PHYTOREMEDIATION CASE STUDY, MANHATTAN KANSAS

by

ASHLEY MARIE STIFFARM

B.S. Haskell Indian Nations University, 2012

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTERS OF SCIENCE

Department of Horticulture Forestry Recreation Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Approved by:

Major Professor
Dr. Charles Barden

Abstract

Contaminated water poses a major environmental and human health problem, which may be resolved by using the emerging phytoremediation technology. This plant-based cost-effective approach to remediation takes advantage of the ability of plants to concentrate elements and compounds from the environment, to absorb and transpire large amounts of water, and to metabolize various molecules in their tissues. The city of Manhattan's Biosolids Farm located near Manhattan, Kansas is using the emerging technology of phytoremediation. The Biosolids Farm remediation began in the mid 1990's; with a large planting of alfalfa with the goal of absorbing excess nitrates from soil and ground water. In 2004, hundreds of trees were planted, to serve as a protective buffer between the biosolids disposal area and the Kansas River. In 2006, a trench study was installed to improve tree establishment on a sandy outwash area close to the Kansas River using Siberian elm seedlings and rooted cottonwood cuttings from Nebraska and true cottonwood seedlings from Missouri. Treatments included trenching, dairy cattle composted manure, and tree shelters. This planting was done to serve as a vegetative barrier and to aid in reducing nitrate movement into the Kansas River. There were interaction between the tree sources and the trenching, compost and shelter treatments. The treatments showed significant interactions with tree sources with the addition of compost and shelters with a p value of 0.0438, and trenching and compost p-value 0.0021. Tree survival was significantly improved with the use of tree shelters.

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Acknowledgements

I would like to thank my major professor Dr. Barden and committee members Dr. Nelson, and Dr. Hutchinson. I would also like to think the city of Manhattan, KS workers for all of their help with this project.

Dedication

I dedicate all this hard work to my father, Larry Stiffarm and Mother, Becky Stiffarm.

Preface

This thesis is original, unpublished, independent work by the author, A. Stiffarm.

Chapter 1 - Introduction

Over centuries, human activities have had negative influences on the environment. Industrialization, mining and military activities as well as farming and waste disposal have contaminated environments with high concentrations of heavy metals and organic pollutants. In addition to their negative effects on ecosystems and other natural resources, these sites pose a great danger to public health, because pollutants can enter food through agricultural products or leaching into ground water (EC 2002; EEA 2003). Contamination of precious resources such as soil, water, air, and food sources can have devastating health and economic impacts.

Contaminated soils and water pose a major environmental and human health problem, which could be remediated through emerging phytoremediation technologies. Phytoremediation is an alternative or complimentary technology that can be used alongside, or in some cases in place of mechanical conventional clean-up technologies that often require high capital inputs and are labor and energy intensive. Phytoremediation is an in situ remediation technology that utilizes the inherent abilities of a living plant. It is ecologically friendly, solar-energy driven clean up technology, based on the concept of using nature to cleanse nature. Various research has documented the process of phytoremediation to improve contaminated water, both domestic and industrial waste water ranging from the use of micro-organisms, shrubs and trees (Hussein et al. 2004). When accessing groundwater contamination there are other things that need to be addressed, such as the conservation of the habitats surrounding the environment, the quality of water, the infiltration rate of the soil and potential for run off and soil erosion, and the hydrology of the area in general.

Groundwater

Groundwater is an essential, important natural resource that is mismanaged and over used. Figure 1.1 shows the total groundwater withdrawals from 2005 for the United States. This figure shows the amount of groundwater withdrawn from each state. The future and security of our ground water is uncomforting. It is definitely a resource that is taken for granted.

Groundwater is water located beneath the surface in soil pore spaces/voids and in permeable geological formations. Sources of groundwater include infiltration of precipitation on land surfaces, and water that flows through the aquifer (Robertson 1990). Groundwater is an "out of sight, out of mind" concept. Concepts of groundwater that are important to understand is, how it is part of the water cycle, and the importance of protecting and maintaining the quality and quantity of this water resource. In 2005, the United States Geological Survey, stated groundwater to be an important source of freshwater, making up 97 percent of the world's accessible freshwater reserves. In addition, about two billion people depend on groundwater for everyday needs (USGS, 2005). The importance of groundwater for the existence of human society cannot be overemphasized. Groundwater is the major source of drinking water in both urban and rural areas (Kelly, 2008; Foster, 2002). Not to mention it is an important source of water for the agricultural and the industrial sectors (Foster and Chiton, 1998). Figure 1.2 shows the different uses for groundwater extraction during the year of 2005.The largest amount of groundwater used is for irrigation at 53,500 million gallons per year, followed second by public supply at 14,600 million gallons per day. The least amount of groundwater withdrawn was for livestock at 1,290 million gallons per day. Groundwater is an important and vital part of the hydrological cycle, its availability depends on rainfall, withdrawals and recharge conditions. The demand for water has increased over the years and this has led to water scarcity in many parts of the world (USGS 2005). The situation is aggravated by the problem of water pollution or contamination. Together these factors make up the ground water crisis. The groundwater crisis is not the result of natural factors; it has been caused by human actions. Studies done by Harter (2003), from the University of California have supported evidence that in the past two decades; the water level in several parts of the country has been falling rapidly due to an increase in extraction. The number of wells drilled for irrigation and mining have rapidly and universally increased (Harter 2003). Intense competition among users — agriculture, industry, and domestic sectors — is driving the groundwater table lower (Frezze and Cherry 1979). The quality of groundwater is getting severely affected by widespread pollution from surface runoff, discharge of untreated waste water through bores and leachate, and from unscientific disposal of solid wastes. These issues reduce the quality of our fresh water resource.

Groundwater Contamination and Depletion

Groundwater is an integral part of the environment. There has been a lack of adequate consideration to water conservation, efficiency in water use, water re-use, groundwater recharge, and ecosystem sustainability (Narasimhan 2010). The causes of low groundwater availability in many regions are also directly linked to reductions is forest cover and soil degradation (Otten et al. 1997).

Pollution of groundwater resources has become a major problem today. The pollution of air, water, and land has an effect on the pollution and contamination of groundwater. If not treated properly; the solid, liquid, and the gaseous waste that is generated results in pollution of the environment (Robert et al.1999). Groundwater plays an important role in the hydrologic cycle. For example, when the air is polluted, and a rainfall event occurs, the pollutants will settle on the ground, which can then seep into and contaminate the groundwater resources. Another way the groundwater can be contaminated is through water extraction. Water extraction without proper recharge and leaching of pollutants from pesticides and fertilizers into the aquifers has polluted groundwater supplies (Robertson 1990). In addition, leachates from agriculture, industrial waste, and the municipal solid waste have also polluted surface water and groundwater (Foster and Chiton 1998). Some 45 million people around the world over are affected by water pollution marked by excess fluoride, arsenic, and iron (Gleick 1998).

Accountabilities

It is important to realize that groundwater is not a resource that should be utilized unmindfully simply because it is available in abundant quantities. Problems and issues such as over saturated soil, salinity, agricultural toxins, and industrial effluents, all need to be properly considered. Other than legislation and checks to conserve and improve the quality of groundwater, society itself plays a very important role. During the last decade there has been a rising awareness among people on the need for conservation and development of groundwater. A study from Peterson and Bernardo (2003) observed how social, ecological and agricultural changes affect the sustainability of the groundwater resource by examining changes in the mixture of both irrigated and nonirrigated crops because there is an increasing percentage of irrigated area being planted with water-intensive crops (corn and alfalfa) instead of less-water-demanding alternatives such as wheat, sorghum, and soybeans (Peterson and Bernardo 2003). Water use has to be integrated effectively with groundwater recharge. Groundwater is a part of the larger ecosystem, with the soils and substrate that interact with the groundwater just as importance as the water itself. In dry, arid regions renovation of forest tanks (small reservoirs) and other water infrastructures such as bores or pumps are shown to have a significant impact on wildlife and forest cover (Raintree 1987). Similarly, in cities such as Wichita Kansas, there is a need to recharge the groundwater aquifer because of the high degree of dependence on them for drinking water (Lauigne et al. 2010a). Rainwater harvesting systems have been installed in many cities. All these can help maintain the groundwater level. But more importantly, community awareness and management of groundwater resources should be enhanced. The author believes government should implement effective groundwater legislation and regulations through self-regulation by communities and local institutions. External support agencies should support groundwater resource management. Environmental restoration should be promoted along with household water security. Yet no single action whether community based, legislation, traditional water harvesting systems, or reliance on market forces will in itself alleviate the groundwater crisis. The effective answer to the groundwater crisis is to integrate conservation and development activities – from water extraction to water management at the local levels; making communities aware and involving them fully is critical for success. All this will ultimately pave the way for combining conservation of the environment with the basic needs of people.

Phytoremediation

Contaminated soils and water pose a major environmental and human health problem, which could be remediated through emerging phytoremediation technologies. Figure 1.3 lays out the different processes of phytoremediation. Plants have the ability to use natural processes to use and take up contaminants from the soil, air and water. This plant-based cost-effective approach to remediation takes advantage of the plant's ability to concentrate elements and compounds from the environment, to absorb and transpire large amounts of water, and to metabolize various molecules in their tissues. There is growing concern that a wide variety of toxic organic chemicals are being introduced accidently or deliberately into the environment. The earth's environment has seen affects from industrialism since the beginning of the 1800's (Hudson 1992).

In the United States environmental contamination is regionally specific. In the Northwestern region the majority of environmental contamination is caused from mining. The materials that are being mined include metals such as nickel and copper, and natural resources such as coal and oil. Leachates from strip mining are the most common contaminant found in the groundwater (USEPA 1993). Throughout the Midwest, agriculture is the dominant source of water contamination. Large scale farming operations leach nitrates through the soil regolith, during a large rainfall event these nutrients enter the groundwater causing the water to become un-potable. The Northeastern region of the United States is known as the industrial region of the country. Heavy metals from the manufacturing can make its way into the water supply, causing excess time, energy, and funding to clean the water.

When considering developing a remediation for a contaminated area, one needs to keep in mind that the type of remediation used is site specific. There are some instances where using phytoremediation to remediate an area would not be appropriate. Often times, a contaminated area requires a combination of remediation efforts. For example, an area may require a large scale excavation on site for immediate remediation. After excavation, vegetation can be planted over the contaminated region to take up left over or arising contamination of the area for future control of the site. The vegetation cover is dependent on the climate of the region, topography of the area and the substrate the vegetation is going to be planted on, seasonality of uptake, and the contaminant needed for remediation. These limitations can inform the type of phytoremediation or whether phytoremediation is even practical on a given site. There are various types of phytoremediation including phytoextraction, rhizofiltration, phytostabilization, phytodegradation, and phytovolatilization. The type of remediation to use is determined by the contamination along with the environment. Phytoextraction removes metals or organics from soils by accumulating them in the biomass of the plants. Phytodegradation, or phytotransformation, is the use of plants to uptake, store, and degrade organic pollutants. Rhizofiltration involves the removal of pollutants from aqueous sources by the plant roots. Phytostabilizaton reduces the bioavailability of the pollutants by immobilizing or binding them to the soil matrix, or transforming them and release them into the atmosphere. Most scientific and commercial interest in phytoremediation now focuses on phytoextraction, phyto-transpiration, and phytodegradation, using selected plant species grown on contaminated soils. Since the plants take up the contaminants the plants need to be harvested and handled appropriately depending on which contaminant was being remediated. In essence, phytoextraction removes pollutants from contaminated soils, and concentrates them in the biomass.

Several studies over the years have looked at contamination in both soil and water. In these studies trees were used for remediating these sites (Aitchison et al. 2004, Bragg et al. 1994, and Jones et al. 2006). Phytoremediation applications can be designed to capture contaminated groundwater plumes to prevent off-site migration and/or decrease downward migration of contaminants. Trees and grasses act as a solar "pump" removing water from soils and aquifers through transpiration. Contaminant plume capture relies on the formation of a cone of depression within an aquifer due to uptake of water and transpiration by plants.

Sometimes, it is not the function of the plants directly that degrades the contaminants. For an example, the relationship between microbial communities and the plant roots. Fortunately, the rhizosphere of most plants promotes a wealth of microorganisms that can contribute significantly to the degradation of petroleum hydrocarbons during phytoremediation. Thus, a plant may not directly act upon these contaminants; but the plant enhances the microbial community within its root zone to a great extent, and it is the microbial community that does the remediation.

The key to forming a successful barrier against plume migration is for trees to be rooted into a shallow water table. Phreatophytes are deep-rooted plants that are able to extract water from the saturated zone, and include poplars (*Populus* spp.) and willows (*Salix* spp.) which are most often used for hydraulic control. When planted, poplars and willows usually reach optimum working conditions after 3-4 years when they reach canopy closure, intercepting most of the direct sunlight (Cunningham and Ow 1996). The application of phytoremediation requires that the bottom of the aquifer be confined by materials of low hydraulic conductivity such as clay, shale, or rock and does not "leak" water vertically down to another unit. However, plume capture is not limited to shallow aquifers, as poplar trees planted in well casings have been used to tap water tables at a depth of 10-m (Gatliff 1994).

Application of Phytoremediation

Phytoremediation is a relatively new technology that has been studied in many different scenarios. A study was conducted through the USDA Forest Service in the Rock Mountain research area in Fort Collins, Colorado (Hinesly 2003). This study focuses on remediation of both agricultural and industrial waste areas by using *Populus* species. Plant and organisms modify the environment in which they inhabit. We can infer from this that plants can potentially cleanse the soil, air, and water of pollutants (Brown 1995). Other research has been done providing evidence that woody plants are ideal for remediation purposes, since they can be planted over large areas at low cost and they can concentrate and degrade environmental pollutants for a long period of time (Moffat 1995).

Populus tree species includes aspen, cottonwood, and poplar. These trees are used widely in phytoremediation work because they are easily established in a wide variety of regions. They are cost effective, grow fast, and have extensive root systems. Also *Populus* species are known to survive well in both saturated and unsaturated soils. Therefore it is beneficial to use *Populus* trees in riparian zone for remediation; the soils in a riparian zone are periodically saturated.

Neutralization of pollutants through phytoremediation includes absorption, accumulation, immobilization, and sequestration. All plants have the ability to accumulate metals. In addition to metal accumulation, research on municipal sludge systems have demonstrated the ability of *Populus* trees to take up and tolerate high levels of nutrients and contaminants (Salt et al.1995).

Nitrate contamination is one of the most common pollutants of groundwater. High nitrate levels are usually linked to agricultural practices. Excessive nitrates are affecting groundwater supplies in many areas. *Populus* trees have the ability to root deeply and absorb nutrients quickly. *Populus* species and hybrids are commonly used because they are easily propagated and or cloned.

There is much more to remediation then the plants being adapted into the area and absorbing nutrients. It is important to consider soil characteristics and the role it plays in phytoremediation. Soils physical and chemical processes and the microbial activity in the soil affect the plant's ability to take up, and or sequester environmental pollutants. This area of enriched soil properties and microorganisms is the rhizosphere. Trees are known to support a diverse population of microbes, bacteria, and fungi. In most cases the microorganisms are involved in the remediation process through aiding plant absorption of contaminants, or degrading and metabolizing pollutants in the soil adjacent to the root systems in the rhizosphere. There is a symbiotic relationship with the microorganisms and the plants during mitigation of environmental pollutants. Many microbes are "fed" by root exudates of carbohydrates (Giboy et al. 1979).

A study in Australia documented different remediation efforts to alleviate soil and groundwater contamination caused from over usage of landfills (Dolk et al. 1998). Australia is the second highest producer of waste per person in the world at approximately 650 kilograms per person a year; second only to the United States America, which produces approximately 715 kilograms per person. Remediating landfill contamination with phytoremediation was reported (DCC 2009). Byproducts from industry and municipalities are major contaminators to the environment in Australia. Landfills are put in place for various byproducts. Landfills are needed, yet there are repercussions for them. Landfills cause environmental issues, such as gas emission, leachate release, and are known to add heavy metals to soil and groundwater.

Landfills are heavily regulated in most developed countries and carefully managed (Jones 2006). The management of landfills is critical. Concerns of unmanaged landfill sites include soil and groundwater contamination, gas emissions, and the consequent negative health effects associated with the escape of hazardous compounds. Some management practices for insuring contamination security at landfills are, clay capping, and phytocapping. The cap layer consists of the drainage layer, a thick layer of sand or gravel and a thick plastic mesh called a geonet (Lichet 2001). The geonet is used to drain excess precipitation from the protective cover of soil to enhance stability and help prevent infiltration. The next layer in the cap is the geo-membrane, this is a thick plastic layer that forms a cap that prevents excess precipitation from entering the landfill and forming leachate. This layer is important to preventing escape of landfill gas, and reduces the odor. Lastly a compacted layer of clay is placed over the waste to form a cap.

