Impacts of industrial water composition on *Salicornia* in a hydroponic system

by

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Abstract

The energy sector needs to transition to renewable energy to provide energy and economic security in the future (Murray & King, 2012). Liquid biofuels are an important renewable fuel in this transition because they are the preferred renewable energy source in the transportation sector (Lange, 2007), and the only renewable energy alternative for the aviation industry [International Air Transport Association (IATA), 2015]. Biofuels produced from food crops (first-generation biofuels) are being produced at an industrial scale, but they create several environmental and social conflicts (Mohr & Raman, 2013). Currently, there is a demand for the next generation of biofuels to resolve the environmental and social conflicts associated with first-generation biofuels. *Salicornia*, a salt tolerant oil seed crop (Panta et al., 2014), is one feedstock that might be able to resolve some of those conflicts because it can be irrigated with saline water (Warshay et al., 2017). The ability of *Salicornia* to tolerate saline environments suggests that it might be able to be cultivated in a hydroponic system designed to treat industrial wastewater. A hydroponic system designed to treat industrial wastewater and produce *Salicornia* as a biofuel feedstock could prevent some of the detrimental effects of industrial sources of saline water on terrestrial and aquatic ecosystems (Gerhart et al., 2006), and produce a feedstock that resolves some of the issues with first-generation biofuels.

The first step in the development of the proposed hydroponic system is to determine if *Salicornia* can be cultivated with industrial wastewater in a hydroponic system. Studies were conducted with two sources of industrial wastewater, Flue Gas Desulfurization (FGD) wastewater and Cooling Tower Blowdown Water (CTBW), to determine how the composition of water affects the germination, survivability, early seedling growth, and lignocellulosic composition of *Salicornia*. The composition of water was shown to have no effect on seed

germination and visual signs of phytotoxicity. These studies found that full strength CTBW and 20% FGD wastewater could be used to cultivate *Salicornia* in a hydroponic system if nutrients are added. Full strength FGD wastewater was shown to have a negative impact on seedling growth. These studies also found that *Salicornia* is not a good lignocellulosic biofuel feedstock because of its low lignocellulosic composition (e.g. 14.9-9.1% glucan, 13.2-6.7% xylan, 5.2-2.4% arabinan, and 9.8-6.2% lignin). However, a large percentage of the extractives content is unidentified and could have a monetary value. Additional research is needed to determine if a hydroponic system that cultivates *Salicornia* is able to provide any water quality treatment.

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List of Abbreviations

ASTM	-	American Society of Testing and Materials
CAA	-	Clean Air Act
CN	-	Cetane number
CTBW	-	Cooling Tower Blowdown Water
DI	-	Deionized
DM	-	Dry Matter
EC_e	-	Soil Electrical Conductivity
EC_w	-	Electrical Conductivity of Water
EIA	-	U.S. Energy Information Administration
ELG	-	Effluent Limitation Guidelines
EPA	-	U.S. Environmental Protection Agency
EPAP	-	Electrical and Power Affiliate Program
EPRI	-	Electric Power Research Institute
EU	-	European Union
FAME	-	Fatty Acid Methyl Ester
FAO	-	Food and Agriculture Organization of the United Nations
FGD	-	Flue Gas Desulfurization
GHG	-	Greenhouse Gas
HEFTA	-	Hydro-Processed Esters and Fatty Acids
HPLC	-	High-Performance Liquid Chromatography
IATA	-	International Air Transport Association
ICP	-	Inductively Coupled Plasma Mass Spectrometry
IV	-	Iodine Value
KSRE	-	Kansas State Research and Extension
KSU	-	Kansas State University
MCL	-	Maximum Concentration Level
MHS	-	Modified Hoagland's Nutrient Solution
NASA	-	National Aeronautics and Space Administration
NREL	-	National Renewable Energy Laboratory
RSB	-	Round Table on Sustainable Biomaterials

SBRC	-	Sustainable Bioenergy Research Consortium
SEAS	-	Seawater Energy and Agriculture System
SN	-	Saponification number
TDS	-	Total Dissolved Solids
TSS	-	Total Suspended Solids
US	-	United States of America

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Chapter 1 - Introduction

1.1 Problem Statement

The transition to renewable energy is the only way to provide energy and economic security in the future (Murray & King, 2012). Liquid biofuels are the preferred renewable energy source in the transportation sector because they require less infrastructure to produce, distribute, store and use compared to renewable electricity (Lange, 2007). In addition, liquid biofuels are the only renewable energy alternative for the aviation industry [International Air Transport Association (IATA), 2015]. For liquid biofuels to be sustainable and environmentally friendly, the feedstock used for production should meet the requirements set by the Round Table on Sustainable Biomaterials (RSB) (IATA, 2015). In a broader sense, sustainable biomaterials (1) should not require arable land or freshwater resources needed for food/feed production, (2) should have a low carbon footprint that does not lead to deforestation, and (3) should not cause adverse environmental or social impacts (Hendricks et al., 2011).

Salicornia is one feedstock that might be able to meet those requirements (Warshay et al., 2017). *Salicornia* is of special interest as a biofuel feedstock because it is one of the best-known salt tolerant oil seed crops (Panta et al., 2014). A key advantage of *Salicornia* is that it can be grown with saline water (Ventura & Sagi, 2013). This is an advantage because the cultivation of crops with saline water is one way to decrease water scarcity, which is one of the greatest challenges of the twenty-first century [Food and Agriculture Organization of the United Nations (FAO), 2012]. Saline water can come from natural or industrial sources (Panta et al., 2016). Industrial sources of saline water can have a detrimental effect on terrestrial and aquatic ecosystems (Gerhart et al., 2006). The remediation of industrial waters before they are discharged into receiving water bodies can decrease the detrimental effects of industrial wastewaters. A variety of treatments can remediate industrial wastewater; however, the treatment of industrial water adds additional cost to industrial process. One way to offset the cost of treatment is to produce a secondary revenue stream.

Salicornia grown in a hydroponic system with industrial wastewater might be a solution that is (1) able to provide treatment of industrial wastewater and (2) produce a feedstock that meets the requirements of RSB. The first step of developing a hydroponic system that treats industrial wastewater and produces *Salicornia* as a biofuel feedstock is to determine if *Salicornia* can be cultivated with industrial wastewater in a hydroponic system.

1.2 Objectives

The overall goal of this research is to determine if *Salicornia* can be cultivated with two sources of industrial wastewater, Flue Gas Desulfurization (FGD) wastewater and Cooling Tower Blowdown Water (CTBW), in a hydroponic system. This is the first step in determining if *Salicornia* can be cultivated as a biofuel feedstock in a hydroponic system that provides treatment for FGD wastewater and CTBW. Two species of *Salicornia*, *S. europaea* and *S. bigelovii*, were used in these studies because of they are highly tolerant of salinity, they have favorable biomass properties, and they were available from plant distributers. The research will answer the following questions:

1. Does FGD wastewater and CTBW have an effect on the germination of *S. europaea?*
2. Does FGD wastewater and CTBW have an effect on the seedling survivability of *S. europaea* in a hydroponic system*?*
3. Does FGD wastewater and CTBW have an effect on the early seedling growth of *S. europaea* in a hydroponic system*?*
4. Does FGD wastewater affect the lignocellulosic biomass composition of *S. bigelovii*?

Chapter 2 - Literature Review

2.1 Biofuel

The world consumed 90.3 million barrels per day (b/d) of petroleum and other liquid fuels (natural gas plant liquids, biofuels, gas-to-liquids, and coal-to-liquids) in 2012, which is the equivalent to approximately 190 quadrillion BTU per year [U.S. Energy Information Administration (EIA), 2016] . The EIA (2016) estimates that worldwide consumption of petroleum and other liquid fuels will reach 100 million b/d by 2020 and 121 million b/d by 2040. Murray and King (2012) argue that even though the world might not be running out of oil, it is "running out of oil that can be produced easily and cheaply." Their research has shown that other fossil fuels are not able to make up the production lag created by higher oil prices, which threatens energy and economic security. They concluded that the transition to renewable energy is the only way to provide energy and economic security in the future.

Most sources of renewable energy (wind, solar, water, etc.) can replace energy used for electricity and heat, but liquid biofuels are the only source that provides renewable liquid fuel (Bhaskar et al., 2011). In the transportation sector, 96% of energy consumed comes from petroleum and other liquid fuels (EIA, 2016). Renewable electricity can be used in the transportation sector to power electric modes of transportation or produce H_2-fuel for powering fuel cells. However, both of these alternatives require significantly more development of technologies and infrastructure to produce, distribute, store and use the fuel or energy compared to liquid biofuels (Lange, 2007).

Within the transportation sector, the aviation industry has the highest need for liquid biofuels. This industry requires fuels that meet the current standard for jet fuel and do not require changes to the distribution network or engine fuel system. Fuels that meet this requirement are commonly referred to as “drop-in” fuels. Currently, liquid biofuels are the only available renewable energy alternative for the aviation industry (IATA, 2015). The American Society of Testing and Materials (ASTM) has approved two “drop-in” alternative fuels. The Fisher-Tropsch process was approved in 2009, and the Hydro-Processed Esters and Fatty Acids (HEFA) fuels was approved in 2011 (IATA, 2015). The first commercial flights using alternative fuels used HEFA fuels, which are made through the hydroprocessing of vegetable oils and animal fats (IATA, 2015). Due to the successful implementation of HEFA fuel, the aviation industry is looking for sustainable sources of vegetable oils and animal fats to produce liquid biofuels. To meet sustainability goals, the aviation industry has set three general guidelines for sustainable biomaterials. Under those guidelines, sustainable biomaterials (1) should not require arable land or freshwater resources needed for food/feed production (2) should have a low carbon footprint that does not lead to deforestation, and (3) should not cause adverse environmental or social impacts (Hendricks et al., 2011). More specifically, the aviation industry is looking for biomaterials that meet the recommendations set by the RSB (IATA, 2015). The recommendations set by RSB follow 12 principles (Table 2.1).

Table 2.1 RSB principles for sustainable biomaterials (RSB, 2016).

Principle	Description
Legality	Operations follow all applicable laws and regulations.
Planning, Monitoring & Continuous Improvement	Sustainable operations are planned, implemented, and continuously improved through an open, transparent, and consultative impact assessment and management process and an economic viability analysis.
Greenhouse Gas Emissions	Biofuels contribute to climate change mitigation by significantly reducing life-cycle Greenhouse Gas (GHG) emissions as compared to fossil fuels.
Human and Labor Rights	Operations do not violate human rights or labor rights, and promote decent work and the well-being of workers.
Rural and Social Development	In regions of poverty, operations contribute to the social and economic development of local, rural and indigenous people and communities
Local Food Security	Operations ensure the human right to adequate food and improve food security in food insecure regions.
Conservation	Operations avoid negative impacts on biodiversity, ecosystems, and conservation values.
Soil	Operations implement practices that seek to reverse soil degradation and/or maintain soil health.
Water	Operations maintain or enhance the quality and quantity of surface and groundwater resources, and respect prior formal or customary water rights.
Air Quality	Air pollution shall be minimized along the whole supply chain.
Use of Technology, Inputs, and Management of Waste	The use of technologies shall seek to maximize production efficiency and social and environmental performance, and minimize the risk of damages to the environment and people.
Land Rights	Operations shall respect land rights and land use rights.

RSB: Round Table for Sustainable Biomaterials

Most first-generation biofuels do not meet the meet the recommendations set by the RSB. First-generation biofuels include ethanol and biodiesel produced from food crops (Lee & Lavoic, 2013). First-generation ethanol is commonly produced from sugarcane or corn through the fermentation of C6 sugars using yeast strains. After the sugar is extracted from sugarcane, it can be directly processed into ethanol (Lee & Lavoic, 2013). The starch in corn has to be processed via hydrolysis before it can be fermented into ethanol. First-generation biodiesel is produced by breaking the fatty acid chains in edible oil and replacing them with methanol in a process called transesterification (Lee & Lavoic, 2013).

The production of ethanol and biodiesel with food crops is currently occurring at an industrial scale, but is creates several conflicts. Mohr and Raman (2013) outlined five key conflicts associated with first-generation biofuels; they are (1) food security, (2) large-scale land acquisition, (3) GHG balance, (4) environmental impacts, and (5) other local impacts. In their paper they discuss that even though the exact link between increasing prices and biofuel production is debated, the conflict between the use of arable land to produce fuel or food remains. The demand for land is not only a conflict between food and fuel, but it can result in large-scale land acquisition issues. For example, social issues arise when land that was used to sustain marginalized people is acquired to cultivate feedstocks for biofuel production. The authors state that this violates the rights and livelihoods of those people. In addition, the conversion of forests, peatlands or grasslands for biofuel crops can reduce the carbon sequestration capability of those lands, which decreases the ability of first-generation biofuels to mitigate GHG emissions. The conversion of forests, peatlands or grasslands for biofuel crops can have several environmental impacts such as decreased biodiversity and water preservation. First-generation biofuels can have other local negative impacts on air quality and landscape aesthetics (Mohr & Raman, 2013). These conflicts have led to the search for other feedstocks that resolve some or all of the conflicts associated with first-generation biofuels.

Second-generation biofuels are produced from nonfood crops, such as non-edible lignocellulosic biomass (Lee & Lavoie, 2013). To produce second-generation biofuel, lignocellulosic biomass is converted into liquid biofuel through a thermo or bio pathway. The thermo pathway heats biomass with minimal amounts of oxidizing agents to produce biochar, pyrolytic oil (bio oil), or syngas. The pyrotylic oil and syngas are sent through additional conversion processes to produce liquid biofuels. The bio pathway isolates cellulosic biomass and then uses microorganisms to convert the cellulose into ethanol. Currently this method is not economical. For this method to become economical, all of the carbon content needs to be transformed in to biofuel or biocommodities (Lee & Lavoie, 2013). Algae is another potential biofuel feedstock. The oil extracted from algae is used to produce biodiesel or kerosene grade alkane and does not used arable land. However, algae has several technical challenges such as lipid extraction and dewatering (Lee & Lavidor, 2013). Currently, most second-generations biofuels have some technical challenges, which prevent them from being economically feasible.

Overall, the continued development of renewable energy is needed to provide economic and energy security in the future. Liquid biofuels will be an important component of renewable energy because they are a good alternative to traditional liquid fuels in the transportation sector and are currently the only renewable option in the aviation sector. Within the aviation sector, there is a demand for vegetable oils and animal fats that meet the guidelines outlined by the RSB. Current generations of feedstocks used to produce biofuels cannot meet the demand of the aviation industry for sustainable oil feedstock that can be used to produce HEFA fuel.

2.2 Halophytes

Halophytes are naturally evolved salt tolerant plants (Panta et al., 2014) that are potentially sustainable biofuel feedstocks (Sharma et al., 2016). The definition of a halophyte remains ambiguous because salt tolerance is a complex process in plants (Flower & Colmer, 2008; Panta et al., 2014; Santos et al., 2016). The eHALOPH database, a database of information on halophytes, includes any species that can tolerate at least 7.8 dS m^{-1} Soil Electrical Conductivity (EC_e), which is approximately 80 mM NaCl (Santos et al., 2016). To differ between moderate salt tolerance and more extreme salt tolerance, Flower and Colmer (2008) proposed a higher tolerance of 200 mM NaCl (~20 dS m^{-1}) as the criteria to determine if a plant is a euhalophyte. Euhalphytes are rare amongst flowering plants; there are only 333 species in the eHALOPH database (Santos et al., 2016).

Halophytes are a potential sustainable biofuel feedstock because their salt tolerance allows them to be cultivated without requiring arable land or freshwater (Sharma et al., 2016). Halophytes have been recognized for hundreds of years (Panta et al., 2014); however, their potential as a crop has only developed in the latter half of the twentieth century because of increasing demand for food, fiber, and fuel and diminishing resources of arable land and freshwater (Rozema et al., 2013). Researchers have explored and developed halophytes for use as human food, forages and animal feeds, oilseeds and proteins, energy crops, and for phytoremediation (Panta et al., 2014). Researchers have found that halophytes have compositional characteristics that make them ideal candidates for the production of bioenergy through oil and lignocellulosic biomass; however, there is a significant amount of research that needs to be conducted because large-scale planting of halophytes has not been attempted (Sharma et al., 2016).

Several research groups have recognized halophytes as a potential biofuel feedstock and have begun researching their biomass properties and cultivation techniques. For example, after seeing the need for green energy, especially in the aviation industry, the National Aeronautics and Space Administration (NASA) developed the GreenLab Research Facility to create a 100 percent clean energy laboratory that serves as a framework for self-sustainable renewable energy ecosystems (Hendricks et al., 2011). Since it was completed in 2006, the facility has used simulated coastline halophyte beds, open pond algae systems, and photobioreactors to test third-generation biofuel candidates (Hendricks et al., 2011). Another notable research group working on creating sustainable biofuel through halophyte agriculture is Masdar Institute's Sustainable Bioenergy Research Consortium (SBRC). The SBRC was formed in 2011 as a non-profit consortium with the Masdar Institute, The Boeing Company, Ethiad Airways and the Abu Dhabi Oil Refining Company (Solomon, 2017).

2.3 Salicornia

Both the GreenLab Research Facility and SBRC have identified the genus *Salicornia* as a promising biofuel feedstock. Of the 14 halophyte species tested in the GreenLab Research Facility, the three *Salicornia* species (*S. virginica*, *S. europaea*, and *S. bigelovii*) tested have the most promising biofuel feedstock properties (Hedricks et al., 2011). The SBRC developed their pilot-scale integrated Seawater Energy and Agriculture System (SEAS) to grow *S. bigelovii* (Solomon, 2017). *Salicornia,* commonly known as glasswort or samphire (Davy et al., 2001), is a salt marsh pioneer plant that can be cultivated with saline irrigation water with salinities as high as full-strength seawater (Ventura & Sagi, 2013). *Salicornia* is of special interest as a biofuel feedstock because it is "one of the most successful examples of halophyte cultivation" (Ventura & Sagi, 2013, p. 146), and it is one of the best-known halophytic oil seed crops (Panta et al., 2014).

2.3.1 Oilseed Properties

Glenn et al. (1991) conducted one of the first studies on *S. bigelovii* to identify *Salicornia* as a halophytic oilseed crop. The group conducted field trials on *S. bigelovii* in Puerto Penasco, Sonora, Mexico on sandy soil. In this study, they compared the effects of irritating *S. bigelovii* with saline water from shrimp aquaculture, and saline water with fertilizer. Over the 5-year study period, the mean seed yield was 199 g m^{-2}, which is comparable to soybeans and sunflowers cultivated under non-saline conditions. Higher seed yields, around 270 g m^{-2}, have been reported in greenhouse studies (Zerai et al., 2010). Glenn et al. (1991) also found that the oil (28.2%) and protein (31.2%) content were high in seeds, while the fiber (5.3%) and ash (5.5%) were low. These results lead the authors to conclude that *S. bigelovii* was a promising halophytic oil seed crop. Anwar et al. (2002) also studied the seed oil properties of *S. bigelovii*. They wanted to determine if *S. bigelovii* grown in Pakistan could replace imported edible oils. They found that *S. bigelovii* oil was comparable in composition to safflower oil. They also found that the oilseed and fatty acid properties of *S. bigelovii* grown in Pakistan closely resembled the oilseed and fatty acid properties of *S. bigelovii* grown in the northern Gulf of California (Glenn et al., 1991).

S. bigelovii is not the only *Salicornia* species that has promising oil seed properties. As mentioned earlier, Hendricks et al. (2011) studied three *Salicornia* species in the NASA GreenLab. They found that *S. virginica* was the best overall plant for biofuel production because it had high lipid yields over all salinity levels. They also noted that *S. europaea* and *S. bigelovii* were good candidates for biofuel production because they had adequate lipid production, growth, and seeding.

Abideen et al. (2015) assessed the biodiesel potential of 21 halophytic species including *S. bigelovii*, *S. brachiate* and *S. europaea*. They determined the suitability of each halophyte by comparing the oil content and biodiesel engine performance parameters; saponification number (SN), cetane number (CN), and iodine value (IV). These engine performance parameters are important for various reasons. The SN indicates a key factor of triglycerides in fatty acid methyl ester (FAME) and the CN indicates the time of ignition in the combustion chamber and the combustion quality of the fuel. IV is important because it is an indicator of the fluidity of liquid fuel. Following the standards from the European Union (EU), Germany, and the United States (US), Abideen et al. (2015) found that the oil from all three species of *Salicornia* evaluated were not of sufficient quality for biodiesel production. All *Salicornia* species evaluated in the study had high seed oil contents, which is an important parameter in biodiesel production. However, none of the *Salicornia* species fell into the recommended CN range (Table 2.2). These results are slightly discouraging. However, the available data on *Salicornia* fatty acid composition used to calculate the engine performance parameters is limited to a couple of studies. This data is not a complete representation of *Salicornia* oil because *Salicornia* is not domesticated, which could result in potential variability in the biomass properties (Ventura & Sagi, 2013).

Table 2.2 Biodiesel production parameters of three *Salicornia* species (Abideen et al., 2015).

Plant Species	Oil content (%)	SN	IV	CN
S. bigelovii	30	201	154	39
S. brachiate	22	130	3	82
S. europaea	30	203	56	38
Standard	Higher is better		<115	47<CN<65

Saponification Number (SN), Cetane Number (CN), Iodine Value (IV)

2.3.2 Lignocellulosic Biomass Composition

Although lignocellulosic biomass cannot be used to produce jet fuel, it is a co-product that can be used to make a sustainable system (Warshay et al., 2017). Cybulska et al. (2014b) conducted a study to evaluate *S. bigelovii* straw as a potential lignocellulosic bioethanol feedstock. They found that seedless *S. bigelovii* had an extremely high ash content (43.08 g/100 g Dry Matter (DM)), but the cellulose, lignin and hemicellulose content (

Table 2.3) was comparable to traditional lignocellulosic biomasses. The average cellulose content in *S. bigelovii* is lower than traditional lignocellulosic biomass source, but stems have a higher concentration of cellulose than the spikes (Cybulska et al., 2014a). Using just the stems for ethanol production would increase the cellulose content, which would increase the ethanol potential (Brown et al., 2014).

Table 2.3. Lignocellulosic Composition of *S. bigelovii* biomass (Cybulska et al., 2014b).

Component	g/100 g DM
Glucan	9.1 ± 1.5
Xylan	7.7 ± 0.4
Arabinan	5.5 ± 2.1
Klason Lignin	6.8 ± 1.4
Structural Ash	6.8 ± 0.1
Total extractives	53.7 ± 3.6

DM: Dry Matter

The ash content was mainly composed of extractable ash, which led Cybulska et al. (2014b) to suspect that the ash content could be lowered through washing. When they tested the ability of washing to lower the ash content, they found that a freshwater wash at a low temperature and over a short duration was able to lower the ash content to 9.97 g/100 g DM. They also tested a saline wash to reduce the amount of freshwater used, but they found this method to be ineffective. Later, Alassali et al. (2017) showed that freshwater can be eliminated from the processing of *Salicornia* lignocellulosic biomass by applying green fractionation followed by very low severity hydrothermal pretreatment in the processing of *S. sinus-persica*. With that method, they were able to get an ethanol yield of up to 76.91%. Washed *S. bigelovii* with hydrothermal pretreatment was also shown to be highly digestive and fermentable

(Cybulska et al., 2014b). These studies concluded that both *S. bigelovii* and *S. sinus-persica* are promising lignocellulosic biomass feedstocks once the ash content has been lowered.

2.3.3 Other Uses

Salicornia has been evaluated for several other uses in addition to its biodiesel and bioethanol feedstock properties. Early on *Salicornia* was used as a source of soda ash for glass making before the development of the Leblanc process in 1790 (Davy et al., 2001; Gunning, 2016). Ventura and Sagi (2013) reviewed the existing literature on *Salicornia* to determine it is potential as a vegetable for human consumption. They found that *Salicornia* contains "nutritional metabolites rich in antioxidant compounds that are indispensable to the human diet" (p. 150).

Researchers have also evaluated *Salicornia's* potential as a source of animal feed and fodder. As mentioned earlier, *S. bigelovii* seeds contain a high portion of protein, which can be processed into a meal used for animal feed (Glenn et al., 1991). Researchers found that the *Salicornia* meal is high in saponins (Eganathan et al., 2006; Glenn et al., 1991), which reduced the feed conversion efficiency compared to soybean meal in poultry (Glenn et al., 1991). *S. bigelovii* meal can replace up to 40% of fish meal in Nile Tilapia's (*Oreochromis niloticus)* diet without any effect on weight gain, feed intake, feed conversion, or net protein utilization (Belal & Al-Dosari, 1999). The negative impact of *S. bigelovii* meal on Nile Tilapia at higher concentrations is in part due to the high saponin content of the meal, which can be reduced with the addition of cholesterol (Ríos-Durán et al., 2013). *Salicornia* meal might have industrial applications because of its high protein content (Wu & Sessa, 2004). *Salicornia* is also a potential fodder supplement (Díaz et al., 2013). A two-month trial conducted on lambs in Kuwait found that *S. herbacea* could replace up to 25% of alfalfa in their diet without any negative affect on weight gain (Abdal, 2009). *S. bigelovii* can also partially replace conventional forage for goats (Glenn et al., 1992), rams (Abouheif et al., 2000), and camels (Al-Owaimer, 2000).

2.3.4 Cultivation

Research has shown that *Salicornia* is a versatile halophytic plant, which can be used as a bioethanol and biodiesel feedstock, for human consumption, and as an animal feed and fodder. Despite these favorable properties, limited research has been conducted on the cultivation of *Salicornia* (Ventura & Sagi, 2013). Most of the reported data comes from greenhouse experiments because field data is rarely published (Ventura & Sagi, 2013). Even with limited studies, several key problems with the cultivation of *S. bigelovii* have been identified the most serious of which might be water management (Glenn et al., 2013). Early studies showed that optimal yield of *S. bigelovii* occurs under daily irrigation (Glenn et al., 1991). Glenn et al., (1997) conducted a field trial to determine the water requirement for cultivating *S. bigelovii* with seawater. To determine the optimal irrigation rate they irrigated *S. bigelovii* plots in Puerto Penasco. Sonora, Mexico with seawater daily, at rates ranging from 60-250% pan evaporation. They found that to achieve optimal growth rates with seawater an application of 3 m of water over the annual growing cycle was required. *Salicornia* has successfully been grown in hydroponic culture systems (Ventura & Sagi, 2013), which could offset the issues with daily irrigation.

Another issue associated with the cultivation of *Salicornia* is that the mechanical harvesting of seeds is difficult because the seeds are small, have a tendency to shatter, and undomesticated plants do not have even seed ripening, resulting in a 50% loss of the harvest (Glenn et al., 2013). In addition to other issues, flowering is controlled by the photoperiod (Glenn et al., 2013). Cultivated *S. europaea* has been reported to flower when plants were only a few weeks old resulting in restricted plant development (Davy et al., 2001). Early flowering is affected by day length and plant nutrition (Ventura & Sagi, 2013). The specific impact of day length is dependent on the geographic origin of the phenotype (Ventrua & Sagi, 2013; Ventura et al., 2011). For example, European phenotypes are affected when the day length is shorter than 18-hours and Mediterranean genotypes are affected when the day length is less than 13.5-hours (Ventura et al., 2011).

Undesirable crop characteristics in the wild plants, such as the photoperiod's effect on flowering and seed size, are limiting the large-scale cultivation of *Salicornia* (Glenn et al., 2013; Ventura & Sagi, 2013). The wild germplasm of *S. bigelovii* is different enough to support a breeding program (Jaradat & Shahid, 2012; Lyar et al., 2016; Zerai et al., 2010). In order to improve the cultivation of *Salicornia* a full breeding program that focuses on many agronomic traits is critical (Lyar et al., 2016; Zerai et al., 2010). Breeding programs have shown some success. For example, two breeding programs have shown that measurable increases in seed and biomass yields can be achieved in a relatively short period of time (Zerai et al., 2010); and five cultivars from the Arabian Saline Water Technology Company Limited of Saudi Arabia were found to have good yield and potential seed production (Shahid et al., 2013). However, "despite several decades of research, *Salicornia* remains an undomesticated plant not optimized for yield or oil content" (Warshay et al., 2017, p. 1032).

One key advantage of cultivating *Salicornia* is its ability to germinate under saline conditions (Glenn et al., 2013). The optimal germination conditions of *Salicornia* species are similar to the environmental conditions in which they typically germinate. For example, *S. bigelovii* typically germinates in late fall, under more stressful salinities and lower temperatures. Rivers and Weber (1971) found that optimal germination conditions in the lab matched the natural environmental conditions that *S. bigelovii* typically germinates. They specifically studied the influence of salinity and temperature on seed germination in *S. bigelovii* seeds collected in Texas from undomesticated plants. They found that the maximum rate of germination occurred at 4.4°C and seawater salinity. They also found that germination decreased at 26.6°C. *S. europaea* has almost the opposite response to temperature and salinity. Ungar (1977) found that optimal germination of *S. europaea* seeds collected from a saline pan near Rittman, Ohio had optimal germination at 25°C and zero percent NaCl. *Salicornia europaea* typically germinates in the early spring when there is lower salt stress due to high soil moisture levels. In Ventura and Sagi's (2013) review of *Salicornia* and *Sarcocornia* they found that most species of *Salicornia* can be germinated with irrigation water having salinity concentrations up to 75% seawater (Table 2.4).

Table 2.4. Salt tolerance limits for the germination of *Salicornia* (Ventura & Sagi, 2013).

Plant Species	Salt concentration[a] (mM NaCl)
S. brachystachya	240
S. bigelovii	1000
S. brachiate	600
S. dolistachya	240
S. europaea	850
S. herbacea	1700
S. pacifica var. utahensis	860
S. patula	340
S. persicaa	>500
S. rubra	1000
S. virginica	600

[a]Salt concentration at which germination was reduced from 75-100% to about 10% and less

2.3.5 Salt and Trace Element Tolerance

Despite the current issues with the cultivation of *Salicornia,* there is still a large interest in developing it as a crop because it can mitigate issues with water scarcity. Severe water scarcity is experienced by a significant portion of the world population during at least part of the year (Mekonnen & Hoekstra, 2016). Water scarcity occurs when demand for water exceeds the supply (FAO, 2012). Water scarcity is one of the reasons the aviation industry is looking for feedstocks that do not require freshwater (Hendricks et al., 2011). The FAO cites water scarcity as one of the greatest challenges of the twenty-first century (FAO, 2012). This is especially true for the agriculture sector, because it has the largest consumptive water use and water withdrawal out of all sectors (Frenken & Gillett, 2012). The threat of water scarcity and growing demand for food has pushed the agriculture sector to look for ways to conserve water and improve the efficiency of water use; water reuse is a key alternative to combat water scarcity (Lazarova & Asano, 2005).

Water quality determines the acceptability of using recycled water for a given reuse application, and salinity is one water quality parameter that limits water reuse (Lazarova et al., 2005). Salinity negatively affects plants due to one or more of the following reasons: water stress, ion toxicities, and or ion imbalance (Ayala & O'Leary, 1995). Salinity is typically reported as Electrical Conductivity of Water (EC_w) or Total Dissolved Solids (TDS), and can be categorized into three classes, nonsaline, saline, and brine (Table 2.5) (Lazoravoa et al., 2005).

As mentioned earlier, halophytes are able to mitigate the negative effects of salinity (Sharma et al., 2016). Only 1% of the world's flora is classified as a halophyte (Flowers & Colmer, 2008), and *Salicornia* is part of an even more exclusive subset of halophytes that shows optimal growth in saline conditions (Davy et al., 2001). *Salicornia*, an annual C3 halophyte without salt glands or salt bladders (Kadereit et al., 2007), maintains low water potentials in its tissues in saline environments by accumulating high concentrations of solutes in its shoot tissue (Davy et al., 2001; Grattan et al., 2008; Lv et al., 2011). The exact mechanism of salt tolerance is not fully understood, but Na+/H+ antiporter, V-H+-ATPase, and V-H+-PPase might play important roles in Na+ vacuolar influx in *S. europaea* (Lv et al., 2011). For *S. bigelovii*, optimal growth occurs at 200 mM NaCl (~20 dS m^{-1} EC_w) (Ayla & O'Leary, 1995), and has been successfully irrigated with seawater, 38,000-42,000 mg L^{-1} TDS (~47.5-52.5 dS m^{-1} EC_w) (Glenn et al., 1991). *S. euopaea* is capable of surviving in hypersaline conditions as high as 143 dS m^{-1} (EC_e) (Davy et al., 2001).

Table 2.5. Classification of Water According to Salinity (Lazoravoa et al., 2005).

Salinity Class	EC_W (dS m^{-1})	TDS (mg L^{-1})
Nonsaline water	<0.7	<500
Saline water	0.7-42	500-30,000
Slightly saline water	0.7-3	500-2,000
Medium saline water	3-6	2,000-4,000
Highly saline water	6-14	4,000-9,000
Very highly saline water	14-42	9,000-30,000
Brine	>42	>30,000

EC_W: Electrical Conductivity of Water; TDS: Total Dissolved Solids

While *Salicornia* is able to grow in saline environments, the individual characteristics of these environments affect the quality of the biomass. Cybulska et al. (2014a) conducted a study to determine the effect of salinity and nitrogen concentration on the biomass composition of *S. bigelovii* straw. They conducted their study in Dubai, United Arab Emirates on sandy soils with drip irrigation. They found that salinity significantly affected total extractives, glucan content, and lignin content, each of which is important in the conversion of lignocellulosic feedstock into ethanol. Fertilizer concentrations did not significantly affect composition of lignocellulosic components.

Salinity is not the only water quality parameter that impacts water use for irrigation; high concentrations of many elements can be detrimental to plant growth. The most common ions that could cause toxicity issues are B, Cl, and Na (Lazarova et al., 2005). Ayla and O'Leary (1995) studied the impacts of NaCl concentration on *S. bigelovii* at supra- (600 mM NaCl) and sub-optimal (5 mM NaCl) salinities in a greenhouse study by changing the concentration of NaCl in aerated nutrient solution. They found that growth was reduced under supra-optimal salinity due to Ca^{2+} and Mg^{2+} deficiencies, while suboptimal reductions might be related to ionic relations shown by the accumulation of K^{+}, Ca^{2+}, and Mg^{2+}. The impact of ionic relations was also shown in a study testing the effect of drainage water on *S. bigelovii* (Grattan et al., 2008). In that study, they tested several different concentrations of drainage water and seawater, finding that "the ionic composition of the shoot tissue reflected that of the water used to irrigate the plants" (p. 155). However, regardless of the ionic composition, Na^{+} and Cl^{-} are the preferred cation and anion respectively for osmotic adjustment in *Salicornia* (Díaz et al., 2013; Grattan et al., 2008; Katsching et al., 2013). Concentration of B in excess of 2 mg L^{-1} are toxic to most plants (Lazarova et al., 2005), but *S. bigelovii* did not show any sign of boron toxicity even when irrigated with boron concentrations as high as 28 mg L^{-1} in drainage water (Grattan et al., 2008).

