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DEVELOPING TREES TOLERANT TO DEGRADED MINE SOILS

by

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requirements for the degree of

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Abstract

The project discussed in this thesis is part of a larger project developing trees that can tolerate and withstand heavy metals and acidic soils from historic mining operations in Butte Montana as a solution to re-establishing long-term tree growth on those sites. The project involved growing tree seedlings native to Butte, Montana and planting them on degraded mine soils, tailings, and processing wastes (mine waste) located within the Butte Priority Soil Operable Unit (BPSOU). The seedlings were grown for 34 weeks in a greenhouse located on Montana Tech's campus before being transplanted to a contaminated site (the Clark Mill site) located within the BPSOU. The outcome of the project is expected to lead to a successful solution for re-establishing tree growth in the degraded mine waste in Butte with minimal post-planting human intervention. Work conducted on the project to date has shown successful growth of seedlings in degraded mine waste. It is believed that the final outcome of the project will result in significantly improved reclamation of the BPSOU through tree growth. This will result in improved and maintained water quality in Silver Bow Creek in Butte Area One that can be accomplished with lower development and maintenance costs.

Keywords: Mine tailings, Silver Bow Creek, Native Butte trees, Seed germination.

Dedication

I dedicate this work to my parents and siblings for the continuous love, prayers and support they have shown me throughout my studies.

Acknowledgements

I thank God for taking me through this journey of my career, for His divine favor and strength to complete my graduate studies.

I would like to express my profound thanks to my committee chair and advisor, Dr. Paul Conrad of the Mining Engineering Department of Montana Tech. He provided me with all the support, advice and steered me in the right direction throughout my graduate studies.

I am grateful to Dr. Robert Pal for his continuous assistance throughout this project, for his advice and suggestions on how to get the best out of trees and have them survive. Thanks to Krystal Weilage for her time and effort in getting seeds ready for planting, seedling monitoring and planting on the Clark Mill site.

I also would like to acknowledge Scott Rosenthal, my committee member and the Head of the Mining Engineering Department for his effort and advice for research conducted on this project.

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1. Introduction

Gold was discovered and mined in Butte in 1864. A short time later rich metal-sulfide deposits of copper (Cu) and zinc (Zn) were discovered, which became the primary minerals mined in the area. Lead (Pb), manganese (Mn) and molybdenum (Mo) were also mined in Butte. The resulting development of over 500 underground mines resulted about 16,000 kilometers (km) of underground openings in Butte (Alexander, 2006). By 1884, there were over 300 operating copper mines, at least 10 silver mines and 8 smelters in Butte. Due to the rich mineralization of the Butte area, it is often referred to as the "Richest Hill on Earth". Butte's rich mining history comes at a cost of vast hectares of land contaminated with waste materials from mining, milling, and smelting operations (mine waste). These waste materials have elevated concentrations of arsenic (As), Pb and other heavy metals. Heavy metals from mining and smelting waste have leached and contaminated nearby soils, groundwater and surface water. In 1983, the United States Environmental Protection Agency (EPA) added Silver Bow Creek to the National Priority List (NPL) as a Superfund Site.

In 1987, the EPA categorized superfund sites in the upper Clark Fork River Basin into four contiguous superfund sites that stretches for 225 kilometers. The Butte Priority Soils Operable Unit (BPSOU) is one of the four superfund sites and is approximately 220 km^2 in size, including the entire length of the Silver Bow Creek, the Warm Springs Ponds near Anaconda and contaminated sites within Butte (Figure 1). Remediation works have been done by the EPA since 1987 to prevent contamination of underground water and to prevent contaminated runoffs. Vegetative soil caps have been placed over several contaminated sites to contain the contamination and prevent leaching of toxic substances into the environment (Alexander, 2006).

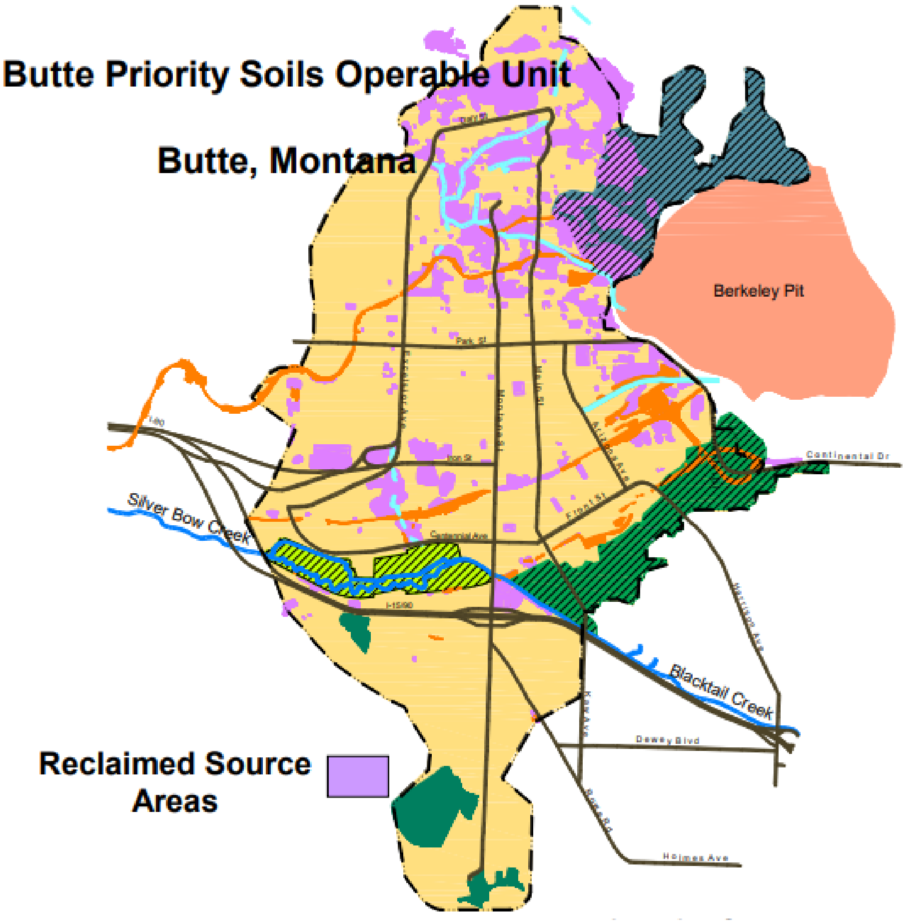

Figure 1: BPSOU showing reclaimed sites (Alexander, 2006)

Mine waste located within Butte are highly acidic and have high heavy metal concentrations resulting in a lack of vegetation growth on them (Figure 2). Since the late 1800s, mine wastes have been transported by runoff into and degraded Silver Bow Creek. Figure 3 shows Silver Bow Creek flooded with contaminated sediments from mining wastes from the Butte area.

Mine waste accumulated from over 100 years of gold, silver, and, especially, copper mining are dispersed throughout Butte posing health risks to human and environmental receptors. Stabilization of mine waste sites is needed to control fugitive dust, prevent run-off of toxic material resulting in subsequent sediment deposition in streams, reducing the volume of water seepage through acidic and heavy metal contaminated material, and improving land productivity and aesthetic values (Watkin, 1982).

Figure 2: Orphan Girl mine waste dump behind Montana Tech (Dunlap, 2017)

Figure 3: Mine Tailings along the Silver Bow Creek floodplain (DeMars, 2019)

Vegetative cover plays a major role in preventing erosion. Research (Gyssels, 2005) has found that root systems affect some physical properties of soil adjacent to plant roots and can impact the soil's erodability and thus the rate of soil erosion. Vegetation controls soil erosion by means of its canopy, roots and litter components. Research work conducted by the University of Kentucky, and others, documents that trees can be successfully grown in blasted and weathered overburden without the presence of topsoil (Conrad, 2002). It has been found that blasted overburden eventually weathers into topsoil, but not for years after trees are planted in it. The research project discussed in this thesis aims at growing trees that can survive and grow in highly acidic and heavy metal contaminated mine waste within the BPSOU. Trees planted in Butte as a result of the project can reduce soil erosion from degraded sites resulting in less eroded soils getting into Silver Bow Creek and degrading both its water quality and stream flow.

Trees seedlings native to Butte are being grown in a greenhouse located on Montana Tech's campus and will be planted in degraded soils located within the BPSOU. Growing trees is expected to help restore vegetative ground cover within the watershed contributing to stream flow in Silver Bow Creek. The project combines research with tree seedling growth to provide a resource for Butte that could produce thousands of tree seedlings each year adapted to the harsh climate and mine waste conditions that exist in the BPSOU. It is anticipated that the trees developed by the project will have the capability for long-term survival and growth because they will be germinated and grown into seedlings in mine waste collected from the BPSOU where they will be planted.

Mine waste samples collected for the project have been evaluated to determine if they lack nutrients or contain substances toxic to the long-term growth and survival of the trees. Toxic levels of metals, high concentrations of soluble salts, extremes in pH, nutrient deficiencies and imbalances, surface crusting, high bulk density, low infiltration rates, high surface temperatures, low cation exchange capacity, restricted microbial activity, low water retention, harsh climatic conditions and surface particle movement are some of the traits of mine waste sites that restrict revegetation efforts (Barth, 1986).

2. Problem Statement

The high heavy metals concentrations and acidic nature of mine waste from historic mining within the BPSOU prevents vegetation growth leading to erosion of contaminated sediments by surface runoff to Silver Bow Creek where they degrade water quality and affect stream flow patterns. According to Larcheveque et al. (2015), stabilization of mine waste dumps and tailings sites by revegetation helps control erosion and potentially eliminate degradation threat to environmental receptors. This project aims at preventing erosion of mine waste by developing contamination tolerant trees and growing them on selected contaminated sites within the BPSOU with minimum human intervention.

2.1. Project Goals

The project is expected to grow and develop tree species native to Butte that are tolerant to contaminations from historic mine waste within the BPSOU. Grown trees will beautify the Butte landscape, provide wildlife habitat and help maintain water quality and enhance stream flow in Silver Bow Creek. The following objectives were pursued in an effort to achieve the goals of this project:

- Acquire mine waste samples from five contaminated sites, grind into usable soil size and determine the level of contamination and needed amenities.
- Acquire seeds of native Butte tree species and prepare for germination.
- Monitor seed growth into seedlings.
- Harden seedlings and transplant to contaminated mine waste on the Clark Mill site in Butte.
- Monitor tree survival rate on the Clark Mill site.

3. Literature Review

3.1. Mine Waste and Tailings

Exploitation of mineral resources can require the clearing of forests and removal of top soil and overburden rock to gain access to the ore. Metal ores are chemicals combined with other elements forming metal-bearing ore minerals that require processing to extract the valuable metals from the unwanted minerals (Lottermoser, 2007). The process of ore removal and valuable mineral separation can generate large volumes of mine waste. Mine wastes are typically composed of waste rock, overburden, mine water, sludge, mill water, slags, roasted ores, ashes, leached ores and/or process water deposited on the earth surface causing land degradation. According to Kamal et al. (2010), mine wastes are typically composed of elevated concentrations of heavy metals and metalloids that adversely affect the microbial community structure, reducing the activity of microbial enzymes, which ultimately impacts soil vegetation.