When distributing waste or byproducts it is illogical to think that there will not be any adverse effects. Contamination is inevitable, but containment of the contamination is the goal. Phytoremediation is a technology used to aid in remediation of the contaminant. Certain plants have to capability to thrive in heavy metal contaminated soils. Within the soil the plants able to accumulated the metal contaminant in the plant tissue, the plant then can be harvested and the contaminated soil would be remediated. When looking at remediating a landfill it is important to focus on high performance plants, since there will be highly variable amounts of contaminates in the soil and water, and micro-site differences, including low moisture, high temperatures, low organic matter, poor soil structure, gas and soil compaction (Jones et al. 2006).

To aid in the success of phytoremediation at landfills, a biosolids application is often used to add organic matter, nutrients and moisture holding capacity to enhance soil fertility (Lichet et al. 2001), which improves plant growth. Biosolids contain high concentration of macronutrients including N, P, S, and Ca. Currently many orchards and large scale farming operations use biosolids as a fertilizer for crop production (Coker, 1983).

Direct Benefits of Phytoremediation

In general, both the public and government officials look favorably upon phytoremediation because it involves using the natural ability of the environment to restore itself (Cunningham et al. 1996). There is a high level of public support for the use of plants in phytoremediation as documented at a series of public focus group meetings to gauge public perceptions and awareness of environmental applications of biotechnology in Canada (McIntyre and Lewis 1997). Phytoremediation also is considered to be more aesthetically pleasing than other remediation techniques (Shimp et al. 1993; Cunningham et al. 1996). Plant samples can be harvested and used as indicators of the extent of remediation or, conversely, contamination (Shimp et al. 1993). There is also the potential to grow various phytoremediation species together on the same site in an attempt to simultaneously remediate various contaminants, including salts, metals, pesticides, and petroleum hydrocarbons. Plants help limit the spread of contamination by removing water from soil, thereby keeping the contaminants from spreading or confining them within or near the root-system (Shimp et al. 1993). Some wetland plants can transport oxygen to the rhizosphere under conditions that may otherwise limit the amount of oxygen available to soil microorganisms, as is the case in soils and sediments saturated with water or contaminated with oil (Shimp et al. 1993; Schnoor et al.1995). Microbial communities in the rhizosphere may be able to biodegrade a wide variety of organic contaminants (Shimp et al. 1993). Finally, phytoremediation may be applied with relative ease using existing agricultural practices at contaminated sites (McIntyre and Lewis 1997).

Indirect Benefits of Phytoremediation

An indirect benefit of phytoremediation is improvement of soil quality by improving soil structure (aggregates), increasing porosity/aggregation and, therefore, water infiltration, providing nutrients (nitrogen-fixing legumes), accelerating nutrient cycling, and increasing soil organic carbon (Schnoor et al., 1995; Cunningham et al., 1996). The use of plants in a remediation effort stabilizes the soil, thus preventing erosion and direct human exposure (i.e., by preventing the consumption of contaminated soil by children and the inhalation of soil particles carried in the wind) (Schnoor et al., 1995; McIntyre and Lewis, 1997). Phytoremediation also helps eliminate secondary air- or water-borne wastes. For example, some plants accumulate PAHs (Polycyclic aromatic hydrocarbons) from the atmosphere (Simonich and Hites, 1994a, 1994b; Edwards, 1983). Likewise, phytoremediation has the potential to help reduce greenhouse gas emissions because it does not require the use of pumps or motors that give off greenhouse gases and plants used in phytoremediation may serve as sinks for the greenhouse gas carbon dioxide (Tsao, 1999a). Trees used in phytoremediation may reduce noise levels from industrial sites (Tsao, 1999a). Likewise, phytoremediation itself is less noisy than other reclamation alternatives. Another indirect benefit is that the growth of certain hardy plants in a contaminated soil can allow for the growth of other, less hardy plants. An experiment outlined by Cunningham et al. (1996) indicated that a tolerant grass species (*Vetiveria zizanioides*) thrived in a clay soil contaminated with up to 3% total petroleum hydrocarbons. The same soil was initially extremely phytotoxic to a variety of crop plants tested. However, after a 1-year period when the soil was cropped to only *V. zizanioides,* several crop species could be grown together with *V. zizanioides* – even though there was no detectable change in the quantity of contaminants.

Limitations to Phytoremediation of Groundwater

The depth of plant roots compared to the depth of contamination is one limitation to phytoremediation. Types of plants used for phytoremediation consist of legumes, grasses, shrubs, and trees. Therefore the root depths are dependent upon the type of vegetation used. The most deeply rooted plants are trees, which is why they are commonly used for groundwater remediation (Hrudey and Pollard 1993). Some trees may have root systems that can extend to a depth of 7 m (Gilman 1990). Most plants do not produce roots to anywhere near this depth and root density generally decreases with depth (Cunningham et al.1995). Consequently, as depth increases beyond one or two meters contaminants typically become relatively immobile to plant roots during water up take (McIntyre and Lewis 1997).

The time required to achieve clean-up standards using phytoremediation may be particularly long for hydrophobic pollutants that are tightly bound to soil particles (Schnoor et al. 1995). Because it is slow, phytoremediation is not an appropriate solution where the target contaminant presents an immediate danger to human health or the environment. If contaminants are tightly bound to soil particles or organic matter, they may not be available to plants or microbes for degradation (Otten et al. 1997; Cunningham and Ow 1996). Environmental conditions, such as soil texture, pH, salinity, oxygen availability, temperature and level of non-hydrocarbon contaminants (e.g., metals) must all be within the limits tolerated by plants (McIntyre and Lewis 1997; Cunningham et al. 1996; Hrudey and Pollard 1993). In addition, plants will not grow if concentrations of the target contaminant are too high. In some situations, phytoremediation of the target contaminant cannot proceed unless the soil is pretreated to reduce phytotoxicity or a resistant plant species is selected (Cunningham and Ow 1996). The effectiveness of phytoremediation also will depend on the chemical nature of the contaminants themselves. For example, there is the potential for water-soluble contaminants to leach away before phytoremediation can reclaim the area (Cunningham et al. 1996; Pierzynski et al. 1994). Similarly, evaporation of volatiles such as petroleum hydrocarbons into the air from the soil directly or through the plant is simply a transfer of the contaminant from one environmental medium to another. As a result, there may be air quality issues resulting from this transfer.

Phytoremediation is a relatively new alternative to remediating contaminants from soil, air, and water by the use of vegetation. Several studies have shown promising evidence for the success of phytoremediation. The success of phytoremediation is dependent upon the contaminant that needs to be remediated, adapted and available vegetation, the substrate, topography of the area, and the climate of the region.

Trees being used for Remediation

One successful method to implement phytoremediation is the use of trees to remediate an area that has soil and or groundwater contamination. Certain plants are better at removing contaminants then others. Plants used for phytoremediation must be able to tolerate the type of concentration of contaminants present. They also must be able to grow and survive in the local climate. Depth of the contamination is another factor. Small plants, such as grasses have been used with areas that have contamination close to the soil surface. On the other hand tree roots grow deeper, thus using trees for remediation allows for contaminants deep in the soil to be remediated. Other advantages for using trees to remediate areas with groundwater and soil contaminant include, controlled soil erosion, aesthetics, and noise reducers and improves surrounding air quality (USEPA 2012).

An example of using trees to remediate groundwater contamination in an area was in 1996 in Maryland at Aberdeen Proving Ground. This area was used to dispose and burn industrial and warfare chemicals from 1940-1970 (USACE 2005). Phytoremediation began in the spring of 1996, with 183 poplar trees planted in one-acre acre lot. The trees drawn in contaminated groundwater and break down contaminations in their root systems. The EPA estimated that within 30 years from the start of the cleanup, the contaminant in the groundwater may be reduced by 85 percent (USEPA 2012).

Populus spp. For Phytoremediation

Populus is the genus name for commonly known trees of poplar, aspen and cottonwood. The genus has a high genetic diversity, and has the ability to rapidly grow to heights of 15-50 m and diameters of 2.5 m (Charest et al. 1992). *Populus* tree species are phreatophyte, which means water loving. They have the ability to root deeply and take up significant amounts of water. Their rapid growth and ability to root to the water table makes them ideal for phytoremediation. Phytoremediation is the use of vegetation for remediating contaminated soil and or groundwater. Poplars are typically used in phytoremediation applications because they are easily propagated, develop deep root systems, exhibit high water uptake rates, and are tolerant of high concentrations of organics (Burken 1993). Several studies have been done using poplar trees for phytoremediation as an alternative to expense water treatment system, and methods that apply waste water to annual crops or pastures (Bing 1996; Erickson 1997; Schnoor 1997; and Watanable 1997).

Tree sources (rooted cutting vs true seedling)

The trees planted for this study include true seedlings of Siberian elm (*Ulmus pumila*), Missouri cottonwood (*Populus deltoides*), and a rooted cottonwood cutting from Nebraska, (*Populus deltoides*). The gross anatomical differences between true seedlings and rooted cuttings can be seen in Figure 1.4. Roots on the rooted cuttings are larger in diameter and longer than roots on the true seedlings.

Establishing Trees

In areas that have contaminated groundwater and need remediation, an ideal choice of vegetation would be trees. But what if the area was not able to establish trees? Some reasons that trees will not establish in an area could be soil type, availability of water, or environmental disturbances such as wildlife and or weather. Understanding the differences in soil types is vital when trying to establish vegetation in an area. Soil types act as blue prints. Soil type can affect tree growth through compaction or low aggregation, water holding capacity, and stability for the tree to grow (Cunningham et al. 1995). Compacted soils suffocate tree roots because of minimal pore spaces. It is these pore spaces within and between the soil aggregates that are essential for storing air and water, microbes, nutrients, and organic matter (Angers 1992). On the other hand, a sandy coarse soil has large pore spaces, yet the coarse texture of the soil doesn't allow for the water and or soil particles to grasp on to. Water holding capacity of a sandy soil is less than that of clay, silty loam soil (Alley et al. 2002).

It is because of those factors that affect tree growth that call for alternative ways of planting trees. Some examples of alternatives for planting trees in a sandy coarse soil include trenching, compost, and shelter addition. The trenches allow for additional protection from wind erosion, and give the trees a head start in rooting deeper in the soil. The addition of compost aids in tree stability, soil water holding capacity, and added nutrients in the soil. And lastly, the addition of the shelter protects the trees from wind erosion, sun damage, minimizes evapotransformation of water from leaves, and protects the trees from wildlife disturbances. Here we look at planting trees in trenches, addition of compost and shelter.

Trenching and Tree Establishment

Root systems are the key component in tree stability. Roots must have the strength to withstand the force of wind without breaking or uprooting (Harris et al. 2004). When roots are decayed, cut, or damaged, tree stability and health may be reduced (Matheny and Clark 1994). The means of tree establishment against wind and gravity load involve a complex set of soil and structural interactions. The trees ability to resist wind and gravity loads is distributed and shared with the associated soil and the tree root system. A trench would allow added protection for the trees. A trench is a long, narrow excavation in the ground, the earth from which is thrown up in the front to serve as a shelter. The addition of trenches allows for stability and success of tree establishment (Miller and Neely 1993). Trenching trees as a method of tree establishment provides favorable rooting space for plants. When trenches were dug in dense subsoil for rows of trees and filled with loose soil, rooting depth in trenches increased as roots took full advantage of the trenching and added aeration of soil (Heilman and Gonzalez 1973).

In a study done by Colie (1988), trenching was used to enhance seedlings in the understory of plantations. Trenching particularly enhanced establishment of understory trees in areas where soil horizons limited soil nutrients and enabled root penetration. In his experiment, first- year tree seedlings were planted in trenched and untrenched plots. Growth differences between trenched and untrenched plots would represent effects of competition for soil resources, primarily water. The results for this study showed survival in trenched and untrenched plots differed significantly. About twice as many seedlings survived in the given period of time in trenched as in untrenched plots. Untrenched forest plots had the greatest mortality; only 5% of the planted seedling survived 75 days (Colie 1988). This study shows the importance of trenching on tree seedling growth vs non trenching.

Shelter Addition

The addition of shelters has shown to be effective in establishing trees, particularly in areas prone to heavy deer damage from browsing or rubbing. Barden and Carlson (2003) did a study on shelters preventing browse and rubbing damage from deer, which increased height growth significantly. The study conducted in Butler County, KS. The effect was consistent across several species, including red oak (*Quercus rubra*), bur oak (*Quercus macrocarpa*), and black walnut (*Juglans nigra*), although cottonwood and Siberian elm were not in the study.

Compost Addition on Tree Establishment

Compost is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost can be rich in nutrients (Watson and Himelick 1998). It is used in gardens, landscaping, horticulture, and agriculture. The compost itself is beneficial for the land in many ways, including as a soil conditioner, a fertilizer, and for the addition of vital humus or humic acids (Obreza and Bison 1989). In land management, compost is useful for erosion control, land and stream reclamation, wetland construction and as landfill cover (Rose and Smith 1997). Tree growth in productive woodlands can be enhanced through application of compost as a substitute for conventional fertilizers (Ashwood et al. 2014). The appropriate amount of compost added is dependent on the capacity of the tree species to utilize the nutrients without resulting in damage to the tree. Tree species must be carefully considered when using organic amendments. The nutrient demand varies between different species of trees. English oak (*Quercus robur*), Ash (*Fraxinus spp*.) and Spruce (*Picea spp*.)are difficult to establish on nutrient deficient sites and will therefore require a higher application rate of organic amendment while alders (*Alnus spp*.) are able to establish quickly on infertile sites (Moffat 2006). Alders can also be beneficial to species with high nitrogen demands because of their ability to fix nitrogen (Moffat 2006).

Additions of organic matter and nutrients via compost can enhance tree growth. The amount of compost used for tree establishment will depend on the species, soil type, and climate.

Purpose of this Study

The purpose of this study is to determine the most effective way of establishing a tree line buffer in sandy coarse soil to aid in phytoremediation of an area. The area of interest is a city managed disposal area for biosolids on cropland, the disposal over the years has caused a nitrate plume in the groundwater system. The tree buffer will aid in phytoremediation of the area and aid as an additional barrier to the river it lies next to. The issue at hand is the area has sandy coarse soil, and trees are not establishing. The tree buffer will show greater success in establishing with the addition of planting treatments and the appropriate tree sources chosen for the study site. The research objectives for the trench study were to first, determine the most effective way in establishing trees in sandy coarse soil. And secondly to document which tree variety performed the best with the added treatments, (trench, compost, and shelter). Through the understanding of these elements we can improve tree establishment success on difficult sites, which will aid in phytoremediation and groundwater security.

