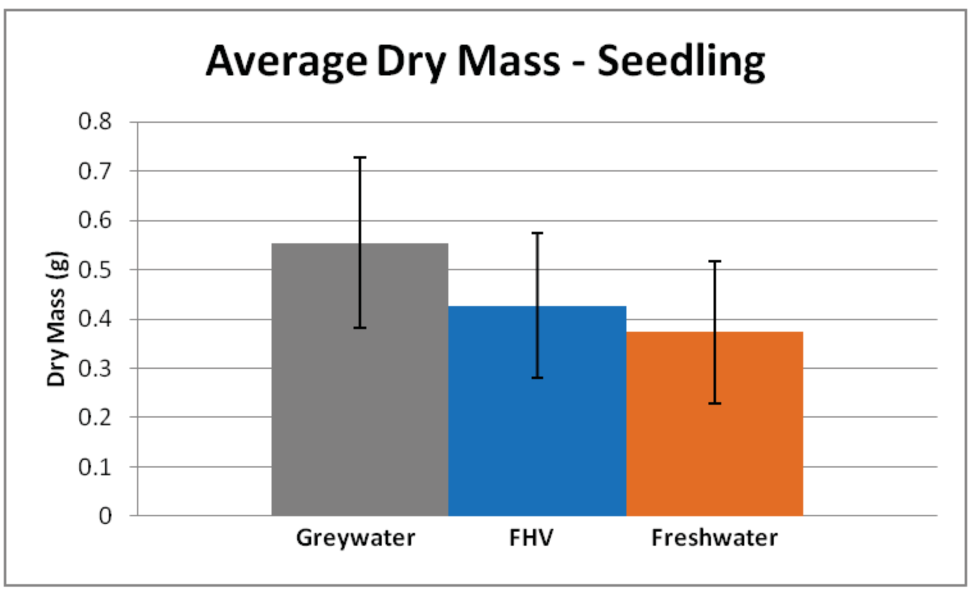


Figure 41: Average final dry mass of seedlings (standard deviation shown by error bars)

4.3 Discussion

Unfortunately, only a few of the plants produced flowers and none produced tomatoes to be able to test for high levels of contaminants. In general, the plants irrigated with

greywater grew faster, produced more leaves, and had more biomass than the other plants. As indicated by the results in Figures 30 and 31, the growth rate of the plants seemed to be more a result of the high volumes of water than the added nutrients in the water. However, the amount of foliage produced by the greywater plants indicates a healthier plant at this stage. If the plants had begun to bear fruit, it would have been possible to determine if the increased leaf production from the added nutrients diverted energy away from flower and fruit production.

There is a risk when watering in large volumes that a plant will not establish a strong root system. However, the mature plants under high volume irrigation were able to grow similar root masses to the plants under low volume irrigation. This indicates the high volume plants would have been able to withstand winds and changes in watering. Because the greywater seedlings were able to grow larger root systems, they would most likely be more stable as they mature, and able to divert more energy to leaf, flower and fruit production.

Another risk of greywater irrigation is that high amounts of nutrients can damage young plants. However, as indicated by Figures 31, 33, 36, 37, 40 and 41, the seedling growth and root development were not hindered.

Overall, the results of this study, though limited in scope, indicate that simple greywater irrigation systems like those established during the project in Chirifoyilli in Ghana as well as those already in place in other villages, serve as a valuable source of nutrients and water, and will likely not harm plants.

Many environmental and public health specialists are concerned with the management and treatment (or lack thereof) of greywater and wastewater in developing nations. Some of the literature addressing wastewater irrigation in developing nations looks only at the issue of untreated wastewater being discharged into surface water that is used directly for water supply (Qadir et al., 2010).This is often the case in developing cities without any collection or treatment infrastructure, or where the population growth has surpassed the infrastructure available. Although this entire system is detrimental to the environment and the human health of those living near this contaminated water, this is not the only option for wastewater irrigation in the developing world and all proposed wastewater irrigation schemes should not be discarded. The system presented in this paper seeks to avoid the exact situation described here by removing much of the standing wastewater so that it does not overflow or get washed by heavy rainstorms into an open water source nearby.