While Na, Cl, and B are toxic to most plants in higher concentrations, other elements are toxic to plants at lower concentrations (Table 2.6) (Lazarova et al., 2005). The mechanisms that allow halophytes to survive in saline environments also allow them to cope with other stressors, such as trace element toxicity (Lutts & Lefèvre, 2015). Plants have adapted to survive high trace element concentrations by accumulating or excluding trace elements (Milić et al., 2012). Hyperaccumulators are plants that accumulate extremely high levels of trace elements (Milić et al., 2012). Milić et al. (2012) studied several halophytes to determine if they could hyperaccumulate Al, Co, Cr, Cu, Fe, Mn, Ni, and Zn from 5 different types of soil. Their results indicated that *S. europaea* was not a hyperaccumulator, but like other halophytes *S. europaea* accumulated higher concentrations of trace elements in its roots. Lin et al. (2000) assessed the ability of *S. bigelovii* to phytoremediate Se contaminated soils in California with a Se loading rate of 957.7 mg Se m^{-2} yr^{-1}. They found that *S. bigelovii* could remove 62 mg of Se per m^2 in one year through volatilization, and if the shoots were harvested a *S. bigelovii* field could remove 72.8 mg Se m^{-2} each year.

Irrigation water with poor water quality also affects plant growth by having a detrimental effect on the soil structure and permeability (Lazarova et al., 2005). For example, the accumulation of sodium disrupts the soil structure, which decreases infiltrations rates and aeration. Bicarbonate and carbonate also have detrimental effects on soil structure. The contamination of crops or groundwater when crops are irrigated with heavily polluted industrial waste discharge is an additional concern that limits the use of some sources of water (Lazarova et al., 2005).

Table 2.6. Recommended Maximum Concentration Level (MCL) of trace elements in irrigation water (Lazarova et al., 2005).

Element		Permanent irrigation MCL (mg/L)	< 20 years irrigation MCL (mg/L)
Al	Aluminum	5	20
As	Arsenic	0.10	2
Cd	Cadmium	0.01	0.05
Cr	Chromium	0.1	1
Co	Cobalt	0.05	5
Cu	Copper	0.20	5.0
F	Fluoride	1	15
Fe	Iron	5	20
Li	Lithium	2.5	
Mn	Manganese	0.2	10
Mo	Molybdenum	0.01	0.05
Ni	Nickel	0.20	2.0
Pd	Lead	5	10
Se	Selenium	0.02	0.02
V	Vanadium	0.10	1
Zn	Zinc	2	10

2.4 Saline Water Sources

Water scarcity is a growing global issue affects all sectors, including agriculture. Halophytes, like *Salicornia*, that can be cultivated with lower quality water, can resolve some of the issues associated with providing food, fuel, and fiber in a water scarce environment. Saline water sources can come from natural or secondary salinized aquifers, subsurface drainage from irrigated fields, industrial sources and brine from desalinization plants (Panta et al., 2016). The disposal of saline water can have detrimental effects on terrestrial and aquatic ecosystems. It is typically diluted by discharging it into freshwater; however, this practice can have adverse effects such as bioaccumulation of toxic element in the food chain (Gerhart et al., 2006). Cooling Tower Blowdown Water (CTBW) from electrical generating stations and large commercial buildings produce the largest category of industrial wastewater in urban areas. CTBW generally has high salinity and anti-scaling chemical compounds (Gerhart et al., 2006).

Another source of industrial wastewater is FGD wastewater. The combustion of coal to generate electricity releases a large amount of pollutants into the flue gas, which have adverse effects on human health and the environment. Consequently, the emission of pollutants in flue gas is regulated by the Clean Air Act (CAA) [U.S. Environmental Protection Agency (EPA), 2016). To meet the regulations set by the CAA, many energy centers use wet FGD systems (Figure 2.1). This treatment method can remove approximately 60,000 tons of sulfur dioxide per year (EPA, 2015b). Wet FGD systems have two stages (Figure 2.1), an oxidation reactor and a sorption spray tower. In the oxidation reactor, a limestone slurry or an alternative sorbent is combined with air to produce the scrubber slurry (Paredez, 2014). In the sorption spray tower, the scrubber slurry made in the oxidation reactor is pumped through slurry spray headers. Flue gas entering from the bottom of the tower comes into contact with the slurry spray as is rises. Sulfur dioxide and other pollutants are scrubbed from the flue gas and are collected in the oxidation reactor. The scrubber slurry is recycled until it exceeds set pollution levels, then it is purged from the system. The purged scrubber slurry is known as FGD wastewater (Paredez, 2014).

The composition of FGD wastewater is highly variable, (Table 2.8), and is dependent on the wet FGD system design, coal types burned, chemical additives, and scrubbing solution source (Eggert et al., 2008). FGD wastewaters commonly contain high TDS, Total Suspended Solids (TSS), and heavy metals (Mooney & Murray-Gulde, 2008). The pollutant loading in FGD wastewater is typically so high that it becomes extremely corrosive and cannot be reused in industrial processes, and is therefore discharged. The EPA (2015a) has recently established Effluent Limitation Guidelines (ELG) to set treatment criteria for the discharge of FGD wastewater (Table 2.7).

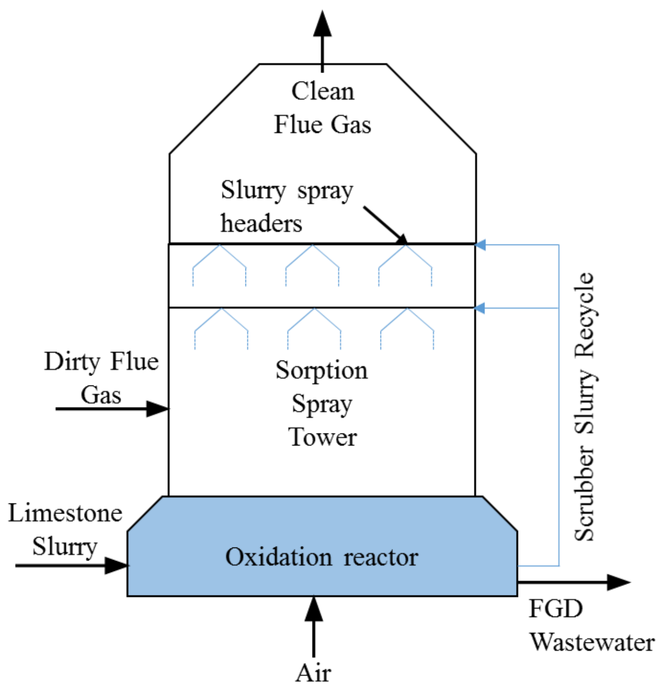


Figure 2.1. Model of a Wet Flue Gas Desulfurization System used in coal-fired electric generating units. Adapted from Paredez, 2014.

Table 2.7. Long-term averages and effluent limitation and standards for Flue Gas Desulfurization wastewater (EPA, 2015a).

Pollutant	Long-term average	Daily maximum limitation	Monthly average limitation
Arsenic (µg/L)	5.98	11	8
Mercury (ng/L)	159	788	356
Nitrate/nitrite (mg/L)	1.3	17	4.4
Selenium (µg/L)	7.5	23	12

Table 2.8. Characteristics of Flue Gas Desulfurization wastewater from eight coal-fired power plants [Electric Power Research Institute (EPRI), 2006].

		Dissolved				Total			
Parameter	**Units**	**Median**	**Range**			**Median**	**Range**		
Aluminum	µg/L	1,000	260	-	18,000	39,000	9,700	-	170,000
Antimony	µg/L	50	10	-	50	280	12	-	500
Arsenic	µg/L	16	4.1	-	110	260	10	-	380
Barium	µg/L	250	97	-	840	2,000	180	-	3,000
Beryllium	µg/L	40	5.2	-	40	220	3.2	-	400
Boron	mg/L	260	15	-	480	200	16	-	450
Cadmium	µg/L	50	13	-	83	280	9.3	-	500
Calcium	mg/L	750	670	-	4,000	2,900	700	-	33,000
Chromium	µg/L	100	14	-	100	600	30	-	1,000
Cobalt	µg/L	78	22	-	100	1,000	22	-	1,000
Copper	µg/L	100	63	-	270	650	100	-	3,300
Iron	µg/L	1,000	130	-	1,000	62,000	1,500	-	280,000
Lead	µg/L	50	6.5	-	50	280	6.8	-	500
Magnesium	mg/L	1,100	390	-	4,400	1,500	440	-	4,300
Manganese	µg/L	6,400	1,700	-	52,000	11,000	1,900	-	52,000
Mercury	µg/L	0.6	0.1	-	8.5	61	8.2	-	99
Molybdenum	µg/L	170	40	-	700	2,500	52	-	2,500
Nickel	µg/L	260	120	-	1,200	1,700	130	-	2,000
Potassium	mg/L	115	21	-	880	99	27	-	577
Selenium	µg/L	1,100	70	-	1,800	1,700	86	-	2,600
Selenium IV	µg/L	410	110	-	430				
Selenium VI	µg/L	6	4.2	-	1,207				
Silver	µg/L	100	13	-	100	550	4	-	1,000
Sodium	mg/L	670	72	-	4,800	320	66	-	45,000
Thallium	µg/L	100	13	-	100	550	5.6	-	1,000
Titanium	µg/L	600	125	-	1,000	10,000	170	-	10,000
Vanadium	µg/L	150	31	-	250	2,500	33	-	2,500
Zinc	µg/L	1,000	100	-	2,800	1,700	180	-	7,100

Acidity	mg CaCO3/L	270	46	-	11,000	370	53	-	10,000
Alkalinity	mg CaCO3/L	180	23	-	520	250	26	-	4,500
Chloride	mg/L	2,400	690	-	23,000	2,400	460	-	25,000
Conductivity	μhos/cm	10,000	4,300	-	63,000	9,500	4,200	-	67,000
Fluoride	mg/L	15	6.5	-	51				
Hardness as CaCO3	mg/L	4,100	3,000	-	5,300	4,300	3,000	-	5,600
pH	pH units	7.3	6.2	-	7.3	6.9	6.1	-	7.3
Sulfate	mg/L	3,200	1,700	-	5,700	9,500	9,500	-	9,500
TDS	mg/L	14,000	6,000	-	50,000	14,000	1,400	-	45,000
TKN	mg N/L	24	2.4	-	58	24	2.1	-	84
TSS	mg/L	4.2	2.2	-	7.6	13,000	33	-	140,000
Flow	mgd	0.19	0.17	-	0.21	0.19	0.17	-	0.21

Several treatment methods are used to meet the ELG for FGD wastewater, including settling ponds, chemical precipitation, biological treatments, constructed wetlands, vapor-compression evaporation systems, and other technologies (EPA, 2009). A key disadvantage of each of these treatment methods is that they currently do not produce any sellable products. The cultivation of *Salicornia* in a hydroponic system that treats FGD wastewater could produce *Salicornia* as a sellable product because *Salicornia* can tolerate saline environments (Davy et al., 2001), volatilize Se (Lin et al., 2000), and accumulate higher concentrations of heavy metals in its roots which keep the shoots of higher quality (Milić et al., 2012). The ability of *Salicornia* to treat industrial wastewater in a hydroponic system has not be studied, but constructed wetlands have been shown to treat highly nutrient-rich saline water from aquaculture and produce *S. europaea* (Webb et al., 2012). The key difference between saline water from aquaculture and industrial wastewater is the composition of trace elements. *Salicornia* is tolerant of some changes in the composition of irrigation water in soil systems (Grattan et al., 2008; Lin et al., 2000), and the salinity of irrigation water has not shown any impact on the lipid content of *Salicornia* (Bomani et al., 2014). The growth of *Salicornia* is impeded by both supra- and sub-optimal salinities (Ayla & O'Leary, 1995), and the composition of the irrigation water affects the lignocellulosic composition (Cybulska et al., 2014a), which could impact its monetary value.

The literature review shows that *Salicornia* cultivated in a hydroponic system with industrial wastewater might be able to (1) provide treatment of industrial wastewater and (2) produce a biofuel feedstock that meets the requirements of RSB. However, it also shows that the composition of industrial wastewater could affect the growth and composition of *Salicornia,* which would directly the two key benefits of this proposed system. The first step in determining if the proposed system is feasible is to determine if *Salicornia* can be cultivated in a hydroponic system with industrial wastewater. The research conducted in the following studies accomplished this by assessing the effects of the composition of water on germination, survivability, and seedling height of *S. europaea* cultivated in an inert media. The effects of water composition on the lignocellulosic composition of *S. europaea* cultivated in an inert media could not be measured due to limited quantities of biomass. Therefore, the effect of water composition on the lignocellulosic composition of *S. bigelovii* cultivated in soil was measured because more biomass was available.

Chapter 3 - Methods and Materials

The composition of industrial wastewater can change at a given location over time and from location to location. Changing composition of water will affect the level of treatment required by a hydroponic system that also cultivates *Salicornia* as a biofuel feedstock. Although *Salicornia* is adapted to grow in environments with changing water composition (Davy et al., 2001), drastic changes in water composition could have a detrimental impact on the growth of *Salicornia*. This is especially true in a hydroponic system, because soil is not present to act as a buffer. Therefore, it is important to understand how the composition of industrial water fluctuates and how the composition could affect the cultivation of *Salicornia.*

To understand how water composition affects the cultivation of *Salicornia,* controlled growth chamber and greenhouse studies on the germination and growth of *Salicornia* using different industrial wastewaters were conducted at Kansas State University (KSU) from September 16, 2016 until June 24, 2017. Two species of *Salicornia, S. europaea* and *S. bigelovii,* were used in these studies because of they are highly tolerant of salinity, they have favorable biomass properties, and they were available from plant distributers. Several preliminary experiments were conducted to determine optimal growing conditions of *Salicornia* in a KSU laboratory and to produce biomass for additional studies. Most of these experiments were unsuccessful at cultivating *Salicornia* in a laboratory setting at KSU. The lessons learned from preliminary experiments aided in the development of the following studies (Table 3.1).

Table 3.1 Key objectives of each study.

Study Name	Key objectives
Saline Water Composition	Determine the composition of different saline water sources.
Germination and Seedling Growth	Determine the effect of FGD wastewater and CTBW on the germination, seedling survivability, and early seedling growth of *S. europaea*.
Biomass Composition	Determine the effect of FGD wastewater on the lignocellulosic composition of *S. bigelovii*

3.1 Saline Water Composition

Several types of saline water were used to determine how the composition of water affects the germination, survivability, early seedling growth, and lignocellulosic composition of *Salicornia*. FGD wastewater and CTBW were used as sources of industrial wastewater in this research because of their availability and potential as a major marginal water source. The composition of FGD wastewater and CTBW were tested because they vary in composition (Table 3.2). Typically, FGD wastewater has elevated TDS, TSS, and heavy metals (Mooney & Murray-Gulde, 2008), while CTBW has elevated salinity and anti-scaling chemical compounds (Gerhart et al., 2006). Synthetic brackish water was used as a saline water reference to compare to industrial wastewater. For comparison between saline water and non-saline water, Modified Hoagland's Nutrient Solution (MHS) and tap water were used.

Table 3.2. Comparison of CTBW and FGD wastewater composition (Mittal & Hoskin, 2006).

Parameter (mg L^{-1})		Typical CTBW	Typical FGD Wastewater
Ca	Calcium	300	6,000
Mg	Magnesium	80	2,000
Na	Sodium	900	2,000
Cl	Chloride	1,100	20,000
TDS		4,000	35,000

CTBW: Cooling Tower Blowdown Water; FGD: Flue Gas Desulfurization

3.1.1 Water Quality Testing

The composition of both FGD wastewater and CTBW vary depending on a variety of factors including the operation and maintenance of the equipment. Sampling over time is needed to determine the range of composition that could be generated and used to cultivate *Salicornia*. Regular sampling of FGD wastewater was not feasible due to the power plant location, but weekly sampling of the cooling towers was conducted (Appendix A). Grab samples were taken by facilities from each cooling tower approximately once a week while the cooling towers were in operation to assess the water quality of the two cooling towers on KSU's Manhattan campus. The cooling towers are not in operation during the winter months, from approximately October until March. In total, 19 samples were collected from October 7, 2016 – July 26, 2017. Once the samples were collected from the cooling tower, they were sent to the KSU Soil Testing lab for analysis. The KSU Soil Testing lab analyzed samples for eight parameters (Table 3.3). The samples were also analyzed for pH and EC_w according to standard protocols (Greenberg et al., 1992).

Table 3.3. Water quality sampling parameters and methods.

Parameter	Units	Method
NH_4^+	mg L^{-1}	(Alpkem Corporation, 1986b)
NO_3^{-1}	mg L^{-1}	(Alpkem Corporation, 1986a)
Cl	mg L^{-1}	(Gelderman et al., 2011)
Ca	mg L^{-1}	ICP
Mg	mg L^{-1}	ICP
Na	mg L^{-1}	ICP
K	mg L^{-1}	ICP
S	mg L^{-1}	ICP

ICP: Inductively Coupled Plasma Mass Spectrometry (Model 720-ES ICP Optical Emission Spectrometer, manufactured by Varian Australia Pty Ltd, Mulgrave, Vic Australia)

3.1.2 Bulk Treatment Solutions

Several treatment solutions were used in in the germination and seedling growth and biomass composition experiments. All experimental solutions were collected and prepared in bulk before experiments began (Table 3.4). Once the experimental solutions were prepared or collected they were analyzed according to the procedure mention in 3.1.1 Water Quality Testing section. All samples were stored at 4^{o}C in 23 L bulk storage containers for the entire experiment.

Table 3.4 Bulk solution sample collection and preparation procedures.

Water Source	Description
Tap Water	Collected from the Throckmorton Greenhouse on KSU's Manhattan Campus
FGD wastewater	Collected from Jeffrey Energy Center, located 8.5 miles northwest of Saint Marys, KS on September 26, 2017
CTBW	Collected from cooling tower 1 located north of Seaton Hall on KSU Manhattan Campus (Appendix A)
MHS	Prepared according to the University of Wisconsin-Madison's Essential Elements for Plant Growth (Table 3.5)
MHS (CTBW)	Prepared according to the University of Wisconsin-Madison's Essential Elements for Plant Growth (Barak, 2009), however, CTBW replaced Deionized (DI) water
Brackish water	Prepared by adding 18 grams of API Aquarium Salt to 982 mL of DI water

Table 3.5. MHS composition (Barak, 2009).

Chemical	Concentration (mM L^{-1})
$NH_4H_2PO_4$	0.4
KNO_3	2.4
$Ca(NO_3)_2$. $4H_2O$	1.6
$MgSO_4$	0.8
Fe as Fe-chelate	0.1
B as $B(OH)_3$	0.023
Mn as $MnCl_2$	0.0045
Cu as $CucCl_2$	0.0003
Zn as $ZnCl_2$	0.0015
Mo as MoO_3	0.0001

3.2 Germination and Seedling Growth

FGD wastewater has high concentrations of several trace elements (Table 2.8) that can be detrimental to plant growth. A preliminary study was conducted to determine if varying concentrations (0, 20, 40, 60, 80, and 100%) of FGD wastewater diluted with MHS had an effect on the germination of *S. europaea*. The preliminary study showed that the concentration of FGD wastewater did not have an effect on the germination of *S. europaea*, but observations showed that growth seemed to be affected. The germination and early seedling growth experiment was designed to assess some of the questions resulting from the preliminary study. Specifically, it was designed to determine if the composition of water used in a hydroponic system influenced the germination, survivability, and seedling height of *S. europaea.* In the study two sources of industrial wastewater were used, FGD wastewater and CTBW. To follow a similar format of the initial study, FGD wastewater was diluted with four other water sources and the dilutions were limited to 0, 20, 60, and 100 percent FGD wastewater because of limited space in the growth chamber (Table 3.6). This resulted in 13 treatments of varying composition (Table 3.7).

Table 3.6. Germination and seedling growth treatment solution composition.

ID	**FGD**	**MHS (CTBW)**	**CTBW**	**Tap Water**	**MHS**
	- - - - - - - - - - - - - - - -		Percent Volume	- - - - - - - - - - - - - - - -	
100% FGD	100	0	0	0	0
CTBW-0% FGD	0	100	0	0	0
CTBW-20% FGD	20	80	0	0	0
CTBW-60% FGD	60	40	0	0	0
MHS (CTBW)-0% FGD	0	0	100	0	0
MHS (CTBW)-20% FGD	20	0	80	0	0
MHS (CTBW)-60% FGD	60	0	40	0	0
Tap Water-0% FGD	0	0	0	100	0
Tap Water-20% FGD	20	0	0	80	0
Tap-60% FGD	60	0	0	40	0
MHS-0% FGD	0	0	0	0	100
MHS-20% FGD	20	0	0	0	80
MHS-60% FGD	60	0	0	0	40

FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Nutrient Solution; CTBW: Cooling Tower Blowdown Water

Each experimental unit consisted of a 2 x 5-inch block of 1 x 1-inch Grodan rockwool cells placed inside of a clear plastic container (2.17 x 6.85 x 4.8 inches). The rockwool had a quarter inch circular depression in the center of the block for seed placement. One *S. europaea* seed was placed inside the center of each rockwool cell, for a total of 10 *S. europaea* seeds per experimental unit. The *S. europaea* seeds were ordered online from AlsaGarden (http://www.alsagarden.com/en/). To begin the experiment, 500 mL of treatment solution was added to each experimental unit, as seen below in Figure 3.1. The experimental units were arranged in a randomized block design.

Table 3.7 Treatment solution water quality composition

		EC	pH	S	K	Na	Mg	Ca	Chloride	NO3-N	NH4-N
Treatment	% FGD	dS m^{-1}		- - - - - - - - - - - - - - - - - -				mg L^{-1}	- - - - - - - - - - - - - - - - - -		
MHS CTBW	0	1.5	8.2	131	146	189	89	165	224	72	6
	20	2.5	8.0	286	160	430	72	294	587	64	6
	60	4.5	7.5	595	190	913	36	552	1313	48	5
MHS	0	0.6	6.0	27	98	1	23	78	4	76	6
	20	1.8	6.2	202	123	280	19	224	411	67	6
	60	4.2	6.6	553	171	838	9	517	1225	49	6
Tap Water	0	0.2	8.7	19	8	31	15	14	58	0	1
	20	1.5	8.4	196	50	304	12	173	454	7	1
	60	4.0	7.7	550	135	850	6	492	1246	19	3
CTBW	0	1.0	8.9	105	42	186	70	111	221	1	0
	20	2.2	8.5	265	78	428	56	251	584	7	1
	60	4.4	7.8	584	149	911	28	530	1311	20	3
FGD	100	6.6	7.0	904	220	1395	0	810	2038	32	5

FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Nutrient Solution; CTBW: Cooling Tower Blowdown Water

Figure 3.1. An example of an experimental unit on day 0.

The first three weeks of the germination and seedling growth experiment was conducted in a Conviron Model PGR15 growth chamber. The growth conditions of the growth chamber were set to a 16-hour day and 8-hour night photoperiod with day maximum temperature of 25°C kept for 8 hours and night minimum temperature of 20°C kept for 8 hours with a 4-hour transition period. The luminance was set to 350±50 µmol/m2/s and relative humidity ranged from 70-90%.

Every 2-3 days, germination (Appendix D), height (Appendix J), and visual phytotoxicity (Appendix H) were recorded. A seed was determined to be germinated if the root radicle had elongated. All visual phytotoxicity data was collect by one researcher, who noted discoloration and deformation of the seedlings. Every seven days the treatment solution was collected and tested for chlorophyll content in order to quantify visual changes in algae growth. To collect the sample, the rockwool was removed and the containers were closed and inverted 5-times to evenly distribute the algae within the remaining solution. The solution was then poured into a 250 mL sample container. Once the treatment solution was removed, the sample containers were rinsed with DI water. Then 250 mL of treatment solution was added and the rockwool was placed back inside the sample containers.

The chlorophyll samples were analyzed according to the ASTM D3731-87 (2012) procedure for analyzing chlorophyll content of algae in surface waters. According to that procedure, 0.2 mL of magnesium carbonate solution was immediately added to the sample. The magnesium carbonate solution was prepared by mixing 1 g of magnesium carbonate with 100 mL of DI water. To extract the pigment, 50 mL of the sample was centrifuged for 20 min at 1000 G with an Eppendrof 5810R centrifuge. The supernatant was then removed with a syringe. The solid was brought to 15 mL by adding 90% aqueous acetone and the sonicated in an ice bath for 20 min. A Fisher Scientific ultrasonic cleaner FS60H set to level 5 was used for sonication. After the samples were sonicated, they were allowed to steep for 24-hours and then centrifuged for 20 min at 1000 G. The supernatant was then removed with a syringe and the absorbance at 750 and 664 nm was measured using a Molecular Devices Spectra MaxPlus 384 Spectrometer.

After 21 days in the growth chamber, the experimental units were moved into the greenhouse, where the same measurements were continued with the exception of chlorophyll until day 65. After day 65, all experimental units were watered with DI water every 2-3 days and with MHS every two weeks.

The Statistical Consulting Lab at Kansas State University was consulted for all statistical methods, and the Statistical Analysis System (SAS) software program was used for all analytics and data management. The germination, survivability, phytotoxicity, absorbance, and height data was analyses using ANOVA. The data and SAS code for statistical analysis is given in Appendix E, G, I, K, and N.

3.3 Biomass Composition

A key benefit of treating industrial wastewater in a hydroponic system with *Salicornia* is that the biomass could be a valuable byproduct. Cybulska et al. (2014a) found that salinity significantly affected total extractives, glucan content, and lignin content, each of which is important in the conversion of lignocellulosic feedstock into ethanol. The biomass composition study was designed to determine if the composition of irrigation water has an effect on the lignocellulosic composition of *S. bigelovii.* Several experiments were started with *S. bigelovii* seeds, but not enough biomass was produced from those studies to determine the lignocellulosic composition. After several months of failing to grow enough biomass of *S. bigelovii* from seeds mature *S. bigelovii* plants were ordered.

Elkhorn Native Plant Nursery in Moss Landing, CA shipped mature *S. bigelovii* plants to KSU's campus located in Manhattan, KS. After the plants arrived on September 26, 2016, they were unpacked, rinsed with tap water, and placed into a container with enough tap water to wet the roots. The plants were kept under a florescent grow light on a 12-hour photo cycle in a temperature-controlled laboratory until October 7, 2016. Since the *S. bigelovii* plants were started in soil, it was not feasible to transfer them into a hydroponic system. The *S. bigelovii* plants were transferred into top soil and moved into the greenhouse on October 7, 2016 (Figure 3.2).

Figure 3.2. Potted *S. bigelovii* plants in greenhouse.

The plants were kept in the greenhouse for 14-weeks to recover from being transported. During this time, the pots were watered every two days with tap water until water ran out of the bottom of the pots. The study began on January 15, 2017 and was conducted under greenhouse conditions (Temperature at 70 ^{o}F).

This study consisted of five treatments; (1) 100% tap water (control), (2) 100% brackish water. (3) 100% FGD wastewater, (4) MHS & brackish water (50:50 v/v), and (5) MHS & FGD wastewater (50:50 v/v). There were four replicates for each treatment, for a total of 20 experimental units in the study.

For two months, 500 mL of these solutions were applied every two days to pots (3.54 kg of top soil) containing transplanted *S. bigelovii*. A portion of the shoots were harvested after 1 month after the initiation of treatments and the entire plant was harvested 2 months after the initiation of treatments. Once the shoots were harvested, they were washed with tap water and then DI water before drying five days at 75 °C in a drying oven. There was not enough biomass from each experimental unit to test the lignocellulosic composition of each experimental unit. To achieve the required 10 g of biomass needed for the determination of structural carbohydrates and lignin, 2.5 g of dried biomass from each replicate was combined.

The chemical composition was determined according to the National Renewable Energy Laboratory (NREL) procedures (Sluiter et al., 2008). In the NREL procedure, biomass was treated with sulfuric acid (72%) at 30 °C for 60 min and hydrolyzed by dilute acid (4%) at 121 °C for another 60 min. After acid hydrolysis, carbohydrates including cellulose and hemicellulose were converted into monosaccharide, which was measured by high-performance liquid chromatography (HPLC) (Shimadzu, Kyoto, Japan) equipped with an RCM monosaccharide column (300×7.8 mm) (Phenomenex, Torrance, CA) and a refractive index detector (RID10A, Shimadzu, Kyoto, Japan). The mobile phase was 0.6 mL min^{-1} of double-distilled water, and the oven temperature was 80℃. Lignin consists of acid insoluble and acid soluble lignin. Acid soluble lignin was measured using a UV-Visible spectrophotometer. Acid insoluble lignin was weighed from the solid after oven heating overnight at 105 °C (the weight of acid insoluble lignin and ash) and then at 575°C for at least 6 h to measure the ash content.

Chapter 4 - Results and Discussion

These studies found that full strength CTBW could be used to cultivate *Salicornia* seedlings in a hydroponic system if nutrients are added. The composition of FGD wastewater was shown to have a detrimental effect on the growth of *Salicornia* seedlings even when diluted to 60% of its original concentration. *Salicornia* seedlings can be cultivated with more dilute concentrations of FGD wastewater, but it is unlikely that using dilute concentrations of FGD wastewater would be an efficient system for the treatment of FGD wastewater and the cultivation of *Salicornia.*

This research also found that *Salicornia* is not a good lignocellulosic biofuel feedstock because of its low lignocellulosic composition. However, a large percentage of the extractives content is unidentified and could have a monetary value. Further testing of *Salicornia* cultivated with CTBW should be conducted to determine if it has value as and animal fodder or has other co-products of value. Low germination and survivability rates across all treatments showed the need of a quality *Salicornia* seed. Finding a uniform and quality source of *Salicornia* seed could be difficult because *Salicornia* is currently not domesticated.

4.1 Saline Water Composition

To understand how industrial waters fluctuates in composition, water quality data was collected from two cooling towers on KSU's campus. This data show that the EC_w of CTBW can vary, but the ratio of inorganic constituents is relatively consistent between samples. Chloride and Na were the dominant inorganic parameters sampled in CTBW (Table 4.1). This is an advantage for using CTBW to cultivate *Salicornia*, because Na^+ and Cl^- are the preferred cation and anion respectively for osmotic adjustment in *Salicornia* (Díaz et al., 2013; Grattan et al., 2008; Katsching et al., 2013). In comparison to CTBW, FGD wastewater has a higher concentration of TDS and it has a different composition of ions (Mittal & Hoskin, 2006). In FGD wastewater, Na^+ is not always the dominant cation (Table 3.2), this could affect the growth of *Salicornia* (Ayla & O'Leary, 1995). In addition, FGD wastewater has elevated concentrations of traces elements, which could be toxic to *Salicornia.*

Table 4.1 Water quality characteristics of KSU CTBW

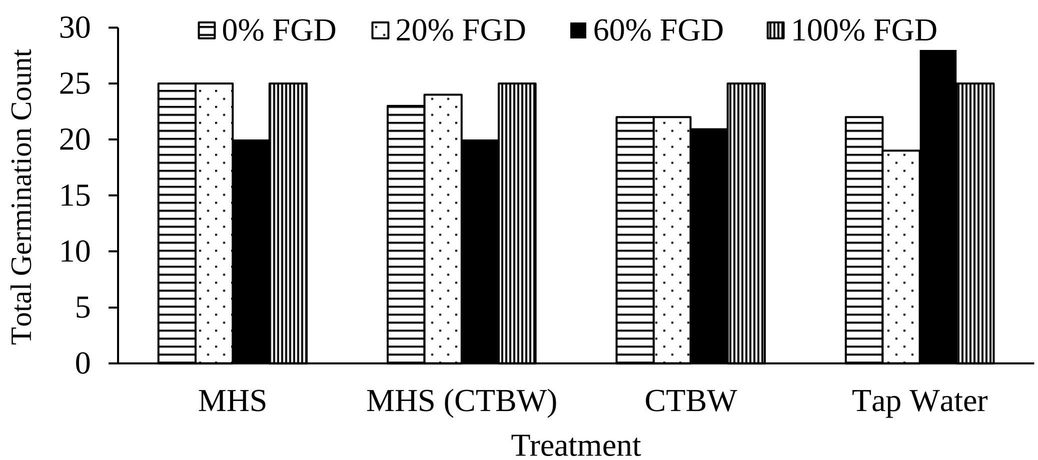
Parameter	Average	Maximum	Minimum	Standard Deviation	N
NH_4^+ (mg L^{-1})	0.38	2.46	0.00	0.73	19
NO_3^- (mg L^{-1})	1.28	2.75	0.20	0.79	19
Chloride (mg L^{-1})	1958.99	12981.00	203.00	3983.34	19
Ca (mg L^{-1})	219.76	1213.44	82.69	298.46	19
Mg (mg L^{-1})	202.98	1502.29	61.90	358.41	19
Na (mg L^{-1})	987.24	10305.80	185.48	2329.36	19
K (mg L^{-1})	87.21	312.76	44.55	79.99	19
S (mg L^{-1})	101.87	144.20	21.38	33.83	19
pH	8.78	9.08	7.99	0.30	15
EC_w (dS m^{-1})	9.19	18.27	1.03	6.71	15

4.2 Germination and Early Seedling Growth

The germination and early seedling growth study found that *S. europaea* could be cultivated in a hydroponic system with full strength CTBW if nutrients are added. FGD wastewater can be used to cultivate *S. europaea* in lower concentrations, but full strength FGD wastewater cannot be used to cultivate *S. europaea.* This study also identified the need of a quality *Salicornia* seed source and the management of algae growth as limiting factors in the cultivation of *S. europaea* in a hydroponic system.

4.2.1 Germination

The first step in assessing if *Salicornia* can be grown in a hydroponic system with industrial wastewater is to determine if the composition of water has an effect on germination. In this study, the composition of water did not have a significant influence (Type III Test P-value = 0.7802) on the percent germination of *S. europaea* (Figure 4.1). This indicates that industrial wastewater of similar composition could be used to germinate *S. europaea* in a hydroponic system. Higher concentrations of NaCl have been shown to negatively influence the germination rate of *S. europaea* (Ungar, 1977). Since the conductivity of experimental solutions only ranged from 6.57-0.58 dS m^{-1} it is possible that industrial wastewater with higher conductivities could influence the germination rate. If industrial wastewater is found to have a significant influence on the germination rate in future studies, the seeds could be germinated with freshwater prior to being irrigated with industrial wastewater.



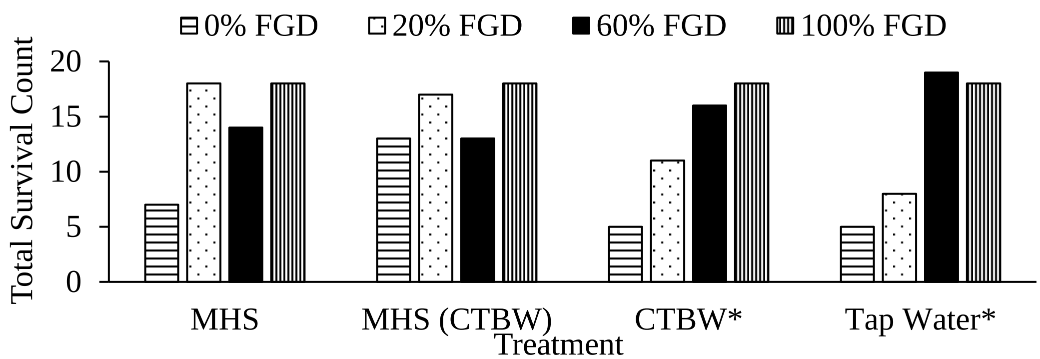
FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure 4.1 Number of seeds germinated in all experimental units with the same treatment on day 21.