Figures

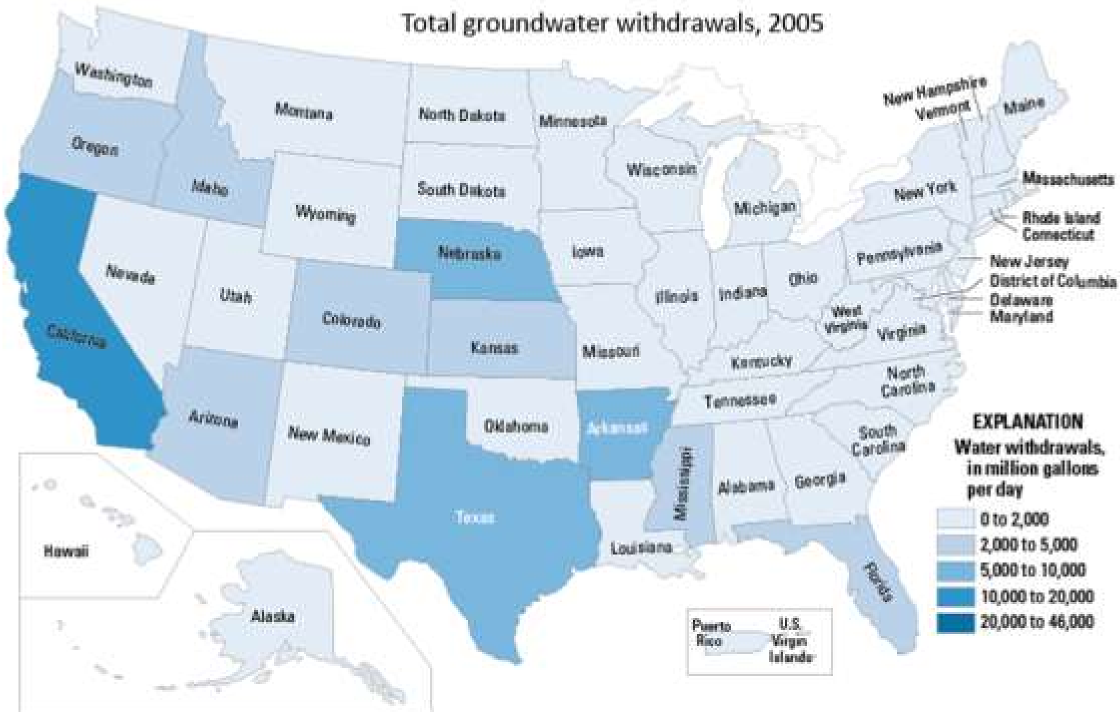

Figure 1.1 USGS 2005 Total Groundwater Withdrawals

U.S. Geological Survey. (2005) National Water Information System Data. (USGS groundwater Data for the Nation), accessed [March 17, 2014], at URL [http://waterdata.usgs.gov/nwis/]

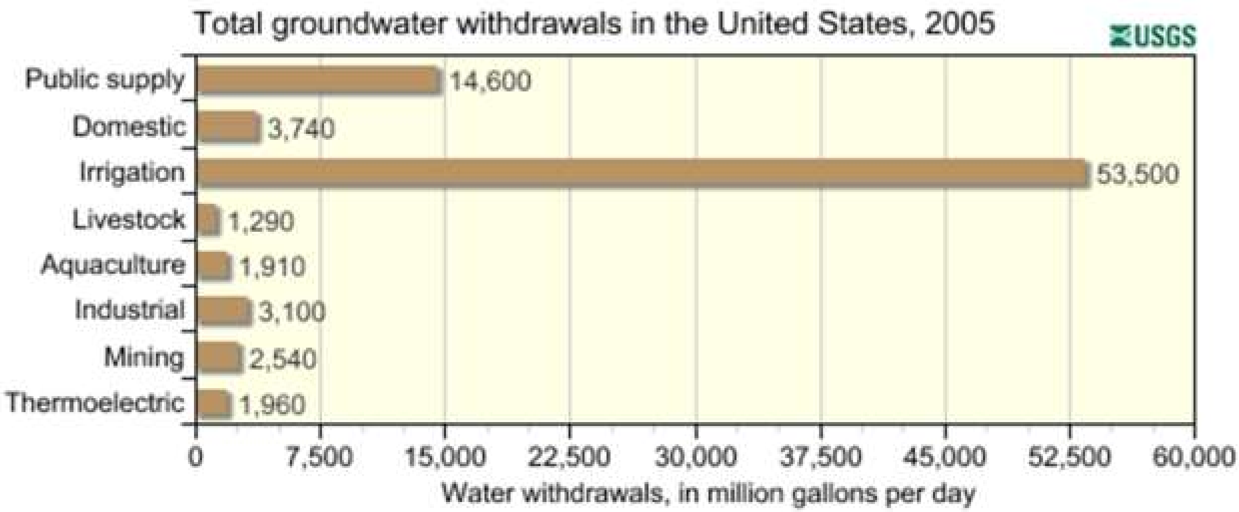

Figure 1.2 USGS 2005 Groundwater Withdrawals

U.S. Geological Survey. (2005) National Water Information System Data. (USGS groundwater Data for the Nation), accessed [March 17, 2014], at URL [http://waterdata.usgs.gov/nwis/].

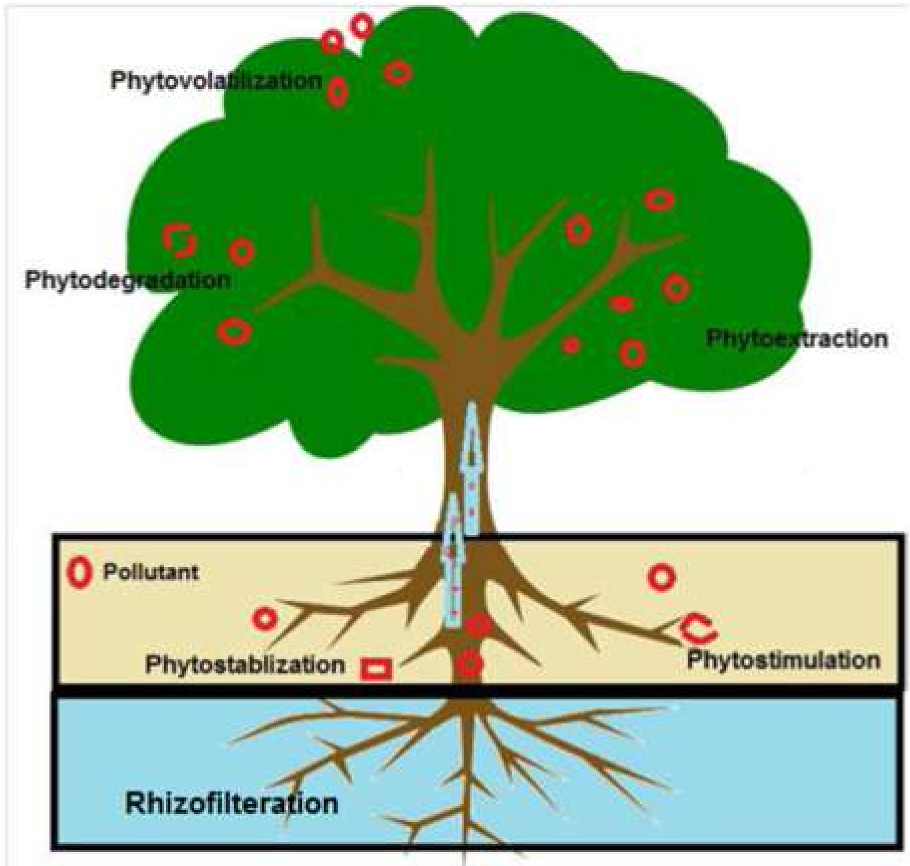

Figure 1.3 Phytoremediation processes

International Journal of Environmental Bioremediation & Biodegradation. 2014, 2(4), 178-191

Figure 1.4 Rooted cutting vs true seedlings. (A) Siberian elm true seedling, (B) Missouri MO cottonwood true seedling, and (C) Nebraska NE cottonwood rooted cutting.

Chapter 2 - Study Site

The area in which the trees are being established is boarding a major river; the land is managed by the City of Manhattan KS. The land that is managed consists of crops, the cropland acts as a recycling system for the cities biosolids.

Background on Biosolids

Individuals turn on their facets to wash dishes or dispose of things down the sink, the same concept is applied to flushing the toilet. It is hard to imagine where the waste from the sink and or toilet ends up. The answer to this un-thought of question is the wastewater treatment facilities. Not every community follows the same protocol for dealing with their municipal waste. Wastewater treatment plants deal with both wastewater and waste solids. Some communities dry landfill their waste solids and others use liquid slurry to apply their waste solids to agricultural lands. Every community has a different plan on how to deal with their waste; the plan depends on available land resources, and approval by state and federal environmental agency regulations. More than $2 billion are spent annually treating and disposing of nearly 5.4 million dry tons of municipal sewage sludge in the United States (Jewell 1994). For this thesis, waste solids will be called biosolids.

Biosolids refers to treated sewage sludge that meets certain EPA pollutant and pathogen levels for land application and surface disposal. The most common treatment of sewage sludge is by anaerobic digestion to “Class B” pathogen reduction levels (Carballa 2009). About 1/3 of the biosolids receive further treatment to Class A pathogen reduction levels, by means such as composting, solar air-drying, alkali treatment, pasteurization, or heat drying (Carballa 2009). Many small treatment plants use methods of treatment other than anaerobic digestion, such as air drying, aerobic digestion, or lime treatment. Under certain conditions, these processes meet Class B pathogen reduction. Over 95% of the sewage sludge meets EPA's most stringent pollutant concentration limits for land application and surface disposal, thus most of the major biosolids producers treat to the category A and B rating (Alexander 2000). Most biosolids are used for growing agricultural non-food crops, for landscaping, as alternative daily cover or final cover at landfills, or are landfilled. A very small amount is incinerated.

Thirty years ago, a large number of American cities dumped their raw sewage directly into our lakes and rivers (USEPA 2000A). Today, because of improved wastewater treatment, our waterways have been cleaned up and made safer. And, because of the strict Federal and State standards, the treated biosolids can be safely recycled. Local governments make the decision whether to recycle the biosolids as a fertilizer, incinerate it or bury it in a landfill. Biosolids are the nutrient-rich organic materials resulting from the treatment of sewage sludge or the name for the solid, semisolid or liquid residue generated during the treatment of domestic sewage in a treatment facility (Mantovi 2005). When treated and processed, sewage sludge becomes biosolids which can be safely recycled and applied as fertilizer to sustainably improve and maintain productive soils and stimulate plant growth. Unlike fresh plant and animal residues that have been incorporated into the soil, most biosolids have been through a biological treatment, where partial decomposition and stabilization have occurred (Hinesly et al. 1982). Thus the presence of stable organic matter positively influences many physical, chemical, and biological processes in the soil.

Biosolids as a Crop Nutrient Source

Finding alternative and sustainable uses for municipal organic sewage sludge provides additional recycling resources by controlling harmful substances to humans and the environment. Land application of biosolids allows for a sustainable disposal for municipal waste. Biosolids contain various chemical elements of mineral and chemical forms, the principal constituents include nitrogen(N), phosphorous (P), and organic carbon (C). These principal constituents promote good soil physical characteristic and provide plant nutrients. Potassium (K) is another important element for vegetative growth, yet is only evident in small quantities in biosolids. Biosolids can have a considerable value for plant nutrients, even though it is not a balanced fertilizer (Galloway and Jacob 1977). Cropland application rates of biosolids have generally been proposed on the basis called “agronomic rates”. Agronomic rates of biosolids application describe beneficial use that will provide the nitrogen requirements or nitrogen removal rates for a realistic yield goal of crops (USEPA 1993). Biosolids have both organic and inorganic forms of N; both forms must be considered when determining the proper amount of biosolids to apply to agricultural lands. Nitrogen from organic N sources must undergo mineralization to inorganic forms before they are available to plants. Nitrogen is available to plants as either ammonium (NH_4^+) or nitrate (NO_3^-).

The P constituent in biosolids contains both organic and inorganic forms, and unlike N, the majority (70-90%) of sludge P is inorganic (Wolf and Baker 1985). When sludge is applied to land, soil chemical adsorption and precipitation processes decrease dissolved P to low levels in the soil solution. When biosolids are applied at rates sufficient to satisfy the N requirements of crops, the amount of added P will frequently exceed plant requirements since P is relatively insoluble and immobile in soil (Kays and Felton, 2012). Thus soil P levels must be monitored to prevent the building up of excessive P, after long term or heavy biosolids application rates.

In addition, biosolids organic matter is a valuable soil conditioner. For example, the addition of biosolids to a finer-textured clay soil can make the soil less compacted and more friable; this increases the amount of pore space available for root growth, and for the entry of water and air into the soil. On the other hand, in coarser- textured soil, biosolids can increase the water holding capacities that in return can reduce irrigation frequency.

City of Manhattan, KS Biosolids Farm

The Manhattan Biosolids Farm where this remediation study was conducted is located in Manhattan, KS (39.183969N, -96.528559W) is a city in Riley County in Northeastern Kansas of the United States, located at the junction of the Kansas River and Big Blue River. The farm is located directly across the Kansas River from the water treatment plant. All of the municipal waste generated by the city of Manhattan is sent to the waste water treatment plant. The water and sludge is treated there and the sludge is sent by pipe across the Kansas River to the lagoon located in the center of the Biosolids farm. The treated water is released into the river. The area is comprised of 460 acres of crop land and a narrow tree lined buffer located on the north edge of the property following the Kansas River. The City of Manhattan, KS began applying biosolids in 1976 to around 160 acres of crop land owned by the city. Manhattan's water treatment plant provides incoming screening and pumping, grit removal, conventional activated sludge treatment, and ultraviolet disinfection. About 2 dry tons of wastewater biosolids are generated per day from the treatment process, or 730 dry tons per year (Durar 2014). Biosolids treatment process consists of aerobic digestion before biosolids are pumped to the City's Biosolids Farm for injection into the land. This was the first biosolids disposal project using sub-surface injection in the State of Kansas (Durar 2014). The process of land application is done by pumping the biosolids first from the holding tank to risers, located in the fields. Biosolids are then pumped to an injection trailer pulled by a tractor for sub-surface injection.

Presently, the city-owned crop land has expanded to 280 acres and the city has acquired the use of an additional 255 acres of leased land shown in Figure 2.1. Biosolids Farm crops consist of corn, sorghum, wheat, and alfalfa. Land application of biosolids is one of the most environmentally acceptable means of biosolids disposal and is recycling in its purest form. The U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), U.S. Food and Drug Administration (FDA), the National Association of Soil Conservation Districts (NASCD), and land grant colleges of agriculture nationwide have sanctioned the recycling of biosolids (Durar 2014).

Issue at hand

During the early 1990’s the City of Manhattan, KS realized they were over applying biosolids to the limited 160 acre land base. A nitrate plume was detected moving towards the Kansas River. Groundwater nitrate levels were detected as high as 40-70 ppm in some areas at the farm. Remediation efforts included ceasing application of biosolids on the original 160 acres, and planting that field to alfalfa, enlarging the area of biosolids application, and reducing the rate to 2 tons/acre/year.

Legumes and N_2 Fixation

Plants have evolved to absorb inorganic N, in the form of ammonium and nitrate. Nitrogen is the main limiting nutrient for crop growth. Agricultural productivity increased dramatically as N fertilizers became widely available (Allos and Bartholemew 1959). However, excessive or inefficient N use can cause contamination of ground and surface water. This is where nitrogen fixing legumes, like alfalfa, maybe helpful. Legumes are one of the few types of plants that have developed symbiotic partnerships with microorganisms that convert atmospheric N_2 gas into plant-available forms (Krauter et al. 2002). N fixation is when bacteria in the soil can infect the root of the plant such as alfalfa. Different than pathogenic bacteria, legumes produce specialized root structures called nodules. These nodules are protected by the plant, they capture N gas from the air and convert it to amino acids that the plant uses for growth (Angers 1992).

Nitrate fixation varies in the presence of other sources of nitrate. Legumes still absorb N from the soil, yet the symbiotic N fixation is an adaptive process, and declines with N uptake from these other sources (Pettygrove et al. 2003). Alfalfa was chosen because it is a vigorous legume that has the ability to root deeply, and produces a high value hay crop. Alfalfa has high N removal potential, a deep effective root zone of as much as several meters below the soil surface and high water use. In addition, loss of N in surface runoff from alfalfa fields is generally low (Miller et al. 1984). With good management, alfalfa reduces nitrate leaching and runoff, and improves soil organic matter, and lowers the need for fertilizer N on future crops. Alfalfa may also be used to reduce excess N that is cycling on farms, and help remediate contaminated soil and water.

Monitoring Wells

When the nitrate plume was detected, the EPA required the City of Manhattan to monitor the nutrients in the groundwater. To sample the groundwater, 16 wells were established throughout the farm in 1995 to monitor nitrate concentrations. An aerial map of the well distribution can be seen in Figure 2.2. The wells are sampled by the city employees three times a year. The nitrate plume was detected moving towards the northeast corner of the farm towards the Kansas River. The wells that are most frequently sampled are wells surrounding the lagoon and also wells located in close proximity to the river.

Overall Improvements

Over the years the city of Manhattan, KS have made some significant improvements to the application and management of the biosolids. Some of the accomplishments include an increased in the amount of land available for biosolids application from 160 acres to 535 acres. Another accomplishment that was achieved was the establishment of a tree buffer alongside the north end of the farm alongside the Kansas River. Biosolids are sampled quarterly to test for nutrients, metals, and pathogens. The soils of the Biosolids Farm are sampled annually for soil nutrients and metals.

Tree buffer

To follow the recommendations in the remediation plan, the City of Manhattan contacted Kansas State University for advice and assistance in establishing a tree buffer alongside the north edge of the Biosolids Farm, adjacent to the Kansas River. Tree buffer establishment began in 2004. The original plan called for a tree lined buffer, 5,800 foot long with three rows of hybrid poplar trees (Barden 2004). Hybrid poplar plantations are a common disposal technique in the Pacific Northwest (Kay and Felton 2012). However these plantations are harvested on a short rotation (8-10 years) for pulp production. Hybrid poplar was recommended by the city's consultant CH2M Hill, but Barden recommended longer lived native and naturalized species be used, to simplify management. The trees used in the buffer include cottonwood species (*Populus deltoides*), Siberian elm (*Ulmus pumila*), Sycamore (*Platanus occidentalis*), and Willow (*Salix* spp). Cottonwoods are much longer-lived (about 80 years), than hybrid poplars and have a higher tolerance to disease and insects. Cottonwoods can also grow very quickly, note the size of seedlings in Figure 2.3 after two growing seasons in the tree buffer planting . The other species of trees are common to the area and will add diversity to the planting.