Opoku-Ware (2018) reported that the pH of mine waste can range from 1.5 to 8. With a pH less than 5 and iron (Fe) presence, Sheoran et al. (2010) reported that toxic metals such as soluble nickel (Ni), Pb and cadmium (Cd) are readily available for absorption by plant roots. Bini (2011) indicated that the metal content of mine waste causes soil and water acidification contamination and destroys vegetation. It is noted that soil can have naturally high concentrations of heavy metals as a result of the weathering of parent material that contained high amounts of metal minerals. As the parent rock fragments, weathers and oxidizes, the pH of mine waste changes drastically. Weathering and oxidation of pyrite bearing rocks decreases soil pH. Carbonate bearing rocks increase soil pH when they weather.

3.1.1. Impact of Heavy Metals on Plants

Mineral elements can be divided into essential nutrients and toxic non-nutrient elements. Essential nutrients are important for plant metabolism and structure and an insufficient supply weakens plants and hinders growth and reproduction. On the other hand, non-nutrient elements can be heavy metals that have no known importance to plant health and are toxic at even lower concentrations. The essential soil nutrients are nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), sulfur (S), silicon (Si), chlorine (Cl), Fe, boron (B), nickel (Ni), sodium (Na), Mn, Zn, Cu, and Mo (DalCorso, 2012). Higher concentrations of some essential minerals such as Cu, Ni and Zn become toxic to most plant species. Studies conducted at the Malanzkhand Copper Project in India found that Cu dust can effect photosynthesis pigmentation secretions resulting in death of many plant species (Ambika, 2016). Cadmium (Cd), mercury (Hg), chromium (Cr), antimony (Sb), silver (Ag), As, and Pb are toxic elements that can cause plant death even at lower concentrations.

Disposal of mine wastes that have high concentrations of heavy metals can be sensitive as the release of heavy metals into the environment can have negative impact on the ecosystem. Heavy metals are non-biodegradable and therefore pose serious danger to plants when their concentrations in plants exceeds optimal levels. At lower concentrations, some metals present in mine waste are essential for cellular functions and are required by plants (Lottermoser, 2007). Heavy metals in soils can induce changes in the physiological, biochemical, and metabolic activities of a plant which can lead to a negative impact on plant growth and inhibition of root growth (Rasafi et al., 2017).

Accumulation of excess amounts of Cd and Pb in plants affect Ca, Mg, K, and P absorption and transport, disturb plant metabolism, and stifle plant growth rate and reproduction (Cheng, 2003). Chromium toxicity in plants impedes shoot growth, reduces the number of leaves and leaf area, causes burns on leaf margins and tips, and causes discoloration and death of plant cells. Arsenic is an enormously toxic element that presents a health threat to both humans and plants. Arsenic presence prevents seed germination and consequently kill seeds (DalCorso, 2012).

3.1.2. Plant Response to Heavy Metal Toxicity

Plants have defense mechanisms to protect themselves from heavy metals toxicity and to maintain essential nutrient uptake and minimize vulnerability to toxic non-essential metals (Manara, 2012). Plants can sense toxic elements and respond by using a signal transduction response to counteract heavy metals toxicity. Signal transduction response by plants is characterized by the synthesis of stress related proteins and signaling molecules, and by the activation of genes that counteract different metal stresses.

Plant roots can perceive toxicity and acclimate to heavy metal stress by triggering signal transduction that leads to changes in molecular events, altered physiological status and microstructure (Zhi-Bin et al., 2016). Plants react differently based on the type of metal contamination. Their plasma membrane can prevent or reduce heavy metals uptake into cells or pump efflux outside of cells in response to heavy metal toxicity.

Aery (2012) indicates that changes in leaf anatomy, shape and size indicates plant adaptability to environmental stress. Black gram (*Phaseolus mungo*) and lentil (*Lens culinaris*) have a defense towards lead contamination by inducing changes in their leaf epidermis such as a reduction in cell size, an increase in the number of stomata and trichomes per unit area and reduction in the size of guard cells. Copper plants (*Ocimum centraliafricanum*) can shed their leaves to dispose of excessive Cu and Ni uptake. Fitzgerald (2010) reports that quaking aspen (*Populus tremuloides*) can tolerate a wide range of environmental and site conditions as well as to low soil-nutrient levels. It also has the ability to alter its leaf shape and size depending on moisture availability.

3.2. Revegetation of mine wastes

Mining operations require the clearing of trees, stripping of top soil and removal of overburden rock to gain access to the valuable minerals. Regulations require the storage of topsoil for post mining reclamation. Toxic materials from mine wastes dumped on mine lands leads the contamination of soils and acid mine drainage. Clearing of forests and topsoil makes mine lands susceptible to erosion and transportation of contaminants into nearby water bodies causing them to degrade. Mining interferes with factors crucial for a healthy ecosystem by destroying soil components, microbe populations, and nutrient cycles leading to the destruction of existing vegetation (Sheoran et al., 2010). Contaminated mine wastes are devoid of vegetative cover due to high acidity and heavy metal toxicity (Anawar et al., 2015).

Hossner and Hons (1992) argues that vegetation, as a means of stabilizing toxic mine waste, is far more desirable than other stabilization techniques. Revegetation of mine waste stabilizes the environment by providing erosion control and elimination of threats to environmental receptors while providing wildlife habitat and aesthetically transforming the landscape that has been disturbed by mining activities (Larcheveque et al., 2015). Vegetation also reduces transpiration of soluble heavy metals into the atmosphere and reduces contamination to rains that can degrade waterbodies (Tordoff et al., 2000). According to Sheoran et al. (2010), vegetation plays a major role in protecting the soil surface against erosion and degradation by stabilizing the soils through development of extensive root systems. A study conducted on the use of revegetation as a means of soil stabilization in mine waste at the Mission

Mine in Arizona found that revegetation stopped erosion of soils which stopped the leaching of nitrates and heavy metals into water resources (Pepper et al., 2003).

Mine wastes are difficult to revegetate due to extreme pH levels, high salt and heavy metals content, and the lack of organic matter, nutrients and soil organisms (Larcheveque et al., 2015). Mine wastes are often deficient in N, P and K which are essential for vegetative growth. Replaced soils must be tested for deficiency of nutrients before revegetation can be successfully attempted. Addition of N, P, and K fertilizers should be applied and maintained for successful revegetation of mine wastes with high Pb and Zn content. In addition, covering mine waste with topsoil provides a growing medium for plants that can reduce leaching and erosion of metals providing beneficial stabilization in mine waste (Hossner, 1992).

3.2.1. Management of contaminants

Mine waste may have physical and chemical properties unsuitable for vegetation growth and may require stabilization to enable them to support plant growth. Stabilization is defined by Dermatas (1995) as a process where additives are mixed with waste to immobilize contaminants and reduce its toxicity. Mine wastes are often acidic and may require pH adjustment to levels desirable for plants and living soil organisms. Hensley et al. (1984) emphasizes that soils with a pH less than 4.0 can be toxic to most plants. Many heavy metals become more water soluble under acidic conditions and can leach through soils and contaminate groundwater and nearby waterbodies (U.S. Department of Agriculture, 1998).

Leaching of industrial contaminants, acidic deposition, or exposure of acidic or alkaline-reactive geologic materials can lower or increase soil pH and cause soil infertility and limit microbial activity (U.S. Environmental Protection Agency, 2007). Pyritic ores or acidic mine wastes are likely to have an adverse effect on disposal environments. Oxidation of pyrite and other sulfides in mine wastes generate large amounts of sulfuric acid. Mine wastes with a pH less than 3.5 due to oxidation of pyrites have been recorded in Butte, MT and Leadville, CO. Mine waste with high concentrations of Zn, Cu, or Ni will need its pH raised above 7.0 to reduce metal solubility, protect plant health and ensure food-chain safety. Mine waste with a very high pH drastically limits P availability and induces high selenium (Se), As, and Mo solubility.

Acidic mine waste lacks the necessary nutrients needed for plant growth. Soil pH influences nutrient availability and affects many micro-organisms (U.S. Department of Agriculture, 1998). Plant nutrients are readily available at a pH range of 5.8 to 7 (Prochnow, 2017). Nutrient availability in soils can be made abundantly available by correcting low soil pH. Highly acidic soils have low Ca, Mg, and P content and high solubility of aluminum (Al), Cu, Mn, Zn, cobalt (Co) and Fe, and low Mo solubility (Figure 4). Alkaline soils have Ca and Mg in abundance but lack P, B, Fe, Mn, Cu and Zn.

Acidic mine wastes need to have pH values that are favorable to soil micro-organisms. Micro-organism activities in soils contribute to release of nutrients present in the soils not readily available for absorption by plant roots. Micro-organisms break down and contribute to the bioavailability of N, P, and sulfur (S) imbedded in soils. Micro-organisms prefer soils with a pH in the range of 6.6 to 7.3 for survival (U.S. Department of Agriculture, 1998). Studies by Fernandez-Calvino and Baath (2010) on bacterial growth in soils with different pH values indicates that soil bacterial growth is strongly influenced by pH. Bacterial growth is lowest in acidic soils and highest in basic soils.

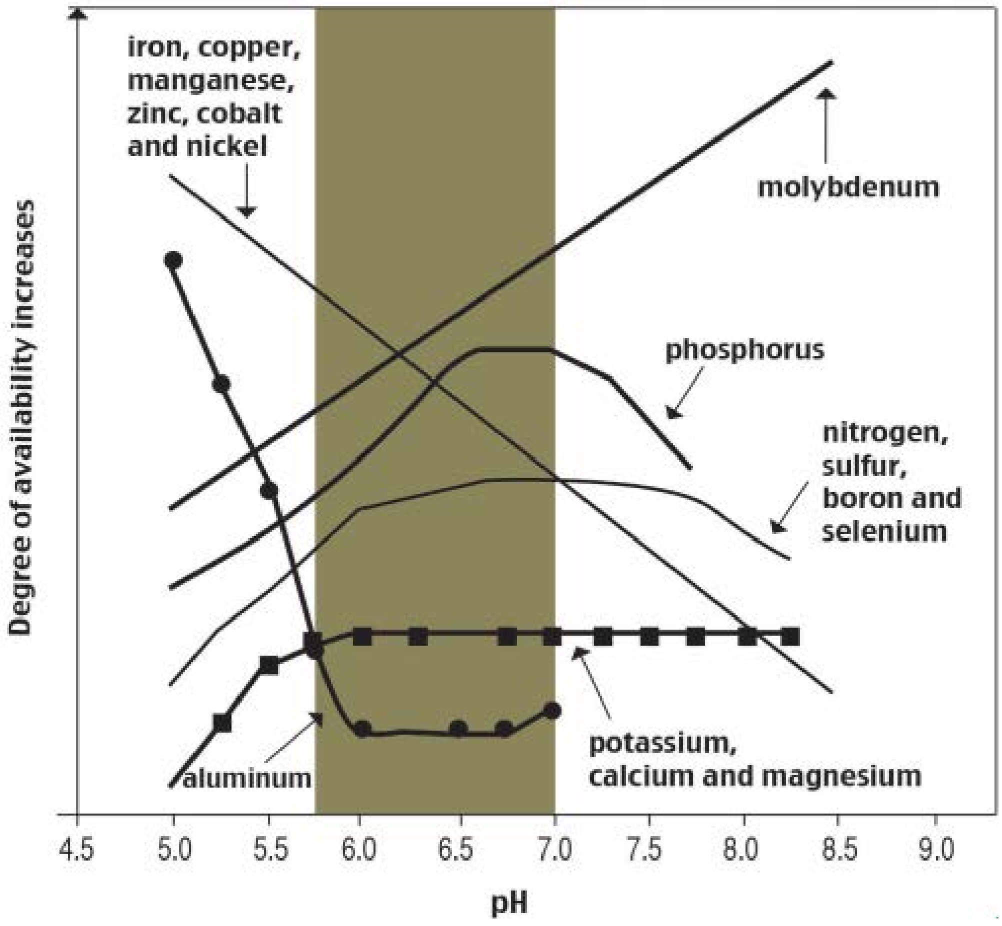

Figure 4: Soil pH effect on nutrient availability (Prochnow, 2017)