The treatment did not have a significant effect on germination, but the low mean germination rate of all treatments (57%) is a concern. Not only was the germination rate low in this study, but all preliminary studies carried out under a variety of conditions showed similarly low germination rates. Shortly after the completion of the germination and early seedling growth experiment, testing started on a pilot scale floating raft system. During testing less than 15% of the seeds germinated, which resulted in low biomass production due to a limited number of plants on each raft. It is unclear why the mean germination rate is low for all treatments. One possibility is that the seed from AlsaGarden was degraded during the shipping process from France. It was difficult to find a supply of *Salicornia* seed that could be shipped to the US. Most research conducted on *Salicornia* uses seeds collected from wild plants or seed obtained from a local supplier. Regions where there is no local supplier or wild plants are less likely to obtain a quality supply of *Salicornia.* A source of quality seed will be a determining factor in the development of a hydroponic system that cultivates *Salicornia.*

4.2.2 Survival

Once the germination study was completed, the survival of seedlings was observed to determine if the composition of water had an effect on the number of plants that survived over time. In this study, all seedlings that grew to a measurable height survived until day 65. This means that the treatments did not have an effect on the survivability of seedlings from day 22 until day 65. However, the treatments did have a significant effect on the number of seedlings that survived until day 65 (Type III Test P-value = 0.0107). A pairwise comparison of treatments did not show any significant differences between treatments, but contrasts were able to show that the percent of FGD wastewater had a significant effect on the survival of seedlings until day 65 when mixed with CTBW and tap water (Figure 4.2). In those treatments, FGD wastewater seems to have a positive influence on survival. Elevated levels of nitrogen in FGD wastewater could enhance the survival of seedlings when mixed with CTBW and tap water, because they do not have any added nutrients. This would also explain why there is not significant difference when FGD wastewater is mixed with MHS and MHS (CTBW), because each of those treatments have added nutrients. The excess nitrogen in FGD wastewater could decrease the cost of adding nutrients to a hydroponic system. Other source of nutrient rich water could also be used to increase the efficiency of cultivating *Salicornia.* Several treatments systems have shown that *Salicornia* can effectively remove nutrients from aquaculture effluent (Gunning, 2016; Webb et al., 2012).



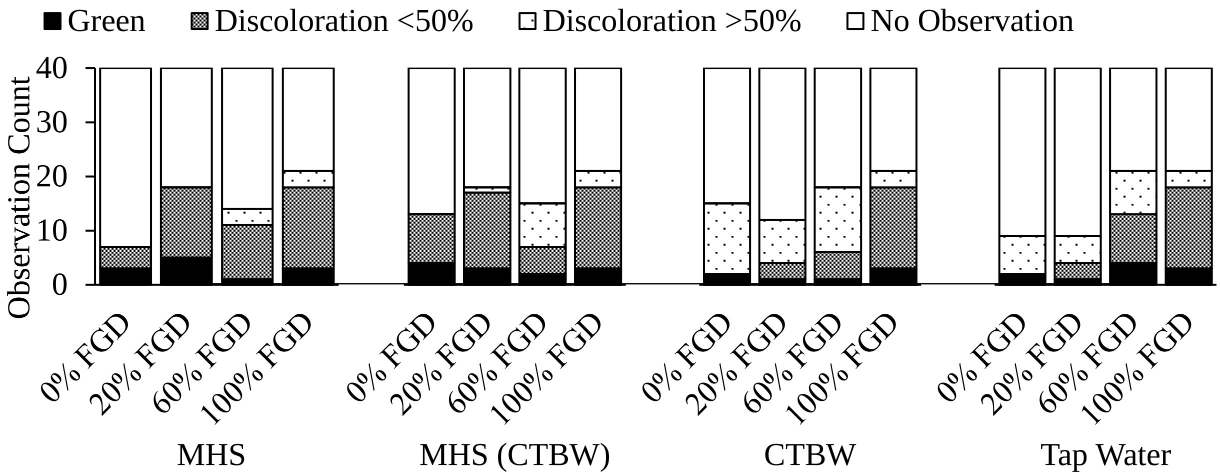
FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure 4.2 Total survival count of each treatment on day 65. *Indicates a significant difference between treatments (Contrast P-value<0.05).

The mean survival rate of germinated seeds across all treatments was 55%. Low survival of germinated seeds coupled with low germination rates resulted in less than 30% of the seeds surviving until day 65. This means that the biomass production potential is low for each seed regardless of the treatment, even without considering the possibility of plant death before maturation. This reconfirms the need for a quality source of seed.

4.2.3 Visual signs of Phytotoxicity

The survivability of seedlings is one measure to understand the effects of a treatment; however, due to the relatively short duration of observation, a treatment could have a negative effect on *S. europaea* but not cause plant death. Any visual indicators of phytotoxicity were recorded gain a better understanding of the effect of water quality on the cultivation of *S. europaea.* Discoloration of the succulent plant tissue to a yellow or red color was the dominant visual sign of phytotoxicity. The only other sign of phytotoxicity was the deformation of succulent leafs of two seedlings. A statistical analysis of the observations showed that on day 65, the treatment had no significant effect on the number of plants with discoloration. This is most likely because very few plants showed no sign of discoloration (Figure 4.3). The percentage of the plant affected by discoloration was also estimated through observation. Treatments without any added nutrients tended to have a larger percentage of seedlings with discoloration affecting over 50% of the visual plant tissue. This is another indicator of the importance of adding nutrients to industrial wastewater in a hydroponic system.

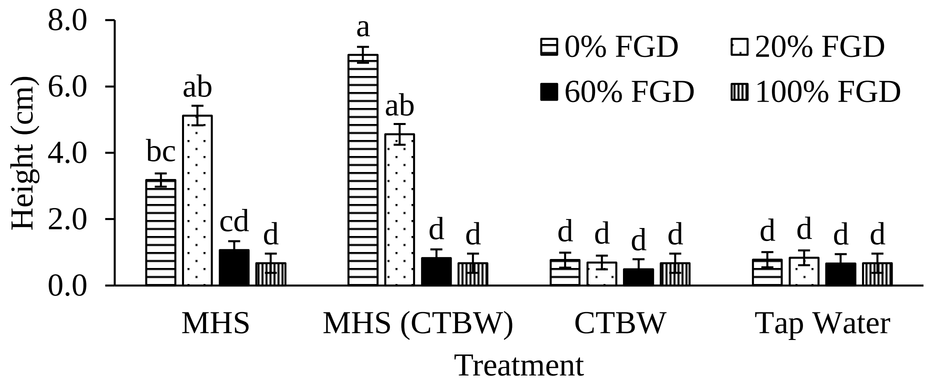


FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure 4.3 Total number of seedlings with signs of phytotoxicity on day 65

4.2.4 Height

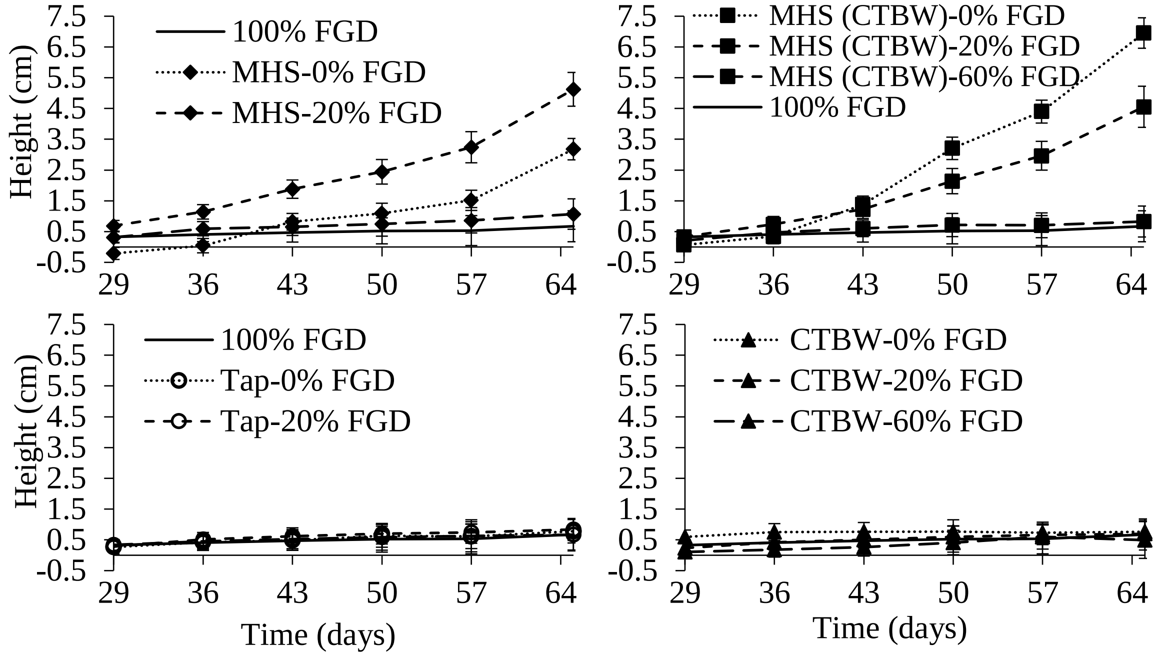
The height is another indicator of the effects of a treatment on the cultivation of *Salicornia*. The height data showed that there were no clear trends between treatments in the first 43 days of the study (Appendix L). Treatments without added nutrients, CTBW and tap water, showed very little growth in the 65-day study period regardless of the FGD wastewater content (Figure 4.5). On day-65, the 0% and 20% FGD treatments without added nutrients were significantly lower than treatments with added nutrients, but there was not significant difference between the 60% FGD wastewater treatments (Figure 4.4). These results suggest that the height of *S. europaea* is affect by the availability of nutrients and the composition of FGD wastewater. Since, there was no control for the concentration of nutrients, it is difficult to definitively show that FGD wastewater had a detrimental effect on height. However, if FGD wastewater did not have a detrimental effect on height a difference between treatments with and without nutrients would be expected for the 60% FGD treatments, because there is a sufficient amount of nutrients in half strength MHS for the cultivation of *Salicornia* in an inert media (Lv et al., 2011). Trace element toxicity could be one reason for reduced height in FGD treatments. The median dissolved concentration of Cd, Co, Mn, Mo, Ni, Se, and V in FGD wastewater (EPRI, 2006) exceeded the MCL of permanent irrigation water (Lazarova et al., 2005).



FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure 4.4 Mean Height at day 65 (Error bars indicate standard error and letters denote significant differences among treatments based on Bonferroni test (P<0.05)).

The composition of ions and cations available for osmotic adjustment has also been shown to affect the growth of *Salicornia* (Ayala & O'Leary, 1995; Kong & Zheng, 2014). This could be the reason for reduced height in FGD treatments because Na^+ is not always the dominant cation (Table 3.2). However, in this study, the ratio of Na to all other cations was similar in both FGD wastewater and CTBW, and chloride was the dominant anion. The low concentration of Cl and Na in 0% FGD MHS (Table 3.7) is likely to be the reason for the difference in height on day-65 between 0% FGD MHS and 0% FGD MTS (CTBW). Overall, this data shows that undiluted FGD wastewater cannot be used to cultivate *S. europaea* in an inert media and nutrients and ion composition are important factor in the cultivation of *S. europaea*.



FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure 4.5 Seedling height over time. Error bars indicate standard error.

4.2.5 Algae Growth

During a preliminary study on germination, a difference in the amount of algae growing in each treatment solution was visually observed, as it was in this study (Appendix O). In some experimental units, the algae growth was so extensive it covered the seed. This was a concern for the experiment because the amount of algae growth could change the external conditions enough to affect germination. In order to understand the impact of algae growth on seed germination, the amount of algae growth was quantified in this study by extracting the chlorophyll from algae cells in the solutions and measuring absorbance at 664 nm and 750 nm. The absorbance at 750 nm is used in to determine the exact concentration of chlorophyll *a*, *b*, and *c*. However, alone it does not indicate the algae concentration (ASTM D3731-87. (2012). After the data was collected it was determined that the exact concentration of chlorophyll *a*, *b*, and *c*, was not important to this analysis so it was not calculated.

A statistical analysis of this data showed that the treatment had no effect on amount of algae for the first two weeks, but by day 21, the treatment had a significant effect on the amount of algae (Table 4.2). A pairwise comparison of the treatments showed a significant difference in absorbance between treatments at 664 nm on day 21 (Figure 4.6). Given these results, the algae growth is not thought to have a significant effect on germination because the treatment did not have a significant effect on germination and it only has a significant effect on algae by the last day of the germination study.

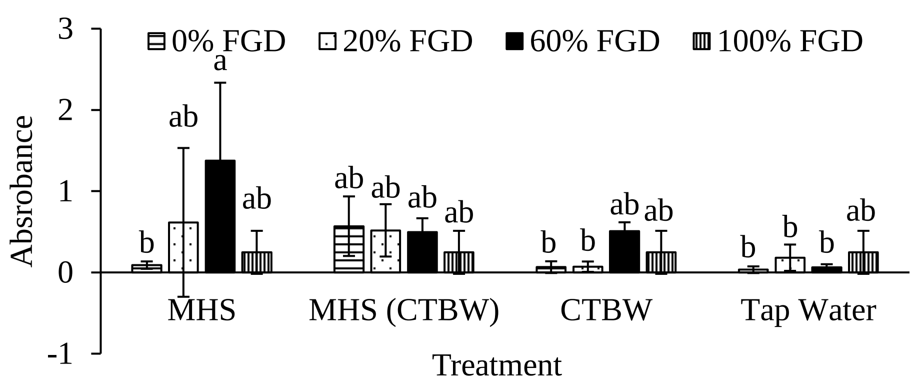


Figure 4.6 Absorbance of treatments at 664 nm on Day 21. Error bars indicate one standard deviation and letters denote significant differences among treatments on a given day based on tukey test (P<0.05)).

Table 4.2 Mean absorbance of treatments

	Day	7	14		21*	
Wavelength		**664 nm**	**750 nm**	**664 nm**	**750 nm**	**664 nm**
Trt	**% FGD**	- - - - - - - - - - - - - - **absorbance** - - - - - - - - - - - - - -				
MHS (CTBW)	0	-0.020	-0.007	0.082	0.256	0.569
	SD	± 0.0013	± 0.0126	± 0.1026	± 0.2828	± 0.3666
	20	-0.025	-0.014	0.168	-0.001	0.518
	SD	± 0.0021	± 0.0046	± 0.1440	± 0.0316	± 0.3222
	60	-0.013	-0.014	0.092	-0.008	0.497
	SD	± 0.0261	± 0.0072	± 0.0929	± 0.0116	± 0.1697
MHS	0	-0.008	-0.018	0.008	-0.015	0.090
	SD	± 0.0393	± 0.0026	± 0.0285	± 0.0056	± 0.0454
	20	-0.030	-0.014	-0.006	-0.018	0.616
	SD	± 0.0011	± 0.0031	± 0.0241	± 0.0051	± 0.9156
	60	-0.022	-0.017	0.100	-0.015	1.377
	SD	± 0.0088	± 0.0074	± 0.1114	± 0.0058	± 0.9579
Tap Water	0	-0.030	-0.017	-0.018	-0.012	0.034
	SD	± 0.0000	± 0.0039	± 0.0068	± 0.0128	± 0.0409
	20	-0.030	-0.018	0.045	-0.019	0.181
	SD	± 0.0005	± 0.0041	± 0.0877	± 0.0019	± 0.1619
	60	-0.030	-0.017	-0.018	0.024	0.064
	SD	± 0.0004	± 0.0036	± 0.0091	± 0.0504	± 0.0370
CTBW	0	-0.055	-0.019	0.010	0.004	0.065
	SD	± 0.0610	± 0.0026	± 0.0372	± 0.0253	± 0.0721
	20	-0.021	-0.017	0.053	-0.022	0.071
	SD	± 0.0024	± 0.0019	± 0.0853	± 0.0008	± 0.0639
	60	-0.030	-0.016	0.087	-0.001	0.509
	SD	± 0.0000	± 0.0057	± 0.0904	± 0.0123	± 0.1086
FGD	100	0.020	-0.018	-0.026	0.220	0.248
	SD	± 0.0852	± 0.0010	± 0.0026	± 0.2316	± 0.2647
Test III P-Value		0.5453	0.4440	0.1035	0.019	0.015

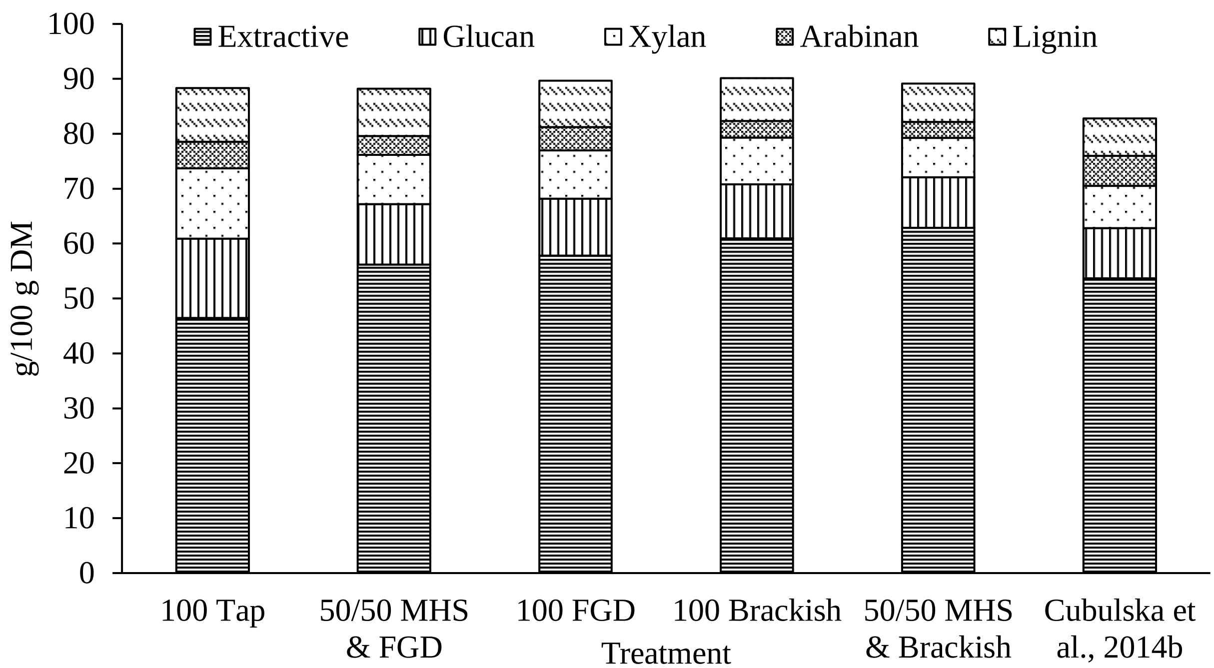
FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water; *Values significantly different according to Tukey Test P-Value <0.05.

Algae growth is also a concern for plant growth in hydroponic systems because it competes with plants for nutrients and can serve as a food source for flies and fungus gnats (Raudales, 2016). The effect of algae on plant growth in this study is limited because nutrient concentrations were maintained over the duration of the study by replacing treatment solutions every seven days. Flies were observed on plants once they were moved to the greenhouse, but plants showed no sign of damage from insects. Even though algae growth was not a significant factor in this study, it should be considered in the development of future studies. In addition to the studies mentioned, three pilot scale floating raft systems have been constructed and are currently going through initial testing. In these systems, algae growth was successfully limited by lowering the amount of light exposed to the nutrient solution by selecting nontransparent materials.

4.3 Biomass Composition

A key benefit of treating industrial wastewater in a hydroponic system with *Salicornia* is that the biomass could be a valuable byproduct. Shoots, roots, and seeds are the three major components of mature *S. bigelovii* that could be harvested and sold as a secondary revenue stream. Oil from the seeds can be used as an edible oil, for biodiesel production, or for HEFA fuel production. The remaining seed meal after oil extraction is high in protein, which makes it a good animal feed supplement (Glenn et al., 1991). The shoots could be used as an animal fodder, a lignocellulosic biomass for ethanol production, or as source of other valuable coproducts. This study was conducted understand the value of *S. bigelovii* shoots and how water composition affects the shoots composition.

Almost half of the DM content of all *S. bigelovii* samples is extractives (Table 4.3), non-structural components such as sucrose, protein, ash, and chlorophyll (Sluiter et al., 2005). The tap water treatment had the lowest concentration of extractives and the rest of the treatments showed little difference in the amount of extractives. While significance cannot be determined in this study, a previous study on the composition of *S. bigelovii* found that salinity affected the total extractive content (Cybulska et al., 2014a). However, it did not have a significant effect on the ash-free water extractive content. No further analysis of extractives was conducted in this study, but Cybulska et al. (2014a) analyzed water extractives of *S. bigelovii* for free sugars (glucose, xylose, and arabinose) and organic acids (acetic, lactic, and formic acid). They were unable to detect any of the organic acids and only very low concentration of glucose and xylose. Therefore, the composition of extractives and its value remains unknown.



FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution

Figure 4.7 Biomass composition of *S. bigelovii* after 2 months of treatment.

The second largest component of *S. bigelovii* in this study was glucan (cellulose). The concentration was highest in tap water treatment and lowest in the 50/50 MHS and brackish water treatment. All treatments by the second month had higher concentrations of glucan compared to Cybulska et al. (2014b) (Figure 4.7). The cellulose content is important in assessing the ethanol production of a feedstock because it is the easiest lignocellulosic component to convert into ethanol (Lee & Laboie, 2013). Compared to other feedstocks raw *S. bigelovii* has a low amount of glucan (Cybulska et a., 2014a), but the amount can be increased to more comparable levels by decreasing the ash content through a freshwater wash (Cybulska et al., 2014b).

Table 4.3 Biomass composition of *S. bigelovii.*

Treatment	Month	Extractive	Glucan	Xylan	Arabinan	Lignin	Ash
	g/100 g DM						
100% Brackish	1	59.48	9.94	8.70	3.65	7.49	0.06
	2	60.98	9.78	8.50	3.00	7.71	0.41
100% FGD	1	56.52	11.68	10.05	4.22	8.25	0.06
	2	57.81	10.25	8.79	8.79	8.37	0.41
100% Tap	1	48.43	13.40	11.79	4.94	9.35	0.02
	2	46.43	14.91	13.23	5.24	9.73	0.39
50/50 MHS & Brackish	1	62.47	9.54	7.07	2.82	6.59	0.01
	2	62.88	9.08	6.69	2.69	7.02	0.23
50/50 MHS & FGD	1	53.45	11.98	9.73	3.72	8.82	0.08
	2	56.20	10.63	8.44	3.29	8.76	0.29
*Cybulska et al., 2014b		53.70	9.10	7.70	5.50	6.80	-

*The lignocellulosic biomass composition of *S. bigelovii* cultivated with 40 g L^{-1} NaCl (Cybulska et al., 2014b).

Hemicellulose is composed of both C5 and C6 sugars which makes it more difficult to convert into ethanol, because C5 sugars do not ferment with classical yeast strains (Lee & Lavoie, 2013). The composition of hemicellulose in *S. bigelovii* is represent by the xylan and arabinan content. The hemicellulose is highest in the tap water treatment, and generally, the xylan content is higher in this study compared to Cybulska et al. (2014b); while the arabinan content is lower (Table 4.3). Lignin is the final component of lignocellulosic biomass. The composition of lignin in *S. bigelovii* is low compared to other lingoncellulosic biomass sources (Cybluska et al., 2014b). The ethanol yield of *S. bigelovii* was not tested in this study, but *S. bigelovii* has been shown to be capable of producing 111 kg ethanol/dry ton (Brown et al., 2014), which is relatively low compared to corn stover (Brown et al., 2014). It is unlikely that the production of ethanol with *S. bigelovii* would be economical, because most ethanol production from lignocellulosic biomass is not economical (Joshi et al., 2017) and *S. bigelovii* has a lower ethanol production compared to other lignocellulosic residues (Brown et al., 2014).

Chapter 5 - Next Steps

The studies conducted showed that *S. europaea* could be cultivated with industrial wastewater in a hydroponic system if additional nutrients were added. However, the seeds used in this study had low germination and survival; these results indicated that the performance of this system would be poor. A good source of seed is required for the development a hydroponic system that treats industrial wastewater and cultivates *Salicornia*. Seeds can be sourced from specialty seed suppliers who cultivate wild plants, but uniform seed will be difficult to source until *Salicornia* is domesticated. Before additional research is conducted on using hydroponic systems to cultivate *Salicornia* and treat industrial wastewater, a source of uniform seed with higher germination rates and survivability should be found.

The development and testing of a pilot scale hydroponic system is an important next step in developing a hydroponic system that provides treatment for industrial wastewater and cultivates *Salicornia*. Initial testing should focus on understanding how water quality affects biomass and seed production, seed quality, water usage, and water treatment. Once these results have been determined, the system can be assessed to determine if a hydroponic system is able to provide treatment of industrial wastewater and cultivate *Salicornia.* Finally, the biomass quality should be assessed to determine is value as an animal fodder or as a source of coproducts, because the research conducted has shown that is not a high value lignocellulosic biofuel feedstock.

A similar system could be developed with other plant species and sources of industrial water. The development of a similar system with other plants and industrial sources of water would require testing similar to what has been completed as part of this research project and proposed.

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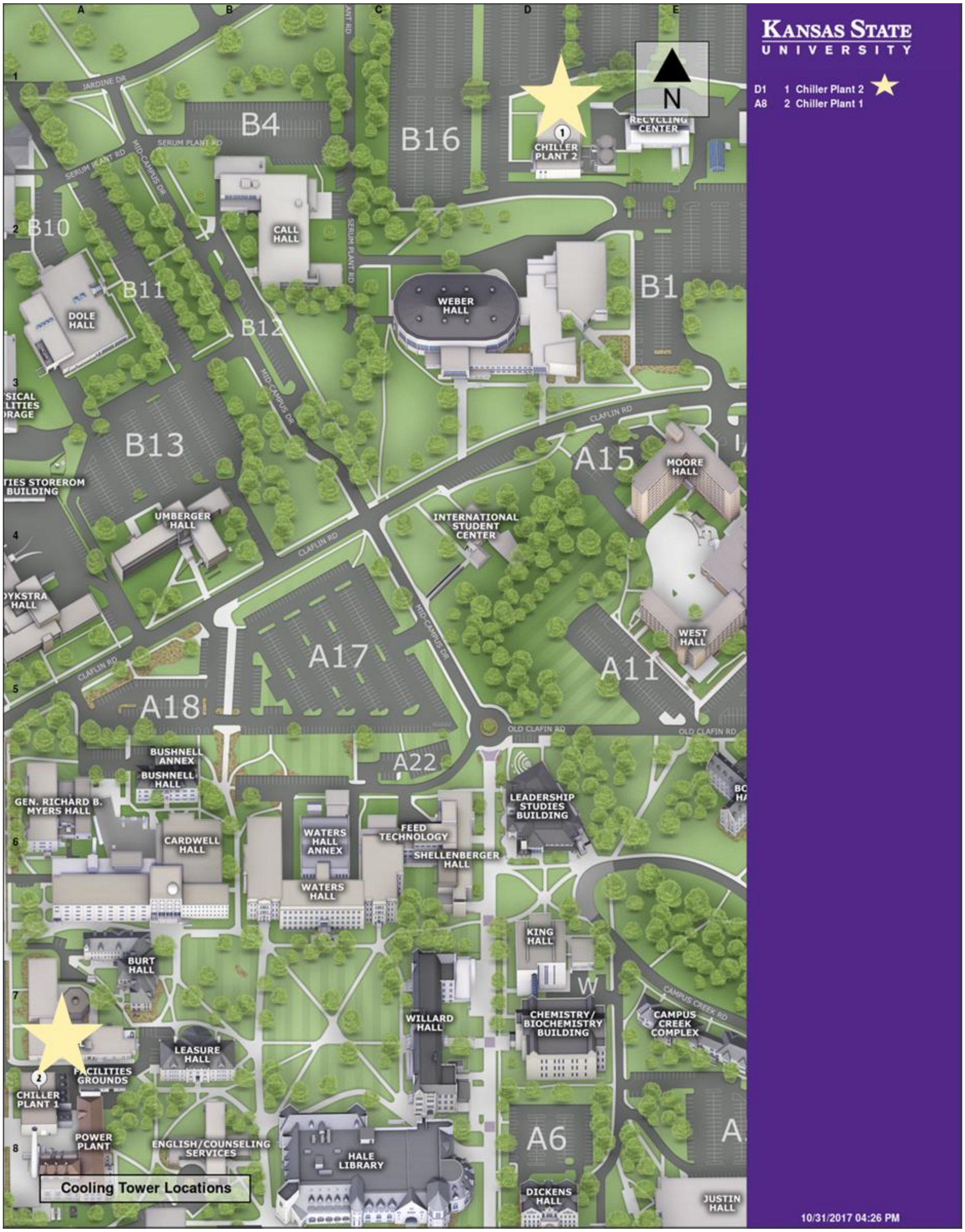
Appendix A - Cooling Tower Locations



Appendix B - CTBW Water Quality Data

Table B.1 CTBW Water Quality Data

	EC	**pH**	**S**	**K**	**Na**	**Mg**	**Ca**	**Cl^-**	**NO_3^-**	**NH_4^+**
Date Taken	**$dS\ m^{-1}$**		**- mg L^{-1}- - - - - - - - - - - - - - - - -**							
10/7/2016	-	-	94	46	188	62	151	203	1.1	0
10/24/2016	-	-	36	263	10306	245	345	12981	0.2	1.8
3/13/2017	13.5	9.0	114	55	253	84	124	253	0.66	[a]ND
3/22/2017	13.3	9.0	98	50	209	74	108	219	0.63	0.06
3/28/2017	13.1	9.0	113	51	189	70	106	234	0.68	0.41
4/3/2017	17.0	9.1	119	53	212	71	108	245	0.71	0.08
4/11/2017	13.5	9.0	110	53	214	72	107	245	0.71	0.17
4/19/2017	13.3	9.0	144	68	284	87	130	304	0.9	0.15
4/24/2017	13.5	9.0	111	52	217	69	105	253	0.85	0.05
5/17/2017	-	-	119	57	227	73	101	255	1.11	<0.01
5/23/2017	-	-	120	61	234	74	98	262	1.35	<0.01
6/19/2017	1.0	8.6	107	46	197	72	86	220	2.11	0.02
6/20/2017	15.5	8.0	21	231	1421	1502	1213	9369	0.31	1.79
6/27/2017	1.0	8.5	106	45	185	71	83	244	2.66	0.01
7/7/2017	1.1	8.9	113	48	210	74	92	257	2.75	0.06
7/7/2017	18.3	8.4	28	313	3552	903	913	10820	1.09	2.46
7/13/2017	1.3	8.6	135	59	230	89	110	297	2.64	0.03
7/20/2017	1.1	8.8	116	49	202	76	89	232	1.9	0.04
7/26/2017	1.3	8.9	131	58	229	92	107	329	1.89	0.08
Average	9.2	8.8	102	87	987	203	220	1959	1.28	0.45

[a]ND: Not Detected

Table B.2 CTBW Sample Notes

Date Taken	[a]CT	*Conductivity	*pH
10/7/2016	CP1	-	-
10/24/2016	CP2	-	-
3/13/2017	CP2	-	-
3/22/2017	CP2	1947	8.7
3/28/2017	CP2	1848	8.7
4/3/2017	CP2	1914	8.2
4/11/2017	CP2	2258	8.5
4/19/2017	CP2	1839	8.4
4/24/2017	CP2	1907	8.4
5/17/2017	CP2	1897	8.4
5/23/2017	CP2	1957	8.3
6/19/2017	CP2	1892	8.9
6/20/2017	CP1	1964	8.6
6/27/2017	CP2	1885	8.8
7/7/2017	CP2	1964	8.6
7/7/2017	CP1	-	
7/13/2017	CP2	1972	8.6
7/20/2017	CP2	1930	8.6
7/26/2017	CP2	2091	8.6

*Conductivity and pH are reported values read form the blowdown towers chemstation; [a]CT: Cooling Tower

Appendix C - Germination and Seedling Growth Key

Table C.1 Summary of the composition and labels of treatments

		FGD	MHS (CTBW)	CTBW	Tap Water	MHS
ID	**Data ID**	- - - - - - - - - - - **Percent Volume** - - - - - - - - -				
100% FGD	FGD-0	100	0	0	0	0
CTBW-0% FGD	BD-0	0	100	0	0	0
CTBW-20% FGD	BD-20	20	80	0	0	0
CTBW-60% FGD	BD-60	60	40	0	0	0
MHS (CTBW)-0% FGD	BDHO-0	0	0	100	0	0
MHS (CTBW)-20% FGD	BDHO-20	20	0	80	0	0
MHS (CTBW)-60% FGD	BDHO-60	60	0	40	0	0
Tap Water-0% FGD	TA-0	0	0	0	100	0
Tap Water-20% FGD	TA-20	20	0	0	80	0
Tap-60% FGD	TA-60	60	0	0	40	0
MHS-0% FGD	HO-0	0	0	0	0	100
MHS-20% FGD	HO-20	20	0	0	0	80
MHS-60% FGD	HO-60	60	0	0	0	40

Appendix Table 1

FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Nutrient Solution; CTBW: Cooling Tower Blowdown Water

Appendix D - Germination Data

Table D.1 Germination data day 1

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
2	HO-60	0	0	0	0	0	0	0	0	0	0	0
3	HO-20	0	0	0	0	0	0	0	0	0	0	0
4	TA-20	0	0	0	0	0	0	0	0	0	0	0
5	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
6	BD-20	0	0	0	0	0	0	0	0	0	0	0
7	BD-0	0	0	0	0	0	0	0	0	0	0	0
8	TA-0	0	0	0	0	0	0	0	0	0	0	0
9	FGD-100	0	0	0	0	0	0	0	0	0	0	0
10	BD-60	0	0	0	0	0	0	0	0	0	0	0
11	HO-0	0	0	0	0	0	0	0	0	0	0	0
12	TA-60	0	0	0	0	0	0	0	0	0	0	0
13	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
14	HO-0	0	0	0	0	0	0	0	0	0	0	0
15	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
16	BD-0	0	0	0	0	0	0	0	0	0	0	0
17	TA-0	0	0	0	0	0	0	0	0	0	0	0
18	FGD-100	0	0	0	0	0	0	0	0	0	0	0
19	HO-60	0	0	0	0	0	0	0	0	0	0	0
20	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
21	HO-20	0	0	0	0	0	0	0	0	0	0	0
22	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
23	BD-60	0	0	0	0	0	0	0	0	0	0	0
24	BD-20	0	0	0	0	0	0	0	0	0	0	0
25	TA-60	0	0	0	0	0	0	0	0	0	0	0
26	TA-20	0	0	0	0	0	0	0	0	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
28	TA-0	0	0	0	0	0	0	0	0	0	0	0
29	BD-60	0	0	0	0	0	0	0	0	0	0	0
30	FGD-100	0	0	0	0	0	0	0	0	0	0	0
31	BD-20	0	0	0	0	0	0	0	0	0	0	0
32	HO-60	0	0	0	0	0	0	0	0	0	0	0
33	HO-0	0	0	0	0	0	0	0	0	0	0	0
34	TA-20	0	0	0	0	0	0	0	0	0	0	0
35	BD-0	0	0	0	0	0	0	0	0	0	0	0
36	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
37	HO-20	0	0	0	0	0	0	0	0	0	0	0
38	TA-60	0	0	0	0	0	0	0	0	0	0	0