Unfortunately the northeastern area in which the trees were planted had extremely sandy coarse soil due deposits from the 1993 flood. The sandy area location can be seen in Figure 2.4. The 2004 and 2005 tree plantings in this area failed. Failure of tree establishment could be answered through the soil type in the area. The sandy coarse soil allows for little stability of the seedlings and rooted cuttings to establish into. The state of Kansas is known to experience high wind speed, because of the little to no aggregation of the soil, the roots of the trees have nothing to hold on to. Wind not only affects the trees ability to root but also causes soil erosion, when the soil erodes the sand particles hit the trees and tear them up. Also water infiltrates faster through a sandy coarse soil (Angers 1992). This means the soil has low water holding capacities. In addition, the trees that were planted did not have additional irrigation, so failure to establishment could be explained by minimal water. Lastly this area is alongside a major river, the riparian area is rich in wildlife, and without added protection of a shelter the trees were susceptible to wildlife disturbances.

Figures

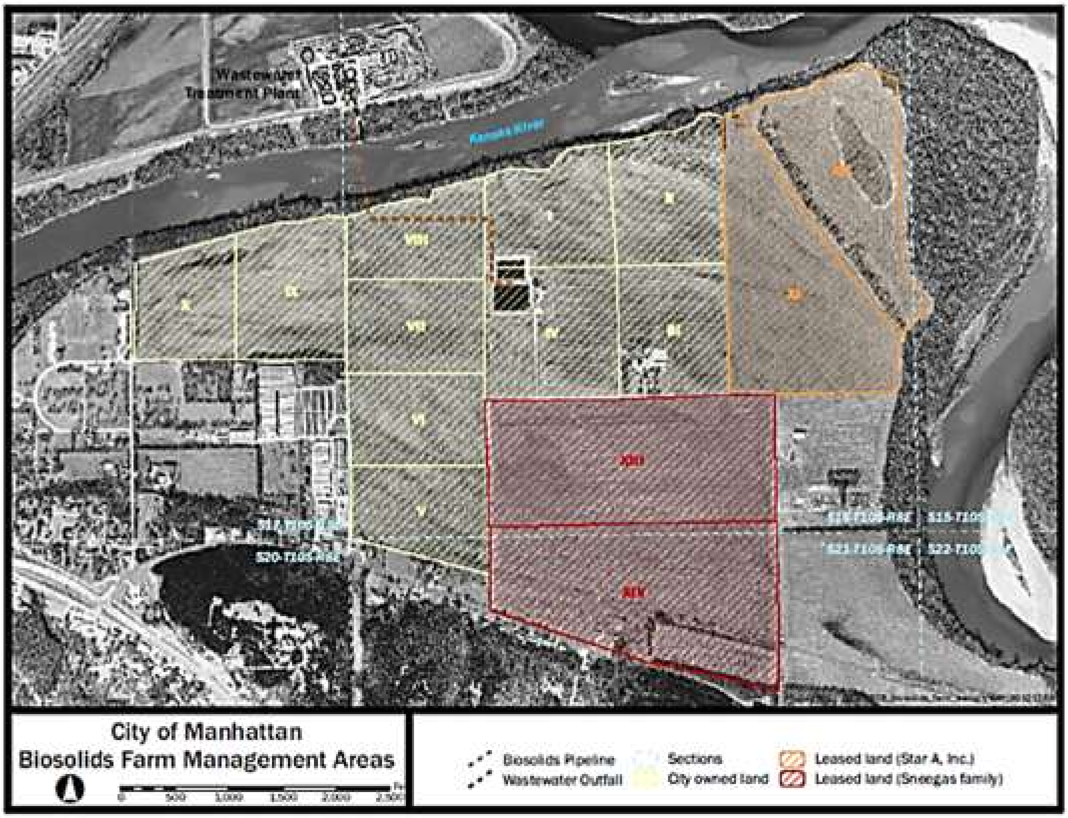

Figure 2.1 City of Manhattan KS Biosolids Farm Management area.

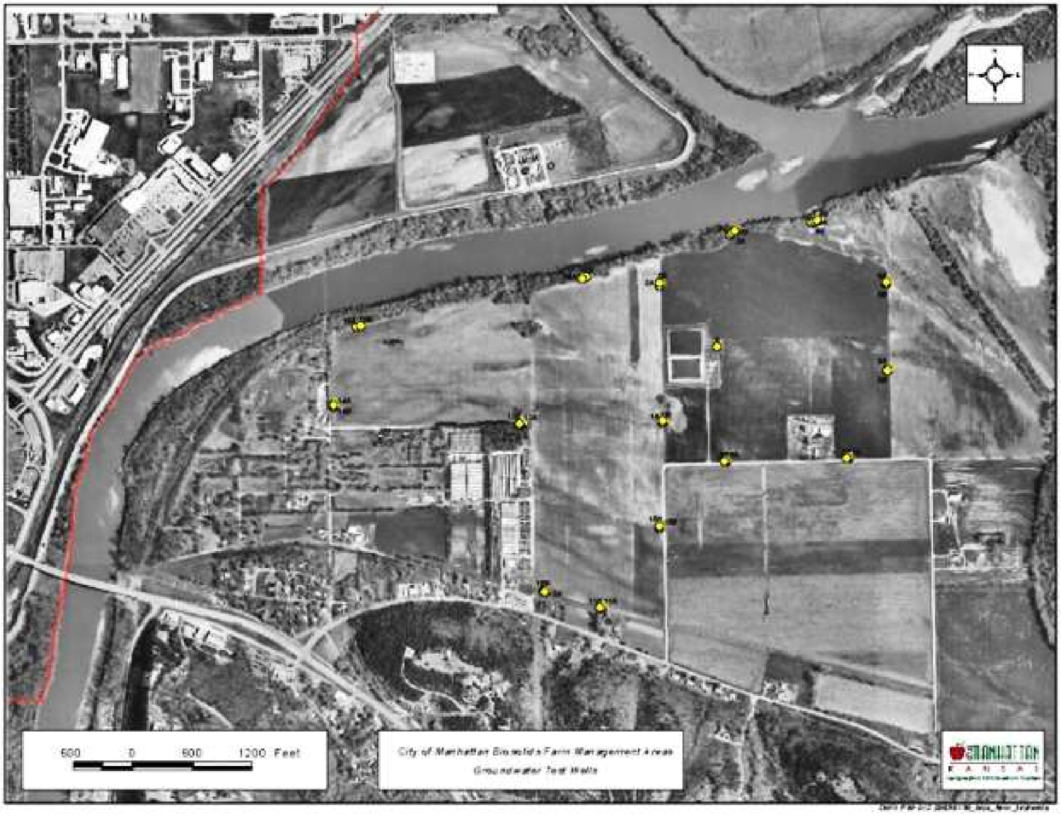

Figure 2.2 City of Manhattan KS, Biosolids Farm groundwater test wells.

Figure 2.3 Cottonwood tree within the tree buffer planting from 2004. Picture with Dr. Barden from Kansas State University, after two growing seasons.

Figure 2.4 Sandy coarse soil area at the Manhattan Biosolids Farm where trees would not establish during the tree buffer planting in 2004. Photo taken of Gary Harter, Manager at the time for the Farm.

Chapter 3 - Materials and Methods

Materials

The primary materials for this study were bare-root propagules of cottonwood seedlings from a nursery in Missouri (MO), rooted cottonwood cuttings from a nursery in Nebraska (NE), Siberian elm seedlings from the Kansas Forest Service (SELM). Each type of seedling was represented by 48 individuals. Refer back to Chapter 1, Figure 1.4 to see seedling types used for the study.

Other supplies needed for this study included 100meter measuring tape and flags to layout the three row and individual plots within each row. After irrigation lines were laid down on the plots the trees seedlings and rooted cuttings were planted. Each source was labeled with different color flags to easily see the difference in sources. Every other tree in the row had a plastic Miracle Tube tree shelter installed as a treatment for the study. The amount of tree shelter use was 72.

Methods

The study was laid out as a split plot design consisting of three rows, each row contained one block. The first step was measuring and flagging the three individual blocks. Each block was measured to190 meters; a t-post was place at each end of the block as a marker. The rows were spaced 7.92 meters apart from one another. The dimensions of the block, tree spacing, and trenching can be seen in Appendix D. Within each block the four whole plots were randomly assigned as; **control** (no trench, no compost); **trench**; **compost**; **trench and compost**. Each whole plot was 43m long, with >2.0 m spacing between whole to keep treatment effects segregated from one another. Refer to Appendix D for overall plot layout.

The trenches were dug by a City of Manhattan employee using a bulldozer. Trenches dimensions were .4m deep x 43m long x 2m wide), and each block had two trenches. After the trenches were dug, the compost was added to the specified trench plus compost plots, and a similar amount added to the compost-only plots. The composted manure was obtained from Kansas State University animal science farm. The amount of compost added as a whole plot was equivalent to 9966kg/ha fresh weight applied to a 2m wide X 12m long area, which filled the trenches. The amount of nutrients added on a fresh weight basis in the compost was estimated as 57.8kg/ha totals N, and 48.9kg/ha total phosphorus, based on published reports of composted dairy cow manure (Diver 2012).

After trenching and compost application was completed, the whole plots were tilled to level the surface and incorporate the compost. Each row had 48 trees. Every whole plot had 12 trees planted 1.8 meters apart; altogether there were four whole plots in each block. The trees that were planted include Missouri cottonwood (MO) seedling, Siberian elm (SELM) seedling, and Nebraska cottonwood (NE) rooted cutting. Within each treatment plot 12 trees were planted in groups of fours, 4 MO cottonwoods, 4SELM, and 4NE cottonwoods. The groups of four trees were randomly placed in the plots throughout the row. Every other tree in each whole plot had a plastic Miracle Tube tree shelter added. After the tree shelters were added to the appropriate trees, drip line irrigation was added to the treatments to insure that every tree received irrigation. Irrigation was provided for the first two summers and tapered off during the second year.

Measuring equipment

Measurements taken include tree height and tree diameter. Trees were measured in 2006, 2007, 2008, 2010, and 2014. The first three measurements of tree heights were done with a telescoping height pole. After the tree's growth exceeded the measuring stick a laser hypsometer was used to measure the heights of the trees. Diameters were recorded at breast height (DBH) of trees using a diameter tape. During years 2006- 2010, trees were measured by KSU workers; 2014 measurements were done by Ashley Stiffarm.

Statistical Analysis

Statistical analysis was done using the SAS 9.3 software program. A PROC MIXED/ LSMEANS statistical analysis of height and DBH was done for composting and trenching treatments along with shelter and trenching treatments. PROC MIXED/LS MEANS was run for survival data to see if the trees survived at a higher rate with or without the shelter. Finally a linear regression was run to examine growth over time for the three tree sources. Refer to Appendix A-C for statistical analysis.

Chapter 4 - Results

The statistical analysis showed significant interactions for height amongst the three tree sources with the treatments of compost and trenching, and shelters and trenching. The statistical analysis also showed significant interactions for DBH amongst the three tree sources with the treatments of shelter and trenching, and compost and trenching. The trees grew quickly, averaging close to 0.7 meters/per year over the 8 years of the study. Tree survival was improved with installation of the shelter. Data from the tree measurements is found in Appendix A, and tree survival data is found in Appendix B. ANOVA tables is found in Appendix C.

Tree Height (meters)

Composting and trenching treatments

Results for PROC MIXED / LSMEANS statistical analysis for the trench study showed significant interactions on height (HT) with tree seedling sources, trench and compost with a p-value of 0.0021. The ANOVA table can be seen in Appendix C1. The addition of compost with trenching amongst the three tree sources only showed significant effect on the Missouri (MO) true seedling tree source and had no significant effect for Nebraska (NE) and Siberian elm (SELM). The MO tree source had a mean height of 3.51 meters inside the trench and 4.96 meters of height without the trenching treatments as seen in Figure 4.1. On the other hand with no compost added the MO source was the only one to show significant effect with the trenching and no trenching treatments, the NE and SELM showed no significant effects with the trench and no trench treatments. The MO tree source grew to the height of 6.43 meters within the trench and 3.5 meters with no trench as seen in Figure 4.2.

Shelter and trenching treatments

Results for PROC MIXED / LSMEANS statistical analysis for the trench study showed significant interactions on height (HT) with tree seedling sources, shelter and trenching with a p-value of 0.0448. The ANOVA table can be seen in Appendix C1. The addition of trenching with shelter amongst the three tree sources only showed significant effect on the Missouri (MO) true seedling tree source and had no significant affect for Nebraska (NE) and Siberian elm (SELM). The MO tree source in trenched plots had a significantly greater mean height of 6.30 meters using shelters and just 3.67 meters of height without shelters, as seen in Figure 4.3. Also with no trenching the MO true seedling tree source showed significant positive effects of the shelter treatments while NE and SELM sources showed no significant effect with treatments. The MO tree source grew to the height of 6.10 meters with shelters and 3.73 meters with no shelters as seen in Figure 4.4.

Tree growth

A volume index was calculated to estimate the growth of trees over the 8 year growing period. As shown in Figure 4.5, tree growth was calculated in DBH^2 X HT. The data points go from 2006 to 2014. The volume index units are in cm^2 X m. All tree sources grew similar diameters over the 8 years of tree growth. A growth curve was done to compare all three tree species with mean heights in meters as shown in Figure 4.6. Throughout the 8 years of tree growth all varieties showed similar heights. The first three years or tree growth The NE, and MO sources showed the fastest growth, but over time slowed down. There were no consistent significant differences between tree sources. With both the volume index and growth curve all tree sources grew at the same rate.

Tree Survival

Tree survival showed significant effects with the shelters with a p value of 0.02 as seen in Appendix C3. The addition of the shelters had an estimated mean of survival at 93% and the no shelter treatment resulting in mean survival of 76%. Thus the tree sources survived better with the addition of the shelter than without a shelter.

Figures

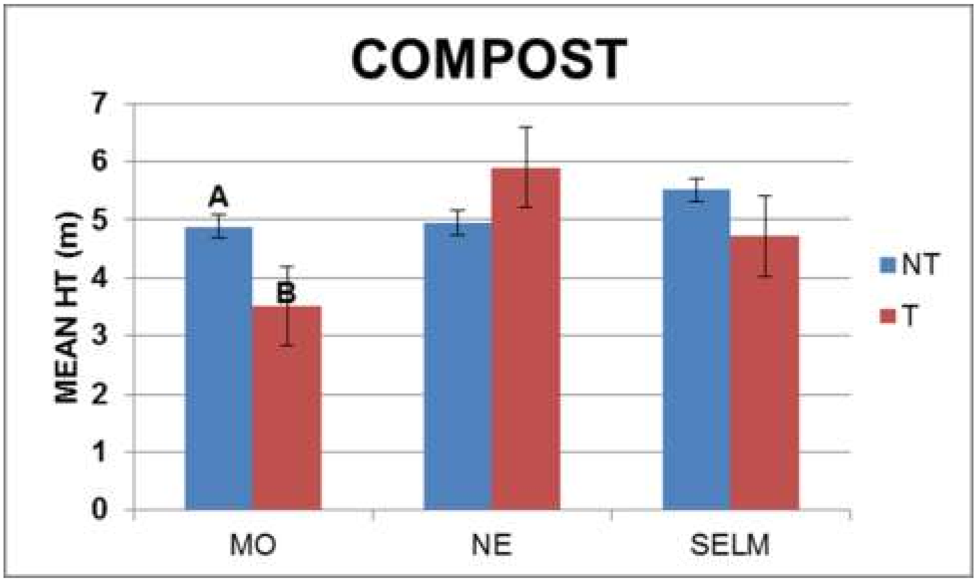

Figure 4.1 Mean height (m) of tree sources with addition of compost in trench and no trench treatments after 8 years of tree growth. MO true seedling was the only tree source that showed significant effects with the addition of compost in the two treatments trenched and no trenched.