Organic or inorganic stabilizers are added to mine waste during revegetation to produce a more chemically stable growing medium capable of supporting vegetation growth. Inorganic stabilizers such as clay (bentonite and kaolinite), cement, fly ash, blast furnace slag, calcium carbonate, Fe/Mn oxides, charcoal, zeolite and organic stabilizers such as bitumen, compost, and manure, or a combination of organic-inorganic amendments may be used (Nikookar, 2015). Cement kiln dust (CaO), limestone (CaCO3), and biocharcoal (biochar) are effective additives that reduce the acidity of mine waste. Examples of organic and inorganic amendments and the heavy metals they immobilize are listed in Tables I and II respectively. Soil amendments help restore soil quality by balancing pH, adding organic matter, increasing water holding capacity, re-establish microbial communities, and alleviate compaction (U.S. Environmental Protection Agency, 2007).

Table I: Organic heavy metal amendments (Nikookar, 2015)

Organic amendment	Heavy metal immobilized
Bark saw dust	Cd, Pb, Hg, Cu
Xylogen	Zn, Pb, Hg
Chitosan	Cd, Cr, Hg
Bagasse	Pb
Poultry manure	Cu, Pb, Zn, Cd
Cattle manure	Cd
Rice hulls	Cd, Cr, Pb
Sewage sludge	Cd
Leaves	Cr, Cd
Straw	Cd, Cr, Pb

Table II: Inorganic heavy metal amendment (Nikookar, 2015)

Inorganic amendment	Heavy metal immobilized
Lime	Cd, Cu, Ni, Pb, Zn
Phosphate	Pb, Zn, Cu, cd
Hydroxyapatite	Zn, Pb, Cu, Cd
Fly ash	Cd, Pb, Cu, Zn, Cr
Slag	Cd, Pb, Zn, Cr
Montmorillonite	Zn, Pb
Portland cement	Cr, Cu, Zn, Pb
Bentonite	Pb

Plants require a good growing medium of not less than 4 inches thick that contains all the needed nutrients for growth. Organic matter addition plays a vital role in contaminated soil revegetation by amending for the lack of nutrients and retention of water needed for plant growth. It is important to include a mixture of materials rich in N and C when rebuilding contaminated soils to reduce the potential of N leaching. The EPA generally recommends a C to N ratio between 20:1 and 40:1. It also may be useful to include a mineral soil amendment such as foundry sand or wood ash as part of the amendment mixture for inorganic bulk and plant nutrients (U.S. Environmental Protection Agency, 2007).

3.2.1.1. Lime application

Although there are many different mine waste neutralization techniques, lime application is the most popular due to its effectiveness in increasing soil pH and its ability to slow down heavy metal mobility and accumulation in plants (Sheoran et al., 2010). A minimum of 785 tonnes/hectare (t/ha) of limestone was applied on soils with a pH less than 5.5 during a recent revegetation project on the Butte Hill (Alexander, 2006). The limestone application was done by sandwiching the limestone between the contaminated soil and the growing medium to prevent the upward movement of acid and metals into the growing medium and uptake by plant roots.

A Southern Indiana coal mine waste with a 2.9 pH was amended with lime and a remarkable pH adjustment was observed after 15 months. Areas that were applied with 39 t/ha of lime saw an increase in pH to 4.8 and on areas applied with 25 t/ha of lime saw an increase in pH to 3.5. Survival rate of plant species like Japanese silverberry (*Elaeagnus umbellate*) was 82% for the 39 t/ha lime treatment site and 53% for the 25 t/ha lime treatment site. This is an indication that pH change from lime treatment of mine spoils is directly related to the amount of lime applied (Hensley, 1984). Tests performed by (Dermatas, 1995) demonstrated that quicklime-sulfate treatment of contaminated soils effectively reduced leachability of As, Cr and Pb. A mixture of quicklime along with a reducing agent, such as fly ash or ferrous salts can also be used to immobilize Cr.

Lime application not only neutralizes soil acidity but also promotes the microbial activity required for converting nutrients into forms that can be utilized by plants. Micro-organisms convert ammonium to nitrate, sulfur to sulfates and enhance the breakdown of certain types of controlled-release fertilizers. Micro-organisms also speed up decomposition of organic matter to release certain forms of nutrients required by plants for growth. Lime application to soil enhances moisture content, degree of aeration, rate of water infiltration and drainage, and root movement throughout the soil profile (Halcomb, 2012).

3.2.1.2. Biochar application

Organic materials from yard debris, hardwood and softwoods, and manures and grasses are turned into biochar for application to contaminated soils. The rich content of essential nutrients like C, N, Ca, P and K of biochar makes it a suitable fertilizer application as an amendment to improve soil health characteristics. The ash content of biochar increases its alkalinity (pH>9) making it suitable for neutralizing acidic soils. Biochars have been effective in neutralizing the acidity of mine waste with high sulfur concentrations (Novak et al., 2016). The ability of biochar to increase pH, soil water retention, nutrient availability, and the binding of heavy metals assist plant growth making it a good amendment for the remediation of degraded mine waste. Studies conducted by Tasneem et al. (2017) showed that biochar addition to soils increased soil pH making it useful in place of lime for remediation of acidic mine waste.

Studies by Park et al. (2011), show that addition of chicken manure-derived biochar to heavy metal contaminated soil significantly reduced Cd and Pb concentrations. Green waste-derived biochar immobilized Cu, Cd and Pb concentrations in contaminated soils. Novak et al. (2016) indicates that biochar can bind heavy metals and improve soil health characteristics. An experiment by Park et al. (2011), conducted with switchgrass showed significant reductions in Cd, Cu, Mn, Pb and Zn with the use of chicken manure-derived biochar. The porosity, surface area and surface functional groups of biochar makes metal electrostatically bind to the surface functional groups. Biochar has asymmetrical plates and porous structure that gives it an excellent metal adsorption capacity (Hayyat et al., 2016).

Hayyat et al. (2016) indicates that the successful application of biochar is largely dependent on the type of biochar and the quality, nature of soil, type of plants, and the type of metal toxicity. Biochar application is also known to increase the germination rate of seeds. Unlike other soil amendment techniques, biochar takes a long time to decompose making it a good option for contaminated mine waste remediation (Novak et al., 2016).

3.2.1.3. Sewage Sludge

Sewage sludge is the waste product from water treatment systems and is mainly composed of runoff, human excreta, and industrial and commercial waste. Sewage sludge may have a high concentration of toxic elements extracted by the wastewater treatment plant to meet discharge water quality requirements. The regulatory requirements for permit acquisition of a sewage sludge disposal site can be expensive and demanding. Sewage sludge is rich in essential plant nutrients and has been utilized for centuries on agricultural lands, forestlands and for reclamation of degraded lands (National Research Council, 1996).

Sewage sludge typically contains 1-6% N, 0.1-2% P and other essential plant nutrients making it useful as a fertilizer amendment for reclamation of mine waste (Table III). The elemental components of sewage sludge are K, Ca, Mg, S, Na, B, Mn, Cu, Mo and Zn. Sewage sludge is also rich in organic matter required by plants for growth. The fertilizer constituents and fast decomposition rate of sewage sludge makes it suitable for application as a soil amendment on mine waste (Reuter, 1997; Forsberg, 2008). Research conducted on the application of sewage sludge as an amendment to mine waste has proven that it improves topsoil development, and increases N accumulation and microbial activities. However, sewage sludge can contain pathogens, toxic elements and heavy metals that can be problematic for the environment.

Table III: Elementary composition of sewage sludge (National Research Council, 1996)

Element	Concentration
% dry weight	
Nitrogen	3
Phosphorus	1.5
Sulfur	1
Calcium	4
Magnessium	0.4
Potassium	0.3
Aluminum	0.5
Iron	1.7
mg/kg weight	
Zinc	1200
Copper	750
Manganese	250
Boron	25
Molybdenum	10
Cobalt	10
Arsenic	10

3.2.1.4. Silicon Waste

Waste from silicon (Si) processing is utilized as a fertilizer in the agricultural sector due to its high silicon content which can be important to plant nutrition. Tubana, et al. (2016), and Rizwan, et al. (2018), have documented that Si fertilizer application increases plant productivity and resistance to biotic and abiotic stresses and improves plant tolerance to moisture deficiency. Silicon is not an essential plant nutrient itself, but is known to enhance disease resistance and help amend for nutrient imbalances in plants. Silicon fertilizer application to mine waste can promote plant resistance to unfavorable environmental conditions posed to plants.

3.2.2. Tree species selection

The success of a revegetation project on mine waste is dependent on the selected tree species and the compatibility of the species to the chemical and physical properties of the waste soil, geographic location and climatic characteristics, surface elevation, season of seeding, compatibility with other vegetation, topographic exposure, and land use objectives. Revegetation is likely to fail if the selected plant species are not compatible with one or more of the waste site characteristics (Hossner, 1992). Aery (2012) emphasizes that plants resistant to heavy metal contamination should be used in the revegetation of mine waste.

Brown and Amacher (1999) indicate that plant species selection for revegetation and reclamation should be based on the species’ adaptability to local conditions. Selected species should have a proven record of tolerance to water deficits, temperature extremes, and nutrient deficiencies; should possess relative vigor during germination and growth; and most importantly, possess the ability to fully grow and reproduce. According to Sheoran at el. (2010), selected tree species must be able to survive and grow in nutrient deficient soils with insufficient water supply. Native plant species are preferred for revegetation because they have survived and reproduced over generations under the environmental conditions of the locality. In addition, native species are accustomed to the unstable climates, predation, disease, herbivory and competitions at the site and have endured the constraints inflicted upon them by the environment, having genetically adapted to the harsh conditions.

3.2.3. Seed priming and germination

Seed development, germination and seedling establishment are the most important stages that determine better future plant establishment and survival. Seeds need special treatment to assist in the germination and early stages of growth.

Martin et al. (2010) and Muhie (2018) define seed priming as a pre-sowing treatment that is used to prepare slow-to-germinate species and weak seedlings with sufficient moisture to start pre-germination metabolic processes without radical protrusion. Moisture availability to seeds is controlled allowing the seeds to soak up sufficient moisture before shoot and root emergence. The moisture provided initiates pre-germination metabolic events. The moisture provided to seeds in priming is inadequate for germination. Priming is mainly done to prepare seeds for germination and growth under unfavorable environmental conditions. Seed germination occurs when the radicle penetrates through the seed coat (Martin et al., 2010).