39	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
40	HO-0	0	0	0	0	0	0	0	0	0	0	0
41	HO-20	0	0	0	0	0	0	0	0	0	0	0
42	HO-60	0	0	0	0	0	0	0	0	0	0	0
43	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
44	FGD-100	0	0	0	0	0	0	0	0	0	0	0
45	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
46	TA-20	0	0	0	0	0	0	0	0	0	0	0
47	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
48	BD-0	0	0	0	0	0	0	0	0	0	0	0
49	TA-0	0	0	0	0	0	0	0	0	0	0	0
50	BD-60	0	0	0	0	0	0	0	0	0	0	0
51	TA-60	0	0	0	0	0	0	0	0	0	0	0
52	BD-20	0	0	0	0	0	0	0	0	0	0	0

See **Error! Reference source not found.** for reference for treatment ID

Table D.2 Germination data day 1

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
2	HO-60	0	0	0	0	0	0	0	0	0	0	0
3	HO-20	0	0	0	0	0	0	0	0	0	0	0
4	TA-20	0	0	0	0	0	0	0	0	0	0	0
5	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
6	BD-20	0	0	0	0	0	0	0	0	0	0	0
7	BD-0	0	0	0	0	0	0	0	0	0	0	0
8	TA-0	0	0	0	0	0	0	0	0	0	0	0
9	FGD-100	0	0	0	0	0	0	0	0	0	0	0
10	BD-60	0	0	0	0	0	0	0	0	0	0	0
11	HO-0	0	0	0	0	0	0	0	0	0	0	0
12	TA-60	0	0	0	0	0	0	0	0	0	0	0
13	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
14	HO-0	0	0	0	0	0	0	0	0	0	0	0
15	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
16	BD-0	0	0	0	0	0	0	0	0	0	0	0
17	TA-0	0	0	0	0	0	0	0	0	0	0	0

18	FGD-100	1	0	0	0	0	0	0	0	0	0	1
19	HO-60	0	0	0	0	0	0	0	0	0	0	0
20	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
21	HO-20	0	0	0	0	0	0	0	0	0	0	0
22	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
23	BD-60	0	0	0	0	0	0	0	0	0	0	0
24	BD-20	0	0	0	0	0	0	0	0	0	0	0
25	TA-60	0	0	0	0	0	0	0	0	0	0	0
26	TA-20	0	0	0	0	0	0	0	0	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
28	TA-0	0	0	0	0	0	0	0	0	0	0	0
29	BD-60	0	0	0	0	0	0	0	0	0	0	0
30	FGD-100	0	0	0	0	0	0	0	0	0	0	0
31	BD-20	0	0	0	0	0	0	0	0	0	0	0
32	HO-60	0	0	0	0	0	0	0	0	0	0	0
33	HO-0	0	0	0	0	0	0	0	0	0	0	0
34	TA-20	0	0	0	0	0	0	0	0	0	0	0
35	BD-0	0	0	0	0	0	0	0	0	0	0	0
36	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
37	HO-20	0	0	0	0	0	0	0	0	0	0	0
38	TA-60	0	0	0	0	0	0	0	0	0	0	0
39	BDHO-20	0	0	0	0	0	0	0	0	0	0	0
40	HO-0	0	0	0	0	0	0	0	0	0	0	0
41	HO-20	0	0	0	0	0	0	0	0	0	0	0
42	HO-60	0	0	0	0	0	0	0	0	0	0	0
43	BDHO-20	0	0	0	0	0	0	0	1	0	0	1
44	FGD-100	0	0	0	0	0	0	0	0	0	0	0
45	BDHO-0	0	0	0	0	0	0	0	0	0	0	0
46	TA-20	0	0	0	0	0	0	0	0	0	0	0
47	BDHO-60	0	0	0	0	0	0	0	0	0	0	0
48	BD-0	0	0	0	0	0	0	0	0	0	0	0
49	TA-0	0	0	0	0	0	0	0	0	0	0	0

50	BD-60	0	0	0	0	0	0	0	0	0	0	0
51	TA-60	0	0	0	0	0	0	0	0	0	0	0
52	BD-20	0	0	0	0	0	0	0	0	0	0	0

See **Error! Reference source not found.** for reference for treatment ID

Table D.3 Germination data day 3

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	0	0	0	1	0	0	0	0	1	3
2	HO-60	1	0	0	0	0	0	0	1	1	1	4
3	HO-20	1	1	1	0	0	0	0	0	1	1	5
4	TA-20	0	1	0	1	1	0	1	0	1	1	6
5	BDHO-0	0	0	1	1	1	1	1	0	0	0	5
6	BD-20	0	1	0	0	0	1	0	0	1	0	3
7	BD-0	1	1	0	1	0	1	1	0	0	1	6
8	TA-0	1	1	1	0	0	1	0	1	1	0	6
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	0	0	1	0	0	1	0	1	0	0	3
11	HO-0	0	0	0	0	0	1	1	0	0	0	2
12	TA-60	1	1	1	0	0	0	1	0	0	0	4
13	BDHO-60	1	1	0	0	1	0	0	1	0	0	4
14	HO-0	0	0	1	1	1	0	0	1	1	0	5
15	BDHO-60	0	0	0	1	1	0	1	0	0	0	3
16	BD-0	0	0	1	0	0	1	0	0	0	0	2
17	TA-0	1	1	0	0	1	1	1	0	1	1	7
18	FGD-100	1	0	1	1	0	0	1	0	1	0	5
19	HO-60	1	1	0	1	1	1	0	0	0	0	5
20	BDHO-20	1	0	0	1	0	1	1	0	1	1	6
21	HO-20	0	0	0	0	0	1	0	1	0	1	3
22	BDHO-0	0	0	0	1	1	1	0	0	0	1	4
23	BD-60	1	0	0	0	1	0	0	0	0	1	3
24	BD-20	0	1	0	1	0	0	0	0	0	0	2

25	TA-60	0	0	0	1	1	1	0	1	0	0	4
26	TA-20	0	0	0	0	0	0	1	1	0	0	2
27	BDHO-0	0	0	0	1	1	0	0	1	0	0	3
28	TA-0	0	0	1	1	0	0	0	1	0	0	3
29	BD-60	0	0	0	0	1	0	0	0	0	1	2
30	FGD-100	1	0	1	0	0	1	1	0	0	0	4
31	BD-20	1	1	0	0	0	1	0	0	0	0	3
32	HO-60	1	0	0	0	0	0	0	0	0	1	2
33	HO-0	1	1	1	1	0	0	1	0	1	0	6
34	TA-20	1	1	0	0	1	1	1	0	0	0	5
35	BD-0	1	1	0	1	0	1	1	0	1	1	7
36	BDHO-60	0	0	0	0	1	1	0	0	1	0	3
37	HO-20	1	0	1	1	0	0	1	1	1	0	6
38	TA-60	0	0	0	0	0	1	1	1	0	0	3
39	BDHO-20	1	0	1	1	0	0	0	0	1	0	4
40	HO-0	0	0	0	1	0	1	1	1	0	0	4
41	HO-20	0	0	0	1	0	0	1	0	0	0	2
42	HO-60	0	0	1	0	0	1	0	0	1	0	3
43	BDHO-20	1	1	0	0	0	0	0	0	0	0	2
44	FGD-100	0	1	1	0	1	1	0	0	0	0	4
45	BDHO-0	1	0	0	0	1	1	0	0	1	0	4
46	TA-20	0	0	0	0	1	1	0	0	0	1	3
47	BDHO-60	1	0	0	1	0	0	1	0	0	0	3
48	BD-0	0	0	0	0	1	0	1	1	0	0	3
49	TA-0	0	1	0	1	1	0	1	1	1	0	6
50	BD-60	1	0	1	1	0	0	0	0	0	0	3
51	TA-60	1	0	1	0	0	1	1	0	0	0	4
52	BD-20	1	1	1	0	0	1	1	0	1	0	6

See **Error! Reference source not found.** for reference for treatment ID

Table D.4 Germination data day 4

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	0	0	1	1	1	0	0	0	1	5
2	HO-60	1	0	0	0	0	0	0	1	1	1	4
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	1	0	1	1	7
5	BDHO-0	1	0	1	1	1	1	1	1	1	0	8
6	BD-20	0	1	0	0	0	1	0	0	1	0	3
7	BD-0	1	1	0	1	0	1	1	1	0	1	7
8	TA-0	1	1	1	0	0	0	0	1	1	0	5
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	0	0	1	0	0	1	0	1	0	1	4
11	HO-0	0	0	1	0	0	1	0	0	0	0	2
12	TA-60	1	1	1	1	1	0	1	1	0	0	7
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6
14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	1	1	1	0	1	1	0	0	6
16	BD-0	0	0	1	0	0	1	0	1	0	0	3
17	TA-0	1	1	0	0	1	1	1	0	1	1	7
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	0	0	0	0	5
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	0	1	0	1	6
22	BDHO-0	0	0	0	1	1	1	0	0	0	1	4
23	BD-60	1	1	0	1	1	0	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	0	0	0	5
25	TA-60	0	1	0	1	1	1	0	1	0	0	5
26	TA-20	0	0	0	0	0	0	1	1	1	0	3
27	BDHO-0	0	0	1	1	1	0	0	1	0	1	5
28	TA-0	1	0	1	1	0	0	0	1	0	1	5
29	BD-60	1	0	0	0	1	0	1	1	0	1	5

30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	0	1	0	0	0	1	4
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	0	1	1	1	1	8
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	1	0	1	0	1	1	0	1	1	7
36	BDHO-60	0	0	0	0	1	1	0	0	1	0	3
37	HO-20	1	0	1	0	1	0	1	1	1	0	6
38	TA-60	1	0	0	0	0	1	1	1	0	0	4
39	BDHO-20	1	0	1	1	0	1	1	0	1	0	6
40	HO-0	0	0	0	1	0	1	0	1	0	0	3
41	HO-20	0	1	0	1	0	0	0	1	1	0	4
42	HO-60	0	0	1	1	1	1	0	1	1	0	6
43	BDHO-20	1	1	1	1	0	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	1	6
45	BDHO-0	1	1	0	1	1	1	0	0	1	1	7
46	TA-20	1	0	0	0	0	0	0	0	0	1	2
47	BDHO-60	1	0	1	1	0	0	1	0	0	0	4
48	BD-0	1	0	0	1	0	1	1	0	0	0	4
49	TA-0	0	1	0	1	1	0	1	0	1	0	5
50	BD-60	1	0	1	1	0	0	1	0	0	0	4
51	TA-60	1	1	1	0	0	1	1	0	1	0	6
52	BD-20	1	1	1	1	0	1	1	1	1	0	8

See **Error! Reference source not found.** for reference for treatment ID

Table D.5 Germination data day 6

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	0	0	1	1	1	0	0	0	1	5
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	1	0	1	0	6
5	BDHO-0	1	0	1	1	1	1	1	1	1	0	8

6	BD-20	0	0	0	1	0	0	0	0	1	0	2
7	BD-0	0	1	1	1	0	1	1	1	0	1	7
8	TA-0	1	1	1	0	0	0	0	1	1	0	5
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	0	0	1	1	0	1	0	1	0	1	5
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	0	1	1	1	0	8
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6
14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	1	1	1	1	0	1	1	0	0	7
16	BD-0	1	0	1	0	1	1	0	1	0	1	6
17	TA-0	1	1	0	1	1	1	1	1	1	1	9
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	0	0	0	0	5
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	0	1	0	1	6
22	BDHO-0	0	0	0	1	1	1	0	0	0	1	4
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	1	1	1	0	0	7
25	TA-60	0	0	0	1	1	1	0	1	0	1	5
26	TA-20	0	0	0	0	0	0	1	1	1	0	3
27	BDHO-0	0	0	1	1	1	0	0	1	0	1	5
28	TA-0	1	0	1	1	0	0	0	1	0	1	5
29	BD-60	1	1	0	0	1	0	1	1	0	1	6
30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	0	1	0	0	1	1	5
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	0	1	0	1	1	7
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	1	0	1	0	1	1	0	1	1	7
36	BDHO-60	0	0	0	0	1	1	0	0	1	0	3
37	HO-20	1	1	1	0	1	0	1	1	0	0	6

38	TA-60	1	1	0	1	0	1	1	1	0	1	7
39	BDHO-20	1	1	1	1	0	1	1	0	1	1	8
40	HO-0	0	0	1	0	0	1	1	1	0	0	4
41	HO-20	1	1	1	1	0	0	0	1	1	0	6
42	HO-60	0	0	1	1	1	1	0	1	0	0	5
43	BDHO-20	1	1	1	0	1	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	1	6
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8
46	TA-20	1	0	0	1	0	1	0	0	0	1	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	0	1	0	1	1	0	0	1	5
49	TA-0	0	1	0	1	1	0	1	0	1	1	6
50	BD-60	1	0	1	1	0	0	1	0	0	0	4
51	TA-60	1	1	1	0	1	1	1	0	1	0	7
52	BD-20	1	1	1	1	0	1	1	1	1	0	8

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Table D. 6 Germination data day 8

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	1	0	0	0	1	6
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	0	0	1	1	6
5	BDHO-0	1	0	1	1	1	1	1	1	1	0	8
6	BD-20	0	1	1	1	0	0	0	0	1	0	4
7	BD-0	0	1	1	1	0	1	1	1	0	1	7
8	TA-0	1	1	1	0	0	0	0	1	1	0	5
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	0	1	0	1	0	1	6
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6

14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	0	1	1	0	1	1	0	0	5
16	BD-0	1	0	1	1	1	1	0	1	0	0	6
17	TA-0	1	1	1	0	0	1	1	1	1	1	8
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	0	0	0	0	5
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	1	0	0	1	6
22	BDHO-0	0	0	0	1	1	1	0	0	1	1	5
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	1	0	0	6
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	0	0	1	1	1	0	3
27	BDHO-0	0	0	1	1	1	0	0	1	0	1	5
28	TA-0	1	0	1	1	0	0	0	1	0	1	5
29	BD-60	1	1	0	0	1	0	1	1	0	1	6
30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	0	1	0	0	0	1	4
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	1	0	0	0	1	6
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	1	0	1	0	1	0	0	1	1	6
36	BDHO-60	1	0	0	0	1	1	0	0	1	0	4
37	HO-20	1	0	1	0	1	0	1	1	0	1	6
38	TA-60	1	1	0	1	1	0	1	1	0	1	7
39	BDHO-20	1	1	1	1	0	1	1	0	1	1	8
40	HO-0	0	0	1	1	0	1	1	1	0	0	5
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	1	1	1	1	1	8
43	BDHO-20	1	1	1	1	1	1	0	0	1	0	7
44	FGD-100	0	1	1	0	1	1	1	0	0	1	6
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8

46	TA-20	1	0	0	1	0	1	0	0	0	0	3
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	0	1	0	1	1	0	0	1	5
49	TA-0	0	1	1	0	1	0	1	0	1	1	6
50	BD-60	1	0	1	1	0	0	1	0	0	0	4
51	TA-60	1	1	1	0	1	1	1	0	1	0	7
52	BD-20	1	1	1	1	0	1	1	1	1	0	8

See **Error! Reference source not found.** for reference for treatment ID

Table D.7 Germination data day 11

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	1	0	0	0	1	6
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	0	1	1	1	7
5	BDHO-0	1	1	1	1	1	1	1	1	1	0	9
6	BD-20	1	1	1	1	0	0	0	0	1	0	5
7	BD-0	0	1	1	1	0	1	1	1	0	1	7
8	TA-0	1	1	0	0	0	0	0	1	1	0	4
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	0	1	0	1	0	1	6
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6
14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	1	1	1	0	1	1	1	1	8
16	BD-0	1	0	1	1	1	1	0	1	0	0	6
17	TA-0	1	1	1	0	1	1	1	1	1	1	9
18	FGD-100	1	1	1	1	1	1	1	1	1	0	9
19	HO-60	1	1	0	1	1	1	1	0	0	0	6
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	1	1	0	1	7

22	BDHO-0	0	0	0	1	1	1	0	0	1	1	5
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	1	0	0	6
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	0	0	1	1	0	0	2
27	BDHO-0	0	1	1	0	1	0	0	1	0	1	5
28	TA-0	0	0	1	1	0	0	0	1	0	1	4
29	BD-60	1	1	0	0	1	0	1	1	1	1	7
30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	1	0	0	0	1	1	5
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	1	0	0	1	1	7
34	TA-20	1	1	0	1	1	1	1	1	0	0	7
35	BD-0	1	1	0	1	0	1	0	0	1	1	6
36	BDHO-60	1	0	0	0	1	1	0	0	1	0	4
37	HO-20	1	0	1	0	1	0	1	1	0	0	5
38	TA-60	1	1	0	1	1	0	1	1	0	1	7
39	BDHO-20	1	1	1	1	0	1	1	0	1	1	8
40	HO-0	0	0	1	1	0	1	1	1	0	0	5
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	1	1	1	1	1	8
43	BDHO-20	1	1	1	1	1	1	0	0	1	0	7
44	FGD-100	0	1	1	0	1	1	1	0	1	1	7
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8
46	TA-20	1	0	0	1	1	1	0	0	0	0	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	0	1	0	1	1	0	0	1	5
49	TA-0	0	1	1	1	1	0	1	1	1	1	8
50	BD-60	1	0	1	1	0	0	1	0	0	0	4
51	TA-60	1	1	1	0	1	1	0	0	1	0	6
52	BD-20	1	1	1	1	0	0	1	1	1	0	7

See **Error! Reference source not found.** for reference for treatment ID

Table D.8 Germination data day 13

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	1	0	0	0	1	6
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	1	0	1	0	6
5	BDHO-0	1	0	1	1	1	1	1	1	1	0	8
6	BD-20	1	0	1	1	0	0	0	0	1	0	4
7	BD-0	0	1	1	1	0	1	1	0	0	1	6
8	TA-0	1	1	1	0	0	0	0	1	1	0	5
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	0	1	0	1	0	1	6
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6
14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	0	1	1	0	1	0	1	0	5
16	BD-0	1	0	1	1	1	1	0	1	0	0	6
17	TA-0	1	1	1	0	0	1	1	0	0	1	6
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	1	0	0	0	6
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	1	1	0	1	7
22	BDHO-0	0	0	0	1	1	0	0	0	1	1	4
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	1	0	0	6
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	1	0	1	1	1	0	4
27	BDHO-0	0	0	1	0	1	0	0	1	0	1	4
28	TA-0	1	0	1	1	0	0	0	1	0	1	5
29	BD-60	1	1	0	0	1	0	1	1	0	1	6

30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	1	0	0	0	1	1	5
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	1	1	1	0	1	8
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	0	0	1	0	1	1	0	1	1	6
36	BDHO-60	1	0	0	1	1	1	0	0	1	0	5
37	HO-20	1	0	1	0	1	0	1	1	0	0	5
38	TA-60	1	1	0	1	0	0	1	1	0	1	6
39	BDHO-20	0	1	1	1	0	1	1	0	0	1	6
40	HO-0	0	0	1	1	0	1	1	1	0	0	5
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	1	1	1	1	1	8
43	BDHO-20	1	1	1	0	1	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	1	6
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8
46	TA-20	1	0	0	1	1	1	0	0	0	0	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	0	1	0	1	1	0	0	1	5
49	TA-0	0	1	1	0	1	0	1	0	1	1	6
50	BD-60	1	0	1	1	0	0	1	0	0	0	4
51	TA-60	1	1	1	0	1	1	0	0	1	0	6
52	BD-20	1	1	1	1	0	1	1	1	0	0	7

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Table D.9 Germination data day 15

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	0	0	0	0	1	5
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	0	0	1	0	5
5	BDHO-0	1	0	1	1	1	1	1	1	1	0	8

6	BD-20	1	1	1	1	0	0	0	0	1	0	5
7	BD-0	0	1	1	1	0	1	1	0	0	1	6
8	TA-0	1	1	0	0	0	0	0	1	1	0	4
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	1	1	0	1	0	1	7
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	0	1	1	1	1	0	0	0	0	5
14	HO-0	0	1	1	1	0	0	1	1	1	0	6
15	BDHO-60	1	0	0	1	1	0	1	1	1	0	6
16	BD-0	1	0	1	1	1	1	0	0	0	0	5
17	TA-0	1	1	1	0	0	0	1	1	1	1	7
18	FGD-100	1	1	1	1	1	1	1	1	1	0	9
19	HO-60	1	1	0	1	1	1	1	0	0	0	6
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	1	1	1	1	1	0	1	8
22	BDHO-0	0	1	0	0	1	1	0	0	1	1	5
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	1	0	0	6
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	0	0	1	1	1	0	3
27	BDHO-0	0	0	1	0	1	0	0	1	0	1	4
28	TA-0	0	0	1	1	0	0	0	1	0	1	4
29	BD-60	1	1	0	0	1	0	1	1	0	1	6
30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	1	0	0	0	0	1	4
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	1	1	0	1	1	8
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	0	0	1	0	1	0	0	1	1	5
36	BDHO-60	1	0	0	1	1	1	0	0	1	0	5
37	HO-20	1	0	1	0	1	0	1	1	0	0	5

38	TA-60	1	1	0	1	0	0	1	1	0	1	6
39	BDHO-20	0	1	1	1	0	1	1	0	0	1	6
40	HO-0	0	0	1	1	1	1	1	1	0	0	6
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	1	1	1	1	1	8
43	BDHO-20	1	1	1	0	1	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	1	6
45	BDHO-0	0	1	0	1	1	1	0	1	1	1	7
46	TA-20	1	0	0	1	1	1	0	0	0	0	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	0	1	0	1	1	0	0	1	5
49	TA-0	0	1	1	1	1	0	1	1	1	1	8
50	BD-60	1	0	1	0	0	0	1	0	0	0	3
51	TA-60	0	1	0	1	0	1	1	0	0	1	5
52	BD-20	1	1	1	0	0	0	1	1	0	0	5

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Table D.10 Germination data day 18

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	0	0	0	0	1	5
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	1	0	1	0	6
5	BDHO-0	1	0	1	1	1	1	1	1	1	0	8
6	BD-20	1	1	1	1	0	0	0	0	1	0	5
7	BD-0	0	1	1	1	0	1	1	0	1	1	7
8	TA-0	1	1	1	0	0	0	0	1	0	0	4
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	0	1	0	1	0	1	6
11	HO-0	0	0	1	0	1	1	1	0	0	0	4
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6

14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	0	1	1	0	1	1	0	0	5
16	BD-0	1	0	1	1	0	1	0	1	0	0	5
17	TA-0	1	1	1	0	0	0	1	1	1	1	7
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	1	0	0	0	6
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	1	1	0	1	7
22	BDHO-0	0	0	0	0	1	1	0	0	1	1	4
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	1	0	0	6
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	1	0	1	1	0	0	3
27	BDHO-0	0	0	1	0	1	0	0	1	0	1	4
28	TA-0	0	0	1	1	0	0	0	1	0	1	4
29	BD-60	1	1	0	0	1	0	1	1	0	1	6
30	FGD-100	1	1	1	0	0	1	1	1	0	1	7
31	BD-20	1	1	0	0	1	0	0	0	1	1	5
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	1	1	1	1	1	9
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	1	0	1	0	0	0	0	1	1	5
36	BDHO-60	1	0	0	1	1	1	0	0	1	0	5
37	HO-20	1	0	1	0	1	0	1	1	0	1	6
38	TA-60	1	1	0	1	0	1	1	1	0	1	7
39	BDHO-20	1	1	1	1	0	1	1	0	1	1	8
40	HO-0	0	1	1	1	1	1	1	1	0	0	7
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	1	1	1	1	1	8
43	BDHO-20	1	1	1	0	1	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	1	6
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8

46	TA-20	1	0	0	1	1	1	0	0	0	0	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	1	1	0	1	1	0	0	1	6
49	TA-0	0	1	1	1	1	0	1	1	1	1	8
50	BD-60	1	0	1	0	0	0	1	0	0	0	3
51	TA-60	1	1	1	0	1	1	1	0	1	0	7
52	BD-20	1	1	1	1	0	0	1	1	0	0	6

See **Error! Reference source not found.** for reference for treatment ID

Table D.11 Germination data day 20

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	1	0	0	0	1	6
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	1	0	1	0	6
5	BDHO-0	1	0	1	1	1	1	1	1	0	0	7
6	BD-20	1	1	1	1	0	0	0	0	1	0	5
7	BD-0	0	1	1	1	0	1	1	0	1	1	7
8	TA-0	1	1	1	0	0	0	0	1	0	0	4
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	0	1	0	1	0	1	6
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6
14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	0	1	1	0	1	0	0	0	4
16	BD-0	1	0	1	1	0	1	0	0	0	0	4
17	TA-0	1	1	1	0	0	0	1	1	1	1	7
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	1	0	0	0	6
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	1	1	0	1	7

22	BDHO-0	0	0	0	0	1	1	0	0	1	1	4
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	1	1	0	1	1	0	0	6
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	0	0	1	1	0	0	2
27	BDHO-0	0	0	1	0	1	0	0	1	0	1	4
28	TA-0	0	0	1	1	0	0	0	1	0	1	4
29	BD-60	1	1	0	0	1	0	1	1	0	1	6
30	FGD-100	0	1	1	0	0	1	1	1	0	1	6
31	BD-20	1	1	0	0	1	0	0	0	1	1	5
32	HO-60	1	1	1	0	0	0	0	0	0	1	4
33	HO-0	1	1	1	1	0	1	1	1	1	1	9
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	1	0	1	0	0	1	0	1	1	6
36	BDHO-60	1	0	0	1	1	1	0	0	1	0	5
37	HO-20	1	0	1	0	1	0	1	1	0	1	6
38	TA-60	1	1	0	1	0	1	1	1	0	1	7
39	BDHO-20	0	1	1	1	0	1	1	0	1	1	7
40	HO-0	0	1	1	1	0	1	1	1	0	0	6
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	0	1	1	1	1	7
43	BDHO-20	1	1	1	0	1	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	0	5
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8
46	TA-20	1	0	0	1	1	1	0	0	0	0	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	0	1	0	1	1	0	0	1	5
49	TA-0	0	1	1	1	1	0	1	1	1	1	8
50	BD-60	1	0	1	0	0	0	1	0	0	0	3
51	TA-60	1	1	1	0	1	1	1	0	1	0	7
52	BD-20	1	1	1	1	1	0	1	1	1	0	8

See **Error! Reference source not found.** for reference for treatment ID

Table D.12 Germination data day 22

ID	Trt	A	B	C	D	E	F	G	H	I	J	Total
1	BDHO-20	1	1	0	1	1	0	0	0	0	1	5
2	HO-60	1	0	0	1	0	0	0	1	1	1	5
3	HO-20	1	1	1	0	0	1	0	0	1	1	6
4	TA-20	0	1	1	1	1	0	0	0	1	0	5
5	BDHO-0	1	0	1	1	1	1	1	1	0	0	7
6	BD-20	1	1	1	1	0	0	0	0	1	0	5
7	BD-0	0	1	1	1	0	1	1	0	1	1	7
8	TA-0	1	1	1	0	0	0	0	1	0	0	4
9	FGD-100	0	1	1	0	1	1	0	1	1	0	6
10	BD-60	1	0	1	1	0	1	0	1	0	1	6
11	HO-0	0	0	1	0	0	1	1	0	0	0	3
12	TA-60	1	1	1	1	1	1	1	1	1	0	9
13	BDHO-60	1	1	0	0	1	1	1	1	0	0	6
14	HO-0	0	1	1	1	1	0	1	1	1	0	7
15	BDHO-60	1	0	0	1	1	0	1	0	0	0	4
16	BD-0	1	0	1	1	0	1	0	1	0	0	5
17	TA-0	1	1	1	0	1	0	1	1	0	1	7
18	FGD-100	1	1	1	1	1	0	1	1	1	0	8
19	HO-60	1	1	0	1	1	1	1	0	0	0	6
20	BDHO-20	1	0	0	1	0	1	1	1	1	0	6
21	HO-20	0	1	1	0	1	1	1	1	0	1	7
22	BDHO-0	0	0	0	0	1	1	0	0	1	1	4
23	BD-60	1	0	0	1	1	1	0	0	1	1	6
24	BD-20	0	1	1	0	1	0	1	1	0	0	5
25	TA-60	0	0	0	1	1	1	0	1	1	1	6
26	TA-20	0	0	0	0	1	0	1	1	1	0	4
27	BDHO-0	0	0	1	0	1	0	0	1	0	1	4
28	TA-0	0	0	1	1	0	0	0	1	0	1	4
29	BD-60	1	1	0	0	1	0	1	1	0	1	6
30	FGD-100	0	1	1	0	0	1	1	1	0	1	6

31	BD-20	1	1	0	0	1	0	0	0	1	1	5
32	HO-60	1	0	1	0	0	0	0	0	0	1	3
33	HO-0	1	1	1	1	0	1	1	1	1	1	9
34	TA-20	1	1	0	0	1	1	1	1	0	0	6
35	BD-0	1	0	0	1	0	0	0	0	1	1	4
36	BDHO-60	1	0	0	1	1	1	0	0	1	0	5
37	HO-20	1	0	1	0	1	0	1	1	0	1	6
38	TA-60	1	1	0	1	0	0	1	1	0	1	6
39	BDHO-20	0	1	1	1	0	1	1	0	1	1	7
40	HO-0	0	0	1	1	1	1	1	1	0	0	6
41	HO-20	1	1	1	1	0	1	0	1	0	0	6
42	HO-60	0	0	1	1	1	0	1	1	0	1	6
43	BDHO-20	1	1	1	0	1	1	0	0	1	0	6
44	FGD-100	0	1	1	0	1	1	1	0	0	0	5
45	BDHO-0	1	1	0	1	1	1	0	1	1	1	8
46	TA-20	1	0	0	1	1	1	0	0	0	0	4
47	BDHO-60	1	0	1	1	0	0	1	0	0	1	5
48	BD-0	0	1	1	1	0	1	1	0	0	1	6
49	TA-0	0	1	1	0	1	0	1	1	1	1	7
50	BD-60	1	0	1	0	0	0	1	0	0	0	3
51	TA-60	1	1	1	0	1	1	1	0	1	0	7
52	BD-20	1	1	1	1	0	0	1	1	1	0	7

See **Error! Reference source not found.** for reference for treatment ID

Appendix E - Germination SAS Code

Table E.1 SAS Germination Datasheet (Day 22)

ID	Trt	Block	Germination Rate	count	total
1	BDHO-20	A	0.5	5	10
2	HO-60	A	0.5	5	10
3	HO-20	A	0.6	6	10
4	TA-20	A	0.5	5	10
5	BDHO-0	A	0.7	7	10
6	BD-20	A	0.5	5	10
7	BD-0	A	0.7	7	10
8	TA-0	A	0.4	4	10
9	FGD-100	A	0.6	6	10
10	BD-60	A	0.6	6	10
11	HO-0	A	0.3	3	10
12	TA-60	A	0.9	9	10
13	BDHO-60	A	0.6	6	10
14	HO-0	B	0.7	7	10
15	BDHO-60	B	0.4	4	10
16	BD-0	B	0.5	5	10
17	TA-0	B	0.7	7	10
18	FGD-100	B	0.8	8	10
19	HO-60	B	0.6	6	10
20	BDHO-20	B	0.6	6	10
21	HO-20	B	0.7	7	10
22	BDHO-0	B	0.4	4	10
23	BD-60	B	0.6	6	10
24	BD-20	B	0.5	5	10
25	TA-60	B	0.6	6	10
26	TA-20	B	0.4	4	10
27	BDHO-0	C	0.4	4	10
28	TA-0	C	0.4	4	10
29	BD-60	C	0.6	6	10
30	FGD-100	C	0.6	6	10
31	BD-20	C	0.5	5	10
32	HO-60	C	0.3	3	10
33	HO-0	C	0.9	9	10
34	TA-20	C	0.6	6	10
35	BD-0	C	0.4	4	10
36	BDHO-60	C	0.5	5	10
37	HO-20	C	0.6	6	10
38	TA-60	C	0.6	6	10

39	BDHO-20	C	0.7	7	10
40	HO-0	D	0.6	6	10
41	HO-20	D	0.6	6	10
42	HO-60	D	0.6	6	10
43	BDHO-20	D	0.6	6	10
44	FGD-100	D	0.5	5	10
45	BDHO-0	D	0.8	8	10
46	TA-20	D	0.4	4	10
47	BDHO-60	D	0.5	5	10
48	BD-0	D	0.6	6	10
49	TA-0	D	0.7	7	10
50	BD-60	D	0.3	3	10
51	TA-60	D	0.7	7	10
52	BD-20	D	0.7	7	10

See **Error! Reference source not found.** for reference for treatment ID

SAS Code

```
proc import datafile="/home/erica120/sasuser.v94/Research/Germination.xlsx"

out= germination

DBMS=xlsx

replace;

Getnames=yes;

sheet='data';

*range='SAS Analysisa1:c61';

run;

proc glimmix data=germination;

class Block Trt ID;

model count/total=Trt/ ddf=36 solution;

*random intercept/subject=block;

run;
```

Appendix F - Survival Data

Table F. 1 Survival data

ID	TRT	UNIT	Status_Sur
A	BDHO-20	1	0
B	BDHO-20	1	0
C	BDHO-20	1	0
D	BDHO-20	1	1
E	BDHO-20	1	1
F	BDHO-20	1	0
G	BDHO-20	1	0
H	BDHO-20	1	0
I	BDHO-20	1	0
J	BDHO-20	1	1
A	HO-60	2	0
B	HO-60	2	0
C	HO-60	2	0
D	HO-60	2	0
E	HO-60	2	0
F	HO-60	2	0
G	HO-60	2	0
H	HO-60	2	1
I	HO-60	2	1
J	HO-60	2	1
A	HO-20	3	1
B	HO-20	3	1
C	HO-20	3	1
D	HO-20	3	0
E	HO-20	3	0
F	HO-20	3	0
G	HO-20	3	0
H	HO-20	3	0

I	HO-20	3	1
J	HO-20	3	0
A	TA-20	4	0
B	TA-20	4	0
C	TA-20	4	0
D	TA-20	4	1
E	TA-20	4	1
F	TA-20	4	0
G	TA-20	4	0
H	TA-20	4	0
I	TA-20	4	1
J	TA-20	4	0
A	BDHO-0	5	0
B	BDHO-0	5	0
C	BDHO-0	5	1
D	BDHO-0	5	1
E	BDHO-0	5	1
F	BDHO-0	5	1
G	BDHO-0	5	1
H	BDHO-0	5	1
I	BDHO-0	5	0
J	BDHO-0	5	0
A	BD-20	6	0
B	BD-20	6	0
C	BD-20	6	0
D	BD-20	6	1
E	BD-20	6	0
F	BD-20	6	0
G	BD-20	6	0
H	BD-20	6	0
I	BD-20	6	1
J	BD-20	6	0

A	BD-0	7	0
B	BD-0	7	0
C	BD-0	7	0
D	BD-0	7	0
E	BD-0	7	0
F	BD-0	7	1
G	BD-0	7	0
H	BD-0	7	0
I	BD-0	7	0
J	BD-0	7	1
A	TA-0	8	0
B	TA-0	8	0
C	TA-0	8	0
D	TA-0	8	0
E	TA-0	8	0
F	TA-0	8	0
G	TA-0	8	0
H	TA-0	8	0
I	TA-0	8	0
J	TA-0	8	0
A	FGD-100	9	0
B	FGD-100	9	0
C	FGD-100	9	1
D	FGD-100	9	0
E	FGD-100	9	1
F	FGD-100	9	1
G	FGD-100	9	0
H	FGD-100	9	1
I	FGD-100	9	1
J	FGD-100	9	0
A	BD-60	10	0
B	BD-60	10	0