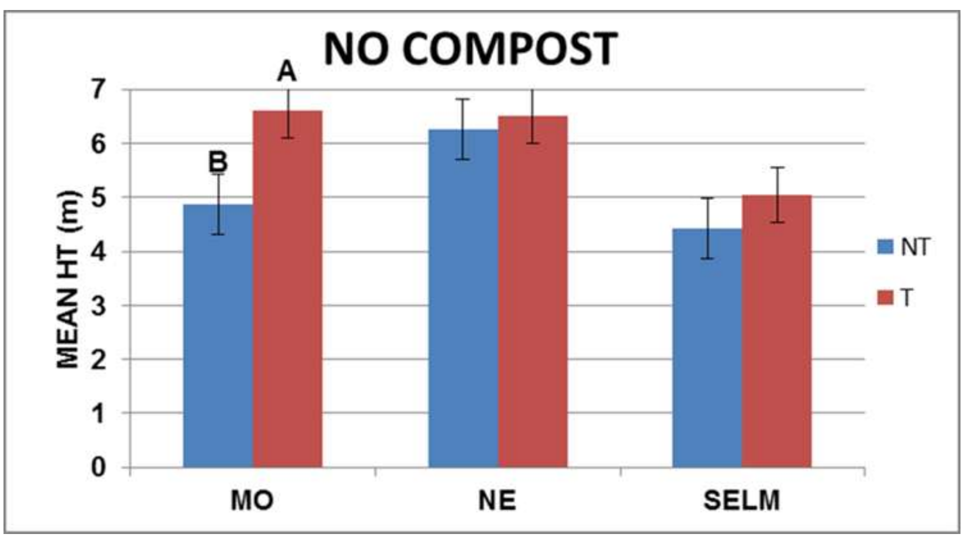

Figure 4.2 Mean height (m) of tree sources with no addition of compost in trenching and no trenching treatments after 8 years of tree growth. MO true seedling was the only tree source that showed significant effects with no addition of compost in the two treatments trenched and no trenched.

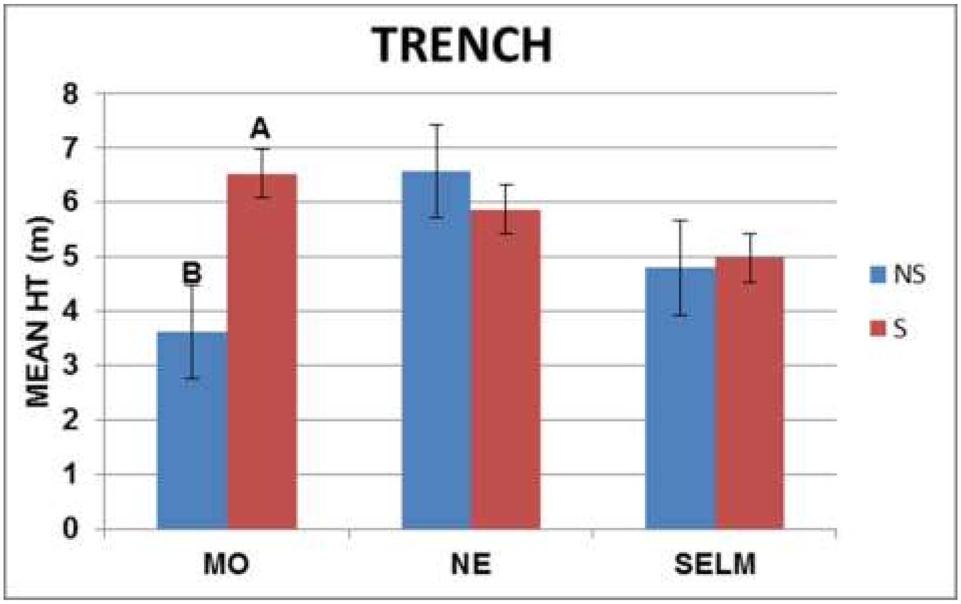

Figure 4.3 Mean height (m) of tree sources in trenches with and without shelter treatments after 8 years of tree growth. MO true seedling was the only tree source that showed significant effects with trenching in the two treatments shelter and no shelter.

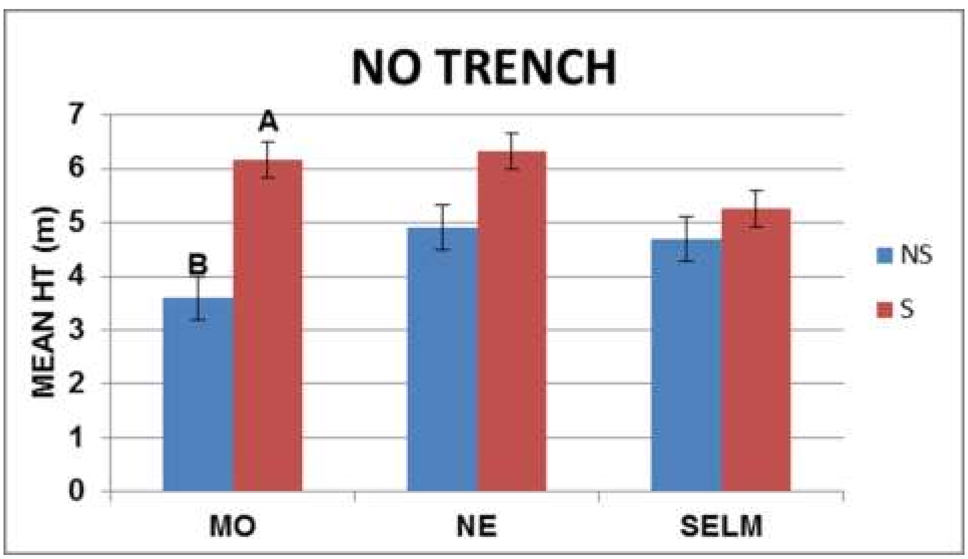

Figure 4.4 Mean height (m) of tree sources in no trench with and without shelter treatments after 8 years of tree growth. MO true seedling was the only tree source that showed significant effects with no addition of trenches in the two treatments shelter and no shelter.

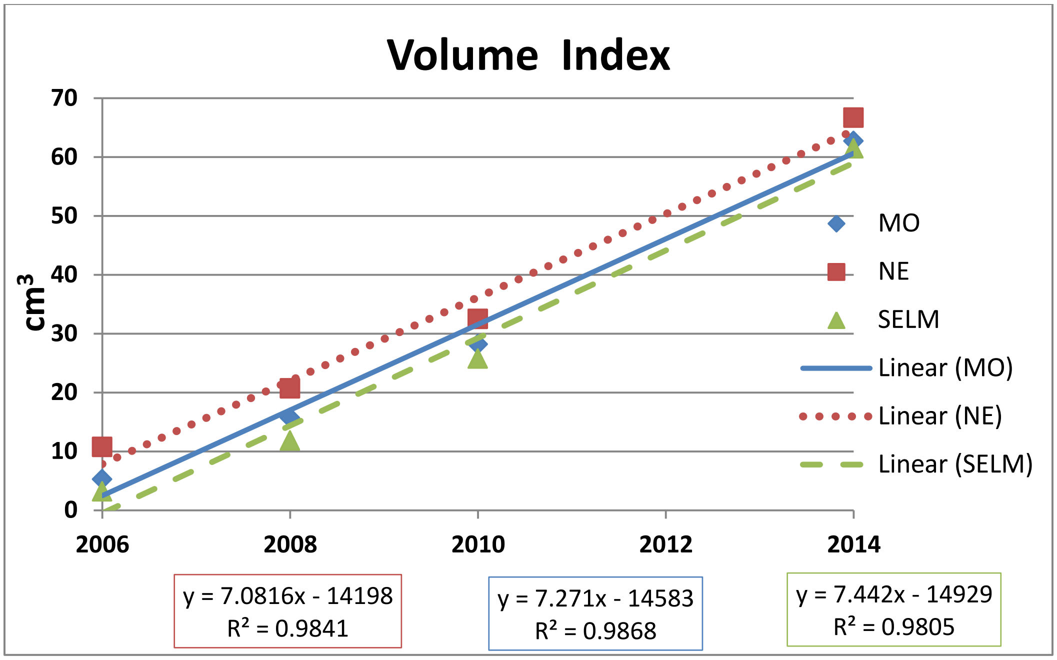

Figure 4.5 Volume Index Growth Curve (cm^3) for all three tree sources. Eight years of tree growth all tree sources showed similar diameter growth with NE tree source showing the largest growth in diameter.

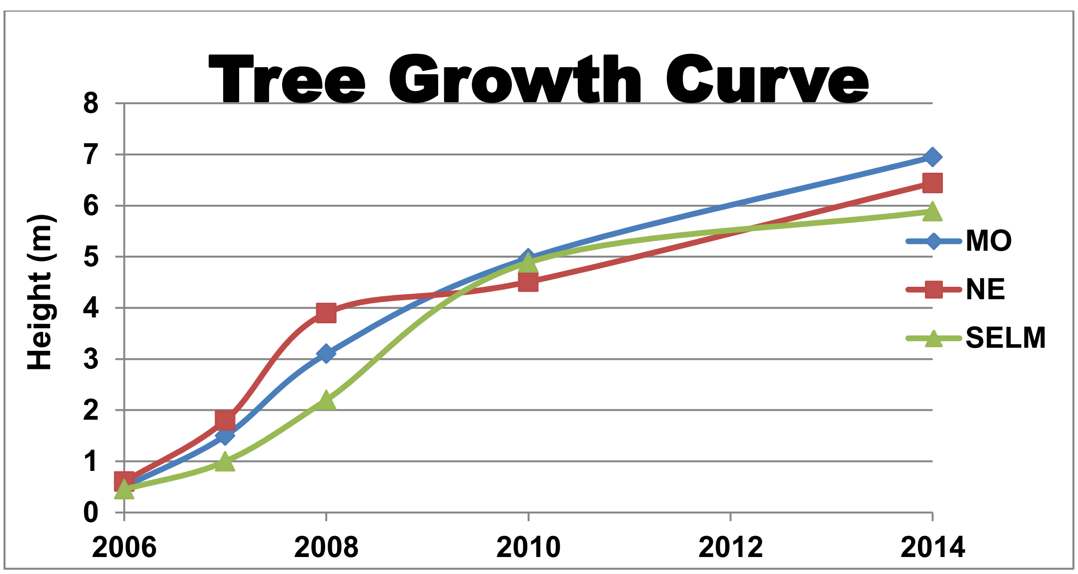

Figure 4.6 Eight year tree growth curve for height (m) for all three tree source. There was no consistent significant differences in growth with the three tree sources, NE source grew the fastest, followed by MO, then SELM.

Figure 4.7 Google earth photo of the trench study in taken in 2013. The yellow box is designating the trees in the trench study.

Chapter 5 - Discussion

Tree Heights

Compost and Trenching Effect on Height

Missouri (MO) true seedlings showed the only significant effect with the trenching treatments while the Nebraska (NE), and Siberian elm (SELM) tree sources did not show significant effects with the trenching treatments. The MO source grew taller with the no trenching treatment than the trenching treatment with compost. The amount of compost that was added to the treatment beds was equivalent to a rate of 9966 kg/ha. Inside the trench the compost may not have been as well incorporated with the soil. In the no trench and compost treatment the compost was spread on the surface and lightly disked in. The mixture of the compost with the soil on the untrenched treatments, may have made a better rooting environment. This could be one reason why the MO tree source grew significantly taller with compost in the no trenching treatment plot than in a trenching treatment plot (Figure 4.1). The SELM had a similar, although not statistically significant result.

Another explanation for the MO tree source significant effectiveness and NE and SELM no significant effectiveness with trenching treatments is root morphology. As explained in the introduction, root morphology at the time of planting was different in each tree type depending on whether it was a true seedling or rooted cutting. The NE tree source was a rooted cutting, and its root system was more extensive with many more large diameter lateral roots. Also, there are likely significant genetic differences between the two cottonwood sources.

The SELM is a true seedling, yet the difference between it and MO is the fibrous roots. The SELM root morphology is less vigorous looking than the NE, but it has a large amount of fibrous roots. The MO source had fewer fibrous roots and is the least vigorous of all three tree sources; it is also a true seedling. This can explain why the MO tree source showed significant effects between the two treatments, the seedling may have been overwhelmed by the concentrated nutrients within the trench and compost treatment.

Lastly, the soil water holding capacity should have increased with the compost treatments, particularly inside the trenches. The coarse sandy soil on the site is excessively well drained, thus water would infiltrate the soil quickly. Water moves more quickly through a coarser textures soil because of the larger pore space.

No Composting and Trenching Treatments for Heights

With no addition of compost to the trenching treatments the MO tree source was the only tree source to show significant effects with the treatments of trenching and no trenching. The NE and SELM tree sources showed no significant effects with the trenching treatments. All tree sources did grow taller within a trench with no compost added.

The trenches in this treatment may have added extra stability and early protection for the trees to grow. The trench may have protected the seedlings from the damaging effects of windblown sand in this exposed area. Thus the added stability of the trenches may have aided in the growth of the tree source.

An explanation for why the MO tree source showed the significant effects between the two treatments could be due to the root morphology. The root system for the true seedling MO source had few coarse lateral roots and not many fibrous roots, and the seedling stem was very slender. The addition of fibrous roots increases the surface area of the root system, allowing the seedling to absorb water and nutrients, and have extra stability in the soil. Without the fibrous roots and without the trenching the seedling is less likely to establish in the harsh environment.

Trenching allowed for the tree sources to root deeper in the soil profile and aided in relieving some of the disturbances for the tree sources. Trenches may have also expected to improve the available moisture that the tree sources could access.

Trenching and shelter treatments for Heights

The MO tree source showed significant effects with the shelter treatments and the NE, SELM showed no significant effects with the shelter treatments. MO source grew much taller with the addition of the shelters than without. The shelters gave the tree source added protection from the desiccating wind the first year or two and thus less evapotranspiration losses. The shelter also provided continued protection from wildlife. Thus the use of water and nutrients was better managed and utilized by those trees that were in the shelter than without a shelter.

The addition of the trenches with the shelter showed the tallest growth with the MO source. Again it is the added protection that allowed the tree seedling to focus primarily on growth because it was protected from damages such as wind and wildlife interaction. With no shelter the tree was susceptible to damage, even though it had added stability it exposed to more wind and or wildlife disturbances. This MO source took advantage of the added protection and preferred the shelter and trenching than the non shelter and trenching.

No trenching and shelter treatments for Heights

The MO tree source showed significant effects with the shelter treatments and the NE, and SELM tree sources showed no significant effects with the shelter treatments. All trees grew taller with additions of shelter in the no trenching treatment.

MO tree source showed the significant differences between the two treatments because of the root morphology, and added protection with the tree shelter. The root morphology for the MO true seedling is visually weaker than the other two sources because of its minimal fibrous root system. Without having the excess roots for added stability the tree seedling is more likely to feel disturbances and its growth is hindered by that. The addition of the shelter allows the true seedling to have less transpiration losses from the leaves, wildlife damage, and wind damage.

Tree Growth

Trees were measured in 2006, 2008, 2010, and 2014, over the years all of the trees have grown close to the same rate as one another as seen in Figure 4.5.The R^2 values for all three tree sources are >0.98. The tree source that grew the tallest over the eight years of tree growth was the NE rooted cutting, followed by MO cottonwood true seedling tree source, and SELM true seedling. The NE sources was the only rooted cutting tree source, remembering that the rooted cutting tree source had vigorous root system and numerous amounts of fibrous roots more so than the other two sources The volume index is supposed to be a better representation of tree growth over time factoring in DBH growth over time as seen in Figure 4.5. The cottonwood trees did grow slightly taller than the elm trees. There were already naturalized Siberian elm trees growing in the vicinity and this is why they were planted in the trench study.

The rooted cutting was at an advantage for the first couple of years after planting, growing the tallest, the fastest of all other tree sources as seen in Figure 4.6. The thicker stem and heavy root system allowed the juvenile tree to better establish in the area quicker and be less susceptible to disturbances. Towards the last year of data collection the cottonwood tree sources grew close to the same heights. The NE source was at 650cm and the MO tree source was at 642 cm. Regardless of root systems the cottonwood tree sources showed the best potential for tree growth in the area over the 8 years.

Trees were also examined to see which tree source showed better survival with and without the shelters. Data for tree survival can be seen in Appendix B and the ANOVA table for survival data can be seen in Appendix C3. The trees did show a significant effect with the addition of the tree shelter with a p-value of 0.0205. Tree sources had a higher survival with the addition of the shelter than without the shelter. With the shelter the trees showed an estimated survival of 93% and without the shelters the trees showed an estimated survival of 76%. The trees ability to establish and survive better with the shelter agrees with several other studies. The shelters add extra protection and stability for the tree to grow. Not only is the tree protected from wind and wildlife damage, they are also protected from full sun. During the first year or two the leaves are growing inside the shelters, in a greenhouse-like environment. The tree is using less resources not needing to replace foliage browsed off by deer, and suffering less evapotranspiration stress, and can focus on just growth.