Wastewater contains numerous pathogens that are detrimental to human health and the environment, along with heavy metals if industrial wastewater is included (Qadir et al., 2010). Farmers coming into contact with untreated wastewater when using it for irrigation may be exposed to parasitic worms, protozoa, viruses and bacteria (Qadir et al., 2010). Microbes appear in greywater from fecal contamination, which will likely appear in smaller amounts from laundry and bathing water, and viruses may enter greywater from infected persons (World Health Organization, 2006c). Consuming crops irrigated with wastewater puts a person at higher risk of hookworm, *Ascaris* infections, and enteric

disease (Qadir et al., 2010). However, parasitic protozoa and helminthes are too large to pass through the soil particle matrix and the root structure (Eriksson et al., 2002), and so these pathogens will likely not enter the edible part of the plant. Women will come into contact with the crops more often than any other target groups because they are most likely to be the ones growing, selling and preparing vegetables irrigated with wastewater (Qadir et al., 2010). Most external contamination would be eliminated by properly washing and cooking vegetables. In implementing greywater irrigation projects, it is necessary to step back and look at the broader issues of the lack of hygiene, sanitation, and safe food preparation practices in many of these rural areas.

Irrigating with wastewater or greywater is not good for all situations or for all plants. Leafy vegetables such as lettuce and cabbage take up much more water than other vines and trees and nutrients from the water are more likely to be found in the edible portion of the plant (World Health Organization, 2006c). Because they grow closer to the ground, these vegetables are also at higher risk of the edible parts coming in contact with the greywater (World Health Organization, 2006c). Leafy vegetables also accumulate higher levels of certain metals (Qadir et al., 2010). Root vegetables like yams and cassava should also not be irrigated with wastewater, as the edible portion of the plant comes in direct contact with the wastewater. Also, metal concentrations in roots tends to higher than in leaves (Qadir et al., 2010). Vegetables that would be eaten raw should also not be irrigated with greywater, as cooking vegetables would kill many of the microbes that might reach the edible portion of the plant (World Health Organization, 2006c). Planting in mounds and establishing a furrow irrigation system reduces the risk of plant shoots and edible portions having direct contact with the greywater (Environmental Protection Agency, 2012). Certain soil, such as clay, slows infiltration, and greywater may still accumulate at the irrigation site. Adaptations should be made for each situation to provide enough plants or a large enough area for greywater to infiltrate.

There are concerns that intentional wastewater irrigation can pollute ground or surface water (Qadir et al., 2010). There are also concerns that prolonged irrigation with greywater leads to an accumulation of detergent and salts in soil (Eriksson et al., 2002). In certain situations these are legitimate concerns. However, in the case of the existing wastewater disposal system in Ghana, there is already risk of contaminating ground water, surface water, and soil. The greywater gardens would help reduce the risk of contaminating these other sources by decreasing ponding. Under ideal conditions, a greywater outlet should be at least 1.5 meters above the highest groundwater table (World Health Organization, 2006c). This standard is met in the village of Chirifoyilli, where the groundwater table is about 4 meters below the surface.

Some elements of greywater and wastewater might be harmful to plants. Soap contains alkali salts, and water with high levels of alkali may harm plants (Eriksson et al., 2002). Detergents contain surfactants and may have additional builders, bleaches, and enzymes, depending on the type of detergent (Eriksson et al., 2002). These elements are less of a concern in the bath area gardens in rural Ghana, however, as people in the village often use locally made shea soap which does not contain many of these additives.

SECTION 5: CONCLUSION AND FUTURE WORK

5.1 Contributions of this Study

This lab experiment shows that plants irrigated with greywater in high volumes will benefit both from the increased water and the added nutrients. Seedlings irrigated with greywater develop sufficient root systems and demonstrate increased early stages of growth. The higher levels of nitrogen in the water led to an increase in leaf development.

Wastewater collection and management is a serious problem that is often not properly addressed or regulated in developing countries. In attempts to meet the Millennium Development Goals (MDGs), development organizations have been focusing on water supply infrastructure, but many recent projects for water systems are only a quick and temporary solution for the problem as perceived by outsiders, and they do not address the poorly managed wastewater which led to the initial contamination of drinking water supplies (Qadir et al., 2010). By demonstrating the potential for greywater irrigation of fruits and vegetables in a region with malnutrition and malaria rates, this project addresses several of the MDGs – eradicating extreme poverty and hunger (MDG 1), reducing childhood mortality (MDG 4), combating malaria and other diseases (MDG 6), and ensuring environmental sustainability (MDG 7).

The first MDG is to eradicate extreme poverty and hunger, with specific aims to reduce the number of people living on less than one dollar a day by half and reduce the proportion of people who suffer from hunger by half (United Nations, 2008). This project aims to increase a farmer's crop and income with irrigation, and increase the amount of food available for the farmer's family. It would allow farmers to grow throughout the dry season, selling their crops year round and for a higher price during the high demand season. The extra nutrients in the greywater would provide natural and free fertilizer. This study provides evidence that plants grow bigger and faster with the added water and nutrients provided by a greywater irrigation system.