Seed priming is done to minimize seed germination failures associated with unfavorable environmental conditions or due to seed quality and structure related problems. Jisha (2013) and Muhie (2018) indicate that seed priming improves the germination of several plant species and provides better germination for seedlings in unfavorable growing environments. Seed pretreatment through priming is an easy and cost-effective approach used to overcome stresses related to moisture and temperature. Primed seeds can germinate over a broader temperature range making them less sensitive to oxygen deficiency as compared to unprimed seeds. Hamed (2013) states that priming greatly improves germination rate, uniform seedling emergence and strong seedling establishment.

4. Research Approach

4.1. Soil sample collection

Mine waste samples were collected from five sites located within the BPSOU (Inkoom et al, 2019). All of the locations from which soil samples were taken had no vegetative growth. Figure 5 shows the locations where mine waste samples were collected. The samples were un-sized and then crushed to pass a No. 14 US mesh (1.4mm) screen. Crushing was done on the samples to provide a mine waste soil with a larger surface area per unit volume for a good growth medium for seedlings.

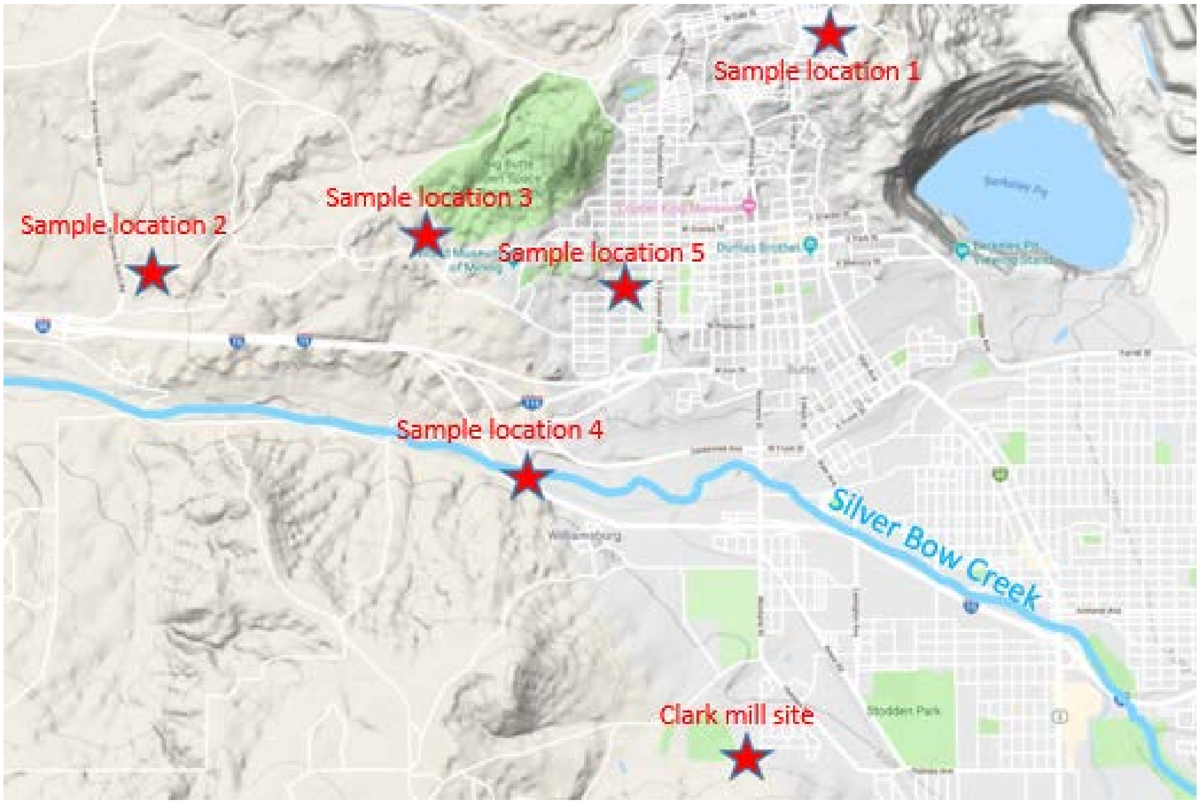

Figure 5: Location of the 5 soil sampling locations within the BPSOU

4.1.1. Laboratory analyses

The mine waste soils were analyzed to determine their metallic contents and amenities needed to support plant growth. The soils were tested for pH, acid extractable metals, total major elements, clay content and the mineralogy (Opoku-Ware, 2018). The pH of the mine waste soils were determined in 1:1 soil-water suspension using a pH electrode. Sample 2 was highly acidic with a pH of 1.97 and may not be suitable for plant growth. Samples 1, 3, and 4 were also acidic with 5.82, 4.88 and 6.06 pH respectively. The U.S. Natural Resource Conservation Service (2011) indicates that plants grow best if soil pH is close to neutral (6.5 to 7.5), but some plant species prefer more acidic soils and others perform well in basic soils. Neutral soils have optimal nutrient availability and are ideal for plant growth. Acidic soils have deficient levels of Ca, Mg, N, P, B, and Mo and abundant levels of Al and Mn. Alkaline soils have deficient levels of P, Fe, Cu, Mn, and B.

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and X-Ray Fluorescence (XRF) tests were performed to determine the elemental composition of the mine waste soils (Inkoom et al, 2019). The results of the ICP-OES tests performed are presented in Table IV. The results show that some of the mine waste soils have unacceptable concentrations of Pb according to the EPA's action levels for heavy metal concentrations within the BPSOU (Table V). Table IV also shows the method detection limit (MDL) that the ICP-OES test can measure and the percent solids of the samples tested. By EPA standards, samples 1, 3 and 4 have elevated Pb levels.

Accumulation of heavy metals such as Cu and Pb in plants causes discoloration and death of leaves, slacks plant growth, disrupts photosynthesis, reduces chlorophyll production and disturbs enzyme activities (Rasafi et al., 2017). The United States Department of Agriculture (2000) indicates that heavy metal accumulation in soils is harmful to humans and animals. Human exposure to heavy metals can lead to chronic sickness. Long-term human exposure to Pb can lead to mental lapse. Prolonged human exposure to Cd is known to cause kidney, liver and gastrointestinal tract problems. Arsenic causes skin poisoning, and affects kidneys and the central nervous system.

Table IV: Acid extractable metals by ICP-OES – Dry weight (mg/kg) (Opoku-Ware, 2018)

Sample ID	1:1 pH	% Solids	Ag	As	Cd	Cu	Mn	Pb	Zn
MDL	--	--	1.6	0.14	0.05	0.65	0.45	0.10	0.73
Sample 1	5.82	94.7	44.3	24.6	18.9	144	4,625	2,928	3,242
Sample 2	1.97	95.8	73.7	183	4.08	75.0	607	816	312
Sample 3	4.88	97.0	74.2	175	8.75	156	7,905	4,780	2,385
Sample 4	6.06	96.4	12.5	115	19.3	71.6	12,401	2,346	5,494
Sample 5	8.43	93.3	<13	7.69	2.60	8.17	184	13.1	78.2

Table V: Maximum permissible heavy metal concentrations within the BPSOU (U.S. Environmental Protection Agency, 2006)

Heavy metal	Exposure Scenario	Concentration (mg/kg)
Lead	Residential	1200
	Non-residential	2300
Arsenic	Residential	250
	Commercial	500
Mercury	Residential	147

X-Ray Diffraction (XRD) of the mine waste soils were also performed to determine the mineralogy and clay content. The XRD analysis provides information on the primary and secondary mineral contents of a mine waste soils. Table VI presents the mineralogy of the mine waste soils. They are composed mainly of quartz, feldspar, mica and muscovite. These minerals weather and influence the physical and chemical properties of the mine waste soil.

Table VI: Mineralogy by XRD analysis (Wt %) (Opoku-Ware, 2018)

Mineral	Sample 1	Sample 2	Sample3	Sample 4	Sample 5
Quartz	19.3	42.3	45.0	46.7	11.5
Feldspar	55.7	23.8	47.3	21.9	88.4
Microcline	--	23.8	41.6	21.9	--
Orthoclase	22.9	--	--	--	22.1
Albite	32.8	--	5.7	--	66.3
Mica	23.9	31.3	7.7	24.1	--
Muscovite	23.9	25.3	7.7	13.8	--
Kaolinite	--	--	--	10.3	--
Lepidolite	--	2.1	--	--	--
Dickite	--	3.9	--	--	--
Hornblende	1.1	--	--	--	--
Jarosite	--	2.5	--	--	--
Pyrite	--	--	--	5.3	--
Calcite	--	--	--	2.0	--

X-Ray Fluorescence (XRF) analysis was also performed on mine waste soils. The results presented in Table VII show that all of the mine waste soils have limited concentrations of P and K. These are essential nutrients needed for plant growth and well-being. Plants require sufficient proportions of N, P, K, Ca, Mg, S, Fe, Zn, Mn, Cu, B, Mo and Cl for normal growth (Uchida, 2000). However, each plant specie is unique and has an optimum nutrient range as well as minimum requirements needed for growth.

Table VII: Total metal composition by XRF analysis (Wt. %) (Opoku-Ware, 2018)

Sample ID	Al	Ca	Fe	K	Mg	Mn	P	Si
Sample 1	6.47	1.40	4.94	3.18	1.01	0.62	0.06	22.7
Sample 2	8.30	0.49	2.85	5.68	0.62	0.11	0.06	21.9
Sample 3	7.07	0.44	1.58	4.73	0.19	1.07	0.04	29.0
Sample 4	7.86	1.62	3.24	4.07	0.80	1.36	0.05	23.4
Sample 5	9.74	1.78	1.61	3.09	0.91	0.02	0.04	32.0

4.2. Species selection and germination

Trees native to Butte are presented in Table VIII (Anderson, 2015). The decision to use trees native to Butte is because native species have adapted to the local climate and have a greater possibility of eliminating climate concerns. Growing trees, especially in Butte can be labor intensive, expensive, and require long-term maintenance. There are no plans for watering, controlling competing vegetation growth, protecting against tree damage, tree replacement, etc. in the project. Species that have a record of survival under the harsh Butte Montana climate with no human intervention have been selected for this project (Inkoom et al, 2019). Tree species selected for this project are listed in Table IX. Sagebrush is often planted on reclaimed mine sites in the Powder River Coal Basin.