Chapter 6 - Conclusion

In the end, a vigorously growing tree buffer was able to be established in the area where little vegetation was established, and it was adjacent to the wells with the highest recorded nitrate levels before the planting. It was important to be able to establish trees in the area to allow for added protection for the Kansas River and groundwater resources from the Biosolids Farm. After the failed tree planting on the site, the City of Manhattan and Kansas State University were able collaborate and make the trench study happen. The study had minimal funding, and thus without the in-kind equipment use, and cooperative labor provided by the two entities trees would have never been established and the threat to the Kansas River and the groundwater would have continued.

The difficulty in establishing trees in the area was due to the sandy coarse soil left over from the flood in 1993. In Figure 2.4, it shows the City of Manhattan worker shoveling the sand; and you can see the desert-like quality of the area and start to understand why trees wouldn't establish easily in this area. The first two plantings failed due to soil type and lack of irrigation, and environmental disturbances from deer and wind. The trench study was designed to address these issues. The research objectives for this study was to first, determine the most effective way for establishing trees in coarse sandy soil. Second objective was to document tree source performances and to see which tree source performed the best. The remediation objective was to get trees established on this problematic site. All of these objectives were accomplished. Now that all objectives were accomplished we can recommend the appropriate tree source and planting type for phytoremediation at a site with sandy coarse soil. The tree source recommended for planting is the Nebraska rooted cutting and MO true seedling cottonwood varieties. Even though there was little differences in tree grow in all sources I would choose these tree sources because they had the greater growth within the first couple of years of tree growth as seen in Figure 4.6. The issue at hand was getting trees to establish in the area, these two sources established quickly. Treatments that would be recommended would be shelters additions to the trees, Appendix C.3 shows the ANOVA Table for survival with shelter and the tree showed significant survival with the addition of the shelter then without the shelter. All data can be seen in Appendix A-C, explains the only significant treatment was the addition of shelter.

Tree establishment in the area was successful, refer to Figure 4.7. This figure shows the trees within the trench study in 2013. The trees are still thriving to this day and the ecosystem in the area has dramatically changed. The right choice of tree sources, the added nutrients and stability of the compost and the added protection from the trenches and shelters, and irrigation allowed for the trees to become established on the site. All three tree sources performed well.

Chapter 7 - References

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Appendix A - Trench Study Data

ROW	SPP.	SHELTER	TRENCH	COMPOST	REP	YEAR	DBH (cm)	HT (m)
1	MO	NS	NT	C	1	2006	0.3	0.6
1	MO	NS	NT	C	2	2006	0	0
1	MO	NS	NT	NC	1	2006	0	0
1	MO	NS	NT	NC	2	2006	1.8	2.8
1	MO	NS	T	C	1	2006	0	0
1	MO	NS	T	C	2	2006	0	0
1	MO	NS	T	NC	1	2006	2.3	2.5
1	MO	NS	T	NC	2	2006	1.7	4.4
1	MO	S	NT	C	1	2006	1.6	3.3
1	MO	S	NT	C	2	2006	2	3.1
1	MO	S	NT	NC	1	2006	2.7	3.8
1	MO	S	NT	NC	2	2006	1.8	3
1	MO	S	T	C	1	2006	3.5	4.2
1	MO	S	T	C	2	2006	3	3.7
1	MO	S	T	NC	1	2006	2.5	3.5
1	MO	S	T	NC	2	2006	2.2	3.6
1	NB	NS	NT	C	1	2006	0	0
1	NB	NS	NT	C	2	2006	0	0
1	NB	NS	NT	NC	1	2006	1.8	2.3
1	NB	NS	NT	NC	2	2006	2.3	3.4
1	NB	NS	T	C	1	2006	3.1	3.7
1	NB	NS	T	C	2	2006	2.9	4.1
1	NB	NS	T	NC	1	2006	2.8	4.3
1	NB	NS	T	NC	2	2006	1.3	3.9
1	NB	S	NT	C	1	2006	2.2	3.3
1	NB	S	NT	C	2	2006	1	2.2
1	NB	S	NT	NC	1	2006	2.1	3.4
1	NB	S	NT	NC	2	2006	1.2	3.8
1	NB	S	T	C	1	2006	3.1	3.7
1	NB	S	T	C	2	2006	3.1	3.8
1	NB	S	T	NC	1	2006	2.7	3.5
1	NB	S	T	NC	2	2006	2.6	3.9
1	SELM	NS	NT	C	1	2006	1	0.8
1	SELM	NS	NT	C	2	2006	0.8	0.7
1	SELM	NS	NT	NC	1	2006	2	1.9
1	SELM	NS	NT	NC	2	2006	1	0.9
1	SELM	NS	T	C	1	2006	1.4	1.6
1	SELM	NS	T	C	2	2006	1.6	2.3
1	SELM	NS	T	NC	1	2006	1	1

1	SELM	NS	T	NC	2	2006	1.2	1.3
1	SELM	S	NT	C	1	2006	1.5	2.6
1	SELM	S	NT	C	2	2006	1.1	2
1	SELM	S	NT	NC	1	2006	1.1	2.4
1	SELM	S	NT	NC	2	2006	1.9	2.9
1	SELM	S	T	C	1	2006	2.3	0
1	SELM	S	T	C	2	2006	1.4	2.7
1	SELM	S	T	C	3	2006	2.1	3
1	SELM	S	T	NC	1	2006	2	2.7
1	SELM	S	T	NC	2	2006	0.4	2.2
2	MO	NS	NT	C	1	2006	2.6	2.2
2	MO	NS	NT	C	2	2006	2.3	0
2	MO	NS	NT	NC	1	2006	2.1	2.6
2	MO	NS	NT	NC	2	2006	0	0
2	MO	NS	T	C	1	2006	1.6	0
2	MO	NS	T	C	2	2006	2.2	0
2	MO	NS	T	NC	1	2006	2.2	4
2	MO	NS	T	NC	2	2006	2.1	2.8
2	MO	S	NT	C	1	2006	1.9	3.1
2	MO	S	NT	C	2	2006	2.2	3.4
2	MO	S	NT	NC	1	2006	1.2	2.8
2	MO	S	NT	NC	2	2006	2.1	2.9
2	MO	S	T	C	1	2006	1	4.3
2	MO	S	T	C	2	2006	1.6	3.5
2	MO	S	T	NC	1	2006	1.4	3.8
2	MO	S	T	NC	2	2006	1.6	3.3
2	NB	NS	NT	C	1	2006	1.2	3.2
2	NB	NS	NT	C	2	2006	1.5	3.1
2	NB	NS	NT	NC	1	2006	2.6	3.6
2	NB	NS	NT	NC	2	2006	1.5	4.1
2	NB	NS	T	C	1	2006	2.2	0
2	NB	NS	T	C	2	2006	1.4	4.4
2	NB	NS	T	NC	1	2006	3.1	3.6
2	NB	NS	T	NC	2	2006	3	2.8
2	NB	S	NT	C	1	2006	2.3	3.2
2	NB	S	NT	C	2	2006	1.3	3.4
2	NB	S	NT	NC	1	2006	2.1	3.2
2	NB	S	NT	NC	2	2006	2	3.7
2	NB	S	T	C	1	2006	2.7	4.4
2	NB	S	T	NC	1	2006	2.1	4.2
2	NB	S	T	NC	2	2006	1.5	3.6
2	SELM	NS	NT	C	1	2006	1.4	1.7
2	SELM	NS	NT	C	2	2006	1.6	1.1

2	SELM	NS	NT	NC	1	2006	1.5	1.6
2	SELM	NS	NT	NC	2	2006	2.6	0
2	SELM	NS	T	C	1	2006	1	2.5
2	SELM	NS	T	C	2	2006	2.8	1.1
2	SELM	NS	T	NC	1	2006	1.2	1.6
2	SELM	NS	T	NC	2	2006	0.7	1.6
2	SELM	S	NT	C	1	2006	3	3.4
2	SELM	S	NT	C	2	2006	2.2	3.2
2	SELM	S	NT	NC	1	2006	1.1	3.1
2	SELM	S	NT	NC	2	2006	3.1	0
2	SELM	S	T	C	1	2006	2.2	2.1
2	SELM	S	T	C	2	2006	1.7	2.7
2	SELM	S	T	NC	1	2006	3.1	1.8
2	SELM	S	T	NC	2	2006	2.5	2
3	MO	NS	NT	C	1	2006	1.7	3
3	MO	NS	NT	C	2	2006	0.1	2.1
3	MO	NS	NT	NC	1	2006	3.3	3
3	MO	NS	NT	NC	2	2006	2.5	2.8
3	MO	NS	T	C	1	2006	0	0
3	MO	NS	T	C	2	2006	1.8	3
3	MO	NS	T	NC	1	2006	0	0
3	MO	NS	T	NC	2	2006	3.6	4.6
3	MO	S	NT	C	1	2006	1.1	1.3
3	MO	S	NT	C	2	2006	2	2.4
3	MO	S	NT	NC	1	2006	3	3.5
3	MO	S	NT	NC	2	2006	0	0
3	MO	S	T	C	1	2006	1	2.6
3	MO	S	T	C	2	2006	0	0
3	MO	S	T	NC	1	2006	3.1	4
3	MO	S	T	NC	2	2006	4	4.2
3	NB	NS	NT	C	1	2006	1.6	2.9
3	NB	NS	NT	NC	1	2006	4.2	4.4
3	NB	NS	NT	NC	2	2006	0	0
3	NB	NS	T	C	1	2006	3.9	4.3
3	NB	NS	T	C	2	2006	3.7	4.4
3	NB	NS	T	NC	1	2006	2.8	3
3	NB	NS	T	NC	2	2006	4.7	5.4
3	NB	NS	T	NC	3	2006	3.8	5.2
3	NB	S	NT	NC	1	2006	2.8	4.3
3	NB	S	NT	NC	2	2006	2.4	3.5
3	NB	S	T	C	1	2006	2.9	4.8
3	NB	S	T	C	2	2006	0	0
3	NB	S	T	C	3	2006	2.6	3.9

3	NB	S	T	NC	1	2006	3.5	5.3
3	NB	S	T	NC	2	2006	3.3	5.7
3	NB	S	T	NC	3	2006	0	0
3	SELM	NS	NT	C	1	2006	2	2.6
3	SELM	NS	NT	C	2	2006	1.6	3
3	SELM	NS	NT	NC	1	2006	1.6	0.5
3	SELM	NS	NT	NC	2	2006	0.9	1.2
3	SELM	NS	T	C	1	2006	0	0
3	SELM	NS	T	C	2	2006	1.8	2
3	SELM	NS	T	NC	1	2006	2	2.6
3	SELM	NS	T	NC	2	2006	2.2	2.5
3	SELM	S	NT	C	1	2006	1.5	0.8
3	SELM	S	NT	C	2	2006	0.7	0.8
3	SELM	S	NT	NC	1	2006	1.5	2.7
3	SELM	S	NT	NC	2	2006	1.5	3
3	SELM	S	T	C	1	2006	1.3	3.2
3	SELM	S	T	C	2	2006	1.5	2.7
3	SELM	S	T	NC	1	2006	2	3.2
3	SELM	S	T	NC	2	2006	1.4	2.7
1	MO	NS	NT	C	1	2008	1.5	0
1	MO	NS	NT	C	2	2008	0	0
1	MO	NS	NT	NC	1	2008	0	0
1	MO	NS	NT	NC	2	2008	3.4	5.3
1	MO	NS	T	C	1	2008	0	0
1	MO	NS	T	C	2	2008	0	0
1	MO	NS	T	NC	1	2008	3.1	5
1	MO	NS	T	NC	2	2008	2.5	6.9
1	MO	S	NT	C	1	2008	1.8	5
1	MO	S	NT	C	2	2008	2.5	5
1	MO	S	NT	NC	1	2008	4.5	6
1	MO	S	NT	NC	2	2008	3.2	5.1
1	MO	S	T	C	1	2008	5.3	6.7
1	MO	S	T	C	2	2008	5	5.4
1	MO	S	T	NC	1	2008	3.8	5.5
1	MO	S	T	NC	2	2008	3.2	6
1	NB	NS	NT	C	1	2008	0	0
1	NB	NS	NT	C	2	2008	0	0
1	NB	NS	NT	NC	1	2008	3.7	4.3
1	NB	NS	NT	NC	2	2008	3	5.4
1	NB	NS	T	C	1	2008	4.5	5.5
1	NB	NS	T	C	2	2008	4.3	6.3
1	NB	NS	T	NC	1	2008	4.4	6.6
1	NB	NS	T	NC	2	2008	2	6.4

1	NB	S	NT	C	1	2008	2.9	4.7
1	NB	S	NT	C	2	2008	1.5	2.5
1	NB	S	NT	NC	1	2008	4.8	5.2
1	NB	S	NT	NC	2	2008	3.5	5.7
1	NB	S	T	C	1	2008	5	5.3
1	NB	S	T	C	2	2008	3.8	5.4
1	NB	S	T	NC	1	2008	4.6	6.2
1	NB	S	T	NC	2	2008	4.3	5.9
1	SELM	NS	NT	C	1	2008	2.1	2.4
1	SELM	NS	NT	C	2	2008	1.3	1.7
1	SELM	NS	NT	NC	1	2008	3.3	3.7
1	SELM	NS	NT	NC	2	2008	2.5	1.9
1	SELM	NS	T	C	1	2008	1.7	2.5
1	SELM	NS	T	C	2	2008	2.4	3.9
1	SELM	NS	T	NC	1	2008	1.6	2.9
1	SELM	NS	T	NC	2	2008	2.1	2.7
1	SELM	S	NT	C	1	2008	2	4.1
1	SELM	S	NT	C	2	2008	1.8	2.1
1	SELM	S	NT	NC	1	2008	4.5	4.1
1	SELM	S	NT	NC	2	2008	2.7	3
1	SELM	S	T	C	1	2008	3.2	0
1	SELM	S	T	C	2	2008	2.7	3.4
1	SELM	S	T	C	3	2008	4.5	5
1	SELM	S	T	NC	1	2008	1.3	4.4
1	SELM	S	T	NC	2	2008	1.8	2.8
2	MO	NS	NT	C	1	2008	3.2	5
2	MO	NS	NT	C	2	2008	5	0
2	MO	NS	NT	NC	1	2008	4.7	4.4
2	MO	NS	NT	NC	2	2008	0	0
2	MO	NS	T	C	1	2008	0	0
2	MO	NS	T	C	2	2008	0	0
2	MO	NS	T	NC	1	2008	4.2	5.9
2	MO	NS	T	NC	2	2008	3.7	5.4
2	MO	S	NT	C	1	2008	3.3	5
2	MO	S	NT	C	2	2008	5.3	5.2
2	MO	S	NT	NC	1	2008	3.1	3.3
2	MO	S	NT	NC	2	2008	4.7	5.3
2	MO	S	T	C	1	2008	5.3	6.1
2	MO	S	T	C	2	2008	4.7	5.3
2	MO	S	T	NC	1	2008	4.1	5.9
2	MO	S	T	NC	2	2008	4.3	5.6
2	NB	NS	NT	C	1	2008	3.3	5.4
2	NB	NS	NT	C	2	2008	4.2	4.8

2	NB	NS	NT	NC	1	2008	4	5.7
2	NB	NS	NT	NC	2	2008	4.3	5.4
2	NB	NS	T	C	1	2008	0	0
2	NB	NS	T	C	2	2008	5	5.3
2	NB	NS	T	NC	1	2008	3.6	6
2	NB	NS	T	NC	2	2008	4.6	5.1
2	NB	S	NT	C	1	2008	4.7	5.1
2	NB	S	NT	C	2	2008	4.9	5.1
2	NB	S	NT	NC	1	2008	4	5
2	NB	S	NT	NC	2	2008	3.8	5.5
2	NB	S	T	C	1	2008	4.7	6.8
2	NB	S	T	NC	1	2008	4.3	5.8
2	NB	S	T	NC	2	2008	4.3	5.1
2	SELM	NS	NT	C	1	2008	4.1	3.1
2	SELM	NS	NT	C	2	2008	3	2.2
2	SELM	NS	NT	NC	1	2008	3.4	3.7
2	SELM	NS	NT	NC	2	2008	0	0
2	SELM	NS	T	C	1	2008	3.8	4.4
2	SELM	NS	T	C	2	2008	3.2	2.3
2	SELM	NS	T	NC	1	2008	3.5	2.1
2	SELM	NS	T	NC	2	2008	5.7	2.5
2	SELM	S	NT	C	1	2008	4.8	4.9
2	SELM	S	NT	C	2	2008	4	4.8
2	SELM	S	NT	NC	1	2008	4	4.7
2	SELM	S	NT	NC	2	2008	0	0
2	SELM	S	T	C	1	2008	3.3	3
2	SELM	S	T	C	2	2008	4.5	4.1
2	SELM	S	T	NC	1	2008	4.1	2.9
2	SELM	S	T	NC	2	2008	3	2.3
3	MO	NS	NT	C	1	2008	3.7	4.3
3	MO	NS	NT	C	2	2008	1.8	2.8
3	MO	NS	NT	NC	1	2008	5.2	4.9
3	MO	NS	NT	NC	2	2008	5.8	5.2
3	MO	NS	T	C	1	2008	0	0
3	MO	NS	T	C	2	2008	2.4	4.5
3	MO	NS	T	NC	1	2008	0	0
3	MO	NS	T	NC	2	2008	5.8	6.3
3	MO	S	NT	C	1	2008	5	1.6
3	MO	S	NT	C	2	2008	4.4	4.8
3	MO	S	NT	NC	1	2008	6	5.3
3	MO	S	NT	NC	2	2008	0	0
3	MO	S	T	C	1	2008	1.8	4.5
3	MO	S	T	C	2	2008	0	0