The fourth MDG is to reduce childhood mortality by two thirds (Ghana Statistical Service, 2010). Sustainable wastewater solutions accepted and used by the local population, such as the greywater schemes shown in this project, would help to achieve this goal by reducing a child's risk of diarrheal diseases from exposure to or drinking contaminated water. The extra fruit and vegetables produced by a greywater irrigation system would provide valuable vitamins and minerals to the family, specifically the children who are at risk of malnutrition in this region.

The sixth MDG includes combating malaria and other diseases (United Nations, 2008). Eliminating pooling water would help to reduce breeding areas for mosquitoes and other disease carrying insects. Along with the many other malaria reducing programs, measures like this would help to bring down the high death rate from malaria in the region.

The seventh MDG is to ensure environmental sustainability, which includes providing access to safe drinking water and sanitation to half of the world population who currently live without. Greywater irrigation would reduce the amount of contaminated water pooling outside of homes and being washed into surface water. Using greywater in place of fertilizer and insecticide would reduce exposure to these strong chemicals, as well as reduce the amount which is washed into drinking water supplies. Using greywater also helps to conserve scarce drinking water supplies.

The large scale projects implemented by development agencies often fail to address the underlying issues facing the target community. This project provides a simple solution which families can implement themselves for no cost. The design is flexible, so that new trees can be planted as the home changes and grows. The greywater gardens provide a product -- trees, fruits and vegetables -- which are desirable to the local population, increasing the commitment and personal investment people are willing to make for their project. It is often smaller, local changes, spread from household to household, which may have more significant and lasting impacts on people and communities (Esteva & Prakash, 1998).

5.2 Limitations and Future Work

Certain variables may have affected the results of this experiment and should be accounted for in future lab work. First, the clay used in the laboratory experiment was obtained from a till-floored lake plain deposit. It is a younger soil, with higher levels of organic matter, compared to the clay soil found in northern Ghana. This organic material would have been benefitted the plant growth of all the plants and would have made the greywater a less significant addition of nutrients.

Ideal fertilizer ratios recommended for growing tomato plants are either an even distribution of nitrogen, phosphorus and potassium (such as 10%-10%-10%) or a lower amount of nitrogen to encourage fruit rather than leaf development (such as 5%-10%-10%) (Buff, 1999). The ratio of nitrogen to phosphorus in the secondary effluent used in the experiment was 5:1 (potassium was not measured at the wastewater treatment plant). This high nitrogen to phosphorus ratio probably influenced the high leaf count found on the greywater irrigated plants, and may have encouraged more foliage production than fruit production at later phases of plant development.

In future similar laboratory experiments, a better greenhouse with growing lamps rather than fluorescent shop lights, and temperature control should be used. A future experiment could randomize the tomato cultivars. Also, future studies should allow more time for similar experiments and should allow for more replications.

Although the body of research on greywater irrigation is growing as water shortages affect more regions around the world, most of this research is focused on wealthier nations with very different resources and public health concerns, than the developing world (Al-Hamaiedeh & Bino, 2010; Faruqui & Al-Jayyousi, 2002; Matos, Sampaio, &

Bentes, 2012; World Health Organization, 2006c). Some research is being conducted in cities of developing nations on wastewater irrigation (Drechsel et al., 2006; International Water Management Institute, 2008), but little attention has been paid to more rural areas of poor nations where there may not be resources and oversight to monitor wastewater or greywater reuse. There is often only reporting on wastewater irrigation systems which require significant renovation to a current system or practice (Drechsel et al., 2006), ignoring poorer populations where small changes to the home layout or daily practices would improve water management. More studies are needed on how simple, low-tech wastewater irrigation will affect plants and the wellbeing of rural households.

Ideally, future testing would take place in the field rather than in a laboratory setting. Field studies would be able to monitor the attitudes of the household stakeholders towards the greywater-irrigated produce. A variety of plants and trees indigenous to the field area should be tested to determine if the effects vary between different kinds of plants. More water and soil samples should be collected and tested for wastewater elements. Variations in primary filtration methods could be tested in the future such as simple gravel beds from the bath area drains. In future studies, the edible portion of plants should be tested to determine if it is safe for human consumption. Different parts of the plants such as root, stem, and leaves should be tested for fecal coliform. Finally, future work should include more social aspects to include target populations such as education materials to promote the recommended use and limitations of greywater and wastewater irrigation. Community surveys should be conducted to determine the households' opinions and determine if they prefer the greywater garden scheme.