Table VIII: Species native to Butte, Montana (Anderson, 2015)

Species	**Family**
Quaking Aspen (*Populus tremuloides*)	Salicaceae
Douglas Fir (*Pseudotsuga menziesii*)	Pinaceae
Mountain Ash (*Sorbus aucuparia*)	Rosaceae
Canada Red Choke Cherry (*Prunus virginiana*)	Rosaceae
Engelmann Spruce (*Picea engelmannii*)	Pinaceae
Subalpine Fir (*Abies lasiocarpa*)	Pinaceae
Creeping Juniper (*Juniperus horizontalis*)	Cupressaceae
Shrubby Potentilla (*Potentilla fruticosa*)	Rosaceae

Table IX: Native Butte Montana tree species used for the project (Inkoom et al, 2019)

Species	**Family**
Quaking Aspen (*Populus tremuloides*)	Salicaceae
Shrubby Potentilla (*Potentilla fruticosa*)	Rosaceae
Big Sagebrush (*Artemisia tridentata*)	Asteraceae
Chokecherry (*Prunus virginiana*)	Rosaceae

Fitzgerald (2010) reported that quaking aspen is a widely distributed tree specie tolerable to a wide range of environmental and site conditions. Aspen has several physiological attributes that allows it to grow in cold temperatures and short growing seasons, tolerate low soil-nutrient levels and alter its leaf morphology (size and shape) depending on moisture availability.

It is desired to see if the growing trees in this project become self-perpetuating ecosystems. This is typically practiced for re-vegetation during mine reclamation under Section

515(b) 19 of PL 95-87: The Surface Mining Control and Reclamation Act (Hall, et al. 2009). If this is achieved on the project, growing trees in Butte in the future will become less expensive and more successful than is currently achieved as a result of the project. The methods and techniques used and evaluated in the project will focus on promoting survivable trees with low human intervention and maintenance.

4.2.1. Seed priming for germination

The selected tree species require pre-treatment prior to germination. The seeds are primed by regulating moisture content and temperature to aid the germination process. The priming process for quaking aspen (*Populus tremuloides*), shrubby potentilla (*Potentilla fruticosa*), and big sagebrush (*Artemisia tridentata*) is the same. The seeds are sprinkled onto separate trays filled with potting mix and sprayed with water. Seeds of the three species germinate after two weeks. The germinated seeds are then planted in the mine waste soil.

Chokecherry requires seed dormancy by cold stratification before germination. The seeds are put in a net and tied for air and moisture exposure. A zip lock bag is filled with coconut fiber that is wetted with water. The net containing the seeds is then placed on the coconut fiber in the zip lock bag and sealed. The zip lock bag is placed in a refrigerator at 2-5 ^{o}C. The seeds are checked weekly for germination before planting in the mine waste soil. The germination period of chokecherry is two months (Inkoom et al, 2019).

4.2.2. Tree growth

The ICP-OES and XRF tests performed indicate that all the mine waste soils are heavily contaminated with heavy metals and lack nutrients that plants require for growth and well-being. Osmocote classic fertilizer, composed of 14% each of N, P, and K, was mixed with the mine waste soil to amend for the lack of plant nutrients providing a growing medium. Planting tubes with a 3.8 cm diameter and 21 cm depth with a small hole at the base were used for planting. The base holes are filled with cotton to prevent the growing medium from pouring out and also to allow excess water to drain.

Each growing medium consists of 1.09 L of mine waste soil mixed with 6.02 g of fertilizer. The resulting mixture was used to fill the tubes and heavily watered to eliminate voids in the soil and allow the growing medium particles to settle. The seeds were then planted in the growing medium. A potting mix, composed of a 1:1 mixture of peat moss and vermiculite with a ph of 5.3 served as a control growing medium to which tree growth in the mine waste soil growing medium will be compared (Opoku-Ware, 2018). Potting mix has all the nutrient required for good plant growth. Table X presents the quantity of each tree species planted. Ten seeds each of quaking aspen (*Populus tremuloides*) and big sagebrush (*Artemisia tridentata*) and 5 seeds each of shrubby potentilla (*Potentilla fruticosa*) and chokecherry (*Prunus virginiana*) were planted in each mine waste soil growing medium and in the control growing medium.

Table X: Number of each specie planted

Species	**Number Planted**
Quaking aspen (*Populus tremuloides*)	60
Shrubby potentilla (*Potentilla fruticosa*)	30
Big sagebrush (*Artemisia tridentata*)	60
Chokecherry (*Prunus virginiana*)	30

The germinated seeds were placed in the Montana Tech greenhouse located on the Montana Tech campus. The greenhouse has ideal conditions for tree growth and operates at a 20 °C average temperature and 65% humidity. The trees are watered twice daily. Figure 6 shows the initial planting stage of the trees.

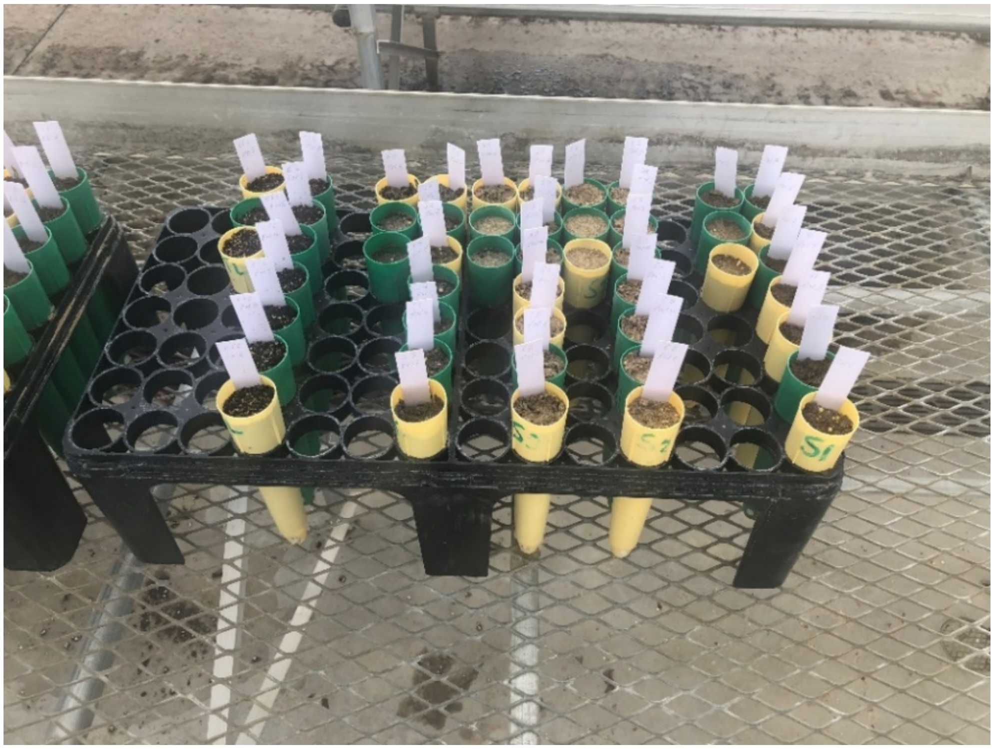

Figure 6: Seeds planted and placed in the Montana Tech greenhouse

4.3. Growth Monitoring

Quaking aspen (*Populus tremuloides*) and big sagebrush (*Artemisia tridentata*) seedlings were grown for 34 weeks. Shrubby potentilla (*Potentilla fruticosa*) and chokecherry (*Prunus virginiana*) were grown for 29 weeks. Growth height of the trees were monitored weekly and the heights were recorded. Figure 7 shows the growth of the tree species after 34 and 29 weeks of growth, respectively (Inkoom et al, 2019).

Seedlings that grew longer than 10 cm were transplanted into 6.5 cm diameter and 36 cm deep pots to accommodate root growth. The seedlings were carefully taken out of the smaller tubes and placed in the bigger pots. Each seedling transplanted into a bigger pot was topped off with the same growing medium type as they were initially grown in the smaller tube. Some seedlings began to show brownish leaf color after transplanting into the bigger pots and some died after 9 weeks. Figure 8 shows seedlings changing leaf color after 2 weeks.

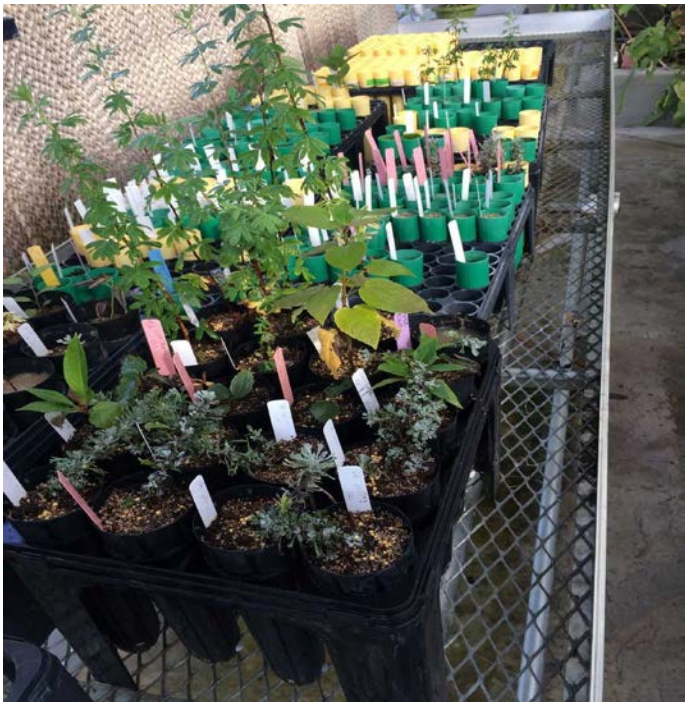

Figure 7: Seedling growth after 34 weeks

Figure 8: Brownish leaf coloration

Three chokecherry (*Prunus virginiana*), seven shrubby potentilla (*Potentilla fruticosa*) and two quaking aspen (*Populus tremuloides*) seedlings died after transplanting. This death is believed to be attributed to the possible damaging of roots during the transplanting process. Figure 9 shows seedlings dead 9 weeks after transplanting respectively.

Figure 9: Some of the trees did not survive after transplanting

4.4. Planting on Clark mill

After 34 and 29 weeks of growth, the surviving seedlings were mature enough for planting on a selected mine waste site. The Clark Mill site located in Butte was selected for planting of the matured seedlings. The site has a history of contamination from smelting waste disposal and Montana Tech was already conducting other vegetation growth research on the site. The laboratory results from a Mehlich 1 test performed on Clark Mill site mine waste samples is presented in Table XI.

Table XI: Clark mill site test results: Mehlich 1 mg/kg (ppm)

Base Saturation	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	Zn
74.0	1039.2	1.1	1.6	34.5	53.5	161.0	146.8	101.0	9.9	0.4	38.3	3.2	78.2

In October 2018, seedlings grown in mine waste soils in the Montana Tech greenhouse were exposed to the outside climate for one day prior to planting at the Clark Mill site. This was done so that the seedlings could acclimate to the Butte growing conditions. Sixty-one seedlings were planted at the Clark Mill site: 19 quaking aspen (*Populus tremuloides*), 19 big sagebrush (*Artemisia tridentata*), 16 shrubby potentilla (*Potentilla fruticosa*), and 7 chokecherry (*Prunus virginiana*) seedlings. The planted seedlings are shown in Figures 10 and 11. Each red flag indicates a location where a seedling is planted (Inkoom et al, 2019).