3	MO	S	T	NC	1	2008	6.3	6
3	MO	S	T	NC	2	2008	5.8	6.3
3	NB	NS	NT	C	1	2008	3	3.9
3	NB	NS	NT	NC	1	2008	4.5	6
3	NB	NS	NT	NC	2	2008	0	0
3	NB	NS	T	C	1	2008	4.1	6.2
3	NB	NS	T	C	2	2008	4.1	6.3
3	NB	NS	T	NC	1	2008	5	6.2
3	NB	NS	T	NC	2	2008	6.4	6.9
3	NB	NS	T	NC	3	2008	4.1	6.5
3	NB	S	NT	NC	1	2008	5.1	5.4
3	NB	S	NT	NC	2	2008	2.8	5.3
3	NB	S	T	C	1	2008	4.6	6.3
3	NB	S	T	C	2	2008	0	0
3	NB	S	T	C	3	2008	4.2	5
3	NB	S	T	NC	1	2008	5.8	6.2
3	NB	S	T	NC	2	2008	6.2	6.2
3	NB	S	T	NC	3	2008	0	0
3	SELM	NS	NT	C	1	2008	4.1	4.1
3	SELM	NS	NT	C	2	2008	3	3.4
3	SELM	NS	NT	NC	1	2008	3.4	2.5
3	SELM	NS	NT	NC	2	2008	5.6	2.4
3	SELM	NS	T	C	1	2008	0	0
3	SELM	NS	T	C	2	2008	6.4	4
3	SELM	NS	T	NC	1	2008	4.2	4.3
3	SELM	NS	T	NC	2	2008	5.8	4.5
3	SELM	S	NT	C	1	2008	3.9	2.3
3	SELM	S	NT	C	2	2008	2.4	4.4
3	SELM	S	NT	NC	1	2008	6.6	4.6
3	SELM	S	NT	NC	2	2008	4.9	4.3
3	SELM	S	T	C	1	2008	3.8	4.1
3	SELM	S	T	C	2	2008	4.3	4.2
3	SELM	S	T	NC	1	2008	3.9	4.1
3	SELM	S	T	NC	2	2008	4.4	4.7
1	MO	NS	NT	C	1	2010	2.3	0
1	MO	NS	NT	C	2	2010	0	0
1	MO	NS	NT	NC	1	2010	0	0
1	MO	NS	NT	NC	2	2010	4.2	6.9
1	MO	NS	T	C	1	2010	0	0
1	MO	NS	T	C	2	2010	0	0
1	MO	NS	T	NC	1	2010	5.5	8
1	MO	NS	T	NC	2	2010	4.2	7.5
1	MO	S	NT	C	1	2010	2.5	8.8

1	MO	S	NT	C	2	2010	2.8	8.1
1	MO	S	NT	NC	1	2010	5.2	8.1
1	MO	S	NT	NC	2	2010	4.7	9.2
1	MO	S	T	C	1	2010	7	7
1	MO	S	T	C	2	2010	5.5	9.8
1	MO	S	T	NC	1	2010	4.4	8.7
1	MO	S	T	NC	2	2010	6	8.1
1	NB	NS	NT	C	1	2010	0	0
1	NB	NS	NT	C	2	2010	0	0
1	NB	NS	NT	NC	1	2010	4.3	9.4
1	NB	NS	NT	NC	2	2010	3.8	7.9
1	NB	NS	T	C	1	2010	4.9	6.9
1	NB	NS	T	C	2	2010	5.1	9.4
1	NB	NS	T	NC	1	2010	5.1	9.8
1	NB	NS	T	NC	2	2010	3.5	6.7
1	NB	S	NT	C	1	2010	3.6	7.9
1	NB	S	NT	C	2	2010	2	6.6
1	NB	S	NT	NC	1	2010	5.4	6.1
1	NB	S	NT	NC	2	2010	4.1	9.4
1	NB	S	T	C	1	2010	6.7	7.5
1	NB	S	T	C	2	2010	4.4	9.3
1	NB	S	T	NC	1	2010	4.9	7.6
1	NB	S	T	NC	2	2010	4.8	6.1
1	SELM	NS	NT	C	1	2010	2.7	6.5
1	SELM	NS	NT	C	2	2010	1.7	4.9
1	SELM	NS	NT	NC	1	2010	3.8	5.5
1	SELM	NS	NT	NC	2	2010	5.1	7.3
1	SELM	NS	T	C	1	2010	2.5	5
1	SELM	NS	T	C	2	2010	2.6	5.5
1	SELM	NS	T	NC	1	2010	2.8	6.4
1	SELM	NS	T	NC	2	2010	4.3	8.9
1	SELM	S	NT	C	1	2010	2.4	8.4
1	SELM	S	NT	C	2	2010	2.6	5.5
1	SELM	S	NT	NC	1	2010	6.1	9.4
1	SELM	S	NT	NC	2	2010	4.5	6.1
1	SELM	S	T	C	1	2010	0	0
1	SELM	S	T	C	2	2010	3.2	6.1
1	SELM	S	T	C	3	2010	5	6.7
1	SELM	S	T	NC	1	2010	2.1	5.3
1	SELM	S	T	NC	2	2010	4.6	5.7
2	MO	NS	NT	C	1	2010	4.5	8
2	MO	NS	NT	C	2	2010	0	0
2	MO	NS	NT	NC	1	2010	5.33	6.2

2	MO	NS	NT	NC	2	2010	0	0
2	MO	NS	T	C	1	2010	0	0
2	MO	NS	T	C	2	2010	0	0
2	MO	NS	T	NC	1	2010	5	8.8
2	MO	NS	T	NC	2	2010	4.2	7.8
2	MO	S	NT	C	1	2010	4.3	8.1
2	MO	S	NT	C	2	2010	5.5	7.6
2	MO	S	NT	NC	1	2010	4.5	5.7
2	MO	S	NT	NC	2	2010	5	6.4
2	MO	S	T	C	1	2010	6	8.1
2	MO	S	T	C	2	2010	6	6.6
2	MO	S	T	NC	1	2010	4.5	8.5
2	MO	S	T	NC	2	2010	4.8	8.1
2	NB	NS	NT	C	1	2010	4.4	8
2	NB	NS	NT	C	2	2010	4.7	6.9
2	NB	NS	NT	NC	1	2010	5.5	7.4
2	NB	NS	NT	NC	2	2010	5.5	6.9
2	NB	NS	T	C	1	2010	0	0
2	NB	NS	T	C	2	2010	5.6	7.4
2	NB	NS	T	NC	1	2010	3.9	8.4
2	NB	NS	T	NC	2	2010	5.2	8.4
2	NB	S	NT	C	1	2010	5	6.7
2	NB	S	NT	C	2	2010	5.1	7.5
2	NB	S	NT	NC	1	2010	4.7	7.2
2	NB	S	NT	NC	2	2010	4.6	8.5
2	NB	S	T	C	1	2010	6.4	7.2
2	NB	S	T	NC	1	2010	4.5	7.4
2	NB	S	T	NC	2	2010	4.7	8.5
2	SELM	NS	NT	C	1	2010	4.8	7.1
2	SELM	NS	NT	C	2	2010	4.2	5.2
2	SELM	NS	NT	NC	1	2010	3.7	4.6
2	SELM	NS	NT	NC	2	2010	0	0
2	SELM	NS	T	C	1	2010	4.7	7.3
2	SELM	NS	T	C	2	2010	3.8	7
2	SELM	NS	T	NC	1	2010	4.3	5.9
2	SELM	NS	T	NC	2	2010	6.2	4.8
2	SELM	S	NT	C	1	2010	5.3	5.8
2	SELM	S	NT	C	2	2010	4.4	6
2	SELM	S	NT	NC	1	2010	4.4	5
2	SELM	S	NT	NC	2	2010	0	0
2	SELM	S	T	C	1	2010	3.9	7.4
2	SELM	S	T	C	2	2010	5.3	6.8
2	SELM	S	T	NC	1	2010	4.6	6.5

2	SELM	S	T	NC	2	2010	3.6	4.4
3	MO	NS	NT	C	1	2010	3.9	7.1
3	MO	NS	NT	C	2	2010	2.4	6.2
3	MO	NS	NT	NC	1	2010	5.8	7.3
3	MO	NS	NT	NC	2	2010	6.3	7.7
3	MO	NS	T	C	1	2010	0	0
3	MO	NS	T	C	2	2010	2.9	8.8
3	MO	NS	T	NC	1	2010	0	0
3	MO	NS	T	NC	2	2010	7.5	8.7
3	MO	S	NT	C	1	2010	5.3	6.6
3	MO	S	NT	C	2	2010	4.9	9.4
3	MO	S	NT	NC	1	2010	6.5	8.4
3	MO	S	NT	NC	2	2010	0	0
3	MO	S	T	C	1	2010	2.2	10
3	MO	S	T	C	2	2010	0	0
3	MO	S	T	NC	1	2010	7.1	8
3	MO	S	T	NC	2	2010	6	7.6
3	NB	NS	NT	C	1	2010	3.3	6.9
3	NB	NS	NT	NC	1	2010	5.8	8
3	NB	NS	NT	NC	2	2010	0	0
3	NB	NS	T	C	1	2010	4.9	7.8
3	NB	NS	T	C	2	2010	4.7	8.6
3	NB	NS	T	NC	1	2010	5.6	7.7
3	NB	NS	T	NC	2	2010	7.3	8.4
3	NB	NS	T	NC	3	2010	5.4	7.3
3	NB	S	NT	NC	1	2010	5.6	
3	NB	S	NT	NC	2	2010	3.1	7.7
3	NB	S	T	C	1	2010	5	8.9
3	NB	S	T	C	2	2010	0	0
3	NB	S	T	C	3	2010	4.5	7.6
3	NB	S	T	NC	1	2010	6.4	8.3
3	NB	S	T	NC	2	2010	7	7.4
3	NB	S	T	NC	3	2010	0	0
3	SELM	NS	NT	C	1	2010	4.3	10
3	SELM	NS	NT	C	2	2010	3.6	8.9
3	SELM	NS	NT	NC	1	2010	3.6	5.5
3	SELM	NS	NT	NC	2	2010	5.9	5.2
3	SELM	NS	T	C	1	2010	0	0
3	SELM	NS	T	C	2	2010	7.1	6.9
3	SELM	NS	T	NC	1	2010	4.9	6.5
3	SELM	NS	T	NC	2	2010	6.2	6.9
3	SELM	S	NT	C	1	2010	4.2	6.7
3	SELM	S	NT	C	2	2010	2.9	7.7

3	SELM	S	NT	NC	1	2010	7	5.9
3	SELM	S	NT	NC	2	2010	5.2	6.1
3	SELM	S	T	C	1	2010	4.2	7.2
3	SELM	S	T	C	2	2010	4.9	7.1
3	SELM	S	T	NC	1	2010	4.5	6.1
3	SELM	S	T	NC	2	2010	5.3	6.7
1	MO	NS	NT	C	1	2014	3.6	0
1	MO	NS	NT	C	2	2014	0	0
1	MO	NS	NT	NC	1	2014	0	0
1	MO	NS	NT	NC	2	2014	7.3	8.9
1	MO	NS	T	C	1	2014	0	0
1	MO	NS	T	C	2	2014	0	0
1	MO	NS	T	NC	1	2014	8.7	11.8
1	MO	NS	T	NC	2	2014	6.5	13.9
1	MO	S	NT	C	1	2014	3.9	11.9
1	MO	S	NT	C	2	2014	3.7	11.6
1	MO	S	NT	NC	1	2014	8.8	11.8
1	MO	S	NT	NC	2	2014	6.9	11.2
1	MO	S	T	C	1	2014	11.2	8.5
1	MO	S	T	C	2	2014	8	11.2
1	MO	S	T	NC	1	2014	6.5	13.1
1	MO	S	T	NC	2	2014	9.9	14.5
1	NB	NS	NT	C	1	2014	0	0
1	NB	NS	NT	C	2	2014	0	0
1	NB	NS	NT	NC	1	2014	7.9	13
1	NB	NS	NT	NC	2	2014	7.5	12.4
1	NB	NS	T	C	1	2014	5.5	7.8
1	NB	NS	T	C	2	2014	7.1	11.3
1	NB	NS	T	NC	1	2014	7.4	14.2
1	NB	NS	T	NC	2	2014	4.6	7.2
1	NB	S	NT	C	1	2014	4.4	11.2
1	NB	S	NT	C	2	2014	3.8	8.2
1	NB	S	NT	NC	1	2014	10.6	8.2
1	NB	S	NT	NC	2	2014	8	13.6
1	NB	S	T	C	1	2014	8.8	9
1	NB	S	T	C	2	2014	6.2	11.2
1	NB	S	T	NC	1	2014	7.5	9.3
1	NB	S	T	NC	2	2014	5.3	11.7
1	SELM	NS	NT	C	1	2014	3.9	7.5
1	SELM	NS	NT	C	2	2014	3.3	6.2
1	SELM	NS	NT	NC	1	2014	7	10.3
1	SELM	NS	NT	NC	2	2014	10	10.8
1	SELM	NS	T	C	1	2014	5.9	6.9

1	SELM	NS	T	C	2	2014	5.8	9.1
1	SELM	NS	T	NC	1	2014	5.5	8.4
1	SELM	NS	T	NC	2	2014	6	14.4
1	SELM	S	NT	C	1	2014	3.7	9.1
1	SELM	S	NT	C	2	2014	5	7.2
1	SELM	S	NT	NC	1	2014	10.9	11.7
1	SELM	S	NT	NC	2	2014	7.8	9.5
1	SELM	S	T	C	1	2014	0	0
1	SELM	S	T	C	2	2014	6.6	7.5
1	SELM	S	T	C	3	2014	8.7	7.5
1	SELM	S	T	NC	1	2014	3.9	6.6
1	SELM	S	T	NC	2	2014	6.4	7.3
2	MO	NS	NT	C	1	2014	7.4	11.9
2	MO	NS	NT	C	2	2014	0	0
2	MO	NS	NT	NC	1	2014	7.9	11.7
2	MO	NS	NT	NC	2	2014	0	0
2	MO	NS	T	C	1	2014	0	0
2	MO	NS	T	C	2	2014	0	0
2	MO	NS	T	NC	1	2014	8	10.5
2	MO	NS	T	NC	2	2014	6.2	9.1
2	MO	S	NT	C	1	2014	6.3	12.8
2	MO	S	NT	C	2	2014	8.6	10.7
2	MO	S	NT	NC	1	2014	6.8	11.4
2	MO	S	NT	NC	2	2014	8.1	11.5
2	MO	S	T	C	1	2014	9.4	8.7
2	MO	S	T	C	2	2014	9.1	9.3
2	MO	S	T	NC	1	2014	6.5	9
2	MO	S	T	NC	2	2014	6.8	10
2	NB	NS	NT	C	1	2014	6.1	11.2
2	NB	NS	NT	C	2	2014	6.3	10.3
2	NB	NS	NT	NC	1	2014	7.5	10.3
2	NB	NS	NT	NC	2	2014	7.3	8.3
2	NB	NS	T	C	1	2014	0	0
2	NB	NS	T	C	2	2014	7.5	11.5
2	NB	NS	T	NC	1	2014	4.6	11.9
2	NB	NS	T	NC	2	2014	9.2	9.1
2	NB	S	NT	C	1	2014	7	8.6
2	NB	S	NT	C	2	2014	7	8.8
2	NB	S	NT	NC	1	2014	6.3	10.8
2	NB	S	NT	NC	2	2014	6.2	11
2	NB	S	T	C	1	2014	7.2	10.2
2	NB	S	T	NC	1	2014	6.4	10.1
2	NB	S	T	NC	2	2014	5.4	9