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Appendix 1: Standard Deviations and t-tests

Table 27: Standard Deviation - Full Grown Plant Height (Figure 30, pg 47)

Greywater (cm)	Freshwater High Volume (cm)	Freshwater (cm)
8.16	8.03	7.08
7.35	6.54	6.55
7.86	6.18	6.89
6.87	5.74	7.77
6.67	7.50	9.87
6.78	8.75	12.6
8.43	11.0	13.2
9.01	12.3	12.5
11.0	13.6	12.4
13.2	15.3	12.4
14.3	16.9	13.7
15.5	19.0	15.5
17.3	21.3	16.3
20.1	24.5	19.0

Table 28: Standard Deviation - Seedling Height (Figure 31, pg 48)

Greywater (cm)	Freshwater High Volume (cm)	Freshwater (cm)
2.09	1.62	2.23
3.54	2.41	2.72
4.06	3.14	3.39
5.45	4.33	3.82
6.37	6.14	4.68
7.43	7.28	5.65
8.50	7.99	6.65
10.0	8.94	7.91
10.8	9.96	9.17
11.6	10.1	9.08
12.5	11.1	9.03
13.8	11.9	9.18
14.7	12.7	9.26
17.2	13.8	9.39

Table 29: Standard Deviation – Full Grown Plant Leaf Count (Figure 32, pg 49)

Greywater (leaf count)	Freshwater High Volume (leaf count)	Freshwater (leaf count)
18.1	12.8	15.5
15.5	11.7	14.2
8.80	14.1	16.7
16.3	16.7	17.4
23.1	17.7	21.2
21.9	16.1	22.9
28.4	19.6	25.3
38.3	24.0	30.3
47.5	21.8	24.3
53.6	24.1	21.5
61.2	29.6	19.4
56.9	32.6	22.9
63.8	42.5	28.6
58.1	47.2	22.6

Table 30: Standard Deviation – Seedling Leaf Count (Figure 33, pg 49)

Greywater (leaf count)	Freshwater High Volume (leaf count)	Freshwater (leaf count)
6.94	4.67	4.77
6.34	4.63	5.02
6.09	5.83	4.42
6.21	7.56	5.97
5.72	9.02	7.20
6.29	10.1	7.35
6.86	10.0	7.97
8.00	9.71	9.83
8.98	11.1	13.9
9.60	11.6	14.1
10.1	13.8	12.7
11.3	13.2	13.2
11.2	13.3	13.9
18.3	14.7	14.7

Table 31: T-test Results – Paired Two Sample for Means

Full Grown Plant Height (Figure 30, pg 47)

	F (G)	*F (FHV)*		*F (FHV)*	*F (F)*		*F (G)*	*F (F)*
Mean	110.5556	108		108	91.66667		110.5556	91.66667
Variance	454.5278	674.25		674.25	407		454.5278	407
Observations	9	9		9	9		9	9
Pearson Correlation	0.926673			0.729931			0.749715	
Hypothesized Mean Difference	0			0			0	
df	8			8			8	
t Stat	0.756235			2.754287			3.850236	
P(T<=t) one-tail	0.235594			0.012447			0.002438	
t Critical one-tail	1.859548			1.859548			1.859548	
P(T<=t) two-tail	0.471188			0.024893			0.004876	
t Critical two-tail	2.306004			2.306004			2.306004	

Table 32: T-test Results – Paired Two Sample for Means

Seedling Height (Figure 31, pg 48)

	S (G)	*S (FHV)*		*S (FHV)*	*S (F)*		*S (G)*	*S (F)*
Mean	39.27273	34.90909		34.90909	23.18182		39.27273	23.18182
Variance	324.4182	209.8909		209.8909	96.96364		324.4182	96.96364
Observations	11	11		11	11		11	11
Pearson Correlation	0.607895			0.59525			0.461464	
Hypothesized Mean Difference	0			0			0	
df	10			10			10	
t Stat	0.982337			3.322801			3.324508	
P(T<=t) one-tail	0.174551			0.003855			0.003844	
t Critical one-tail	1.812461			1.812461			1.812461	
P(T<=t) two-tail	0.349103			0.007711			0.007689	
t Critical two-tail	2.228139			2.228139			2.228139	

Table 33: T-test Results – Paired Two Sample for Means

Full Grown Plant Leaf Count (Figure 32, pg 49)