The trees were planted using a hand-held drill creating a 10 cm diameter, 18 cm deep hole. The roots of the seedlings were spread out loosely in the hole and the plants placed vertically. Lose soil was placed in the hole and compacted to prevent voids that can cause the seedlings to die. Compaction also creates a concave shape on the surface that retains moisture critical for seedling survival. Unlike in the greenhouse where the seedlings had constant water supply and favorable temperature and humidity, the seedlings at the Clark Mill site are allowed to grow and survive with no human intervention (Inkoom et al, 2019).

Figure 10: Shrubby Potentilla (Potentilla fruticosa) (Inkoom et al, 2019)

Figure 11: Trees planted at the Clark mill site (Inkoom et al, 2019)

5. Data Analysis

5.1. Greenhouse growth and survival rate

The tree seedlings were monitored in the greenhouse weekly and their growth heights recorded. Seedling heights for quaking aspen (*Populus tremuloides*) and big sagebrush (*Artemisia tridentata*) were monitored for 34 weeks while those for shrubby potentilla (*Potentilla fruticosa*) and chokecherry (*Prunus virginiana*) were monitored for 29 weeks. The weekly measured heights of the seedlings are presented in Appendix A. The average survival rates of the four tree species grown in the five mine waste soil growing media and the potting mix control growing medium are presented in Table XII.

Table XII: Average survival rate of each tree species (%)

Growing medium	pH	Quaking Aspen	Sagebrush	Shrubby Potentilla	Chokecherry	Overall Average
Sample 1	5.82	80	10	100	60	62.5
Sample 2	1.97	10	0	100	40	37.5
Sample 3	4.88	0	0	60	0	15
Sample 4	6.06	80	30	100	40	62.5
Sample 5	8.43	10	50	100	40	50
Potting Mix	5.3	60	100	100	60	80

Tree growth in the potting mix growing control medium had the highest survival rate of 80%. The higher tree survival rate in the potting mix growing control medium is attributed to the essential nutrients content. Tree growth in samples 1 and 5 each had a 62.5% survival rates and sample 5 had a 50% survival rate. Samples 2 and 3 had 37.5% and 15% tree survival rates respectively. The low tree survival rates in samples 2 are believed to be due to the acidic nature of the mine waste soil growing media. Many plants require neutral soils for growth. Sample 2 had a pH of 1.97 and sample 3 a pH of 4.88. Table I, shows that sample 3 had the highest Pb contamination with a 4,780 mg/kg concentration. The low survival rate of sample 3 is believed to be due to the elevated Pb concentration and the acidic nature of the mine waste soil growing medium. Figure 12 graphically presents the survival rate of each tree specie in the five mine waste soil growing media and potting mix control growing medium.

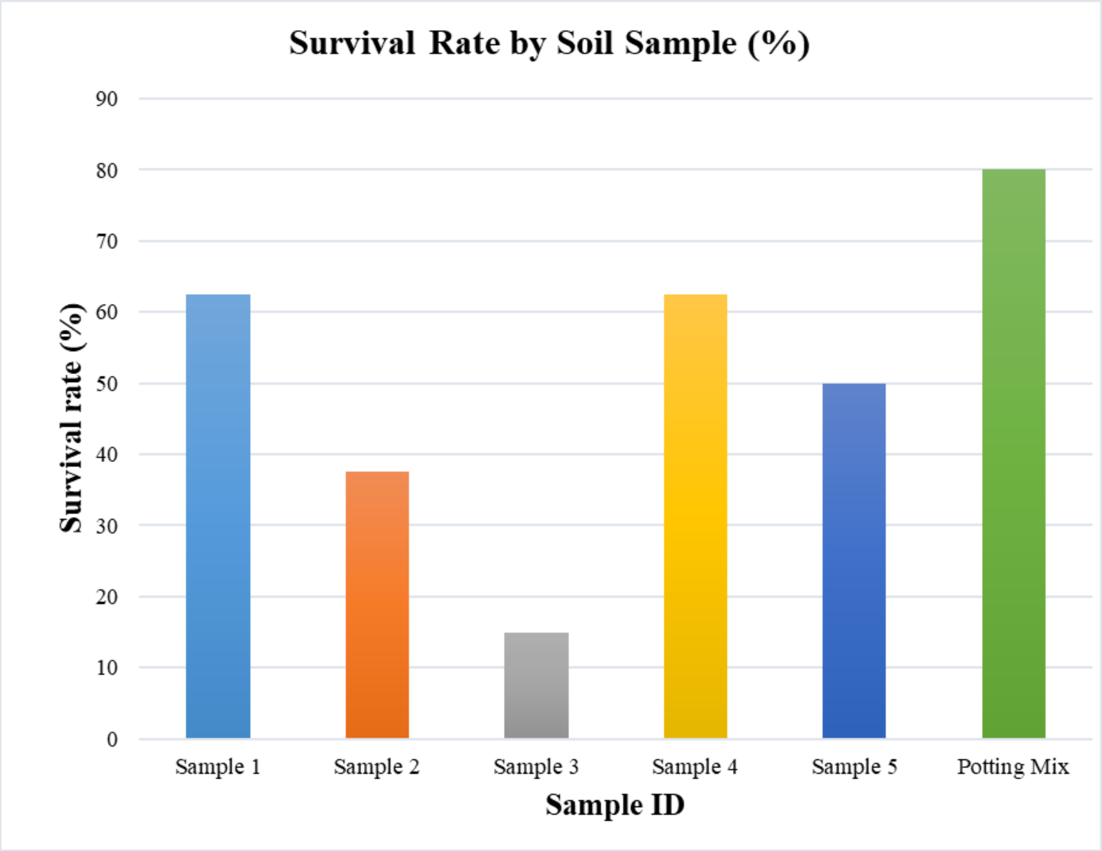

Figure 12: Overall average survival by growth medium

The survival rates in the mine waste soil growing media and the potting mix control growing medium is an indication that pH probably does play a major role in the revegetation of contaminated mine wastes. To get vegetation to grow in samples 2 and 3, the pH may need to be amended to levels that are tolerable to plants. Figure 13 shows the relationship between the average tree survival rate and the pH of the five mine waste soil growing media and the potting mix control growing medium. The trend line indicates that survival rate increases with increasing pH.

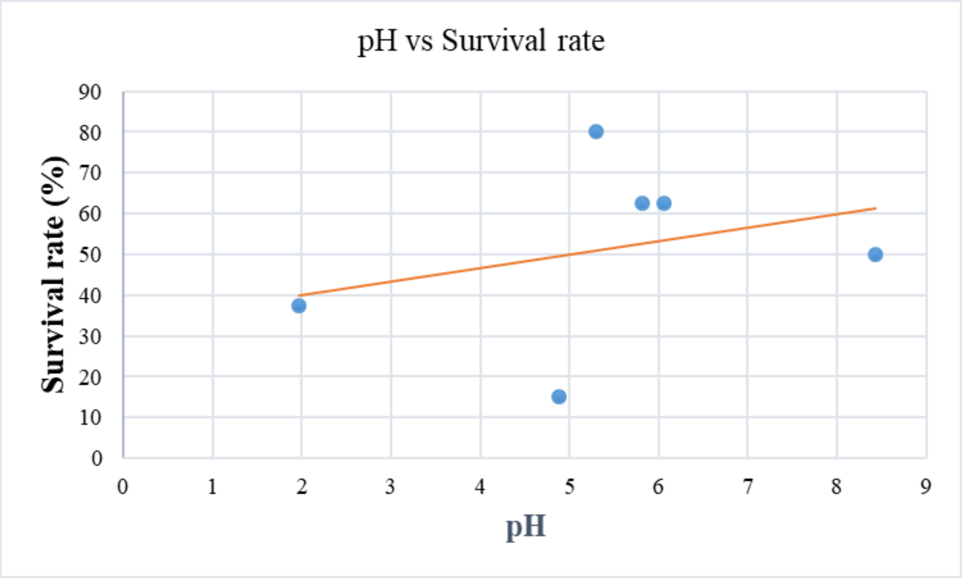

Figure 13: Growing media pH vs survival rate

Shrubby potentilla (*Potentilla fruticosa*) is the only specie that survived growing in sample 3 with 60% of the seedlings surviving. All of the other tree species had a 0% survival rate. The 60% survival rate of shrubby potentilla (*Potentilla fruticosa*) and the 0% survival rate of the other tree species in sample 3 is an indication that shrubby potentilla (*Potentilla fruticosa*) may be more tolerant to the contaminations present than quaking aspen (*Populus tremuloides*), big sagebrush (*Artemisia tridentata*) and chokecherry (*Prunus virginiana*). Also, survival of shrubby potentilla (*Potentilla fruticosa*) in sample 3 is an indication that some tree species are more tolerant to acidic soils and/or heavy metal concentrations than other tree species.

Table XIII and Figure 14 present the overall average survival rate of the tree species grown in the five mine waste soil growing media. Shrubby potentilla (*Potentilla fruticosa*) had a 92% survival rate, the highest of the five mine waste soil growing media. Big sagebrush (*Artemisia tridentata*) had the lowest with an 18% survival rate and may be an indication that it is not tolerant to heavy metals contamination. Quaking aspen (*Populus tremuloides*) and chokecherry (*Prunus virginiana*) both had a 36% survival rate.

Table XIII: Average survival rate of each tree species (%)

Specie	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average Survival Rate (%)
Quaking Aspen	80	10	0	80	10	36
Sagebrush	10	0	0	30	50	18
Shrubby Potentilla	100	100	60	100	100	92
Chokecherry	60	40	0	40	40	36

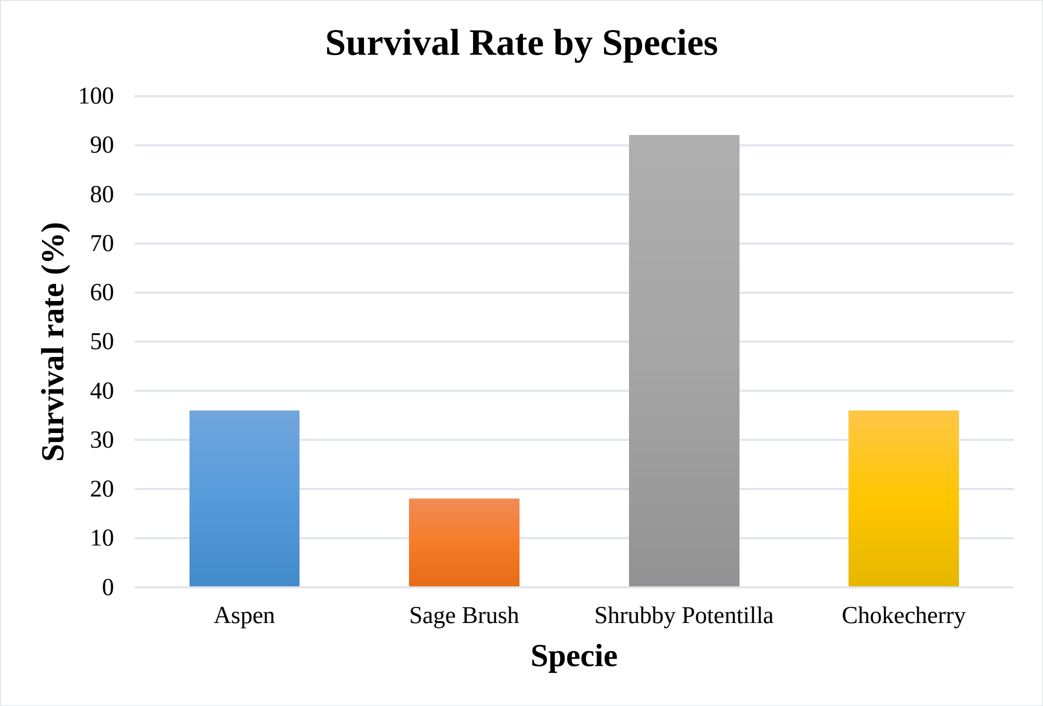

Figure 14: Graphical representation of species survival in five soil samples

5.2. Desired Measure for Success

For the project to be considered successful, developed seedlings planted in the Clark Mill site must survive. It is expected that not all of the seedlings planted on the Clark Mill site will survive. Most of the mine waste sites in Butte have few if any trees growing on them. For this project, it is desired that at least one of every two trees planted in the BPSOU will survive long-term.