2	SELM	NS	NT	C	1	2014	5.7	9.2
2	SELM	NS	NT	C	2	2014	4.9	10.2
2	SELM	NS	NT	NC	1	2014	6.8	7.9
2	SELM	NS	NT	NC	2	2014	0	0
2	SELM	NS	T	C	1	2014	7	11.2
2	SELM	NS	T	C	2	2014	5.1	10.9
2	SELM	NS	T	NC	1	2014	6.7	8.3
2	SELM	NS	T	NC	2	2014	7.5	7
2	SELM	S	NT	C	1	2014	6	7.7
2	SELM	S	NT	C	2	2014	4.7	8.9
2	SELM	S	NT	NC	1	2014	5.8	6.8
2	SELM	S	NT	NC	2	2014	0	0
2	SELM	S	T	C	1	2014	4.9	10.6
2	SELM	S	T	C	2	2014	6.8	11.7
2	SELM	S	T	NC	1	2014	6.4	8.3
2	SELM	S	T	NC	2	2014	6.3	7.4
3	MO	NS	NT	C	1	2014	8	11.5
3	MO	NS	NT	C	2	2014	7	8.9
3	MO	NS	NT	NC	1	2014	8.1	10.8
3	MO	NS	NT	NC	2	2014	10.9	10.1
3	MO	NS	T	C	1	2014	0	0
3	MO	NS	T	C	2	2014	6.9	13.8
3	MO	NS	T	NC	1	2014	0	0
3	MO	NS	T	NC	2	2014	9	10.8
3	MO	S	NT	C	1	2014	8.2	11.1
3	MO	S	NT	C	2	2014	7	12.3
3	MO	S	NT	NC	1	2014	7.3	10.5
3	MO	S	NT	NC	2	2014	0	0
3	MO	S	T	C	1	2014	6.7	14.6
3	MO	S	T	C	2	2014	0	0
3	MO	S	T	NC	1	2014	10	10.2
3	MO	S	T	NC	2	2014	10	11.2
3	NB	NS	NT	C	1	2014	9	14.3
3	NB	NS	NT	NC	1	2014	8.4	12.1
3	NB	NS	NT	NC	2	2014	0	0
3	NB	NS	T	C	1	2014	9.3	11.2
3	NB	NS	T	C	2	2014	10	11.6
3	NB	NS	T	NC	1	2014	6.3	9.6
3	NB	NS	T	NC	2	2014	9.7	10.2
3	NB	NS	T	NC	3	2014	6.9	10.2
3	NB	S	NT	NC	1	2014	7.5	10.9
3	NB	S	NT	NC	2	2014	6.6	12.1
3	NB	S	T	C	1	2014	10.4	10.5

3	NB	S	T	C	2	2014	0	0
3	NB	S	T	C	3	2014	9.3	10
3	NB	S	T	NC	1	2014	9.2	9.8
3	NB	S	T	NC	2	2014	7.5	8.5
3	NB	S	T	NC	3	2014	0	0
3	SELM	NS	NT	C	1	2014	7.9	15.2
3	SELM	NS	NT	C	2	2014	9	12.4
3	SELM	NS	NT	NC	1	2014	6.9	9.2
3	SELM	NS	NT	NC	2	2014	8.3	10.3
3	SELM	NS	T	C	1	2014	0	0
3	SELM	NS	T	C	2	2014	14.3	9.7
3	SELM	NS	T	NC	1	2014	6.6	8.5
3	SELM	NS	T	NC	2	2014	10.2	9.9
3	SELM	S	NT	C	1	2014	8.3	13.7
3	SELM	S	NT	C	2	2014	7.4	13.9
3	SELM	S	NT	NC	1	2014	10.1	11.2
3	SELM	S	NT	NC	2	2014	7.8	10.9
3	SELM	S	T	C	1	2014	9	12.4
3	SELM	S	T	C	2	2014	7.1	10.9
3	SELM	S	T	NC	1	2014	5.7	9.1
3	SELM	S	T	NC	2	2014	8.8	9.2

KEY

MO= Missouri nursery cottonwood tree true seedling variety

NB= Nebraska nursery cottonwood tree rooted cutting variety

SELM= Siberian elm tree true seedling from Kansas forest service

NS= NO SHELTER

S= SHELTER

NT= NO TRENCH

T= TRENCH

NC= NO COMPOST

C= COMPOST

Appendix B - Tree Survival Data

ROW	SPP.	TREATMENT	SHELTER	SURVIVAL
1	SELM	trench	shelter	100
2	SELM	trench	shelter	100
3	SELM	trench	shelter	100
1	MO	trench	shelter	100
2	MO	trench	shelter	100
3	MO	trench	shelter	100
1	NB	trench	shelter	50
2	NB	trench	shelter	100
3	NB	trench	shelter	100
1	SELM	compost	shelter	100
2	SELM	compost	shelter	100
3	SELM	compost	shelter	100
1	MO	compost	shelter	100
2	MO	compost	shelter	100
3	MO	compost	shelter	0
1	NB	compost	shelter	100
2	NB	compost	shelter	100
3	NB	compost	shelter	100
1	SELM	trecomp	shelter	100
2	SELM	trecomp	shelter	100
3	SELM	trecomp	shelter	100
1	MO	trecomp	shelter	100
2	MO	trecomp	shelter	100
3	MO	trecomp	shelter	100
1	NB	trecomp	shelter	50
2	NB	trecomp	shelter	100
3	NB	trecomp	shelter	100

1	SELM	control	shelter	100
2	SELM	control	shelter	50
3	SELM	control	shelter	100
1	MO	control	shelter	100
2	MO	control	shelter	100
3	MO	control	shelter	100
1	NB	control	shelter	100
2	NB	control	shelter	100
3	NB	control	shelter	100
1	SELM	trench	nonshe	100
2	SELM	trench	nonshe	100
3	SELM	trench	nonshe	100
1	MO	trench	nonshe	50
2	MO	trench	nonshe	100
3	MO	trench	nonshe	0
1	NB	trench	nonshe	100
2	NB	trench	nonshe	100
3	NB	trench	nonshe	100
1	SELM	compost	nonshe	100
2	SELM	compost	nonshe	100
3	SELM	compost	nonshe	100
1	MO	compost	nonshe	100
2	MO	compost	nonshe	50
3	MO	compost	nonshe	100
1	NB	compost	nonshe	100
2	NB	compost	nonshe	100
3	NB	compost	nonshe	0
1	SELM	trecomp	nonshe	50
2	SELM	trecomp	nonshe	100
3	SELM	trecomp	nonshe	100
1	MO	trecomp	nonshe	50

2	MO	trecomp	nonshe	0
3	MO	trecomp	nonshe	100
1	NB	trecomp	nonshe	100
2	NB	trecomp	nonshe	0
3	NB	trecomp	nonshe	100
1	SELM	control	nonshe	100
2	SELM	control	nonshe	50
3	SELM	control	nonshe	100
1	MO	control	nonshe	50
2	MO	control	nonshe	50
3	MO	control	nonshe	50
1	NB	control	nonshe	50
2	NB	control	nonshe	100
3	NB	control	nonshe	100

Key

MO= Missouri nursery cottonwood tree true seedling variety

NB= Nebraska nursery cottonwood tree rooted cutting variety

SELM= Siberian elm tree true seedling from Kansas forest service

Trecomp= trench compost

Nonshe= No shelter

Control= No trench and no compost

Appendix C - ANOVA Tables

Table C.1ANOVA Table for HT

HEIGHT				
Effect	Num DF	Den DF	F Value	Pr > F
spp	2	544	8.44	0.0002
shelter	1	544	27.99	<.0001
spp*shelter	2	544	13.30	<.0001
trench	1	544	1.15	0.2834
spp*trench	2	544	0.83	0.4367
shelter*trench	1	544	2.63	0.1052
spp*shelter*trench	2	544	2.75	0.0648
compost	1	544	10.75	0.0011
spp*compost	2	544	7.01	0.0010
shelter*compost	1	544	9.51	0.0022
spp*shelter*compost	2	544	3.15	0.0438
trench*compost	1	544	8.48	0.0037
spp*trench*compost	2	544	6.26	0.0021
shelte*trench*compos	1	544	1.15	0.2834
spp*shel*trenc*compo	2	544	0.22	0.7998

Table C.2 ANOVA Table for DBH

DBH				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
spp	2	544	3.50	0.0308
shelter	1	544	19.81	<.0001
spp*shelter	2	544	8.37	0.0003
trench	1	544	3.22	0.0732
spp*trench	2	544	1.48	0.2283
shelter*trench	1	544	0.07	0.7883
spp*shelter*trench	2	544	5.84	0.0031
compost	1	544	22.66	<.0001
spp*compost	2	544	2.54	0.0796
shelter*compost	1	544	6.64	0.0102
spp*shelter*compost	2	544	1.75	0.1750
trench*compost	1	544	0.21	0.6505
spp*trench*compost	2	544	5.25	0.0055
shelte*trench*compos	1	544	1.72	0.1909
spp*shel*trenc*compo	2	544	0.46	0.6330

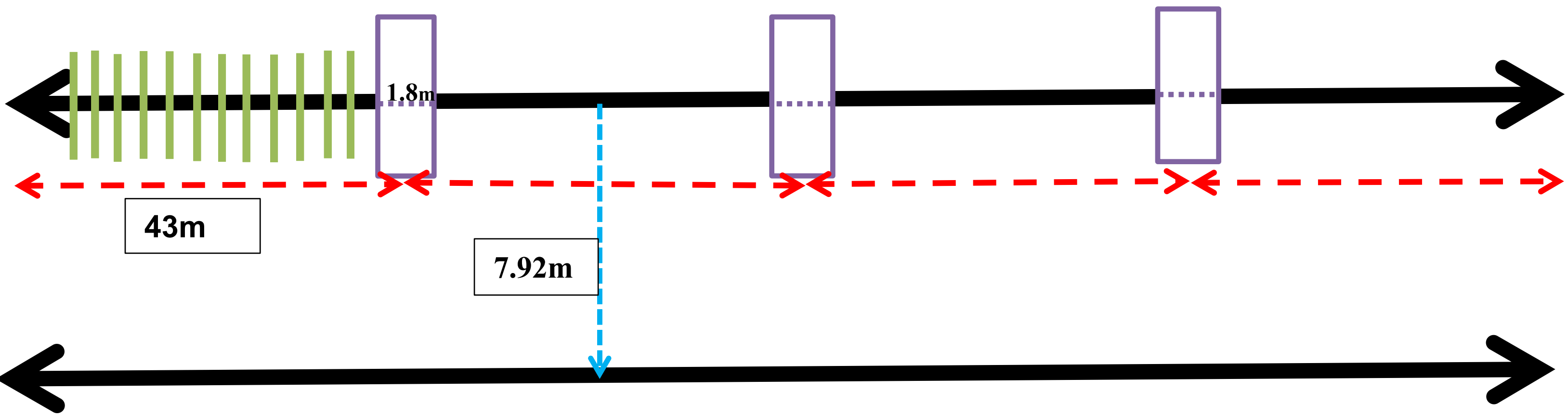
Table C.3 Tree Survival

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
source	2	46	2.44	0.0984
shelter	1	46	5.76	0.0205
source*shelter	2	46	1.56	0.2210
tret	3	46	0.27	0.8491
source*tret	6	46	0.31	0.9303
tret*shelter	3	46	0.53	0.6617
source*tret*shelter	6	46	1.13	0.3583

Effect=shelter Method=Tukey(P<0.05) Set=1

Obs	shelter	Estimate	Standard Error	Letter Group
1	shelter	93.0556	4.91046	A
2	nonshe	76.3889	4.91046	B

Appendix D - Trench Study Layout



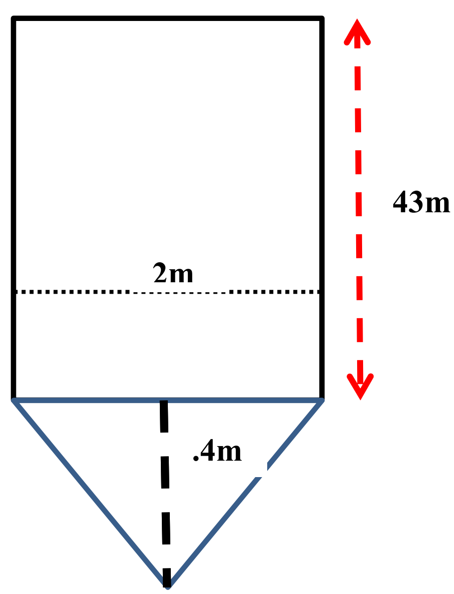
KEY

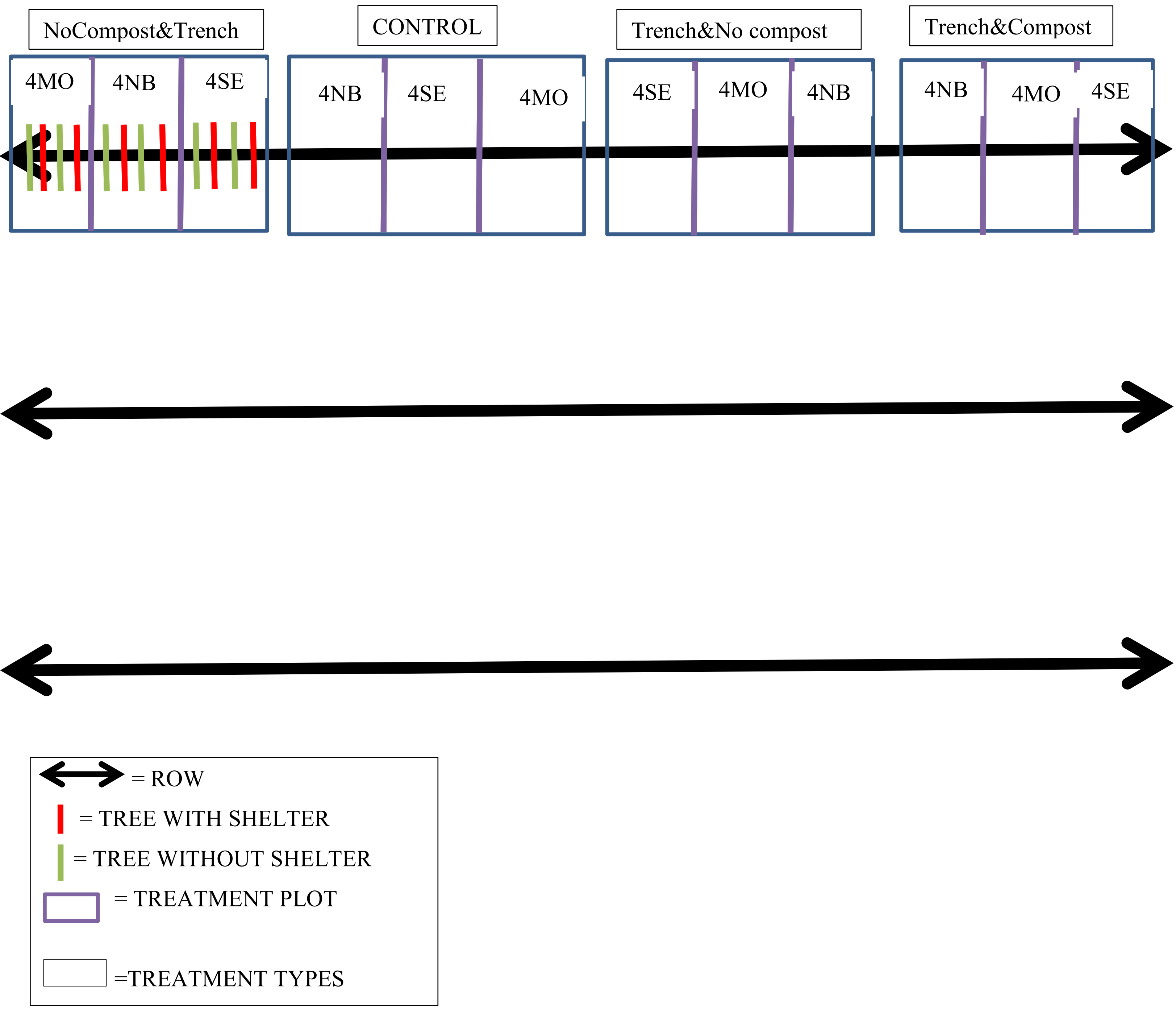
= Trees
= length of treatment plots
= Breaks in-between treatments
= rows (190m long)
= Distance between rows

*Trees were space 1.8m apart

*All three row resemble the first row shown

TRENCH





*All three rows resemble the first row, only thing different is the placement of treatments and tree sources placement with in the treatments.

* Every other tree is sheltered in each treatment