C	BD-60	10	0
D	BD-60	10	1
E	BD-60	10	0
F	BD-60	10	0
G	BD-60	10	0
H	BD-60	10	1
I	BD-60	10	0
J	BD-60	10	1
A	HO-0	11	0
B	HO-0	11	0
C	HO-0	11	0
D	HO-0	11	0
E	HO-0	11	0
F	HO-0	11	0
G	HO-0	11	1
H	HO-0	11	0
I	HO-0	11	0
J	HO-0	11	0
A	TA-60	12	1
B	TA-60	12	1
C	TA-60	12	0
D	TA-60	12	0
E	TA-60	12	0
F	TA-60	12	1
G	TA-60	12	1
H	TA-60	12	0
I	TA-60	12	1
J	TA-60	12	0
A	BDHO-60	13	0
B	BDHO-60	13	0
C	BDHO-60	13	0
D	BDHO-60	13	0

E	BDHO-60	13	1
F	BDHO-60	13	1
G	BDHO-60	13	1
H	BDHO-60	13	0
I	BDHO-60	13	0
J	BDHO-60	13	0
A	HO-0	14	0
B	HO-0	14	0
C	HO-0	14	0
D	HO-0	14	1
E	HO-0	14	0
F	HO-0	14	0
G	HO-0	14	0
H	HO-0	14	0
I	HO-0	14	0
J	HO-0	14	0
A	BDHO-60	15	1
B	BDHO-60	15	0
C	BDHO-60	15	0
D	BDHO-60	15	0
E	BDHO-60	15	1
F	BDHO-60	15	0
G	BDHO-60	15	1
H	BDHO-60	15	0
I	BDHO-60	15	0
J	BDHO-60	15	0
A	BD-0	16	0
B	BD-0	16	0
C	BD-0	16	0
D	BD-0	16	0
E	BD-0	16	0
F	BD-0	16	0

G	BD-0	16	0
H	BD-0	16	0
I	BD-0	16	0
J	BD-0	16	0
A	TA-0	17	0
B	TA-0	17	0
C	TA-0	17	0
D	TA-0	17	0
E	TA-0	17	0
F	TA-0	17	0
G	TA-0	17	1
H	TA-0	17	0
I	TA-0	17	0
J	TA-0	17	0
A	FGD-100	18	0
B	FGD-100	18	1
C	FGD-100	18	1
D	FGD-100	18	0
E	FGD-100	18	1
F	FGD-100	18	0
G	FGD-100	18	1
H	FGD-100	18	0
I	FGD-100	18	1
J	FGD-100	18	0
A	HO-60	19	1
B	HO-60	19	1
C	HO-60	19	0
D	HO-60	19	1
E	HO-60	19	1
F	HO-60	19	1
G	HO-60	19	0
H	HO-60	19	0

I	HO-60	19	0
J	HO-60	19	0
A	BDHO-20	20	1
B	BDHO-20	20	0
C	BDHO-20	20	0
D	BDHO-20	20	1
E	BDHO-20	20	0
F	BDHO-20	20	0
G	BDHO-20	20	1
H	BDHO-20	20	0
I	BDHO-20	20	1
J	BDHO-20	20	0
A	HO-20	21	0
B	HO-20	21	1
C	HO-20	21	1
D	HO-20	21	0
E	HO-20	21	0
F	HO-20	21	1
G	HO-20	21	1
H	HO-20	21	0
I	HO-20	21	0
J	HO-20	21	1
A	BDHO-0	22	0
B	BDHO-0	22	0
C	BDHO-0	22	0
D	BDHO-0	22	0
E	BDHO-0	22	0
F	BDHO-0	22	0
G	BDHO-0	22	0
H	BDHO-0	22	0
I	BDHO-0	22	0
J	BDHO-0	22	1

A	BD-60	23	1
B	BD-60	23	0
C	BD-60	23	0
D	BD-60	23	1
E	BD-60	23	1
F	BD-60	23	1
G	BD-60	23	0
H	BD-60	23	0
I	BD-60	23	1
J	BD-60	23	1
A	BD-20	24	0
B	BD-20	24	1
C	BD-20	24	1
D	BD-20	24	0
E	BD-20	24	1
F	BD-20	24	0
G	BD-20	24	1
H	BD-20	24	1
I	BD-20	24	0
J	BD-20	24	0
A	TA-60	25	0
B	TA-60	25	0
C	TA-60	25	0
D	TA-60	25	0
E	TA-60	25	1
F	TA-60	25	1
G	TA-60	25	0
H	TA-60	25	1
I	TA-60	25	1
J	TA-60	25	0
A	TA-20	26	0
B	TA-20	26	0

C	TA-20	26	0
D	TA-20	26	0
E	TA-20	26	0
F	TA-20	26	0
G	TA-20	26	1
H	TA-20	26	0
I	TA-20	26	0
J	TA-20	26	0
A	BDHO-0	27	0
B	BDHO-0	27	0
C	BDHO-0	27	0
D	BDHO-0	27	0
E	BDHO-0	27	0
F	BDHO-0	27	0
G	BDHO-0	27	0
H	BDHO-0	27	1
I	BDHO-0	27	0
J	BDHO-0	27	1
A	TA-0	28	0
B	TA-0	28	0
C	TA-0	28	1
D	TA-0	28	1
E	TA-0	28	0
F	TA-0	28	0
G	TA-0	28	0
H	TA-0	28	1
I	TA-0	28	0
J	TA-0	28	0
A	BD-60	29	0
B	BD-60	29	1
C	BD-60	29	0
D	BD-60	29	0

E	BD-60	29	1
F	BD-60	29	0
G	BD-60	29	0
H	BD-60	29	1
I	BD-60	29	0
J	BD-60	29	1
A	FGD-100	30	0
B	FGD-100	30	0
C	FGD-100	30	1
D	FGD-100	30	0
E	FGD-100	30	0
F	FGD-100	30	1
G	FGD-100	30	1
H	FGD-100	30	0
I	FGD-100	30	0
J	FGD-100	30	0
A	BD-20	31	1
B	BD-20	31	1
C	BD-20	31	0
D	BD-20	31	0
E	BD-20	31	0
F	BD-20	31	0
G	BD-20	31	0
H	BD-20	31	0
I	BD-20	31	0
J	BD-20	31	0
A	HO-60	32	1
B	HO-60	32	0
C	HO-60	32	1
D	HO-60	32	0
E	HO-60	32	0
F	HO-60	32	0

G	HO-60	32	0
H	HO-60	32	0
I	HO-60	32	0
J	HO-60	32	1
A	HO-0	33	1
B	HO-0	33	1
C	HO-0	33	0
D	HO-0	33	1
E	HO-0	33	0
F	HO-0	33	0
G	HO-0	33	0
H	HO-0	33	0
I	HO-0	33	0
J	HO-0	33	0
A	TA-20	34	1
B	TA-20	34	0
C	TA-20	34	0
D	TA-20	34	0
E	TA-20	34	0
F	TA-20	34	1
G	TA-20	34	1
H	TA-20	34	0
I	TA-20	34	0
J	TA-20	34	0
A	BD-0	35	0
B	BD-0	35	0
C	BD-0	35	0
D	BD-0	35	0
E	BD-0	35	0
F	BD-0	35	0
G	BD-0	35	0
H	BD-0	35	0

I	BD-0	35	1
J	BD-0	35	1
A	BDHO-60	36	0
B	BDHO-60	36	0
C	BDHO-60	36	0
D	BDHO-60	36	1
E	BDHO-60	36	0
F	BDHO-60	36	1
G	BDHO-60	36	0
H	BDHO-60	36	0
I	BDHO-60	36	1
J	BDHO-60	36	0
A	HO-20	37	1
B	HO-20	37	0
C	HO-20	37	1
D	HO-20	37	0
E	HO-20	37	1
F	HO-20	37	0
G	HO-20	37	1
H	HO-20	37	1
I	HO-20	37	0
J	HO-20	37	0
A	TA-60	38	1
B	TA-60	38	1
C	TA-60	38	0
D	TA-60	38	1
E	TA-60	38	0
F	TA-60	38	0
G	TA-60	38	1
H	TA-60	38	1
I	TA-60	38	0
J	TA-60	38	0

A	BDHO-20	39	0
B	BDHO-20	39	0
C	BDHO-20	39	0
D	BDHO-20	39	1
E	BDHO-20	39	0
F	BDHO-20	39	1
G	BDHO-20	39	1
H	BDHO-20	39	0
I	BDHO-20	39	0
J	BDHO-20	39	1
A	HO-0	40	0
B	HO-0	40	0
C	HO-0	40	1
D	HO-0	40	0
E	HO-0	40	0
F	HO-0	40	0
G	HO-0	40	1
H	HO-0	40	0
I	HO-0	40	0
J	HO-0	40	0
A	HO-20	41	0
B	HO-20	41	1
C	HO-20	41	1
D	HO-20	41	0
E	HO-20	41	0
F	HO-20	41	1
G	HO-20	41	0
H	HO-20	41	1
I	HO-20	41	0
J	HO-20	41	0
A	HO-60	42	0
B	HO-60	42	0

C	HO-60	42	1
D	HO-60	42	1
E	HO-60	42	0
F	HO-60	42	0
G	HO-60	42	1
H	HO-60	42	0
I	HO-60	42	0
J	HO-60	42	0
A	BDHO-20	43	1
B	BDHO-20	43	1
C	BDHO-20	43	1
D	BDHO-20	43	0
E	BDHO-20	43	1
F	BDHO-20	43	1
G	BDHO-20	43	0
H	BDHO-20	43	0
I	BDHO-20	43	1
J	BDHO-20	43	0
A	FGD-100	44	0
B	FGD-100	44	1
C	FGD-100	44	1
D	FGD-100	44	0
E	FGD-100	44	1
F	FGD-100	44	1
G	FGD-100	44	1
H	FGD-100	44	0
I	FGD-100	44	0
J	FGD-100	44	0
A	BDHO-0	45	0
B	BDHO-0	45	0
C	BDHO-0	45	0
D	BDHO-0	45	1

E	BDHO-0	45	1
F	BDHO-0	45	0
G	BDHO-0	45	0
H	BDHO-0	45	1
I	BDHO-0	45	1
J	BDHO-0	45	0
A	TA-20	46	1
B	TA-20	46	0
C	TA-20	46	0
D	TA-20	46	0
E	TA-20	46	0
F	TA-20	46	0
G	TA-20	46	0
H	TA-20	46	0
I	TA-20	46	0
J	TA-20	46	0
A	BDHO-60	47	1
B	BDHO-60	47	0
C	BDHO-60	47	0
D	BDHO-60	47	1
E	BDHO-60	47	0
F	BDHO-60	47	0
G	BDHO-60	47	1
H	BDHO-60	47	0
I	BDHO-60	47	0
J	BDHO-60	47	1
A	BD-0	48	0
B	BD-0	48	0
C	BD-0	48	0
D	BD-0	48	0
E	BD-0	48	0
F	BD-0	48	1

G	BD-0	48	0
H	BD-0	48	0
I	BD-0	48	0
J	BD-0	48	0
A	TA-0	49	0
B	TA-0	49	0
C	TA-0	49	0
D	TA-0	49	0
E	TA-0	49	0
F	TA-0	49	0
G	TA-0	49	0
H	TA-0	49	0
I	TA-0	49	1
J	TA-0	49	0
A	BD-60	50	1
B	BD-60	50	0
C	BD-60	50	1
D	BD-60	50	0
E	BD-60	50	0
F	BD-60	50	0
G	BD-60	50	1
H	BD-60	50	0
I	BD-60	50	0
J	BD-60	50	0
A	TA-60	51	1
B	TA-60	51	1
C	TA-60	51	1
D	TA-60	51	0
E	TA-60	51	0
F	TA-60	51	1
G	TA-60	51	0
H	TA-60	51	0

I	TA-60	51	1
J	TA-60	51	0
A	BD-20	52	0
B	BD-20	52	0
C	BD-20	52	1
D	BD-20	52	0
E	BD-20	52	0
F	BD-20	52	0
G	BD-20	52	0
H	BD-20	52	1
I	BD-20	52	0
J	BD-20	52	0

See **Error! Reference source not found.** for reference for treatment ID; 1 = Subsample survived until day 65; 0 = S ubsample did not survive until day 65

Appendix G - Survival SAS Code

```
proc import datafile="/home/erica120/sasuser.v94/Research/Survivability_time.xlsx"
out= survive
DBMS=xlsx
replace;
Getnames=yes;
run;


*compare survival at day 65;

proc glimmix data=survive   plot=studentpanel;
class TRT ;
model Status_Sur = TRT/link=logit dist=binomial ddf=36;
lsmeans trt/adjust=tukey pdiff;
contrast 'BD' TRT 1 1 -1 0 0 0 -1 0 0 0 0 0 0,
              TRT 1 -1 1 0 0 0 -1 0 0 0 0 0 0,
              TRT 1 -1 -1 0 0 0 1 0 0 0 0 0 0;
contrast 'BDHO' TRT 0 0 0 1 1 -1 -1 0 0 0 0 0 0,
              TRT 0 0 0 1 -1 1 -1 0 0 0 0 0 0,
              TRT 0 0 0 1 -1 -1 1 0 0 0 0 0 0;
contrast 'HO' TRT 0 0 0 0 0 0 1 1 -1 -1 0 0 0,
              TRT 0 0 0 0 0 0 1 -1 1 -1 0 0 0,
              TRT 0 0 0 0 0 0 1 -1 -1 1 0 0 0;
contrast 'TA' TRT 0 0 0 0 0 0 1 0 0 0 1 -1 -1,
              TRT 0 0 0 0 0 0 1 0 0 0 -1 1 -1,
              TRT 0 0 0 0 0 0 1 0 0 0 -1 -1 1;
contrast '0' TRT 1 0 0 1 0 0 0 -1 0 0 -1 0 0,
              TRT 1 0 0 -1 0 0 0 1 0 0 -1 0 0,
              TRT 1 0 0 -1 0 0 0 -1 0 0 1 0 0;
```

```
contrast '20' TRT 0 1 0 0 1 0 0 0 -1 0 0 -1 0,
              TRT 0 1 0 0 -1 0 0 0 1 0 0 -1 0,
              TRT 0 1 0 0 -1 0 0 0 -1 0 0 1 0;
contrast '60' TRT 0 0 1 0 0 1 0 0 0 -1 0 0 -1,
              TRT 0 0 1 0 0 -1 0 0 0 1 0 0 -1,
              TRT 0 0 1 0 0 -1 0 0 0 -1 0 0 1;
run;
```

Appendix H - Phytotoxicity Data

Table H.1 Phytotoxicity data key

ID	Description
0	No plant
G	Green
YR	Yellow and/or Red
RS	Red Shoot
RB	Bottom Leaf Red
RT	Red Tip
D	Dissformaion
R	>50% Red

Table H.2 Raw phytotoxicity data (Day 4).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	YR	0	0	YR	YR	0	0	0	0	YR
2	HO-60	YR	0	0	0	0	0	0	YR	YR	YR
3	HO-20	YR	YR	YR	0	0	YR	0	0	G	G
4	TA-20	0	YR	G	G	YR	0	G	0	YR	G
5	BDHO-0	G	0	YR	YR	YR	G	YR	YR	YR	0
6	BD-20	0	G	0	0	0	G	0	0	YR	0
7	BD-0	G	G	0	G	0	G	YR	G	0	G
8	TA-0	YR	YR	YR	0	0	0	0	YR	YR	0
9	FGD-100	0	G	G	0	G	YR	0	YR	YR	0
10	BD-60	0	0	YR	0	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	YR	0	0	0	0
12	TA-60	YR	YR	YR	YR	YR	0	YR	YR	0	0
13	BDHO-60	YR	YR	0	0	YR	G	YR	YR	0	0
14	HO-0	0	YR	YR	YR	G	0	G	YR	YR	0
15	BDHO-60	YR	0	YR	YR	G	0	G	YR	0	0
16	BD-0	0	0	YR	0	0	G	0	YR	0	0
17	TA-0	YR	G	0	0	YR	YR	YR	0	YR	YR

18	FGD-100	G	G	YR	G	YR	0	YR	YR	YR	0
19	HO-60	YR	YR	0	YR	YR	YR	0	0	0	0
20	BDHO-20	G	0	0	YR	0	YR	YR	YR	G	0
21	HO-20	0	YR	YR	0	YR	YR	0	YR	0	YR
22	BDHO-0	0	0	0	YR	G	YR	0	0	0	G
23	BD-60	YR	YR	0	0	YR	0	0	0	YR	YR
24	BD-20	0	YR	YR	YR	G	0	YR	0	0	0
25	TA-60	0	G	0	YR	YR	YR	0	YR	0	0
26	TA-20	0	0	0	0	0	0	YR	YR	YR	0
27	BDHO-0	0	0	YR	0	YR	0	0	YR	0	YR
28	TA-0	G	0	YR	YR	0	0	0	YR	0	YR
29	BD-60	YR	0	0	0	YR	0	G	YR	0	YR
30	FGD-100	G	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	0	G	0	0	0	YR
32	HO-60	G	YR	YR	0	0	0	0	0	0	YR
33	HO-0	YR	G	G	G	0	0	G	G	G	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0
35	BD-0	G	0	0	G	0	G	G	0	G	G
36	BDHO-60	0	0	0	0	YR	YR	0	0	YR	0
37	HO-20	YR	0	YR	0	YR	0	YR	G	G	0
38	TA-60	YR	0	0	0	0	G	YR	YR	0	0
39	BDHO-20	0	0	YR	YR	0	YR	YR	0	G	0
40	HO-0	0	0	0	G	0	G	0	G	0	0
41	HO-20	0	YR	0	G	0	0	0	YR	YR	0
42	HO-60	0	0	YR	YR	YR	G	0	G	YR	0
43	BDHO-20	YR	YR	YR	0	0	YR	0	0	YR	0
44	FGD-100	0	G	YR	0	YR	YR	G	0	0	YR
45	BDHO-0	YR	YR	0	YR	YR	G	0	0	G	YR
46	TA-20	YR	0	0	0	0	0	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	YR	0	0	0
48	BD-0	G	0	0	YR	0	YR	G	0	0	0
49	TA-0	0	YR	0	YR	YR	0	YR	0	YR	0

50	BD-60	YR	0	YR	G	0	0	0	0	0	0
51	TA-60	G	YR	YR	0	0	YR	YR	0	G	0
52	BD-20	YR	YR	YR	YR	0	YR	G	YR	G	0

Table H.3 Raw phytotoxicity data (Day 6).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	YR	0	0	YR	YR	G	0	0	0	YR
2	HO-60	YR	0	0	YR	0	0	0	YR	YR	YR
3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	YR	G	YR	G	0	YR	0	G	0
5	BDHO-0	G	0	G	YR	YR	G	G	YR	YR	0
6	BD-20	0	0	0	YR	0	0	0	0	YR	0
7	BD-0	0	G	YR	YR	0	G	G	G	0	G
8	TA-0	YR	YR	YR	0	0	0	0	YR	YR	0
9	FGD-100	0	G	G	0	G	YR	0	G	YR	0
10	BD-60	0	0	YR	YR	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	YR	YR	0	0	0
12	TA-60	G	G	0	YR	YR	0	YR	G	YR	0
13	BDHO-60	YRF	YR	0	0	YR	G	YR	YR	0	0
14	HO-0	0	YR	YR	YR	G	0	G	YR	YR	0
15	BDHO-60	YR	YR	YR	YR	G	0	G	G	0	0
16	BD-0	G	0	YR	0	YR	G	0	G	0	0
17	TA-0	YR	G	YR	0	YR	YR	YR	YR	YR	YR
18	FGD-100	G	G	YR	G	YR	0	YR	YR	YR	0
19	HO-60	YR	YR	0	YR	YR	YR	0	0	0	0
20	BDHO-20	YR	0	0	G	0	YR	G	YR	G	0
21	HO-20	0	YR	YR	0	YR	YR	0	YR	0	YR
22	BDHO-0	0	0	0	YR	GF	YR	0	0	0	G
23	BD-60	YR	0	0	YR	YR	G	0	0	YR	YR
24	BD-20	0	YR	YR	YR	G	G	YR	YR	0	0
25	TA-60	0	0	0	YR	YR	YR	0	YR	0	YR
26	TA-20	0	0	0	0	0	0	G	YR	YR	0

27	BDHO-0	0	0	YR	0	YR	0	0	G	0	G
28	TA-0	G	0	YR	G	0	0	0	YR	0	YR
29	BD-60	YR	YR	0	0	YR	0	YR	YR	0	YR
30	FGD-100	G	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	0	G	0	0	YR	YR
32	HO-60	G	YR	G	0	0	0	0	0	0	YR
33	HO-0	YR	G	YR	G	0	0	G	0	G	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0
35	BD-0	G	0	0	G	0	G	0	0	G	G
36	BDHO-60	0	0	0	0	YR	YR	0	0	YR	0
37	HO-20	YR	0	YR	0	YR	0	YR	G	0	0
38	TA-60	YR	YR	0	YR	0	G	YR	YR	0	0
39	BDHO-20	G	G	YR	YR	0	YR	G	0	G	YR
40	HO-0	0	0	YR	0	0	YR	YR	G	0	0
41	HO-20	YR	YR	YR	G	0	0	0	YR	YR	0
42	HO-60	0	0	YR	YR	YR	G	0	G	0	0
43	BDHO-20	G	YR	YRF	0	YR	YR	0	0	YR	0
44	FGD-100	0	G	YR	0	YR	YR	G	0	0	YR
45	BDHO-0	YR	YR	0	YR	YR	G	0	YR	G	YR
46	TA-20	YR	0	0	YR	0	YR	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	G	0	0	YR
48	BD-0	0	G	0	G	0	YR	G	0	0	YR
49	TA-0	0	YR	0	YR	YR	0	YR	0	YR	YR
50	BD-60	G	0	YR	G	0	0	YR	0	0	0
51	TA-60	G	YR	YR	0	G	YR	YR	0	G	0
52	BD-20	YR	YR	YR	YR	0	0	G	YR	YR	0

Table H.4 Raw phytotoxicity data (Day 8).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	YR	YR	0	YR	G	G	0	0	0	YR
2	HO-60	YR	0	0	YR	0	0	0	YR	YR	G

3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	YR	G	G	G	0	0	0	YR	G
5	BDHO-0	G	0	G	YR	0	G	G	YR	0	0
6	BD-20	0	G	G	YR	0	0	0	0	YR	0
7	BD-0	0	G	YR	G	0	G	G	G	0	G
8	TA-0	G	YR	YR	0	0	0	0	YR	G	0
9	FGD-100	0	G	G	0	G	YR	0	G	YR	0
10	BD-60	YR	0	YR	YR	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	YR	G	0	0	0
12	TA-60	G	G	YR	YR	YR	0	YR	G	YR	0
13	BDHO-60	YRF	G	0	0	YR	G	YR	YR	0	0
14	HO-0	0	YR	YR	YR	G	0	G	G	G	0
15	BDHO-60	YR	0	0	YR	YR	0	G	YR	0	0
16	BD-0	YR	0	YR	YR	YR	G	0	G	0	0
17	TA-0	YR	G	YR	0	0	YR	G	YR	YR	YR
18	FGD-100	YR	G	YR	G	YR	0	YR	YR	G	0
19	HO-60	YR	YR	0	YR	YR	YR	0	0	0	0
20	BDHO-20	YR	0	0	G	0	YR	G	YR	G	0
21	HO-20	0	YR	YR	0	YR	YR	YR	0	0	YR
22	BDHO-0	0	0	0	YR	G	YR	0	0	YR	G
23	BD-60	YR	0	0	YR	YR	G	0	0	YR	YR
24	BD-20	0	YR	YR	YR	G	0	YR	YR	0	0
25	TA-60	0	0	0	YR	YR	YR	0	YR	YR	YR
26	TA-20	0	0	0	0	0	0	G	YR	YR	0
27	BDHO-0	0	0	YR	YR	YR	0	0	G	0	G
28	TA-0	G	0	YR	G	0	0	0	YR	0	YR
29	BD-60	YR	YR	0	0	G	0	G	G	0	G
30	FGD-100	G	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	0	YR	0	0	0	YR
32	HO-60	G	YR	G	0	0	0	0	0	0	YR
33	HO-0	YR	G	YR	G	0	G	0	0	0	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0

35	BD-0	G	YR	0	G	0	G	0	0	G	G
36	BDHO-60	YR	0	0	0	YR	YR	0	0	G	0
37	HO-20	YR	0	YR	0	G	0	G	G	0	YR
38	TA-60	YR	YR	0	YR	YR	0	YR	YR	0	G
39	BDHO-20	G	YR	YR	YR	0	YRF	G	0	G	YR
40	HO-0	0	0	YR	G	0	YR	YR	YR	0	0
41	HO-20	YR	YR	YRF	G	0	G	0	YR	0	0
42	HO-60	0	0	YR	YR	YR	G	YR	G	YR	YR
43	BDHO-20	G	YR	YRF	G	YR	YR	0	0	YR	0
44	FGD-100	0	G	YR	0	YR	YR	G	0	0	0
45	BDHO-0	YR	YR	0	YRF	YR	G	0	YR	G	YR
46	TA-20	YR	0	0	YR	0	YR	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	G	0	0	YR
48	BD-0	0	G	0	G	0	G	G	0	0	YR
49	TA-0	0	YR	YR	0	YR	0	YR	0	YR	YR
50	BD-60	G	0	YR	G	0	0	YR	0	0	0
51	TA-60	G	YR	G	0	G	YR	YR	0	G	0
52	BD-20	YR	YR	YR	YR	0	YR	G	YR	G	0

Table H.5 Raw phytotoxicity data (Day 11).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	YR	YR	0	YR	G	YR	0	0	0	YR
2	HO-60	YR	0	0	YRF	0	0	0	YR	YR	G
3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	YR	G	G	G	0	0	YR	G	YR
5	BDHO-0	YR	YR	G	YR	YR	G	G	YR	YR	0
6	BD-20	YR	G	G	YR	0	0	0	0	YR	0
7	BD-0	0	G	YR	YR	0	G	G	G	0	G
8	TA-0	YR	YR	0	0	0	0	0	YR	YR	0
9	FGD-100	0	D	G	0	G	YR	0	G	G	0
10	BD-60	YR	0	YR	G	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	YR	G	0	0	0

12	TA-60	G	G	YR	YR	YR	G	YR	G	YR	0
13	BDHO-60	YRF	G	0	0	YR	G	YR	YR	0	0
14	HO-0	0	YR	YR	YR	YR	0	G	YR	YR	0
15	BDHO-60	G	0	YR	YR	G	0	G	YR	YR	YR
16	BD-0	YR	0	YR	YR	YR	G	0	YR	0	0
17	TA-0	YR	G	YR	0	YR	YR	G	YR	YR	YR
18	FGD-100	YR	G	YR	G	YR	YR	YR	YR	G	0
19	HO-60	YR	YR	0	G	YR	YR	YR	0	0	0
20	BDHO-20	YR	0	0	G	0	YR	G	YR	G	0
21	HO-20	0	YR	YR	0	YR	YR	G	YR	0	YR
22	BDHO-0	0	0	0	YR	G	YR	0	0	YR	G
23	BD-60	YR	0	0	YR	YR	G	0	0	G	YR
24	BD-20	0	YR	G	YR	G	0	YR	YR	0	0
25	TA-60	0	0	0	YR	YR	YR	0	YR	YR	YR
26	TA-20	0	0	0	0	0	0	G	YR	0	0
27	BDHO-0	0	G	YR	0	YR	0	0	G	0	G
28	TA-0	0	0	YR	G	0	0	0	YR	0	YR
29	BD-60	YR	YR	0	0	G	0	YR	G	YR	G
30	FGD-100	YR	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	YR	0	0	0	G	YR
32	HO-60	G	YR	G	0	0	0	0	0	0	YR
33	HO-0	YR	G	YR	G	0	G	0	0	YR	YR
34	TA-20	YR	YR	0	YR	G	G	YR	YR	0	0
35	BD-0	G	YR	0	G	0	YR	0	0	G	G
36	BDHO-60	YR	0	0	0	G	YR	0	0	G	0
37	HO-20	YR	0	G	0	G	0	G	G	0	0
38	TA-60	G	YR	0	G	YR	0	YR	YR	0	YR
39	BDHO-20	YR	YR	YR	YR	0	YR	G	0	YR	YR
40	HO-0	0	0	YR	G	0	YR	YR	YR	0	0
41	HO-20	YR	YR	YRF	G	0	G	0	YR	0	0
42	HO-60	0	0	G	YR	YR	G	YR	YR	YR	YR
43	BDHO-20	D	YR	YR	YR	YR	YR	0	0	YR	0

44	FGD-100	0	G	YR	0	YR	YR	G	0	YR	YR
45	BDHO-0	YR	YR	0	YR	G	G	0	YR	G	YR
46	TA-20	G	0	0	YR	YR	YR	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	G	0	0	YR
48	BD-0	0	G	0	G	0	YR	G	0	0	YR
49	TA-0	0	YR	YR	YR	YR	0	YR	YR	YR	G
50	BD-60	G	0	YR	G	0	0	YR	0	0	0
51	TA-60	G	YR	G	0	G	YR	0	0	G	0
52	BD-20	YR	YR	YR	YR	0	0	G	YR	YR	0

Table H.6 Raw phytotoxicity data (Day 13).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	YR	YR	0	YR	G	G	0	0	0	YR
2	HO-60	YR	0	0	YR	0	0	0	G	YR	G
3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	G	G	G	G	0	G	0	G	0
5	BDHO-0	YR	0	G	G	G	G	G	YR	YR	0
6	BD-20	YR	0	G	YR	0	0	0	0	YR	0
7	BD-0	0	G	YR	YR	0	G	G	0	0	G
8	TA-0	YR	YR	YR	0	0	0	0	YR	YR	0
9	FGD-100	0	D	G	0	G	YR	0	G	G	0
10	BD-60	YR	0	YR	G	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	YR	G	0	0	0
12	TA-60	YR	G	YR	YR	YR	G	YR	YR	G	0
13	BDHO-60	YR	YR	0	0	YR	YR	YR	YR	0	0
14	HO-0	0	YR	YR	YR	YR	0	G	YR	YR	0
15	BDHO-60	G	0	0	YR	G	0	G	0	YR	0
16	BD-0	YR	0	YR	YR	YR	G	0	YR	0	0
17	TA-0	YR	G	YR	0	0	YR	G	0	0	YR
18	FGD-100	YR	G	YR	G	YR	0	YR	YR	G	0
19	HO-60	YR	YR	0	YR	YR	YR	YR	0	0	0
20	BDHO-20	YR	0	0	G	0	YR	G	YR	G	0

21	HO-20	0	YR	YR	0	YR	YR	G	YR	0	G
22	BDHO-0	0	0	0	YR	G	0	0	0	YR	G
23	BD-60	YR	0	0	YR	YR	G	0	0	YR	YR
24	BD-20	0	YR	G	YR	G	0	YR	YR	0	0
25	TA-60	0	0	0	YR	YR	G	0	G	YR	YRF
26	TA-20	0	0	0	0	YR	0	YR	G	G	0
27	BDHO-0	0	0	YRF	0	YR	0	0	G	0	G
28	TA-0	G	0	YR	G	0	0	0	YR	0	YR
29	BD-60	YR	YR	0	0	G	0	YR	YR	0	YR
30	FGD-100	YR	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	YR	0	0	0	YR	YR
32	HO-60	G	YR	G	0	0	0	0	0	0	YR
33	HO-0	YR	G	YR	G	0	G	YR	YR	0	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0
35	BD-0	G	0	0	G	0	YR	YR	0	G	G
36	BDHO-60	YR	0	0	G	G	YR	0	0	G	0
37	HO-20	YR	0	YR	0	G	0	G	G	0	0
38	TA-60	G	YR	0	YR	0	0	YR	YR	0	YR
39	BDHO-20	0	YRF	YR	YR	0	YR	G	0	0	YR
40	HO-0	0	0	YR	G	0	YR	YR	YR	0	0
41	HO-20	YR	YR	YRF	G	0	G	0	YR	0	0
42	HO-60	0	0	G	YR	YR	YR	YR	YR	YR	YR
43	BDHO-20	D	YR	YRF	0	YR	YR	0	0	YR	0
44	FGD-100	0	G	YR	0	YR	YR	G	0	0	YR
45	BDHO-0	YR	YR	0	YR	G	G	0	YR	G	YR
46	TA-20	G	0	0	YR	YR	YR	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	G	0	0	YR
48	BD-0	0	G	0	G	0	G	G	0	0	YR
49	TA-0	0	YR	YR	0	YR	0	YR	0	G	G
50	BD-60	G	0	YR	G	0	0	YR	0	0	0
51	TA-60	G	G	G	0	G	YR	0	0	G	0
52	BD-20	YR	YR	YR	YR	0	YR	G	YR	0	0

Table H.7 Raw phytotoxicity data (Day 15).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	YR	YR	0	YR	G	0	0	0	0	YR
2	HO-60	YR	0	0	YRF	0	0	0	YR	YR	G
3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	YR	G	G	G	0	0	0	G	0
5	BDHO-0	YR	0	G	G	G	G	G	YR	YR	0
6	BD-20	YR	YR	YR	YR	0	0	0	0	YR	0
7	BD-0	0	G	YR	YR	0	G	G	0	0	G
8	TA-0	YR	YR	0	0	0	0	0	YR	YR	0
9	FGD-100	0	G	G	0	G	YR	0	G	G	0
10	BD-60	YR	0	YR	YR	YR	G	0	G	0	G
11	HO-0	0	0	YR	0	0	YR	G	0	0	0
12	TA-60	G	G	G	YR	YR	G	G	YR	G	0
13	BDHO-60	YRF	YR	0	0	YR	YR	YR	YR	0	0
14	HO-0	0	YR	YR	YR	0	0	G	YR	YR	0
15	BDHO-60	YR	0	0	YR	G	0	G	YR	YR	0
16	BD-0	YR	0	YR	YRF	YR	G	0	0	0	0
17	TA-0	YR	G	YR	0	0	0	G	YR	YR	G
18	FGD-100	YR	G	YR	G	YR	YR	G	YR	G	0
19	HO-60	YR	G	0	G	G	G	G	0	0	0
20	BDHO-20	YR	0	0	G	0	YR	G	YR	G	0
21	HO-20	0	YR	YR	G	YR	YR	F	YR	0	G
22	BDHO-0	0	YR	0	0	G	YR	0	0	YR	G
23	BD-60	YR	0	0	YR	YR	G	0	0	YR	YR
24	BD-20	0	G	G	YR	G	0	YR	YR	0	0
25	TA-60	0	0	0	YR	YR	YR	0	G	YR	YRF
26	TA-20	0	0	0	0	0	0	G	G	YR	0
27	BDHO-0	0	0	YR	0	YR	0	0	G	0	G
28	TA-0	0	0	YR	G	0	0	0	YR	0	YR
29	BD-60	YR	YR	0	0	G	0	YR	YR	0	G
30	FGD-100	YR	G	G	0	0	YR	G	YR	0	YR