Trees and shrubs were planted by the Montana Tech Native Plant Program in 2017 and the survival rates were determined a year later. The trees and shrubs had 13% and 39% survival rate respectively. The survival rate of this project will be compared to the previous tree planting work done in this area.

5.3. Survival rate on Clark Mill site

Seedlings were planted on the Clark Mill site in October 2018 and observed in April 2019 to determine their survival rates. Each seedling was observed to determine its survival or mortality rate. Figures 15 and 16 show the survival of big sagebrush (*Artemisia tridentata*) and shrubby potentilla (*Potentilla fruticosa*) respectively after snow melt. Shrubby potentilla (*Potentilla fruticosa*) seedlings have begun developing new leafs and this is an indication of their survival and growth during the winter. Survival rates of the four tree species planted at the Clark Mill site are presented in Table XIV.

Table XIV: Survival rate of seedlings planted on Clark Mill site

Specie	Number Planted	Survived seedlings	Survival rate (%)
Quaking Aspen	19	4	21
Sage Brush	19	18	95
Shrubby Potentilla	16	14	88
Chokecherry	7	5	71

Big sagebrush (*Artemisia tridentata*), shrubby potentilla (*Potentilla fruticosa*) and chokecherry (*Prunus virginiana*) respectively had 95%, 88% and 71% survival rates. Quaking aspen (*Populus tremuloides*) had the lowest survival rate of 21%. Even though big sagebrush (*Artemisia tridentata*) had a very low survival rate in the mine waste soil samples, it has shown good survival on the Clark Mill site with only one seedling dying. The survival rates of the tree species are likely to change with time. The trees will be monitored over time for possible survival rate reduction.

Figure 15: Sagebrush plant on the Clark Mill site

Figure 16: Shrubby Potentilla survival on the Clark Mill site

6. Conclusion

Revegetation of contaminated mine tailings spoils is a sustainable approach that aims at preventing erosion of contaminants to nearby waterbodies and degradation of nearby soils. Selection of tree species accustomed to the growing environment and tolerable to heavy metals toxicity is key to the success of a revegetation project on mine waste. Some tree species can tolerate heavy metal concentrations better than others and the heavy metal tolerance of the selected tree species should be considered.

Survival rate of trees on mine waste is influenced by the specie type used, level of heavy metal concentration, soil pH, planting technique and the time of planting. The physical and chemical characteristics of the mine waste should be determined to understand the amenities needed for a successful revegetation project. Soil pH is one of the most important factors to consider when revegetating contaminated soils. Soil pH affects the bioavailability of nutrients that trees require for growth. Acidic soils also increase the bioavailability of heavy metals for absorption by plant roots. It is therefore necessary to balance soil pH to keep heavy metals out of solution and to maximize nutrient availability for plant absorption.

The success observed to date on this project provides an early indication that it is possible to successfully grow trees on mine wastes in Butte using seedlings developed from seeds grown in the mine wastes in which they will eventually be planted.

7. Future work

Seedlings planted on the Clark Mill site should be monitored over time to determine their tolerance to the mine waste there and the harsh Butte climate growing conditions.

The application of sewage sludge and silicon processing waste to adjust the pH of the mine wastes should be carried out to determine their impact on tree survival rate.

An underground greenhouse is being constructed at the Montana Tech Underground Mine Education Center (UMEC) where trees will be grown into seedlings for planting on mine waste sites in the BPSOU.

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9. Appendix A

Growth Medium:	SITE 1																												
Tree Specie:	POTENTILLA																												
Location:																													
Sample Number	Tree Height (cm)																												
	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	2.6	3.1	3.1	3.4	2.5	3.9	4.1	4.9	5.1	5.1	5.1	6.0	5.9	6.2	6.3	6.5	6.6	6.5	6.7	7.6	7.0	7.0	6.8	6.5	5.6	5.6	5.3	5.3	5.3
2	3.3	3.3	3.4	3.5	2.9	3.6	3.5	3.8	3.7	4.0	4.0	4.0	3.8	3.6	3.3	3.9	3.5	3.9	3.6	3.7	3.5	3.5	3.7	3.7	2.8	2.2	2.4	2.5	2.5
3	2.9	3.4	2.6	3.1	2.4	3.1	3.2	3.3	3.2	3.5	3.5	3.7	3.6	3.5	2.1	2.2	2.6	2.0	2.6	2.4	2.8	2.6	2.6	2.8	2.8	2.8	2.7	2.8	2.8
4	1.5	2.2	2	2	1.8	2.2	2.4	2.3	2.3	2.4	1.5	1.5	1.4	1.5	1.5	1.5	1.3	1.3	1.3	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
5	2.6	2.7	2.9	2.7	2.4	3	3	3.1	3.5	3.3	4.5	4.9	5.2	5.6	5.3	5.2	5.6	5.6	5.2	5.2	5.0	4.3	4.4	4.2	4.5	4.4	4.1	4.1	4.1
Average	**2.6**	**2.9**	**2.8**	**2.9**	**2.4**	**3.2**	**3.2**	**3.5**	**3.6**	**3.7**	**3.7**	**4.0**	**4.0**	**4.1**	**3.7**	**3.9**	**3.9**	**3.9**	**3.9**	**4.0**	**3.9**	**3.7**	**3.7**	**3.7**	**3.4**	**3.2**	**3.1**	**3.2**	**3.2**
Count	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
St. Dev.	**0.7**	**0.5**	**0.5**	**0.6**	**0.4**	**0.7**	**0.6**	**1.0**	**1.0**	**1.0**	**1.4**	**1.7**	**1.7**	**1.9**	**2.1**	**2.1**	**2.2**	**2.2**	**2.1**	**2.6**	**2.3**	**2.2**	**2.1**	**2.0**	**1.7**	**1.8**	**1.6**	**1.6**	**1.6**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Growth Medium:	SITE 2																												
Tree Specie:	POTENTILLA																												
Location:																													
Sample Number	Tree Height (cm)																												
	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	2.7	2.8	2.4	2.5	1.9	2.2	2.3	1.9	1.6	1.7	1.7	1.7	1.7	1.7	1.8	1.7	1.7	1.7	1.8	1.7	1.7	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.6
2	1.3	2.1	2.1	2.5	1.9	2.5	2.5	2.7	2.8	3.4	4.4	5.3	6.4	7.5	8.3	9.4	10.4	11.7	13.5	13.9	13.9	13.5	12.0	11.7	12.0	11.9	11.8	11.8	11.8
3	1.1	1.2	1	1.4	1.3	1.6	1.7	1.8	1.6	1.7	1.8	1.7	1.8	1.7	1.7	1.7	1.6	1.8	2.5	2.9	3.3	3.4	3.5	3.6	3.6	4.2	4.9	5.4	5.5
4	2.1	1.9	1.5	2.3	1.8	2.4	2.4	2.8	2.8	3.2	4.1	4.3	5.8	7.7	8.1	8.6	9.2	9.5	9.4	9.4	9.2	7.9	8.0	7.9	8.0	8.0	7.9	8.0	8.0
5	1.3	1.5	1.3	1.5	1.1	1.6	1.4	1.3	1.2	1.3	1.3	1.4	1.2	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Average	**1.7**	**1.9**	**1.7**	**2.0**	**1.6**	**2.1**	**2.1**	**2.1**	**2.0**	**2.3**	**2.7**	**2.9**	**3.4**	**3.9**	**4.2**	**4.5**	**4.8**	**5.1**	**5.6**	**5.8**	**5.8**	**5.5**	**5.2**	**5.2**	**5.2**	**5.3**	**5.4**	**5.6**	**5.6**
Count	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
St. Dev.	**0.7**	**0.6**	**0.6**	**0.5**	**0.4**	**0.4**	**0.5**	**0.6**	**0.7**	**1.0**	**1.5**	**1.8**	**2.5**	**3.4**	**3.7**	**4.2**	**4.6**	**5.1**	**5.5**	**5.6**	**5.6**	**5.2**	**4.7**	**4.5**	**4.7**	**4.6**	**4.5**	**4.5**	**4.5**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Growth Medium	SITE 3																												
Tree Specie:	POTENTILLA																												
Location:																													
Sample Number	Tree Height (cm)																												
	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	1.5	1.5	1.5	1.5	1.3	1.5	0.9	0.8	0.8	0.9	0.9	0.8	0.9	0.9	0.9	0.8	0.7	-	-	-	-	-	-	-	-	-	-	-	-
2	1.8	1.8	1.4	1.5	1.2	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3	1.7	1.7	1.7	1.6	1.3	1.7	1.2	1.3	1.1	1.1	0.9	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1
4	1.5	1.7	1.5	1.6	1.2	1.2	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1
5	1.7	1.8	1.6	1.8	1.3	1.2	1	1.0	1.0	1.1	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	-
Average	**1.6**	**1.7**	**1.5**	**1.6**	**1.3**	**1.3**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**
Count	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**
St. Dev.	**0.13**	**0.12**	**0.11**	**0.12**	**0.05**	**0.38**	**0.16**	**0.21**	**0.15**	**0.16**	**0.15**	**0.17**	**0.16**	**0.17**	**0.16**	**0.21**	**0.27**	**0.21**	**0.16**	**0.16**	**0.10**	**0.10**	**0.10**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**60%**	**60%**