	F (G)	*F (FHV)*		*F (FHV)*	*F (F)*		*F (G)*	*F (F)*
Mean	168.4444	142.5556		142.5556	110.6667		168.4444	110.6667
Variance	3798.028	2508.028		2508.028	574.75		3798.028	574.75
Observations	9	9		9	9		9	9
Pearson Correlation	0.520428			0.43599			0.544879	
Hypothesized Mean Difference	0			0			0	
df	8			8			8	
t Stat	1.396374			2.120248			3.297734	
P(T<=t) one-tail	0.100064			0.0334			0.005448	
t Critical one-tail	1.859548			1.859548			1.859548	
P(T<=t) two-tail	0.200128			0.066799			0.010896	
t Critical two-tail	2.306004			2.306004			2.306004	

Table 34: T-test Results – Paired Two Sample for Means

Seedling Leaf Count (Figure 33, pg 49)

	S (G)	*S (FHV)*		*S (FHV)*	*S (F)*		*S (G)*	*S (F)*
Mean	59.54545	51.63636		51.63636	39.90909		59.54545	39.90909
Variance	367.2727	236.2545		236.2545	239.0909		367.2727	239.0909
Observations	11	11		11	11		11	11
Pearson Correlation	0.192887			0.577542			0.05519	
Hypothesized Mean Difference	0			0			0	
df	10			10			10	
t Stat	1.18515			2.744681			2.719144	
P(T<=t) one-tail	0.131679			0.010333			0.010796	
t Critical one-tail	1.812461			1.812461			1.812461	
P(T<=t) two-tail	0.263358			0.020666			0.021592	
t Critical two-tail	2.228139			2.228139			2.228139	

Appendix 2: Greywater test results

Table 35: Water quality of greywater sample from bath area drain

Parameter	Unit	Ghana Bath-area waste water	EPA guidelines (food crop irrigation)	WHO standards	Average lab irrigation
Nitrate (NO_3-N)	mg/l	13.73	< 5		4.6 (NH_3-N)
Phosphate (PO_4-P)	mg/l	10.63	2		0.9 (Total P)
Potassium	mg/l	64			
Fecal coliform	CFU/100ml	$28x10^4$	0	≤ 200	63
BOD	mg/l	14.0	≤ 10	≤ 20	3.5 (CBOD)
pH	pH-unit	7.95	6 - 9		
TDS	mg/l	774.9		≤ 20 (TSS)	2.6 (VSS)
Dissolved Oxygen	mg/l	14.5			
COD	mg/l	1915			
Total coliform	CFU/100ml	$482x10^4$			
E. coli	CFU/100ml	$11x10^4$			
Conductivity	µS/cm	1218			
Total Alkalinity	mg/l	960			
Turbidity	NTU	66			
Temp	°C	25.4			
Bicarbonate	mg/l	1171			
Sulphate (SO_4)	mg/l	274			
Chloride	mg/l	395			
Calcium	mg/l	80.2			
Magnesium	mg/l	60.6			
Sodium	mg/l	160			
Silica (SiO_4)	mg/l	190			
Tot. Hardness	mg/l	450			
Cal. Hardness	mg/l	250			
Mag.Hardness	mg/l	199.5			
Iron	mg/l	25.791			
Manganese	mg/l	0.2547			
Zinc	mg/l	0.1791			
Copper	mg/l	0.0225			

Appendix 3: Photograph Permission

Documentation for Figure 19, page 35:

Re: [WEB Form - Viagrow Gardening Products | ViaVolt Horticultural Lighting Products]

Contact Viagrow <viagrowgardeningproducts@gmail.com>
Mon, Apr 13, 2015 at 11:37 AM To: cfagan@mtu.edu

Hello Chelsea,

Thank you for using our products and also for asking permission to use our photo. You are welcome to use the photo of our Viagrow Tomato Planter Raised Beds as per your request for the purpose you described in your email. All other reproductions will require their own permission. Thank you for providing proper citations and we appreciate your patronage.

Kind Regards, David

Documentation for Figure 18, page 34:

seeds@rareseeds.com <seeds@rareseeds.com> Tue, Apr 14, 2015 at 8:05 AM

To: Chelsea Fagan <cfagan@mtu.edu>

Good morning Chelsea,

Thank you for using Baker Creek heirloom seeds in your project. You have permission to use the seed package photographs in your report. Please include our website www.rareseeds.com in the credit citation. Good luck to you. Please let me know if I can be of any further assistance.

Best regards,
Kathy

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