31	BD-20	G	YR	0	0	YR	0	0	0	0	YR
32	HO-60	G	YR	G	0	0	0	0	0	0	YR
33	HO-0	YR	G	YR	G	0	G	YR	0	YR	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0
35	BD-0	G	0	0	G	0	G	0	0	G	G
36	BDHO-60	YR	0	0	G	YR	YR	0	0	G	0
37	HO-20	YR	0	YR	0	G	0	YR	G	0	0
38	TA-60	YR	YR	0	YR	0	0	YR	YR	0	YR
39	BDHO-20	0	YRF	YR	YR	0	YR	G	0	0	YR
40	HO-0	0	0	YR	G	YR	YR	YR	YR	0	0
41	HO-20	YR	YR	YR	G	0	G	0	YR	0	0
42	HO-60	0	0	G	YR	YR	YR	YR	YR	YR	YR
43	BDHO-20	YRD	YR	YR	0	YR	YR	0	0	YR	0
44	FGD-100	0	G	YR	0	YR	YR	G	0	0	YR
45	BDHO-0	0	YR	0	YR	G	G	0	YR	G	YR
46	TA-20	G	0	0	YR	YR	YR	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	G	0	0	YR
48	BD-0	0	G	0	G	0	G	G	0	0	YR
49	TA-0	0	YR	YR	YR	YR	0	YR	YR	YR	G
50	BD-60	G	0	YR	0	0	0	YR	0	0	0
51	TA-60	G	YR	G	0	G	YR	0	0	G	0
52	BD-20	YR	YR	YR	0	0	0	G	YR	0	0

Table H.8 Raw phytotoxicity data (Day 18).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	G	YR	0	YR	G	0	0	0	0	YR
2	HO-60	YR	0	0	YR	0	0	0	YR	YR	G
3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	G	G	G	G	0	G	0	D	0
5	BDHO-0	YR	0	G	G	G	G	G	YR	YR	0
6	BD-20	YR	YR	YR	YR	0	0	0	0	YR	0
7	BD-0	0	G	YRF	YR	0	G	G	0	YR	G

8	TA-0	YR	YR	YR	0	0	0	0	YR	0	0
9	FGD-100	0	D	G	0	G	YR	0	G	G	0
10	BD-60	YR	0	YR	YR	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	YR	YR	G	0	0	0
12	TA-60	YR	G	G	YR	YR	G	YR	YR	G	0
13	BDHO-60	YR	YR	0	0	YR	YR	YR	YR	0	0
14	HO-0	0	YR	YR	YR	YR	0	G	YR	YR	0
15	BDHO-60	G	0	0	YR	G	0	G	YR	0	0
16	BD-0	G	0	YR	YRF	0	G	0	YR	0	0
17	TA-0	YR	G	YR	0	0	0	G	G	YR	G
18	FGD-100	YR	G	G	G	G	0	YR	YR	G	0
19	HO-60	YR	YR	0	G	YR	YR	G	0	0	0
20	BDHO-20	YR	0	0	G	0	YR	G	YR	G	0
21	HO-20	0	G	YR	0	YR	YR	F	YR	0	YR
22	BDHO-0	0	0	0	0	YR	G	0	0	G	YR
23	BD-60	YR	0	0	YR	YR	G	0	0	G	YR
24	BD-20	0	G	G	YR	G	0	YR	G	0	0
25	TA-60	0	0	0	YR	YR	YR	0	G	YR	YR
26	TA-20	0	0	0	0	YR	0	G	G	0	0
27	BDHO-0	0	0	YRF	0	YR	0	0	G	0	G
28	TA-0	0	0	YR	G	0	0	0	YR	0	YR
29	BD-60	YR	YR	0	0	G	0	YR	G	0	G
30	FGD-100	YR	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	YR	0	0	0	YR	YR
32	HO-60	G	YR	G	0	0	0	0	0	0	YR
33	HO-0	YR	G	YR	G	0	G	YR	YR	YR	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0
35	BD-0	G	G	0	G	0	0	0	0	G	YR
36	BDHO-60	YR	0	0	YR	G	G	0	0	G	0
37	HO-20	YR	0	YR	0	G	0	YR	G	0	YR
38	TA-60	G	YR	0	G	0	YR	YR	YR	0	G
39	BDHO-20	G	F	YR	YR	0	YR	G	0	YR	YR

40	HO-0	0	YR	YR	G	YR	YR	G	YR	0	0
41	HO-20	YR	G	YRF	G	0	F	0	YR	0	0
42	HO-60	0	0	G	G	YR	YR	YR	YR	YR	YR
43	BDHO-20	D	YR	YR	0	YR	G	0	0	YR	0
44	FGD-100	0	G	G	0	G	YR	G	0	0	YR
45	BDHO-0	YR	YR	0	YR	G	G	0	YR	G	YR
46	TA-20	G	0	0	YR	YR	YR	0	0	0	0
47	BDHO-60	G	0	G	G	0	0	G	0	0	G
48	BD-0	0	G	YR	G	0	G	G	0	0	YR
49	TA-0	0	YR	YR	G	YR	0	YR	YR	G	G
50	BD-60	G	0	YR	0	0	0	YR	0	0	0
51	TA-60	G	YR	G	0	G	YR	YR	0	G	0
52	BD-20	YR	YR	G	YR	0	0	G	YR	0	0

Table H.9 Raw phytotoxicity data (Day 20).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	G	YR	0	G	G	YR	0	0	0	G
2	HO-60	YR	0	0	YR	0	0	0	YR	YR	G
3	HO-20	YR	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	YR	G	D	G	0	G	0	D	0
5	BDHO-0	YR	0	G	D	G	G	D	YR	0	0
6	BD-20	YR	YR	G	YR	0	0	0	0	YR	0
7	BD-0	0	G	YRF	YR	0	G	G	0	YR	G
8	TA-0	YR	YR	YR	0	0	0	0	YR	0	0
9	FGD-100	0	D	G	0	G	YR	0	G	G	0
10	BD-60	YR	0	YR	YR	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	YR	G	0	0	0
12	TA-60	G	G	G	YR	YR	D	G	G	G	0
13	BDHO-60	YRF	G	0	0	YR	YR	YR	YR	0	0
14	HO-0	0	YR	YR	YR	YR	0	G	YR	G	0
15	BDHO-60	G	0	0	YR	G	0	G	0	0	0
16	BD-0	G	0	YR	F	0	G	0	0	0	0

17	TA-0	YR	G	YR	0	0	0	G	G	YR	G
18	FGD-100	YR	G	G	G	YR	0	YR	YR	G	0
19	HO-60	YR	G	0	G	G	G	G	0	0	0
20	BDHO-20	G	0	0	G	0	YR	G	G	G	0
21	HO-20	0	G	G	0	YR	YR	F	YR	0	YR
22	BDHO-0	0	0	0	0	G	YR	0	0	G	YR
23	BD-60	YR	0	0	YR	G	G	0	0	G	YR
24	BD-20	0	G	G	YR	G	0	YR	YR	0	0
25	TA-60	0	0	0	G	G	G	0	G	YR	G
26	TA-20	0	0	0	0	0	0	0	G	G	0
27	BDHO-0	0	0	YRF	0	YR	0	0	G	0	G
28	TA-0	0	0	G	G	0	0	0	YR	0	YR
29	BD-60	YR	G	0	0	G	0	YR	G	0	G
30	FGD-100	0	G	G	0	0	YR	G	YR	0	YR
31	BD-20	G	YR	0	0	YR	0	0	0	G	YR
32	HO-60	G	YR	YRD	0	0	0	0	0	0	G
33	HO-0	YR	G	YR	YR	0	G	YR	YR	YR	YR
34	TA-20	YR	YR	0	0	G	G	YRD	YR	0	0
35	BD-0	G	YR	0	G	0	0	YR	0	G	YR
36	BDHO-60	YR	0	0	G	D	G	0	0	G	0
37	HO-20	YR	0	G	0	G	0	G	G	0	YR
38	TA-60	G	G	0	G	0	YR	G	YR	0	G
39	BDHO-20	0	YRF	YR	YR	0	YR	G	0	YR	YR
40	HO-0	0	YR	G	G	0	YR	G	YR	0	0
41	HO-20	YR	G	YRF	G	0	F	0	YR	0	0
42	HO-60	0	0	G	D	YR	0	YR	YR	YR	YR
43	BDHO-20	YRD	YR	YR	0	YR	G	0	0	YR	0
44	FGD-100	0	G	G	0	G	YR	G	0	0	0
45	BDHO-0	YR	YR	0	YR	G	G	0	YR	G	YR
46	TA-20	G	0	0	YR	YR	YR	0	0	0	0
47	BDHO-60	G	0	YRF	G	0	0	G	0	0	G
48	BD-0	0	G	0	G	0	G	G	0	0	YR

49	TA-0	0	YR	YR	G	YR	0	YR	G	G	G
50	BD-60	G	0	YR	0	0	0	YR	0	0	0
51	TA-60	G	YR	G	0	G	YR	YR	0	G	0
52	BD-20	YR	YR	G	YR	YR	0	G	G	YR	0

Table H.10 Raw phytotoxicity data (Day 22).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	G	YR	0	G	G	0	0	0	0	G
2	HO-60	YR	0	0	YR	0	0	0	YR	G	G
3	HO-20	G	G	YR	0	0	YR	0	0	G	G
4	TA-20	0	G	G	D	G	0	0	0	D	0
5	BDHO-0	G	0	G	G	G	G	D	YR	0	0
6	BD-20	YR	YR	YR	YR	0	0	0	0	YR	0
7	BD-0	0	G	F	YR	0	G	G	0	YR	G
8	TA-0	YR	YR	YR	0	0	0	0	RY	0	0
9	FGD-100	0	D	G	0	G	G	0	G	G	0
10	BD-60	YR	0	YR	YR	0	G	0	G	0	YR
11	HO-0	0	0	YR	0	0	0	G	0	0	0
12	TA-60	G	G	G	YR	YR	G	G	YR	G	0
13	BDHO-60	YR	G	0	0	YR	G	G	YR	0	0
14	HO-0	0	YR	YR	YR	YR	0	G	YR	G	0
15	BDHO-60	G	0	0	YR	G	0	G	0	0	0
16	BD-0	G	0	YR	YR	0	G	0	YR	0	0
17	TA-0	YR	G	YR	0	YR	0	G	G	0	G
18	FGD-100	YR	G	G	G	G	0	G	YR	G	0
19	HO-60	YR	G	0	G	G	G	G	0	0	0
20	BDHO-20	G	0	0	G	0	YR	G	G	G	0
21	HO-20	0	G	G	0	YR	YR	G	YR	0	G
22	BDHO-0	0	0	0	0	G	YR	G	YR	0	0
23	BD-60	YR	0	0	YR	G	G	0	0	G	YR
24	BD-20	0	G	G	0	G	0	G	G	0	0
25	TA-60	0	0	0	YR	G	G	0	G	YR	G

26	TA-20	0	0	0	0	YR	0	G	G	YR	0
27	BDHO-0	0	0	YR	0	YR	0	0	G	0	G
28	TA-0	0	0	G	G	0	0	0	YR	0	YR
29	BD-60	YR	G	0	0	G	0	YR	G	0	G
30	FGD-100	0	G	G	0	0	G	G	YR	0	YR
31	BD-20	G	YR	0	0	YR	0	0	0	G	YR
32	HO-60	G	0	G	0	0	0	0	0	0	G
33	HO-0	YR	G	YR	YR	0	G	YR	G	YR	YR
34	TA-20	YR	YR	0	0	G	G	YR	YR	0	0
35	BD-0	G	0	0	G	0	0	0	0	G	G
36	BDHO-60	YR	0	0	G	G	G	0	0	G	0
37	HO-20	YR	0	G	0	G	0	YR	G	0	YR
38	TA-60	G	G	0	G	0	0	G	G	0	G
39	BDHO-20	0	YR	YR	YR	0	YR	G	0	YR	YR
40	HO-0	0	0	G	G	YR	YR	G	YR	0	0
41	HO-20	YR	G	YR	G	0	F	0	YR	0	0
42	HO-60	0	0	G	D	YR	0	YR	YR	0	YR
43	BDHO-20	YRD	YR	YR	0	YR	G	0	0	YR	0
44	FGD-100	0	G	G	0	G	YR	G	0	0	0
45	BDHO-0	YR	YR	0	YR	G	G	0	YR	YR	YR
46	TA-20	G	0	0	YR	YR	YR	0	0	0	0
47	BDHO-60	G	0	YR	G	0	0	G	0	0	G
48	BD-0	0	G	YR	G	0	G	G	0	0	YR
49	TA-0	0	YR	YR	0	YR	0	YR	G	G	G
50	BD-60	G	0	YR	0	0	0	YR	0	0	0
51	TA-60	G	0	YR	0	0	0	YR	0	0	0
52	BD-20	YR	YR	G	0	0	YR	G	G	YR	0

Table H.11 Raw phytotoxicity data (Day 29).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	G	YRE	0	G	G	0	0	0	0	G
2	HO-60	0	0	0	0	0	0	0	G	G	G

3	HO-20	G	G	G	0	0	0	0	0	G	0
4	TA-20	0	0	0	G	0	0	0	0	G	0
5	BDHO-0	0	0	G	G	0	G	G	0	0	0
6	BD-20	0	0	0	YR	0	0	0	0	GE	0
7	BD-0	0	0	YRF	0	0	YR	G	0	0	G
8	TA-0	0	0	0	0	0	0	0	YR	0	0
9	FGD-100	0	G	G	0	G	G	0	G	G	0
10	BD-60	0	0	0	G	0	G	0	G	0	0
11	HO-0	0	0	0	0	0	0	G	0	0	0
12	TA-60	0	G	0	0	0	G	G	0	G	0
13	BDHO-60	0	0	0	0	G	G	G	0	0	0
14	HO-0	0	0	0	G	0	0	0	0	0	0
15	BDHO-60	G	0	0	G	G	0	G	0	0	0
16	BD-0	G	0	0	0	0	0	0	0	0	0
17	TA-0	0	G	0	0	0	0	G	0	0	0
18	FGD-100	0	G	G	0	G	0	G	0	G	0
19	HO-60	G	G	0	G	G	G	G	0	0	0
20	BDHO-20	GRT	0	0	G	0	YR	G	0	G	0
21	HO-20	0	G	G	0	0	G	GF	0	0	G
22	BDHO-0	0	0	0	0	0	0	0	0	0	YR
23	BD-60	G	0	0	G	G	G	0	0	G	G
24	BD-20	0	G	G	0	G	0	G	G	0	0
25	TA-60	0	0	0	0	G	0	0	G	G	0
26	TA-20	0	0	0	0	0	0	YR	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	G	0	G
28	TA-0	0	0	G	G	0	0	0	G	0	0
29	BD-60	0	GF	0	0	G	0	0	G	0	G
30	FGD-100	0	0	G	0	0	G	G	0	0	0
31	BD-20	YR	0	0	0	0	0	0	0	0	0
32	HO-60	G	0	GE	0	0	0	0	0	0	G
33	HO-0	G	GRT	0	G	0	0	0	0	0	0
34	TA-20	G	0	0	0	0	G	G	0	0	0

35	BD-0	G	0	0	G	0	0	0	0	G	G
36	BDHO-60	0	0	0	G	G	G	0	0	G	0
37	HO-20	G	0	G	0	G	0	YR	0	0	0
38	TA-60	G	G	0	G	0	0	G	G	0	0
39	BDHO-20	0	0	0	G	0	GRT	G	0	0	0
40	HO-0	0	0	G	0	0	0	G	0	0	0
41	HO-20	0	G	GE	0	0	GF	0	0	0	0
42	HO-60	0	0	GRT	G	0	0	G	0	0	0
43	BDHO-20	YRE	G	0	0	G	G	0	0	G	0
44	FGD-100	0	G	G	0	G	0	G	0	0	0
45	BDHO-0	0	0	0	G	G	0	0	G	G	0
46	TA-20	GRT	0	0	0	0	0	0	0	0	0
47	BDHO-60	G	0	GF	G	0	0	GRT	0	0	G
48	BD-0	0	G	0	0	0	G	GRT	0	0	0
49	TA-0	0	0	0	0	0	0	0	0	G	0
50	BD-60	G	0	GRT	0	0	0	G	0	0	0
51	TA-60	G	G	G	0	G	G	0	0	G	0
52	BD-20	0	G	YRRT	0	0	0	G	G	0	0

Table H.12 Raw phytotoxicity data (Day 36).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	0	0	0	RS	RT	0	0	0	0	RT
2	HO-60	0	0	0	0	0	0	0	G	YR	YR
3	HO-20	RB	RBRT	RS	0	0	0	0	0	G	0
4	TA-20	0	0	0	G	0	0	0	0	D	0
5	BDHO-0	0	0	G	RS	0	RT	RTRS	0	0	0
6	BD-20	0	0	0	YR	0	0	0	0	YR	0
7	BD-0	0	0	RTRS	0	0	YR	RT	0	0	YR
8	TA-0	0	0	0	0	0	0	G	0	0	0
9	FGD-100	0	G	RB	0	RB	RSD	0	G	RB	0

10	BD-60	0	0	0	YR	0	G	0	RT	0	0
11	HO-0	0	0	0	0	0	0	G	0	0	0
12	TA-60	0	RB	0	0	0	RB	RB	0	RB	0
13	BDHO-60	0	0	0	0	YR	RBRS	YR	0	0	0
14	HO-0	0	0	0	G	0	0	0	0	0	0
15	BDHO-60	G	0	0	G	G	0	YR	0	0	0
16	BD-0	G	0	0	0	0	G	0	0	0	0
17	TA-0	0	YR	0	0	0	0	RBRS	0	0	0
18	FGD-100	0	RB	G	0	RBRS	0	RBRS	0	RBRSRT	0
19	HO-60	G	YR	0	G	RB	RS	0	0	0	0
20	BDHO-20	RSRT	0	0	RT	0	RBRS	RS	0	YR	0
21	HO-20	0	RBRS	RBRS	0	0	YR	G	0	0	RBRS
22	BDHO-0	0	0	0	0	0	0	0	0	0	YR
23	BD-60	G	0	0	RTRS	YR	RB	0	0	RB	G
24	BD-20	0	YR	YR	0	YR	0	YR	YR	0	0
25	TA-60	0	0	0	0	D	G	0	RBRS	G	0
26	TA-20	0	0	0	0	0	0	R	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	G	0	G
28	TA-0	0	0	G	RS	0	0	0	G	0	0
29	BD-60	0	YR	0	0	YR	0	0	YR	0	YR
30	FGD-100	0	0	RB	0	0	G	RB	0	0	0
31	BD-20	RB	0	0	0	0	0	0	0	0	0
32	HO-60	RB	0	D	0	0	0	0	0	0	RB
33	HO-0	G	G	0	RB	0	0	0	0	0	0
34	TA-20	YR	0	0	0	0	RTRB	RSD	0	0	0
35	BD-0	YR	0	0	G	0	0	0	0	RTRSRB	RB
36	BDHO-60	0	0	0	G	G	RB	0	0	RB	0

37	HO-20	G	0	RBRS	0	RBRS	0	RB	G	0	0
38	TA-60	G	G	0	RBRS	0	0	RBRS	G	0	0
39	BDHO-20	0	0	0	RS	0	RBRS	RS	0	0	0
40	HO-0	0	0	G	0	0	0	RS	0	0	0
41	HO-20	0	G	G	0	0	G	0	D	0	0
42	HO-60	0	0	RB	D	0	0	G	0	0	0
43	BDHO-20	YR	G	G	0	G	RBRS	0	0	RS	0
44	FGD-100	0	RB	G	0	RS	0	G	0	0	0
45	BDHO-0	0	0	0	RT	G	0	0	RS	G	0
46	TA-20	RBRS	0	0	0	0	0	0	0	0	0
47	BDHO-60	RBRS	0	0	G	0	YR	0	0	0	YR
48	BD-0	0	YR	0	0	0	YR	YR	0	0	0
49	TA-0	0	0	0	0	0	0	0	0	G	0
50	BD-60	YR	0	YR	0	0	0	RS	0	0	0
51	TA-60	G	RB	RB	0	G	YR	0	0	RB	0
52	BD-20	0	G	R	0	0	0	RTRB	RTRS	0	0

Table H.13 Raw phytotoxicity data (Day 43).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	0	0	0	RBRS	RTRB	0	0	0	0	YR
2	HO-60	0	0	0	0	0	0	0	G	YR	YR
3	HO-20	RT	RTRB	G	0	0	0	0	0	RT	0
4	TA-20	0	0	0	RB	0	0	0	0	G	0
5	BDHO-0	0	0	G	G	0	RT	RTRS	G	0	0
6	BD-20	0	0	0	YRD	0	0	0	0	YRD	0
7	BD-0	0	0	RTRS	0	0	R	G	0	0	YR
8	TA-0	0	0	0	0	0	0	0	G	0	0

9	FGD-100	0	G	RB	0	RTRB	RBRSD	0	RB	RB	0
10	BD-60	0	0	0	RB	0	G	0	RT	0	0
11	HO-0	0	0	0	0	0	0	G	0	0	0
12	TA-60	G	RB	0	0	0	RB	RB	0	RB	0
13	BDHO-60	0	0	0	G	RS	RBRS	RS	0	0	0
14	HO-0	0	0	0	G	0	0	0	0	0	0
15	BDHO-60	G	0	0	G	G	0	RTRB	0	0	0
16	BD-0	G	0	0	0	0	G	0	0	0	0
17	TA-0	0	RT	0	0	0	0	RTRB	G	0	0
18	FGD-100	0	RB	G	0	RBRS	0	RBRS	0	RTRBRS	0
19	HO-60	G	YR	0	RB	RB	RS	0	0	0	0
20	BDHO-20	RTRS	0	0	RTRB	0	G	G	0	G	0
21	HO-20	0	RBRS	RB	0	0	RTRS	G	0	0	RB
22	BDHO-0	0	0	0	0	0	0	0	0	0	G
23	BD-60	G	0	0	RBRS	YR	RB	0	0	RBRS	G
24	BD-20	0	G	RBRS	0	RB	0	YR	YR	0	0
25	TA-60	0	0	0	0	G	G	0	RBRS	G	0
26	TA-20	0	0	0	0	0	0	YR	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	G	0	G
28	TA-0	0	0	G	RS	0	0	0	G	0	0
29	BD-60	0	YR	0	0	RB	0	0	RS	0	RS
30	FGD-100	0	0	RB	0	0	G	RB	0	0	0
31	BD-20	RB	G	0	0	0	0	0	0	0	0
32	HO-60	RB	-	D	0	0	0	0	0	0	RTRB
33	HO-0	G	RS	0	RB	0	0	0	0	0	0
34	TA-20	YR	0	0	0	G	RTRB	RBRS	0	0	0
35	BD-0	YR	0	0	G	0	0	0	0	RBRS	RBRS

36	BDHO-60	0	0	0	RB	D	RB	0	0	RB	0
37	HO-20	G	0	RB	0	RB	0	RB	G	0	0
38	TA-60	RB	RS	0	RBRS	0	0	RBRS	G	0	G
39	BDHO-20	0	0	0	RS	0	RTRBRS	RBRS	0	0	G
40	HO-0	0	0	G	G	0	0	G	0	0	0
41	HO-20	0	RTRB	G	0	0	G	0	G	0	0
42	HO-60	0	0	RB	G	0	0	G	0	0	0
43	BDHO-20	RBRS	G	G	0	G	RBRS	0	0	RS	0
44	FGD-100	0	RB	RB	0	G	G	RB	0	0	0
45	BDHO-0	0	0	0	G	RTRB	RB	0	RS	G	0
46	TA-20	RBRS	0	0	0	0	0	0	0	0	0
47	BDHO-60	RBRS	0	G	G	0	0	RB	0	0	YR
48	BD-0	0	YR	0	0	0	RBRS	YR	0	0	G
49	TA-0	0	0	G	0	0	0	0	0	G	0
50	BD-60	RB	0	RS	0	0	0	G	0	0	0
51	TA-60	G	RB	RB	0	G	RS	0	0	RB	0
52	BD-20	0	RB	R	0	0	0	R	YR	0	0

Table H.14 Raw phytotoxicity data (Day 50).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	0	0	0	RTRB	RB	0	0	0	0	YR
2	HO-60	0	0	0	0	0	0	0	RB	YR	YR
3	HO-20	G	RTRB	RB	0	0	0	0	0	RT	0
4	TA-20	0	0	0	RB	G	0	0	0	RBRS	0
5	BDHO-0	0	0	G	RT	G	G	G	G	0	0
6	BD-20	0	0	0	YR	0	0	0	0	YR	0
7	BD-0	0	0	RTRS	0	0	R	YR	0	0	YR

8	TA-0	0	0	0	0	0	0	0	G	0	0
9	FGD-100	0	RB	RB	0	RB	RBD	0	RB	RB	0
10	BD-60	0	0	0	RB	0	G	0	R	0	G
11	HO-0	0	0	0	0	0	0	G	0	0	0
12	TA-60	G	RB	0	0	0	RB	R	0	R	0
13	BDHO-60	0	0	0	0	RB	RB	RB	0	0	0
14	HO-0	0	0	0	G	0	0	0	0	0	0
15	BDHO-60	G	0	0	G	RB	0	R	0	0	0
16	BD-0	G	0	0	0	0	0	0	0	0	0
17	TA-0	0	G	0	0	0	0	R	G	0	0
18	FGD-100	0	RB	RB	G	RB	0	RB	0	RB	0
19	HO-60	G	R	0	R	RB	R	0	0	0	0
20	BDHO-20	RTRB	0	0	RTRB	0	G	RB	0	RB	0
21	HO-20	0	RTRB	RTRB	0	0	RT	G	0	0	RTRB
22	BDHO-0	0	0	0	0	0	0	0	0	0	RT
23	BD-60	G	0	0	RB	R	RB	0	0	RB	YR
24	BD-20	0	YR	R	0	RB	0	YR	YR	0	0
25	TA-60	0	0	0	0	G	G	0	RB	G	0
26	TA-20	0	0	0	0	0	0	R	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	G	0	G
28	TA-0	0	0	G	YR	0	0	0	G	0	0
29	BD-60	0	RB	0	0	RB	0	0	RS	0	RS
30	FGD-100	0	0	RB	0	0	G	RB	0	0	0
31	BD-20	RB	G	0	0	0	0	0	0	0	0
32	HO-60	RTRB	0	D	0	0	0	0	0	0	RTRB
33	HO-0	G	RB	0	RB	0	0	0	0	0	0
34	TA-20	R	0	0	0	G	R	R	0	0	0

35	BD-0	YR	0	0	G	0	0	0	0	R	R
36	BDHO-60	0	0	0	RB	D	RB	0	0	RB	0
37	HO-20	G	0	RB	0	RB	0	RTRB	G	0	0
38	TA-60	RB	RB	0	R	0	0	R	RT	0	G
39	BDHO-20	0	0	0	RTRS	0	RTRB	RB	0	0	G
40	HO-0	0	0	G	G	0	0	RB	0	0	0
41	HO-20	0	RB	G	0	0	RT	0	G	0	0
42	HO-60	0	0	D	G	0	0	G	0	0	0
43	BDHO-20	RB	G	G	0	G	G	0	0	G	0
44	FGD-100	0	RB	RB	0	RS	G	RB	0	0	0
45	BDHO-0	0	0	0	G	RT	0	0	G	G	0
46	TA-20	R	0	0	0	0	0	0	0	0	0
47	BDHO-60	RB	0	G	YR	0	0	YR	0	0	YR
48	BD-0	0	RB	0	0	0	RB	YR	0	0	G
49	TA-0	0	0	0	0	0	0	0	0	G	0
50	BD-60	R	0	R	0	0	0	G	0	0	0
51	TA-60	RB	RB	RB	0	G	RS	0	0	RB	0
52	BD-20	0	G	R	0	0	0	R	RB	0	0

Table H.15 Raw phytotoxicity data (Day 57).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	0	0	0	RB	RB	0	0	0	0	RTRB
2	HO-60	0	0	0	0	0	0	0	RB	RTRB	RTRB
3	HO-20	RTRB	RB	RB	0	0	0	0	0	G	0
4	TA-20	0	0	0	RTRB	G	0	0	0	RTRBRS	0
5	BDHO-0	0	0	RB	RTRB	G	RB	RTRB	G	0	0
6	BD-20	0	0	0	YR	0	0	0	0	YR	0

7	BD-0	0	0	R	0	0	R	G	0	0	R
8	TA-0	0	0	0	0	0	0	0	G	0	0
9	FGD-100	0	RB	RB	0	RB	RB	0	RB	RB	0
10	BD-60	0	0	0	RB	0	G	0	R	0	RS
11	HO-0	0	0	0	0	0	0	G	0	0	0
12	TA-60	G	RB	0	0	0	R	R	0	R	0
13	BDHO-60	0	0	0	0	RB	R	R	0	0	0
14	HO-0	0	0	0	G	0	0	0	0	0	0
15	BDHO-60	G	0	0	0	RB	0	R	0	0	0
16	BD-0	G	0	0	0	0	G	0	0	0	0
17	TA-0	0	G	0	0	0	0	R	G	0	0
18	FGD-100	0	RB	RB	G	RB	0	RB	0	R	0
19	HO-60	G	R	0	R	R	R	0	0	0	0
20	BDHO-20	RB	0	0	RB	0	G	RB	0	RTRB	0
21	HO-20	0	RTRB	RB	0	0	RTRB	G	0	0	RTRB
22	BDHO-0	0	0	0	0	0	0	0	0	0	RTRB
23	BD-60	G	0	0	RB	R	R	0	0	RB	RB
24	BD-20	0	RTRB	R	0	RTRB	0	RB	R	0	0
25	TA-60	0	0	0	0	G	G	0	RB	G	0
26	TA-20	0	0	0	0	0	0	R	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	RB	0	RB
28	TA-0	0	0	G	RT	0	0	0	G	0	0
29	BD-60	G	RS	0	0	RB	0	0	YR	0	YR
30	FGD-100	0	0	RB	0	0	RB	RB	0	0	0
31	BD-20	R	G	0	0	0	0	0	0	0	0
32	HO-60	RTRB	0	RTRB	0	0	0	0	0	0	R
33	HO-0	G	RTRB	0	RTRB	0	0	0	0	0	0

34	TA-20	R	0	0	0	G	R	R	0	0	0
35	BD-0	YR	0	0	G	0	0	0	0	R	R
36	BDHO-60	0	0	0	RB	D	RB	0	0	RB	0
37	HO-20	RB	0	RTRB	0	RB	0	RTRB	R	0	0
38	TA-60	RB	RB	0	R	0	0	R	RT	0	G
39	BDHO-20	0	0	0	RB	0	RB	RB	0	0	G
40	HO-0	0	0	G	0	0	0	RTRB	0	0	0
41	HO-20	0	RB	G	0	0	G	0	G	0	0
42	HO-60	0	0	R	RB	0	0	RB	0	0	0
43	BDHO-20	RB	RB	G	0	G	RB	0	0	RB	0
44	FGD-100	0	RB	RB	0	RB	G	RB	0	0	0
45	BDHO-0	0	0	0	G	G	0	0	RB	RB	0
46	TA-20	RTRB	0	0	0	0	0	0	0	0	0
47	BDHO-60	R	0	G	YR	0	0	YR	0	0	YR
48	BD-0	R	0	R	0	0	0	G	0	0	0
49	TA-0	0	YR	0	0	0	YR	YR	0	0	G
50	BD-60	0	0	0	0	0	0	G	0	G	0
51	TA-60	RB	RB	RB	0	G	RS	0	0	RB	0
52	BD-20	0	G	R	0	0	0	R	RB	0	0

Table H.16 Raw phytotoxicity data (Day 65).

ID	Trt	A	B	C	D	E	F	G	H	I	J
1	BDHO-20	0	0	0	RB	RB	0	0	0	0	RTRB
2	HO-60	0	0	0	0	0	0	0	RB	RTRB	RTRB
3	HO-20	RB	RB	RB	0	0	0	0	0	RT	0
4	TA-20	0	0	0	RB	G	0	0	0	R	0
5	BDHO-0	0	0	RB	RTRB	G	RTRB	RTRB	G	0	0

6	BD-20	0	0	0	YR	0	0	0	0	YR	0
7	BD-0	0	0	R	0	0	R	YR	0	0	YR
8	TA-0	0	0	0	0	0	0	0	YR	0	0
9	FGD-100	0	RB	R	0	RB	RB	0	RB	RB	0
10	BD-60	0	0	0	RB	0	YR	0	R	0	YR
11	HO-0	0	0	0	0	0	0	G	0	0	0
12	TA-60	G	R	0	0	0	R	R	0	R	0
13	BDHO-60	0	0	0	0	RB	R	R	0	0	0
14	HO-0	0	0	0	G	0	0	0	0	0	0
15	BDHO-60	G	0	0	0	RB	0	RTRB	0	0	0
16	BD-0	G	0	YR	0	0	G	0	0	0	0
17	TA-0	0	YR	0	0	0	0	R	G	0	0
18	FGD-100	0	RB	RB	G	RB	0	RB	0	RB	0
19	HO-60	G	RB	0	R	RB	RB	0	0	0	0
20	BDHO-20	RB	0	0	RB	0	YR	RB	0	RB	0
21	HO-20	0	RB	RB	0	0	RB	G	0	0	RB
22	BDHO-0	0	0	0	0	0	0		00	0	RTRB
23	BD-60	YR	0	0	R	R	R	0	0	RB	R
24	BD-20	0	RTRB	R	0	R	0	R	R	0	0
25	TA-60	0	0	0	0	G	G	0	R	R	0
26	TA-20	0	0	0	0	0	0	R	0	0	0
27	BDHO-0	0	0	0	0	0	0	0	RB	0	RB
28	TA-0	0	0	YR	YR	0	0	0	YR	0	0
29	BD-60	G	RB			RB			YR		YR
30	FGD-100	0	G	RB	0	0	RB	RB	0	0	0
31	BD-20	RB	G	0	0	0	0	0	0	0	0
32	HO-60	RB	0	R	0	0	0	0	0	0	R

33	HO-0	RB	RB	0	RB	0	0	0	0	0	0
34	TA-20	R	0	0	0	R	R	RB	0	0	0
35	BD-0	YR	0	0	YR	0	0	0	0	R	R
36	BDHO-60	0	0	0	YR	D	RB	0	0	YR	0
37	HO-20	RTRB	0	RTRB	0	RTRB	0	RTRB	RTRB	0	0
38	TA-60	YR	YR	0	RB	0	0	RB	RB	0	G
39	BDHO-20	0	0	0	RB	0	RB	RB	0	0	G
40	HO-0	0	0	G	0	0	0	RB	0	0	0
41	HO-20	0	G	G	0	0	G	0	G	0	0
42	HO-60	0	0	RTRB	RTRB	0	0	RB	0	0	0
43	BDHO-20	RB	G	G	0	RT	RB	0	0	RB	0
44	FGD-100	0	RB	R	0	RB	G	R	0	0	0
45	BDHO-0	0	0	0	G	RB	0	0	G	RB	0
46	TA-20	RTRB	0	0	0	0	0	0	0	0	0
47	BDHO-60	R	0	G	YR	0	0	R	0	00	R
48	BD-0	0	R	0	0	0	R	YR	0	0	YR
49	TA-0	0	0	0	0	0	0	G	0	YR	0
50	BD-60	R	0	R	0	0	0	RB	0	0	0
51	TA-60	RB	RB	RB	0	RB	RB	0	0	RB	0
52	BD-20	0	0	R	0	0	0	R	RB	0	0

Appendix I - Phytotoxicity SAS Code

Table I.1 Processed phytotoxicity data used for statistical analysis.

Unit	TRT	ID	Day65
A	BDHO-20	1	0
B	BDHO-20	1	0
C	BDHO-20	1	0
D	BDHO-20	1	YR
E	BDHO-20	1	YR
F	BDHO-20	1	0
G	BDHO-20	1	0
H	BDHO-20	1	0
I	BDHO-20	1	0
J	BDHO-20	1	YR
A	HO-60	2	0
B	HO-60	2	0
C	HO-60	2	0
D	HO-60	2	0
E	HO-60	2	0
F	HO-60	2	0
G	HO-60	2	0
H	HO-60	2	YR
I	HO-60	2	YR
J	HO-60	2	YR
A	HO-20	3	YR
B	HO-20	3	YR
C	HO-20	3	YR
D	HO-20	3	0
E	HO-20	3	0
F	HO-20	3	0
G	HO-20	3	0
H	HO-20	3	0

I	HO-20	3	YR
J	HO-20	3	0
A	TA-20	4	0
B	TA-20	4	0
C	TA-20	4	0
D	TA-20	4	YR
E	TA-20	4	G
F	TA-20	4	0
G	TA-20	4	0
H	TA-20	4	0
I	TA-20	4	YR
J	TA-20	4	0
A	BDHO-0	5	0
B	BDHO-0	5	0
C	BDHO-0	5	YR
D	BDHO-0	5	YR
E	BDHO-0	5	G
F	BDHO-0	5	YR
G	BDHO-0	5	YR
H	BDHO-0	5	G
I	BDHO-0	5	0
J	BDHO-0	5	0
A	BD-20	6	0
B	BD-20	6	YR
C	BD-20	6	0
D	BD-20	6	0
E	BD-20	6	0
F	BD-20	6	0
G	BD-20	6	YR
H	BD-20	6	0
I	BD-20	6	0
J	BD-20	6	0

A	BD-0	7	0
B	BD-0	7	0
C	BD-0	7	YR
D	BD-0	7	0
E	BD-0	7	0
F	BD-0	7	YR
G	BD-0	7	YR
H	BD-0	7	0
I	BD-0	7	0
J	BD-0	7	YR
A	TA-0	8	0
B	TA-0	8	0
C	TA-0	8	0
D	TA-0	8	0
E	TA-0	8	0
F	TA-0	8	0
G	TA-0	8	0
H	TA-0	8	YR
I	TA-0	8	0
J	TA-0	8	0
A	FGD-100	9	0
B	FGD-100	9	YR
C	FGD-100	9	YR
D	FGD-100	9	0
E	FGD-100	9	YR
F	FGD-100	9	YR
G	FGD-100	9	0
H	FGD-100	9	YR
I	FGD-100	9	YR
J	FGD-100	9	0
A	BD-60	10	0
B	BD-60	10	0

C	BD-60	10	0
D	BD-60	10	YR
E	BD-60	10	0
F	BD-60	10	YR
G	BD-60	10	0
H	BD-60	10	YR
I	BD-60	10	0
J	BD-60	10	YR
A	HO-0	11	0
B	HO-0	11	0
C	HO-0	11	0
D	HO-0	11	0
E	HO-0	11	0
F	HO-0	11	0
G	HO-0	11	G
H	HO-0	11	0
I	HO-0	11	0
J	HO-0	11	0
A	TA-60	12	G
B	TA-60	12	YR
C	TA-60	12	0
D	TA-60	12	0
E	TA-60	12	0
F	TA-60	12	YR
G	TA-60	12	YR
H	TA-60	12	0
I	TA-60	12	YR
J	TA-60	12	0
A	BDHO-60	13	0
B	BDHO-60	13	0
C	BDHO-60	13	0
D	BDHO-60	13	0

E	BDHO-60	13	YR
F	BDHO-60	13	YR
G	BDHO-60	13	YR
H	BDHO-60	13	0
I	BDHO-60	13	0
J	BDHO-60	13	0
A	HO-0	14	0
B	HO-0	14	0
C	HO-0	14	0
D	HO-0	14	G
E	HO-0	14	0
F	HO-0	14	0
G	HO-0	14	0
H	HO-0	14	0
I	HO-0	14	0
J	HO-0	14	0
A	BDHO-60	15	G
B	BDHO-60	15	0
C	BDHO-60	15	0
D	BDHO-60	15	0
E	BDHO-60	15	YR
F	BDHO-60	15	0
G	BDHO-60	15	YR
H	BDHO-60	15	0
I	BDHO-60	15	0
J	BDHO-60	15	0
A	BD-0	16	G
B	BD-0	16	0
C	BD-0	16	YR
D	BD-0	16	0
E	BD-0	16	0
F	BD-0	16	G

G	BD-0	16	0
H	BD-0	16	0
I	BD-0	16	0
J	BD-0	16	0
A	TA-0	17	0
B	TA-0	17	YR
C	TA-0	17	0
D	TA-0	17	0
E	TA-0	17	0
F	TA-0	17	0
G	TA-0	17	YR
H	TA-0	17	G
I	TA-0	17	0
J	TA-0	17	0
A	FGD-100	18	0
B	FGD-100	18	YR
C	FGD-100	18	YR
D	FGD-100	18	G
E	FGD-100	18	YR
F	FGD-100	18	0
G	FGD-100	18	YR
H	FGD-100	18	0
I	FGD-100	18	YR
J	FGD-100	18	0
A	HO-60	19	G
B	HO-60	19	YR
C	HO-60	19	0
D	HO-60	19	YR
E	HO-60	19	YR
F	HO-60	19	YR
G	HO-60	19	0
H	HO-60	19	0

I	HO-60	19	0
J	HO-60	19	0
A	BDHO-20	20	YR
B	BDHO-20	20	0
C	BDHO-20	20	0
D	BDHO-20	20	YR
E	BDHO-20	20	0
F	BDHO-20	20	YR
G	BDHO-20	20	YR
H	BDHO-20	20	0
I	BDHO-20	20	YR
J	BDHO-20	20	0
A	HO-20	21	0
B	HO-20	21	YR
C	HO-20	21	YR
D	HO-20	21	0
E	HO-20	21	0
F	HO-20	21	YR
G	HO-20	21	G
H	HO-20	21	0
I	HO-20	21	0
J	HO-20	21	YR
A	BDHO-0	22	0
B	BDHO-0	22	0
C	BDHO-0	22	0
D	BDHO-0	22	0
E	BDHO-0	22	0
F	BDHO-0	22	0
G	BDHO-0	22	0
H	BDHO-0	22	0
I	BDHO-0	22	0
J	BDHO-0	22	YR

A	BD-60	23	YR
B	BD-60	23	0
C	BD-60	23	0
D	BD-60	23	YR
E	BD-60	23	YR
F	BD-60	23	YR
G	BD-60	23	0
H	BD-60	23	0
I	BD-60	23	YR
J	BD-60	23	YR
A	BD-20	24	0
B	BD-20	24	YR
C	BD-20	24	YR
D	BD-20	24	0
E	BD-20	24	YR
F	BD-20	24	0
G	BD-20	24	YR
H	BD-20	24	YR
I	BD-20	24	0
J	BD-20	24	0
A	TA-60	25	0
B	TA-60	25	0
C	TA-60	25	0
D	TA-60	25	0
E	TA-60	25	G
F	TA-60	25	G
G	TA-60	25	0
H	TA-60	25	YR
I	TA-60	25	YR
J	TA-60	25	0
A	TA-20	26	0
B	TA-20	26	0

C	TA-20	26	0
D	TA-20	26	0
E	TA-20	26	0
F	TA-20	26	0
G	TA-20	26	YR
H	TA-20	26	0
I	TA-20	26	0
J	TA-20	26	0
A	BDHO-0	27	0
B	BDHO-0	27	0
C	BDHO-0	27	0
D	BDHO-0	27	0
E	BDHO-0	27	0
F	BDHO-0	27	0
G	BDHO-0	27	0
H	BDHO-0	27	YR
I	BDHO-0	27	0
J	BDHO-0	27	YR
A	TA-0	28	0
B	TA-0	28	0
C	TA-0	28	YR
D	TA-0	28	YR
E	TA-0	28	0
F	TA-0	28	0
G	TA-0	28	0
H	TA-0	28	YR
I	TA-0	28	0
J	TA-0	28	0
A	BD-60	29	G
B	BD-60	29	YR
C	BD-60	29	0
D	BD-60	29	0

E	BD-60	29	YR
F	BD-60	29	0
G	BD-60	29	0
H	BD-60	29	YR
I	BD-60	29	0
J	BD-60	29	YR
A	FGD-100	30	0
B	FGD-100	30	G
C	FGD-100	30	YR
D	FGD-100	30	0
E	FGD-100	30	0
F	FGD-100	30	YR
G	FGD-100	30	YR
H	FGD-100	30	0
I	FGD-100	30	0
J	FGD-100	30	0
A	BD-20	31	YR
B	BD-20	31	G
C	BD-20	31	0
D	BD-20	31	0
E	BD-20	31	0
F	BD-20	31	0
G	BD-20	31	0
H	BD-20	31	0
I	BD-20	31	0
J	BD-20	31	0
A	HO-60	32	YR
B	HO-60	32	0
C	HO-60	32	YR
D	HO-60	32	0
E	HO-60	32	0
F	HO-60	32	0

G	HO-60	32	0
H	HO-60	32	0
I	HO-60	32	0
J	HO-60	32	YR
A	HO-0	33	YR
B	HO-0	33	YR
C	HO-0	33	0
D	HO-0	33	YR
E	HO-0	33	0
F	HO-0	33	0
G	HO-0	33	0
H	HO-0	33	0
I	HO-0	33	0
J	HO-0	33	0
A	TA-20	34	YR
B	TA-20	34	0
C	TA-20	34	0
D	TA-20	34	0
E	TA-20	34	YR
F	TA-20	34	YR
G	TA-20	34	YR
H	TA-20	34	0
I	TA-20	34	0
J	TA-20	34	0
A	BD-0	35	YR
B	BD-0	35	0
C	BD-0	35	0
D	BD-0	35	YR
E	BD-0	35	0
F	BD-0	35	0
G	BD-0	35	0
H	BD-0	35	0

I	BD-0	35	YR
J	BD-0	35	YR
A	BDHO-60	36	0
B	BDHO-60	36	0
C	BDHO-60	36	0
D	BDHO-60	36	YR
E	BDHO-60	36	G
F	BDHO-60	36	YR
G	BDHO-60	36	0
H	BDHO-60	36	0
I	BDHO-60	36	YR
J	BDHO-60	36	0
A	HO-20	37	YR
B	HO-20	37	0
C	HO-20	37	YR
D	HO-20	37	0
E	HO-20	37	YR
F	HO-20	37	0
G	HO-20	37	YR
H	HO-20	37	YR
I	HO-20	37	0
J	HO-20	37	0
A	TA-60	38	YR
B	TA-60	38	YR
C	TA-60	38	0
D	TA-60	38	YR
E	TA-60	38	0
F	TA-60	38	0
G	TA-60	38	YR
H	TA-60	38	YR
I	TA-60	38	0
J	TA-60	38	G

A	BDHO-20	39	0
B	BDHO-20	39	0
C	BDHO-20	39	0
D	BDHO-20	39	YR
E	BDHO-20	39	0
F	BDHO-20	39	YR
G	BDHO-20	39	YR
H	BDHO-20	39	0
I	BDHO-20	39	0
J	BDHO-20	39	G
A	HO-0	40	0
B	HO-0	40	0
C	HO-0	40	G
D	HO-0	40	0
E	HO-0	40	0
F	HO-0	40	0
G	HO-0	40	YR
H	HO-0	40	0
I	HO-0	40	0
J	HO-0	40	0
A	HO-20	41	0
B	HO-20	41	G
C	HO-20	41	G
D	HO-20	41	0
E	HO-20	41	0
F	HO-20	41	G
G	HO-20	41	0
H	HO-20	41	G
I	HO-20	41	0
J	HO-20	41	0
A	HO-60	42	0
B	HO-60	42	0

C	HO-60	42	YR
D	HO-60	42	YR
E	HO-60	42	0
F	HO-60	42	0
G	HO-60	42	YR
H	HO-60	42	0
I	HO-60	42	0
J	HO-60	42	0
A	BDHO-20	43	YR
B	BDHO-20	43	G
C	BDHO-20	43	G
D	BDHO-20	43	0
E	BDHO-20	43	YR
F	BDHO-20	43	YR
G	BDHO-20	43	0
H	BDHO-20	43	0
I	BDHO-20	43	YR
J	BDHO-20	43	0
A	FGD-100	44	0
B	FGD-100	44	YR
C	FGD-100	44	YR
D	FGD-100	44	0
E	FGD-100	44	YR
F	FGD-100	44	G
G	FGD-100	44	YR
H	FGD-100	44	0
I	FGD-100	44	0
J	FGD-100	44	0
A	BDHO-0	45	0
B	BDHO-0	45	0
C	BDHO-0	45	0
D	BDHO-0	45	G

E	BDHO-0	45	YR
F	BDHO-0	45	0
G	BDHO-0	45	0
H	BDHO-0	45	G
I	BDHO-0	45	YR
J	BDHO-0	45	0
A	TA-20	46	YR
B	TA-20	46	0
C	TA-20	46	0
D	TA-20	46	0
E	TA-20	46	0
F	TA-20	46	0
G	TA-20	46	0
H	TA-20	46	0
I	TA-20	46	0
J	TA-20	46	0
A	BDHO-60	47	YR
B	BDHO-60	47	0
C	BDHO-60	47	G
D	BDHO-60	47	YR
E	BDHO-60	47	0
F	BDHO-60	47	0
G	BDHO-60	47	YR
H	BDHO-60	47	0
I	BDHO-60	47	0
J	BDHO-60	47	YR
A	BD-0	48	0
B	BD-0	48	YR
C	BD-0	48	0
D	BD-0	48	0
E	BD-0	48	0
F	BD-0	48	YR

G	BD-0	48	YR
H	BD-0	48	0
I	BD-0	48	0
J	BD-0	48	YR
A	TA-0	49	0
B	TA-0	49	0
C	TA-0	49	0
D	TA-0	49	0
E	TA-0	49	0
F	TA-0	49	0
G	TA-0	49	G
H	TA-0	49	0
I	TA-0	49	YR
J	TA-0	49	0
A	BD-60	50	YR
B	BD-60	50	0
C	BD-60	50	YR
D	BD-60	50	0
E	BD-60	50	0
F	BD-60	50	0
G	BD-60	50	YR
H	BD-60	50	0
I	BD-60	50	0
J	BD-60	50	0
A	TA-60	51	YR
B	TA-60	51	YR
C	TA-60	51	YR
D	TA-60	51	0
E	TA-60	51	YR
F	TA-60	51	YR
G	TA-60	51	0
H	TA-60	51	0

I	TA-60	51	YR
J	TA-60	51	0
A	BD-20	52	0
B	BD-20	52	0
C	BD-20	52	YR
D	BD-20	52	0
E	BD-20	52	0
F	BD-20	52	0
G	BD-20	52	YR
H	BD-20	52	YR
I	BD-20	52	0
J	BD-20	52	0

SAS Code

```
proc import datafile="/home/erica120/sasuser.v94/Research/Phytotoxicity_time.xlsx"

out= phytotoxicity

DBMS=xlsx

replace;

Getnames=yes;

Sheet=HML;

run;

proc glimmix data=phytotoxicity plot=studentpanel;

class TRT Day65 ID;

model Day65 (order=freq ref=first)= TRT/ dist=multinomial link=glogit;

random intercept/ subject=ID group=Day65;

run;
```

Appendix J - Height Data

Table J.1 Height data for measureable plants

Plant Height	Treatment	ID	Block	Day
0	BD-60	10D	A	29
0	BD-60	10H	A	29
0	HO-0	11G	A	29
0	TA-60	12A	A	29
0.5	TA-60	12B	A	29
0.1	TA-60	12F	A	29
0.5	TA-60	12G	A	29
1	TA-60	12I	A	29
0	BDHO-60	13E	A	29
0.7	BDHO-60	13F	A	29
0.2	BDHO-60	13G	A	29
0.9	BDHO-20	1D	A	29
0	BDHO-20	1E	A	29
0	BDHO-20	1J	A	29
0	HO-60	2H	A	29
0.1	HO-60	2I	A	29
0	HO-60	2J	A	29
0	HO-20	3A	A	29
0.3	HO-20	3B	A	29
0	HO-20	3C	A	29
0	HO-20	3I	A	29
0	TA-20	4D	A	29
0	TA-20	4E	A	29
0	TA-20	4I	A	29
0	BDHO-0	5C	A	29
0	BDHO-0	5D	A	29
0	BDHO-0	5E	A	29
0	BDHO-0	5F	A	29

0.2	BDHO-0	5G	A	29
0	BDHO-0	5H	A	29
0.2	BD-20	6D	A	29
0	BD-20	6I	A	29
0.3	BD-0	7F	A	29
0.1	BD-0	7J	A	29
0.5	FGD-100	9C	A	29
0.2	FGD-100	9E	A	29
0	FGD-100	9F	A	29
0	FGD-100	9H	A	29
0.4	FGD-100	9I	A	29
0	HO-0	14D	B	29
0	BDHO-60	15A	B	29
0	BDHO-60	15E	B	29
0.5	BDHO-60	15G	B	29
1.1	TA-0	17G	B	29
0.6	FGD-100	18B	B	29
0.6	FGD-100	18C	B	29
0.6	FGD-100	18E	B	29
0.3	FGD-100	18G	B	29
0.4	FGD-100	18I	B	29
0	HO-60	19A	B	29
0.2	HO-60	19B	B	29
0.2	HO-60	19D	B	29
1.5	HO-60	19E	B	29
0	HO-60	19F	B	29
0.6	BDHO-20	20A	B	29
0	BDHO-20	20D	B	29
1.6	BDHO-20	20G	B	29
0	BDHO-20	20I	B	29
0.9	HO-20	21B	B	29
0.3	HO-20	21C	B	29

0	HO-20	21F	B	29
0	HO-20	21G	B	29
2.5	HO-20	21J	B	29
0.4	BDHO-0	22J	B	29
0	BD-60	23A	B	29
0	BD-60	23D	B	29
0	BD-60	23E	B	29
1.5	BD-60	23F	B	29
0.4	BD-60	23I	B	29
0	BD-60	23J	B	29
0	BD-20	24B	B	29
0.8	BD-20	24C	B	29
0.2	BD-20	24E	B	29
0.3	BD-20	24G	B	29
0.2	BD-20	24H	B	29
0	TA-60	25E	B	29
0	TA-60	25F	B	29
0.4	TA-60	25H	B	29
0	TA-60	25I	B	29
0.5	TA-20	26G	B	29
0	BDHO-0	27H	C	29
0	BDHO-0	27J	C	29
0	TA-0	28C	C	29
0	TA-0	28D	C	29
0	TA-0	28H	C	29
0	BD-60	29B	C	29
0.3	BD-60	29E	C	29
0.1	BD-60	29H	C	29
0.4	BD-60	29J	C	29
0.3	FGD-100	30C	C	29
0	FGD-100	30F	C	29
0.2	FGD-100	30G	C	29

0.7	BD-20	31A	C	29
0	BD-20	31B	C	29
1.5	HO-60	32A	C	29
0	HO-60	32C	C	29
0.7	HO-60	32J	C	29
0	HO-0	33A	C	29
0.2	HO-0	33B	C	29
0	HO-0	33D	C	29
0	TA-20	34A	C	29
0.2	TA-20	34F	C	29
0	TA-20	34G	C	29
1.4	BD-0	35I	C	29
1	BD-0	35J	C	29
0	BDHO-60	36D	C	29
0.8	BDHO-60	36F	C	29
0.5	BDHO-60	36I	C	29
0	HO-20	37A	C	29
2.3	HO-20	37C	C	29
3.2	HO-20	37E	C	29
0.5	HO-20	37G	C	29
0	HO-20	37H	C	29
1	TA-60	38A	C	29
0.2	TA-60	38B	C	29
1.2	TA-60	38D	C	29
0.5	TA-60	38G	C	29
0	TA-60	38H	C	29
0	BDHO-20	39D	C	29
0.2	BDHO-20	39F	C	29
0.9	BDHO-20	39G	C	29
0	BDHO-20	39J	C	29
0	HO-0	40C	D	29
0.5	HO-0	40G	D	29

0.3	HO-20	41B	D	29
0.3	HO-20	41C	D	29
0	HO-20	41F	D	29
0	HO-20	41H	D	29
0.5	HO-60	42C	D	29
0	HO-60	42D	D	29
0	HO-60	42G	D	29
0.9	BDHO-20	43A	D	29
0	BDHO-20	43B	D	29
0	BDHO-20	43C	D	29
0	BDHO-20	43E	D	29
1.2	BDHO-20	43F	D	29
0.5	BDHO-20	43I	D	29
0.5	FGD-100	44B	D	29
0	FGD-100	44C	D	29
0.2	FGD-100	44E	D	29
0	FGD-100	44F	D	29
0	FGD-100	44G	D	29
0	BDHO-0	45D	D	29
0	BDHO-0	45E	D	29
0	BDHO-0	45H	D	29
0.4	BDHO-0	45I	D	29
0.8	TA-20	46A	D	29
0.1	BDHO-60	47A	D	29
0	BDHO-60	47D	D	29
0	BDHO-60	47G	D	29
0	BDHO-60	47J	D	29
0.3	BD-0	48F	D	29
0	TA-0	49I	D	29
0.3	BD-60	50A	D	29
0	BD-60	50C	D	29
0	BD-60	50G	D	29

0	TA-60	51A	D	29
1	TA-60	51B	D	29
0.6	TA-60	51C	D	29
0	TA-60	51F	D	29
0.1	TA-60	51I	D	29
0.1	BD-20	52C	D	29
0.1	BD-20	52H	D	29
0.1	BD-60	10D	A	36
0	BD-60	10H	A	36
0	HO-0	11G	A	36
0	TA-60	12A	A	36
0.7	TA-60	12B	A	36
0.1	TA-60	12F	A	36
0.7	TA-60	12G	A	36
1.3	TA-60	12I	A	36
0.6	BDHO-60	13E	A	36
1.1	BDHO-60	13F	A	36
0.8	BDHO-60	13G	A	36
1.6	BDHO-20	1D	A	36
0.4	BDHO-20	1E	A	36
0.4	BDHO-20	1J	A	36
0	HO-60	2H	A	36
0.5	HO-60	2I	A	36
0.4	HO-60	2J	A	36
0.2	HO-20	3A	A	36
1	HO-20	3B	A	36
0.5	HO-20	3C	A	36
0.1	HO-20	3I	A	36
0.4	TA-20	4D	A	36
0	TA-20	4E	A	36
0.1	TA-20	4I	A	36
0	BDHO-0	5C	A	36

0.3	BDHO-0	5D	A	36
0	BDHO-0	5E	A	36
0.3	BDHO-0	5F	A	36
0.9	BDHO-0	5G	A	36
0	BDHO-0	5H	A	36
0.5	BD-20	6D	A	36
0.4	BD-20	6I	A	36
0.5	BD-0	7F	A	36
0.3	BD-0	7J	A	36
0.6	FGD-100	9C	A	36
0.3	FGD-100	9E	A	36
0.2	FGD-100	9F	A	36
0	FGD-100	9H	A	36
0.6	FGD-100	9I	A	36
0	HO-0	14D	B	36
0	BDHO-60	15A	B	36
0.4	BDHO-60	15E	B	36
0.7	BDHO-60	15G	B	36
1.3	TA-0	17G	B	36
0.7	FGD-100	18B	B	36
0.7	FGD-100	18C	B	36
0.8	FGD-100	18E	B	36
0.6	FGD-100	18G	B	36
0.5	FGD-100	18I	B	36
0	HO-60	19A	B	36
0.7	HO-60	19B	B	36
0.5	HO-60	19D	B	36
1.7	HO-60	19E	B	36
0.5	HO-60	19F	B	36
1.5	BDHO-20	20A	B	36
0.6	BDHO-20	20D	B	36
2.5	BDHO-20	20G	B	36

0.2	BDHO-20	20I	B	36
1.6	HO-20	21B	B	36
1	HO-20	21C	B	36
0.3	HO-20	21F	B	36
0	HO-20	21G	B	36
3.3	HO-20	21J	B	36
0.8	BDHO-0	22J	B	36
0	BD-60	23A	B	36
0.2	BD-60	23D	B	36
0.1	BD-60	23E	B	36
1.8	BD-60	23F	B	36
0.5	BD-60	23I	B	36
0	BD-60	23J	B	36
0	BD-20	24B	B	36
1	BD-20	24C	B	36
0.2	BD-20	24E	B	36
0.7	BD-20	24G	B	36
0.4	BD-20	24H	B	36
0.1	TA-60	25E	B	36
0	TA-60	25F	B	36
0.5	TA-60	25H	B	36
0.2	TA-60	25I	B	36
0.7	TA-20	26G	B	36
0.6	BDHO-0	27H	C	36
0.2	BDHO-0	27J	C	36
0	TA-0	28C	C	36
0.3	TA-0	28D	C	36
0	TA-0	28H	C	36
0.1	BD-60	29B	C	36
0.4	BD-60	29E	C	36
0.3	BD-60	29H	C	36
0.6	BD-60	29J	C	36

0.4	FGD-100	30C	C	36
0.1	FGD-100	30F	C	36
0.2	FGD-100	30G	C	36
0.9	BD-20	31A	C	36
0	BD-20	31B	C	36
2	HO-60	32A	C	36
0	HO-60	32C	C	36
1	HO-60	32J	C	36
0.2	HO-0	33A	C	36
1.2	HO-0	33B	C	36
0.6	HO-0	33D	C	36
0.1	TA-20	34A	C	36
0.3	TA-20	34F	C	36
0.4	TA-20	34G	C	36
1.6	BD-0	35I	C	36
1.2	BD-0	35J	C	36
0	BDHO-60	36D	C	36
1.1	BDHO-60	36F	C	36
0.7	BDHO-60	36I	C	36
0	HO-20	37A	C	36
3.2	HO-20	37C	C	36
4	HO-20	37E	C	36
1.1	HO-20	37G	C	36
0	HO-20	37H	C	36
1.2	TA-60	38A	C	36
0.5	TA-60	38B	C	36
1.4	TA-60	38D	C	36
0.6	TA-60	38G	C	36
0	TA-60	38H	C	36
0.2	BDHO-20	39D	C	36
0.7	BDHO-20	39F	C	36
1.7	BDHO-20	39G	C	36

0	BDHO-20	39J	C	36
0	HO-0	40C	D	36
1.3	HO-0	40G	D	36
1.4	HO-20	41B	D	36
1.4	HO-20	41C	D	36
0	HO-20	41F	D	36
0	HO-20	41H	D	36
0.7	HO-60	42C	D	36
0.3	HO-60	42D	D	36
0	HO-60	42G	D	36
1.1	BDHO-20	43A	D	36
0.1	BDHO-20	43B	D	36
0	BDHO-20	43C	D	36
0	BDHO-20	43E	D	36
1.8	BDHO-20	43F	D	36
1.8	BDHO-20	43I	D	36
0.5	FGD-100	44B	D	36
0	FGD-100	44C	D	36
0.4	FGD-100	44E	D	36
0	FGD-100	44F	D	36
0	FGD-100	44G	D	36
0.1	BDHO-0	45D	D	36
0.3	BDHO-0	45E	D	36
0.2	BDHO-0	45H	D	36
0.9	BDHO-0	45I	D	36
0.9	TA-20	46A	D	36
0.2	BDHO-60	47A	D	36
0	BDHO-60	47D	D	36
0.2	BDHO-60	47G	D	36
0.2	BDHO-60	47J	D	36
0.4	BD-0	48F	D	36
0	TA-0	49I	D	36

0.5	BD-60	50A	D	36
0.2	BD-60	50C	D	36
0	BD-60	50G	D	36
0.2	TA-60	51A	D	36
1.1	TA-60	51B	D	36
0.8	TA-60	51C	D	36
0.3	TA-60	51F	D	36
0.2	TA-60	51I	D	36
0.2	BD-20	52C	D	36
0.4	BD-20	52H	D	36
0.3	BD-60	10D	A	43
0	BD-60	10H	A	43
0.8	HO-0	11G	A	43
0	TA-60	12A	A	43
0.6	TA-60	12B	A	43
0.2	TA-60	12F	A	43
0.8	TA-60	12G	A	43
1.5	TA-60	12I	A	43
0.7	BDHO-60	13E	A	43
1.2	BDHO-60	13F	A	43
1.1	BDHO-60	13G	A	43
2.5	BDHO-20	1D	A	43
0.9	BDHO-20	1E	A	43
0.9	BDHO-20	1J	A	43
0.1	HO-60	2H	A	43
0.7	HO-60	2I	A	43
0.6	HO-60	2J	A	43
1	HO-20	3A	A	43
1.7	HO-20	3B	A	43
1.6	HO-20	3C	A	43
0.5	HO-20	3I	A	43
0.6	TA-20	4D	A	43

0	TA-20	4E	A	43
0.3	TA-20	4I	A	43
0.6	BDHO-0	5C	A	43
0.9	BDHO-0	5D	A	43
0	BDHO-0	5E	A	43
1.2	BDHO-0	5F	A	43
3.2	BDHO-0	5G	A	43
0	BDHO-0	5H	A	43
0.6	BD-20	6D	A	43
0.6	BD-20	6I	A	43
0.6	BD-0	7F	A	43
0.3	BD-0	7J	A	43
0.7	FGD-100	9C	A	43
0.3	FGD-100	9E	A	43
0.4	FGD-100	9F	A	43
0.2	FGD-100	9H	A	43
0.5	FGD-100	9I	A	43
0	HO-0	14D	B	43
0	BDHO-60	15A	B	43
0.4	BDHO-60	15E	B	43
0.8	BDHO-60	15G	B	43
1.4	TA-0	17G	B	43
0.7	FGD-100	18B	B	43
0.9	FGD-100	18C	B	43
0.9	FGD-100	18E	B	43
0.7	FGD-100	18G	B	43
0.4	FGD-100	18I	B	43
0.1	HO-60	19A	B	43
0.8	HO-60	19B	B	43
0.7	HO-60	19D	B	43
1.8	HO-60	19E	B	43
0.8	HO-60	19F	B	43

2	BDHO-20	20A	B	43
1	BDHO-20	20D	B	43
3.5	BDHO-20	20G	B	43
0.6	BDHO-20	20I	B	43
2	HO-20	21B	B	43
1.6	HO-20	21C	B	43
0.6	HO-20	21F	B	43
0	HO-20	21G	B	43
3.6	HO-20	21J	B	43
1.3	BDHO-0	22J	B	43
0.1	BD-60	23A	B	43
0.4	BD-60	23D	B	43
0.5	BD-60	23E	B	43
2	BD-60	23F	B	43
0.5	BD-60	23I	B	43
0.1	BD-60	23J	B	43
0	BD-20	24B	B	43
1	BD-20	24C	B	43
0.2	BD-20	24E	B	43
0.8	BD-20	24G	B	43
0.4	BD-20	24H	B	43
0.2	TA-60	25E	B	43
0	TA-60	25F	B	43
0.6	TA-60	25H	B	43
0.5	TA-60	25I	B	43
0.6	TA-20	26G	B	43
2.7	BDHO-0	27H	C	43
1.9	BDHO-0	27J	C	43
0	TA-0	28C	C	43
0.6	TA-0	28D	C	43
0	TA-0	28H	C	43
0.3	BD-60	29B	C	43

0.5	BD-60	29E	C	43
0.4	BD-60	29H	C	43
0.6	BD-60	29J	C	43
0.4	FGD-100	30C	C	43
0.3	FGD-100	30F	C	43
0.2	FGD-100	30G	C	43
0.9	BD-20	31A	C	43
0	BD-20	31B	C	43
2.1	HO-60	32A	C	43
0.1	HO-60	32C	C	43
1	HO-60	32J	C	43
1.4	HO-0	33A	C	43
2.7	HO-0	33B	C	43
1.5	HO-0	33D	C	43
0.2	TA-20	34A	C	43
0.3	TA-20	34F	C	43
0.6	TA-20	34G	C	43
1.6	BD-0	35I	C	43
1.2	BD-0	35J	C	43
0	BDHO-60	36D	C	43
1.4	BDHO-60	36F	C	43
0.8	BDHO-60	36I	C	43
0.5	HO-20	37A	C	43
3.7	HO-20	37C	C	43
4.3	HO-20	37E	C	43
1.6	HO-20	37G	C	43
0	HO-20	37H	C	43
1.2	TA-60	38A	C	43
0.6	TA-60	38B	C	43
1.4	TA-60	38D	C	43
0.5	TA-60	38G	C	43
0.6	TA-60	38H	C	43

0.7	BDHO-20	39D	C	43
1.3	BDHO-20	39F	C	43
2.2	BDHO-20	39G	C	43
0	BDHO-20	39J	C	43
0	HO-0	40C	D	43
2.9	HO-0	40G	D	43
2.7	HO-20	41B	D	43
3.6	HO-20	41C	D	43
0	HO-20	41F	D	43
0	HO-20	41H	D	43
0.8	HO-60	42C	D	43
0.4	HO-60	42D	D	43
0	HO-60	42G	D	43
1.4	BDHO-20	43A	D	43
0.8	BDHO-20	43B	D	43
0	BDHO-20	43C	D	43
0	BDHO-20	43E	D	43
0.7	BDHO-20	43F	D	43
3.8	BDHO-20	43I	D	43
0.5	FGD-100	44B	D	43
0.1	FGD-100	44C	D	43
0.4	FGD-100	44E	D	43
0	FGD-100	44F	D	43
0.1	FGD-100	44G	D	43
1.1	BDHO-0	45D	D	43
1.3	BDHO-0	45E	D	43
0.9	BDHO-0	45H	D	43
2.3	BDHO-0	45I	D	43
1	TA-20	46A	D	43
0.3	BDHO-60	47A	D	43
0.2	BDHO-60	47D	D	43
0.3	BDHO-60	47G	D	43

0.3	BDHO-60	47J	D	43
0.4	BD-0	48F	D	43
0.1	TA-0	49I	D	43
0.6	BD-60	50A	D	43
0.3	BD-60	50C	D	43
0	BD-60	50G	D	43
0.2	TA-60	51A	D	43
1.3	TA-60	51B	D	43
0.8	TA-60	51C	D	43
0.3	TA-60	51F	D	43
0.2	TA-60	51I	D	43
0.4	BD-20	52C	D	43
0.7	BD-20	52H	D	43
0.4	BD-60	10D	A	50
0	BD-60	10H	A	50
1.1	HO-0	11G	A	50
0	TA-60	12A	A	50
0.7	TA-60	12B	A	50
0.2	TA-60	12F	A	50
0.9	TA-60	12G	A	50
1.3	TA-60	12I	A	50
1	BDHO-60	13E	A	50
1.4	BDHO-60	13F	A	50
1.3	BDHO-60	13G	A	50
3.7	BDHO-20	1D	A	50
1.3	BDHO-20	1E	A	50
1.3	BDHO-20	1J	A	50
0.1	HO-60	2H	A	50
0.8	HO-60	2I	A	50
0.9	HO-60	2J	A	50
1.3	HO-20	3A	A	50
2.3	HO-20	3B	A	50

2	HO-20	3C	A	50
0.7	HO-20	3I	A	50
0.6	TA-20	4D	A	50
0	TA-20	4E	A	50
0.3	TA-20	4I	A	50
2.5	BDHO-0	5C	A	50
1.5	BDHO-0	5D	A	50
0	BDHO-0	5E	A	50
2.7	BDHO-0	5F	A	50
5.7	BDHO-0	5G	A	50
0.1	BDHO-0	5H	A	50
0.6	BD-20	6D	A	50
0.6	BD-20	6I	A	50
0.6	BD-0	7F	A	50
0.4	BD-0	7J	A	50
0.6	FGD-100	9C	A	50
0.2	FGD-100	9E	A	50
0.5	FGD-100	9F	A	50
0.3	FGD-100	9H	A	50
0.5	FGD-100	9I	A	50
0	HO-0	14D	B	50
0	BDHO-60	15A	B	50
0.6	BDHO-60	15E	B	50
1	BDHO-60	15G	B	50
1.4	TA-0	17G	B	50
0.7	FGD-100	18B	B	50
0.9	FGD-100	18C	B	50
1	FGD-100	18E	B	50
0.7	FGD-100	18G	B	50
0.4	FGD-100	18I	B	50
0.4	HO-60	19A	B	50
0.9	HO-60	19B	B	50

0.8	HO-60	19D	B	50
1.8	HO-60	19E	B	50
0.9	HO-60	19F	B	50
3.2	BDHO-20	20A	B	50
1.7	BDHO-20	20D	B	50
5.1	BDHO-20	20G	B	50
0.9	BDHO-20	20I	B	50
2.5	HO-20	21B	B	50
2.6	HO-20	21C	B	50
1	HO-20	21F	B	50
0	HO-20	21G	B	50
4.2	HO-20	21J	B	50
2.2	BDHO-0	22J	B	50
0.3	BD-60	23A	B	50
0.6	BD-60	23D	B	50
0.7	BD-60	23E	B	50
2.1	BD-60	23F	B	50
0.6	BD-60	23I	B	50
0.4	BD-60	23J	B	50
0.1	BD-20	24B	B	50
1.1	BD-20	24C	B	50
0.3	BD-20	24E	B	50
1	BD-20	24G	B	50
0.5	BD-20	24H	B	50
0.2	TA-60	25E	B	50
0.5	TA-60	25F	B	50
0.6	TA-60	25H	B	50
0.9	TA-60	25I	B	50
0.7	TA-20	26G	B	50
4.8	BDHO-0	27H	C	50
3.6	BDHO-0	27J	C	50
0	TA-0	28C	C	50

0.7	TA-0	28D	C	50
0.1	TA-0	28H	C	50
0.5	BD-60	29B	C	50
0.6	BD-60	29E	C	50
0.5	BD-60	29H	C	50
0.7	BD-60	29J	C	50
0.4	FGD-100	30C	C	50
0.4	FGD-100	30F	C	50
0.2	FGD-100	30G	C	50
1	BD-20	31A	C	50
0	BD-20	31B	C	50
2.2	HO-60	32A	C	50
0	HO-60	32C	C	50
1.1	HO-60	32J	C	50
2	HO-0	33A	C	50
3.9	HO-0	33B	C	50
2	HO-0	33D	C	50
0.3	TA-20	34A	C	50
0.3	TA-20	34F	C	50
0.8	TA-20	34G	C	50
1.5	BD-0	35I	C	50
1.2	BD-0	35J	C	50
0.1	BDHO-60	36D	C	50
1.4	BDHO-60	36F	C	50
0.8	BDHO-60	36I	C	50
0.6	HO-20	37A	C	50
3.9	HO-20	37C	C	50
4.4	HO-20	37E	C	50
1.8	HO-20	37G	C	50
0.1	HO-20	37H	C	50
1.2	TA-60	38A	C	50
0.7	TA-60	38B	C	50

1.4	TA-60	38D	C	50
0.5	TA-60	38G	C	50
0.6	TA-60	38H	C	50
1.7	BDHO-20	39D	C	50
3	BDHO-20	39F	C	50
3.5	BDHO-20	39G	C	50
0	BDHO-20	39J	C	50
0.4	HO-0	40C	D	50
4.7	HO-0	40G	D	50
3.7	HO-20	41B	D	50
4.9	HO-20	41C	D	50
0.6	HO-20	41F	D	50
0.4	HO-20	41H	D	50
0.9	HO-60	42C	D	50
0.5	HO-60	42D	D	50
0.2	HO-60	42G	D	50
1.8	BDHO-20	43A	D	50
1.2	BDHO-20	43B	D	50
0.7	BDHO-20	43C	D	50
0.6	BDHO-20	43E	D	50
4	BDHO-20	43F	D	50
6.9	BDHO-20	43I	D	50
0.5	FGD-100	44B	D	50
0.1	FGD-100	44C	D	50
0.5	FGD-100	44E	D	50
0	FGD-100	44F	D	50
0.1	FGD-100	44G	D	50
3.5	BDHO-0	45D	D	50
4	BDHO-0	45E	D	50
3.9	BDHO-0	45H	D	50
6.1	BDHO-0	45I	D	50
1	TA-20	46A	D	50

0.3	BDHO-60	47A	D	50
0.2	BDHO-60	47D	D	50
0.3	BDHO-60	47G	D	50
0.5	BDHO-60	47J	D	50
0.4	BD-0	48F	D	50
0.1	TA-0	49I	D	50
0.6	BD-60	50A	D	50
0.3	BD-60	50C	D	50
0.2	BD-60	50G	D	50
0.2	TA-60	51A	D	50
1.2	TA-60	51B	D	50
0.7	TA-60	51C	D	50
0.6	TA-60	51F	D	50
0.3	TA-60	51I	D	50
0.4	BD-20	52C	D	50
0.8	BD-20	52H	D	50
0.5	BD-60	10D	A	57
0	BD-60	10H	A	57
1.7	HO-0	11G	A	57
0	TA-60	12A	A	57
0.6	TA-60	12B	A	57
0.3	TA-60	12F	A	57
0.9	TA-60	12G	A	57
1.4	TA-60	12I	A	57
1	BDHO-60	13E	A	57
1.6	BDHO-60	13F	A	57
1.3	BDHO-60	13G	A	57
5.3	BDHO-20	1D	A	57
1.2	BDHO-20	1E	A	57
1.6	BDHO-20	1J	A	57
0.2	HO-60	2H	A	57
1	HO-60	2I	A	57

0.9	HO-60	2J	A	57
0.7	HO-20	3A	A	57
3	HO-20	3B	A	57
2.6	HO-20	3C	A	57
1.2	HO-20	3I	A	57
0.7	TA-20	4D	A	57
0	TA-20	4E	A	57
0.2	TA-20	4I	A	57
3.4	BDHO-0	5C	A	57
1.7	BDHO-0	5D	A	57
0	BDHO-0	5E	A	57
3.5	BDHO-0	5F	A	57
6.8	BDHO-0	5G	A	57
0.6	BDHO-0	5H	A	57
0.7	BD-20	6D	A	57
0.7	BD-20	6I	A	57
0.5	BD-0	7F	A	57
0.2	BD-0	7J	A	57
0.6	FGD-100	9C	A	57
0.2	FGD-100	9E	A	57
0.6	FGD-100	9F	A	57
0.3	FGD-100	9H	A	57
0.5	FGD-100	9I	A	57
0.4	HO-0	14D	B	57
0.1	BDHO-60	15A	B	57
0.7	BDHO-60	15E	B	57
0.9	BDHO-60	15G	B	57
1.4	TA-0	17G	B	57
0.8	FGD-100	18B	B	57
1	FGD-100	18C	B	57
1	FGD-100	18E	B	57
0.7	FGD-100	18G	B	57

0.4	FGD-100	18I	B	57
0.8	HO-60	19A	B	57
0.9	HO-60	19B	B	57
0.8	HO-60	19D	B	57
2	HO-60	19E	B	57
0.9	HO-60	19F	B	57
4.5	BDHO-20	20A	B	57
3.8	BDHO-20	20D	B	57
6.5	BDHO-20	20G	B	57
1.3	BDHO-20	20I	B	57
3.2	HO-20	21B	B	57
3.9	HO-20	21C	B	57
2	HO-20	21F	B	57
0.1	HO-20	21G	B	57
5.8	HO-20	21J	B	57
3.4	BDHO-0	22J	B	57
0.5	BD-60	23A	B	57
0.6	BD-60	23D	B	57
0.6	BD-60	23E	B	57
2.2	BD-60	23F	B	57
0.6	BD-60	23I	B	57
0.5	BD-60	23J	B	57
0.2	BD-20	24B	B	57
1.4	BD-20	24C	B	57
0.3	BD-20	24E	B	57
1.3	BD-20	24G	B	57
0.5	BD-20	24H	B	57
0.2	TA-60	25E	B	57
0.7	TA-60	25F	B	57
0.7	TA-60	25H	B	57
0.9	TA-60	25I	B	57
0.7	TA-20	26G	B	57

5.7	BDHO-0	27H	C	57
4.6	BDHO-0	27J	C	57
0.1	TA-0	28C	C	57
0.8	TA-0	28D	C	57
0.2	TA-0	28H	C	57
0.7	BD-60	29B	C	57
0.6	BD-60	29E	C	57
0.5	BD-60	29H	C	57
0.8	BD-60	29J	C	57
0.3	FGD-100	30C	C	57
0.4	FGD-100	30F	C	57
0.2	FGD-100	30G	C	57
1.1	BD-20	31A	C	57
0	BD-20	31B	C	57
2.4	HO-60	32A	C	57
0	HO-60	32C	C	57
1.2	HO-60	32J	C	57
2.6	HO-0	33A	C	57
4.9	HO-0	33B	C	57
2.2	HO-0	33D	C	57
0.4	TA-20	34A	C	57
0.3	TA-20	34F	C	57
0.8	TA-20	34G	C	57
1.6	BD-0	35I	C	57
1.3	BD-0	35J	C	57
0.1	BDHO-60	36D	C	57
1.3	BDHO-60	36F	C	57
0.8	BDHO-60	36I	C	57
0.8	HO-20	37A	C	57
4.1	HO-20	37C	C	57
4.4	HO-20	37E	C	57
2	HO-20	37G	C	57

0.1	HO-20	37H	C	57
1.2	TA-60	38A	C	57
0.8	TA-60	38B	C	57
1.5	TA-60	38D	C	57
0.6	TA-60	38G	C	57
0.9	TA-60	38H	C	57
2.2	BDHO-20	39D	C	57
4.9	BDHO-20	39F	C	57
5.1	BDHO-20	39G	C	57
0	BDHO-20	39J	C	57
1.1	HO-0	40C	D	57
5.8	HO-0	40G	D	57
4.8	HO-20	41B	D	57
6	HO-20	41C	D	57
1.5	HO-20	41F	D	57
0.7	HO-20	41H	D	57
0.9	HO-60	42C	D	57
0.6	HO-60	42D	D	57
0.5	HO-60	42G	D	57
2.1	BDHO-20	43A	D	57
1.4	BDHO-20	43B	D	57
1.2	BDHO-20	43C	D	57
0.9	BDHO-20	43E	D	57
4.4	BDHO-20	43F	D	57
8.1	BDHO-20	43I	D	57
0.6	FGD-100	44B	D	57
0.2	FGD-100	44C	D	57
0.6	FGD-100	44E	D	57
0	FGD-100	44F	D	57
0.1	FGD-100	44G	D	57
5.5	BDHO-0	45D	D	57
6	BDHO-0	45E	D	57

4.5	BDHO-0	45H	D	57
9.3	BDHO-0	45I	D	57
1.1	TA-20	46A	D	57
0.4	BDHO-60	47A	D	57
0.2	BDHO-60	47D	D	57
0.3	BDHO-60	47G	D	57
0.5	BDHO-60	47J	D	57
0	BD-0	48F	D	57
0	TA-0	49I	D	57
0.7	BD-60	50A	D	57
0.4	BD-60	50C	D	57
0.5	BD-60	50G	D	57
0.2	TA-60	51A	D	57
1.2	TA-60	51B	D	57
0.8	TA-60	51C	D	57
0.6	TA-60	51F	D	57
0.3	TA-60	51I	D	57
0.2	BD-20	52C	D	57
1.1	BD-20	52H	D	57
0.5	BD-60	10D	A	65
0.1	BD-60	10H	A	65
3.4	HO-0	11G	A	65
0.1	TA-60	12A	A	65
0.7	TA-60	12B	A	65
0.2	TA-60	12F	A	65
1	TA-60	12G	A	65
1.4	TA-60	12I	A	65
1	BDHO-60	13E	A	65
1.7	BDHO-60	13F	A	65
1.3	BDHO-60	13G	A	65
7.3	BDHO-20	1D	A	65
1.6	BDHO-20	1E	A	65

1.9	BDHO-20	1J	A	65
0.4	HO-60	2H	A	65
1.2	HO-60	2I	A	65
1.2	HO-60	2J	A	65
3.5	HO-20	3A	A	65
5.1	HO-20	3B	A	65
4.8	HO-20	3C	A	65
2.5	HO-20	3I	A	65
0.7	TA-20	4D	A	65
0.2	TA-20	4E	A	65
0.2	TA-20	4I	A	65
5.8	BDHO-0	5C	A	65
2.2	BDHO-0	5D	A	65
0.9	BDHO-0	5E	A	65
3	BDHO-0	5F	A	65
7.9	BDHO-0	5G	A	65
2.9	BDHO-0	5H	A	65
0.3	BD-20	6D	A	65
1.1	BD-20	6I	A	65
0.5	BD-0	7F	A	65
0.3	BD-0	7J	A	65
0.7	FGD-100	9C	A	65
0.3	FGD-100	9E	A	65
0.7	FGD-100	9F	A	65
0.3	FGD-100	9H	A	65
0.7	FGD-100	9I	A	65
1.9	HO-0	14D	B	65
0.5	BDHO-60	15A	B	65
0.8	BDHO-60	15E	B	65
1.2	BDHO-60	15G	B	65
1.5	TA-0	17G	B	65
0.7	FGD-100	18B	B	65

1	FGD-100	18C	B	65
0.9	FGD-100	18E	B	65
0.7	FGD-100	18G	B	65
0.6	FGD-100	18I	B	65
1.9	HO-60	19A	B	65
1.2	HO-60	19B	B	65
1	HO-60	19D	B	65
2	HO-60	19E	B	65
1.3	HO-60	19F	B	65
6.8	BDHO-20	20A	B	65
5	BDHO-20	20D	B	65
10.4	BDHO-20	20G	B	65
3.7	BDHO-20	20I	B	65
6.2	HO-20	21B	B	65
7	HO-20	21C	B	65
4.9	HO-20	21F	B	65
1.1	HO-20	21G	B	65
8.3	HO-20	21J	B	65
6.1	BDHO-0	22J	B	65
0.6	BD-60	23A	B	65
0.7	BD-60	23D	B	65
0.7	BD-60	23E	B	65
2.4	BD-60	23F	B	65
0.7	BD-60	23I	B	65
0.5	BD-60	23J	B	65
0.4	BD-20	24B	B	65
1.6	BD-20	24C	B	65
0.4	BD-20	24E	B	65
1.4	BD-20	24G	B	65
0.6	BD-20	24H	B	65
0.2	TA-60	25E	B	65
0.8	TA-60	25F	B	65

0.9	TA-60	25H	B	65
1	TA-60	25I	B	65
0.8	TA-20	26G	B	65
9	BDHO-0	27H	C	65
7.6	BDHO-0	27J	C	65
0.2	TA-0	28C	C	65
0.9	TA-0	28D	C	65
0.3	TA-0	28H	C	65
0.8	BD-60	29B	C	65
0.7	BD-60	29E	C	65
0.6	BD-60	29H	C	65
0.8	BD-60	29J	C	65
0.4	FGD-100	30C	C	65
0.5	FGD-100	30F	C	65
0.3	FGD-100	30G	C	65
1.2	BD-20	31A	C	65
0.1	BD-20	31B	C	65
2.6	HO-60	32A	C	65
0.3	HO-60	32C	C	65
1.3	HO-60	32J	C	65
4.8	HO-0	33A	C	65
6.9	HO-0	33B	C	65
3	HO-0	33D	C	65
0.5	TA-20	34A	C	65
0.3	TA-20	34F	C	65
0.9	TA-20	34G	C	65
1.6	BD-0	35I	C	65
1.2	BD-0	35J	C	65
0.2	BDHO-60	36D	C	65
1.4	BDHO-60	36F	C	65
0.8	BDHO-60	36I	C	65
0.9	HO-20	37A	C	65

4.6	HO-20	37C	C	65
4.5	HO-20	37E	C	65
2.4	HO-20	37G	C	65
0.1	HO-20	37H	C	65
1.2	TA-60	38A	C	65
0.8	TA-60	38B	C	65
1.5	TA-60	38D	C	65
0.5	TA-60	38G	C	65
1	TA-60	38H	C	65
3.4	BDHO-20	39D	C	65
6.8	BDHO-20	39F	C	65
7.4	BDHO-20	39G	C	65
0.5	BDHO-20	39J	C	65
2.6	HO-0	40C	D	65
7.5	HO-0	40G	D	65
7.7	HO-20	41B	D	65
8.6	HO-20	41C	D	65
3.8	HO-20	41F	D	65
1.9	HO-20	41H	D	65
1	HO-60	42C	D	65
0.6	HO-60	42D	D	65
0.7	HO-60	42G	D	65
3.9	BDHO-20	43A	D	65
3	BDHO-20	43B	D	65
2.3	BDHO-20	43C	D	65
1.8	BDHO-20	43E	D	65
5.5	BDHO-20	43F	D	65
11.3	BDHO-20	43I	D	65
0.5	FGD-100	44B	D	65
0.2	FGD-100	44C	D	65
0.7	FGD-100	44E	D	65
0.2	FGD-100	44F	D	65

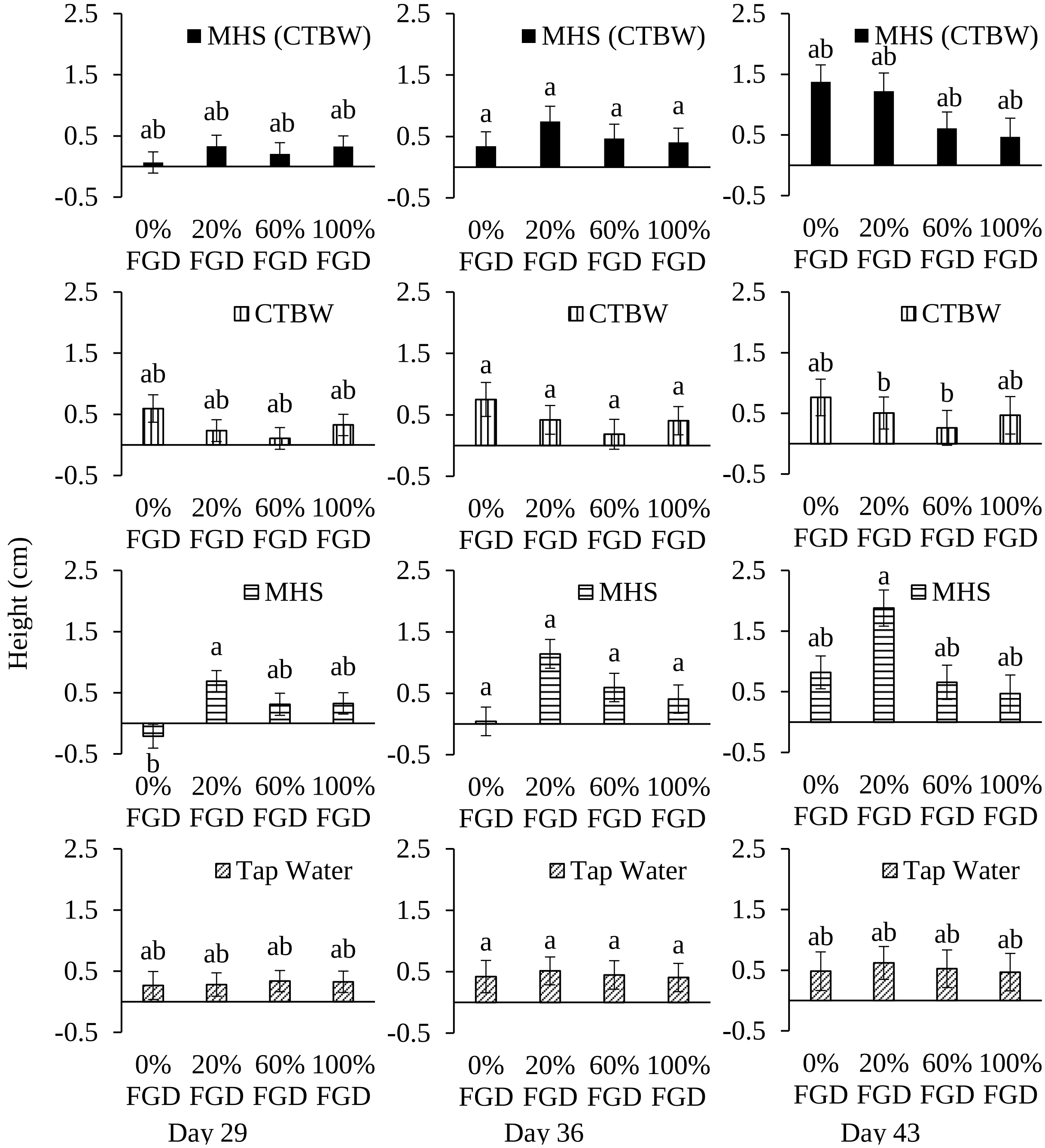
0.1	FGD-100	44G	D	65
8.3	BDHO-0	45D	D	65
9.2	BDHO-0	45E	D	65
7.1	BDHO-0	45H	D	65
12.9	BDHO-0	45I	D	65
1.1	TA-20	46A	D	65
0.5	BDHO-60	47A	D	65
0.2	BDHO-60	47D	D	65
0.2	BDHO-60	47G	D	65
0.5	BDHO-60	47J	D	65
0.5	BD-0	48F	D	65
0.2	TA-0	49I	D	65
0.7	BD-60	50A	D	65
0.4	BD-60	50C	D	65
0.6	BD-60	50G	D	65
0.1	TA-60	51A	D	65
1.3	TA-60	51B	D	65
0.8	TA-60	51C	D	65
0.6	TA-60	51F	D	65
0.3	TA-60	51I	D	65
0.2	BD-20	52C	D	65
1.2	BD-20	52H	D	65

See **Error! Reference source not found.** for reference for treatment ID

Appendix K - Height SAS Code

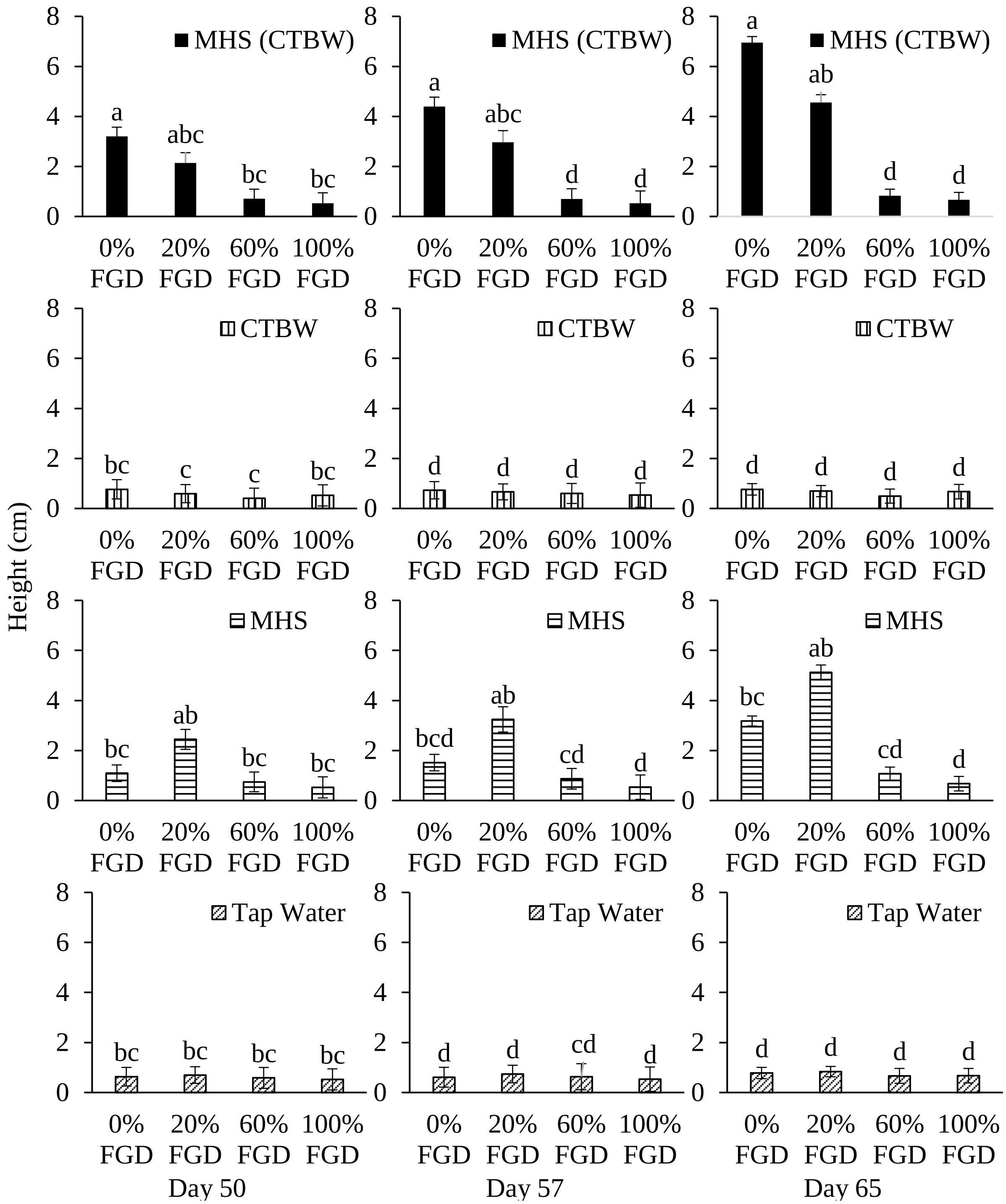
```
proc import datafile="C:\Users\Stat Login\Desktop\garmination\Height.xlsx"
out= height
DBMS=xlsx
replace;
Getnames=yes;
sheet='Measurable Plants';
*range='SAS Analysisa1:c61';
run;
proc glimmix data=height  plot=studentpanel;;
class Treatment ID Block Day;
model Plant_Height= Treatment|Day /ddfm=kr;
random block;
random _residual_/subject=block*Treatment;
lsmeans Treatment/adjust=tukey pdiff;
lsmeans Treatment*Day/slicediff=Day adjust=bon plot=meanplot(join sliceby=Treatment);
nloptions tech=nrridg;
run;
```

Appendix L - Height Results



FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure L.1. Height charts day 43-29. Error bars indicate standard error and letters denote significant differences among treatments on a given day based on Bonferroni test (P<0.05)).



FGD: Flue Gas Desulfurization Wastewater; MHS: Modified Hoagland's Solution; CTBW: Cooling Tower Blowdown Water

Figure L.2 Height Charts day 50-65. Error bars indicate standard error and letters denote significant differences among treatments on a given day based on Bonferroni test (P<0.05)).

Appendix M - Absorbance Data

Table M.1 Absorbance of treatment samples (Day 7-21)

	Day	7		14		21
	Wavelength	664 nm	750 nm	664 nm	750 nm	664 nm
Sample	Treatment	- - - - - - - - - - - - - -		absorbance	- - - - - - - - - - - - - -	
1	BDHO-20	-0.023	-0.017	-0.019	-0.021	0.039
2	HO-60	-0.014	-0.023	-0.017	-0.018	0.311
3	HO-20	-0.029	-0.01	-0.029	-0.021	-0.019
4	TA-20	-0.03	-0.024	-0.026	-0.022	0.069
5	BDHO-0	-0.022	-0.014	0.011	-0.021	0.04
6	BD-20	-0.024	-0.015	0.199	-0.023	0.022
7	BD-0	-0.16	-0.018	-0.026	-0.015	-0.019
8	TA-0	-0.03	-0.021	-0.022	0.008	0.095
9	FGD-100	0.167	-0.017	-0.024	0.019	0.018
10	BD-60	-0.03	-0.006	0.227	0.01	0.614
11	HO-0	-0.03	-0.019	-0.011	-0.009	0.064
12	TA-60	-0.03	-0.014	-0.021	0.105	0.128
13	BDHO-60	0.032	-0.012	-0.026	-0.017	0.504
14	HO-0	0.06	-0.014	0.04	-0.019	0.148
15	BDHO-60	-0.027	-0.004	0.234	-0.013	0.23
16	BD-0	-0.022	-0.02	0.058	-0.012	0.009
17	TA-0	-0.03	-0.011	-0.006	-0.009	0.044
18	FGD-100	-0.031	-0.019	-0.028	0.614	0.697
19	HO-60	-0.012	-0.018	0.252	-0.019	2.021
20	BDHO-20	-0.026	-0.006	0.325	-0.021	0.445
21	HO-20	-0.031	-0.017	0.027	-0.022	0.182
22	BDHO-0	-0.021	0.014	0.1	0.004	0.415
23	BD-60	-0.03	-0.019	-0.019	-0.022	0.327
24	BD-20	-0.018	-0.016	-0.011	-0.021	0.008
25	TA-60	-0.03	-0.012	-0.019	0.026	0.04
26	TA-20	-0.03	-0.013	0.192	-0.018	0.398

27	BDHO-0	-0.019	-0.007	0.241	0.378	0.901
28	TA-0	-0.03	-0.016	-0.019	-0.022	-0.013
29	BD-60	-0.03	-0.018	0.095	0.003	0.557
30	FGD-100	-0.031	-0.017	-0.028	0.141	0.163
31	BD-20	-0.02	-0.017	-0.002	-0.022	0.17
32	HO-60	-0.03	-0.023	0.16	-0.005	2.596
33	HO-0	-0.031	-0.017	0.032	-0.01	0.117
34	TA-20	-0.029	-0.016	-0.018	-0.02	0.27
35	BD-0	-0.015	-0.015	0.034	0.047	0.115
36	BDHO-60	-0.028	-0.016	0.072	0.012	0.698
37	HO-20	-0.03	-0.017	0.007	-0.009	2.197
38	TA-60	-0.031	-0.019	-0.003	-0.012	0.046
39	BDHO-20	-0.023	-0.016	0.289	-0.014	0.674
40	HO-0	-0.031	-0.021	-0.028	-0.022	0.031
41	HO-20	-0.028	-0.012	-0.029	-0.018	0.104
42	HO-60	-0.031	-0.005	0.004	-0.018	0.581
43	BDHO-20	-0.028	-0.017	0.075	0.054	0.913
44	FGD-100	-0.027	-0.019	-0.022	0.107	0.112
45	BDHO-0	-0.019	-0.019	-0.025	0.662	0.921
46	TA-20	-0.029	-0.019	0.033	-0.017	-0.012
47	BDHO-60	-0.03	-0.024	0.089	-0.014	0.556
48	BD-0	-0.021	-0.022	-0.027	-0.006	0.155
49	TA-0	-0.03	-0.02	-0.023	-0.024	0.008
50	BD-60	-0.03	-0.02	0.045	0.004	0.536
51	TA-60	-0.03	-0.021	-0.028	-0.024	0.042
52	BD-20	-0.023	-0.02	0.027	-0.023	0.083

See **Error! Reference source not found.** for reference for treatment ID

Appendix N - Absorbance SAS Code

Day 07

```
proc import datafile="/home/erica120/sasuser.v94/Research/Data_chl.xlsx"
out= Chlorophyll07
DBMS=xlsx
replace;
Getnames=yes;
sheet='07';
*absorbance data from day 07;
run;
proc glimmix data=Chlorophyll07 plots=studentpanel;
class Trt;
model b=Trt/ ddf=36;
*Effect of Treatment on Absorbance at 664nm on day 7;
run;
```

Day 14

```
proc import datafile="/home/erica120/sasuser.v94/Research/Data_chl.xlsx"
out= Chlorophyll14
DBMS=xlsx
replace;
Getnames=yes;
sheet='14';
*absorbance data from day 14;
run;
proc glimmix data=Chlorophyll14 plots=studentpanel;
class Trt;
model a=Trt/ ddf=36;
* Effect of Treatment on Absorbance at 750 nm on day 14;
run;
```

```
proc glimmix data=Chlorophyll14 plots=studentpanel;
class Trt;
model b=Trt/ ddf=36;
* Effect of Treatment on Absorbance at 664 nm on day 14;
run;
```

Day 21

```
proc import datafile="/home/erica120/sasuser.v94/Research/Data_chl.xlsx"
out= Chlorophyll21
DBMS=xlsx
replace;
Getnames=yes;
sheet='21';
*absorbance data from day 21;
run;
proc glimmix data=Chlorophyll21 plots=studentpanel;
class Trt;
model a=Trt/ ddf=36;
lsmeans Trt/adjust=tukey pdiff;
* Effect of Treatment on Absorbance at 750 nm on day 21;
run;
proc glimmix data=Chlorophyll21 plots=studentpanel;
class Trt;
model b=Trt/ ddf=36;
lsmeans Trt/adjust=tukey pdiff;
* Effect of Treatment on Absorbance at 664 nm on day 21;
run;
```

Appendix O - Treatment Photos

MHS-0% FGD

MHS-20% FGD

MHS-60% FGD

100% FGD

MHS (CTBW)-0% FGD

MHS (CTBW)-20% FGD

MHS (CTBW)-60% FGD

100% FGD

CTBW-0% FGD

CTBW-20% FGD

CTBW-60% FGD

100% FGD

Tap Water-0% FGD

Tap Water--20% FGD

Tap Water--60% FGD

100% FGD

Appendix P - Biomass Composition Data

Table P.1 Biomass composition data

Treatment	Month	Extractive	Glucan	Xylan	Arabinan	Lignin	Ash
		- - - - - - - - - g/100 g DM- - - - - - - - -					
100 Brackish	1	59.48	10.33	9.09	3.94	7.49	0.08
		59.48	9.55	8.32	3.35	7.49	0.03
	2	60.98	9.78	8.50	3.00	7.71	0.41
		60.98	9.81	8.56	3.00	8.00	0.35
100 FGD	1	56.52	11.68	10.05	4.22	8.25	0.06
		56.52	11.06	9.12	3.68	8.22	0.03
	2	57.81	10.25	8.79	8.79	8.37	0.41
		57.81	10.43	8.87	4.08	8.54	0.38
100 Tap	1	48.43	13.40	11.79	4.94	9.35	0.02
		48.43	13.48	11.62	4.42	9.29	0.04
	2	46.43	14.91	13.23	5.24	9.73	0.39
		46.43	13.98	12.39	4.44	9.81	0.43
50/50 MHS & Brackish	1	62.47	9.54	7.07	2.82	6.59	0.01
		62.47	9.38	7.53	2.41	6.23	0.03
	2	62.88	9.08	6.69	2.69	7.02	0.23
		62.88	9.32	7.65	3.07	7.04	0.12
50/50 MHS & FGD	1	53.45	11.98	9.73	3.72	8.82	0.08
		53.45	11.92	9.68	3.83	9.11	0.02
	2	56.20	10.63	8.44	3.29	8.76	0.29
		56.20	11.33	9.46	3.61	8.54	0.23