Growth Medium:	SITE 4																												
Tree Specie:	POTENTILLA																												
Location:																													
Sample Number	Tree Height (cm)																												
	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	1.2	2.7	2	2.1	2.1	2	1.8	2.0	1.7	3.2	3.7	4.8	5.5	7.5	9.6	10.3	10.5	10.8	10.5	11.5	11.2	9.6	9.5	9.4	9.4	9.5	9.3	9.3	9.4
2	3.2	3.1	3.3	3.5	2.8	3.6	3.1	3.5	3.7	4.5	5.7	6.3	7.8	9.5	12.5	14.2	14.6	15.2	14.7	15.5	15.5	15.5	15.0	13.2	13.2	13.0	13.0	13.3	13.2
3	2.6	3.5	3.3	3.6	3	3.9	3.9	3.5	4.1	4.4	5.6	8.1	12.0	15.3	17.4	19.4	22.5	26.0	29.0	30.5	30.5	30.4	29.5	25.5	25.5	25.5	25.5	25.5	25.5
4	2.5	2.7	2.6	2.7	2.4	3	3	2.5	2.6	2.5	2.5	2.5	3.1	3.1	3.5	5.1	6.5	8.3	10.0	11.1	10.2	10.5	10.5	10.3	10.1	9.9	9.9	10.0	10.0
5	3	2.8	3.1	3	2.5	3.1	3.5	3.2	3.4	3.5	3.6	4.0	4.8	5.3	6.2	7.3	8.1	9.3	11.2	12.3	12.3	12.4	12.9	12.8	13.6	13.7	14.7	15.2	15.3
Average	**2.5**	**2.96**	**2.86**	**2.98**	**2.56**	**3.12**	**3.06**	**2.94**	**3.1**	**3.62**	**4.22**	**5.14**	**6.64**	**8.14**	**9.84**	**11.3**	**12.4**	**13.9**	**15.1**	**16.2**	**15.9**	**15.7**	**15.5**	**14.2**	**14.4**	**14.3**	**14.5**	**14.7**	**14.68**
Count	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
St. Dev.	**0.8**	**0.3**	**0.6**	**0.6**	**0.4**	**0.7**	**0.8**	**0.7**	**1.0**	**0.8**	**1.4**	**2.2**	**3.4**	**4.7**	**5.4**	**5.7**	**6.4**	**7.2**	**8.0**	**8.2**	**8.4**	**8.5**	**8.1**	**6.5**	**6.5**	**6.5**	**6.5**	**6.5**	**6.5**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Growth Medium	**SITE 5**																												
Tree Specie:	**POTENTILLA**																												
Location:																													
Sample Number	**Tree Height (cm)**																												
	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	2	2.3	2.7	2.7	2.6	3.7	4.3	5.2	5.7	6.7	8.1	7.9	7.9	8.7	10.0	12.0	12.7	13.7	14.4	14.4	14.0	14.5	14.5	14.8	14.6	14.7	14.5	14.6	14.5
2	2.9	3.2	3.1	4	3.4	4.6	5.5	6.4	7.3	8.1	9.7	10.1	10.2	10.0	10.9	11.6	11.8	12.0	12.1	12.0	12.3	12.3	12.2	12.1	11.9	12.0	12.2	12.1	12.2
3	4.5	4.1	4.7	4.6	4.3	6.1	7.8	9.1	10.1	11.9	13.3	13.7	15.2	19.0	20.5	21.9	21.9	24.6	25.6	27.9	29.6	29.8	27.5	27.4	27.4	27.4	27.0	27.2	27.5
4	2.8	3.7	3.8	4.1	3.2	5.2	6.1	6.5	7.4	7.5	7.8	7.9	8.0	10.4	11.4	12.5	12.9	12.9	12.8	13.4	14.3	14.7	15.3	15.2	15.0	15.0	15.9	17.2	17.9
5	3.2	4.3	4	4.9	4.2	6	7.5	8.9	9.6	9.9	10.0	10.3	11.1	13.7	14.8	15.3	15.9	17.2	19.2	21.2	21.9	22.1	22.2	22.2	21.5	22.0	21.6	22.4	22.9
Average	**3.1**	**3.5**	**3.7**	**4.1**	**3.5**	**5.1**	**6.2**	**7.2**	**8.0**	**8.8**	**9.8**	**10.0**	**10.5**	**12.4**	**13.5**	**14.7**	**15.0**	**16.1**	**16.8**	**17.8**	**18.4**	**18.7**	**18.3**	**18.3**	**18.1**	**18.2**	**18.2**	**18.7**	**19.0**
Count	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
St. Dev.	**0.9**	**0.8**	**0.8**	**0.8**	**0.7**	**1.0**	**1.4**	**1.7**	**1.8**	**2.1**	**2.2**	**2.4**	**3.0**	**4.1**	**4.3**	**4.3**	**4.1**	**5.2**	**5.6**	**6.7**	**7.3**	**7.2**	**6.3**	**6.3**	**6.3**	**6.3**	**6.0**	**6.1**	**6.2**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Growth Medium:	**CONTROL**																												
Tree Specie:	**POTENTILLA**																												
Location:																													
Sample Number	**Tree Height (cm)**																												
	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	3.5	4.6	4.5	5.4	4.5	5.2	5.9	7.6	8.7	12.6	18.7	20.2	19.0	20.1	21.6	23.5	24.0	26.3	30.0	32.0	37.7	44.1	51.5	55.0	60.2	60.3	57.5	55.5	56.0
2	2.5	3.1	2.8	3.4	2.9	3.4	3.7	3.9	4.6	4.6	5.6	6.5	9.0	11.8	13.6	18.8	22.5	26.6	30.4	32.4	35.5	39.0	41.3	41.5	41.6	42.0	42.5	42.8	42.5
3	3.7	4.3	3.6	4.7	3.7	4.6	5.4	6.6	6.6	9.3	13.1	15.5	18.5	23.4	25.5	29.2	33.0	36.3	38.7	39.3	40.3	44.0	46.3	47.3	47.3	49.8	52.0	54.2	57.1
4	3.2	3.9	4	4	3.2	5.2	6.3	10.2	12.7	16.5	21.5	24.9	29.0	33.0	34.7	38.6	42.2	45.5	48.3	51.0	54.2	55.2	59.4	59.9	60.0	61.0	63.3	65.5	68.6
5	2.1	3.2	3.1	3.5	2.7	3.4	4.2	5.3	6.7	9.8	12.6	15.5	19.5	23.7	26.5	30.5	33.0	36.6	39.4	40.4	44.5	49.5	54.5	55.8	55.5	57.5	60.3	60.5	61.0
Average	**3.0**	**3.8**	**3.6**	**4.2**	**3.4**	**4.4**	**5.1**	**6.7**	**7.9**	**10.6**	**14.3**	**16.5**	**19.0**	**22.4**	**24.4**	**28.1**	**30.9**	**34.3**	**37.4**	**39.0**	**42.4**	**46.4**	**50.6**	**51.9**	**52.9**	**54.1**	**55.1**	**55.7**	**57.0**
Count	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
St. Dev.	**0.7**	**0.7**	**0.7**	**0.8**	**0.7**	**0.9**	**1.1**	**2.4**	**3.1**	**4.4**	**6.1**	**6.8**	**7.1**	**7.6**	**7.7**	**7.5**	**8.0**	**8.0**	**7.6**	**7.7**	**7.4**	**6.2**	**7.0**	**7.4**	**8.2**	**8.1**	**8.2**	**8.5**	**9.5**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Growth Medium:	**SITE 1**																											
Tree Specie:	**CHOKECHERRY**																											
Location:																												
Sample Number	Tree Height (cm)																											
	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	6.2	5.8	6.1	5	6.3	6.3	6.4	6.4	6.5	6.4	6.2	6.2	6.3	6.4	6.2	6.3	6.3	7.4	7.8	7.7	7.6	7.6	7.5	7.6	7.5	6.7	6.5	6.6
2	5.6	6	6	4.7	5.9	5.8	6.0	6.1	6.0	6.0	6.0	6.0	6.0	6.1	6.0	6.1	6.1	7.3	7.3	4.8	5.0	5.0	4.6	4.5	5.0	4.6	4.7	4.6
3	4.9	5.5	5.7	4.6	5.6	5.8	5.7	5.8	5.8	5.7	5.8	5.8	5.7	5.7	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.6	5.6	5.7
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**5.6**	**5.8**	**5.9**	**4.8**	**5.9**	**6.0**	**6.0**	**6.1**	**6.1**	**6.0**	**6.0**	**6.0**	**6.0**	**6.1**	**6.0**	**6.0**	**6.0**	**6.8**	**7.0**	**6.1**	**6.1**	**6.1**	**5.9**	**5.9**	**6.1**	**5.6**	**5.6**	**5.6**
Count	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
St. Dev.	**0.7**	**0.3**	**0.2**	**0.2**	**0.4**	**0.3**	**0.4**	**0.3**	**0.4**	**0.4**	**0.2**	**0.2**	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**	**1.0**	**1.0**	**1.5**	**1.3**	**1.3**	**1.5**	**1.6**	**1.3**	**1.1**	**0.9**	**1.0**
Survival	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**

Growth Medium:	**SITE 2**																											
Tree Specie:	**CHOKECHERRY**																											
Sample Number		Tree Height (cm)																										
	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	3.6	4.4	4.8	4.1	5.4	5.4	5.5	5.5	5.6	5.6	5.7	5.7	5.7	5.7	5.8	5.7	5.8	4.9	5.2	5.2	5.2	5.1	5.3	5.3	5.3	5.2	5.3	5.3
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	6.2	6.5	7	5.5	5.7	7.2	7.0	7.2	7.2	7.2	7.3	7.0	7.0	7.2	7.2	7.1	7.1	6.5	6.7	6.9	5.8	5.2	5.0	4.1	3.0	3.0	2.9	2.9
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**4.9**	**5.45**	**5.9**	**4.8**	**5.55**	**6.3**	**6.25**	**6.35**	**6.4**	**6.4**	**6.5**	**6.35**	**6.35**	**6.45**	**6.5**	**6.4**	**6.45**	**5.7**	**5.95**	**6.05**	**5.5**	**5.15**	**5.15**	**4.7**	**4.15**	**4.1**	**4.1**	**4.1**
Count	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
St. Dev.	**1.8**	**1.5**	**1.6**	**1.0**	**0.2**	**1.3**	**1.1**	**1.2**	**1.1**	**1.1**	**1.1**	**0.9**	**0.9**	**1.1**	**1.0**	**1.0**	**0.9**	**1.1**	**1.1**	**1.2**	**0.4**	**0.1**	**0.2**	**0.8**	**1.6**	**1.6**	**1.7**	**1.7**
Survival	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**

Growth Medium:	**SITE 3**																											
Tree Specie:		**CHOKECHERRY**																										
Sample Number		Tree Height (cm)																										
	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	2.3	3	3	2.2	3.2	3.1	3.3	3.2	3.2	2.2	2.0	2.0	2.0	2.0	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	3.7	3.5	3.3	2.7	1.5	-	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.8	1.8	1.8	1.1	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**2.6**	**2.767**	**2.7**	**2**	**2.1**	**3.1**	**2.35**	**2.3**	**2.3**	**1.75**	**1.65**	**1.65**	**1.65**	**1.6**	**1.65**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Count	**3**	**3**	**3**	**3**	**3**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
St. Dev.	**1.0**	**0.9**	**0.8**	**0.8**	**1.0**	**-**	**1.3**	**1.3**	**1.3**	**0.6**	**0.5**	**0.5**	**0.5**	**0.6**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Survival	**60%**	**60%**	**60%**	**60%**	**60%**	**20%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

Growth Medium:	**SITE 4**																											
Tree Specie:		**CHOKECHERRY**																										
Sample Number		Tree Height (cm)																										
	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	6.2	6.7	6.5	5.2	6.7	6.5	7.0	6.9	7.2	6.9	6.9	6.8	6.7	6.9	6.9	6.8	6.8	7.0	7.0	7.1	7.1	7.0	6.5	6.7	6.5	6.5	6.4	6.5
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
4	5.8	6.3	6.3	5.3	6.9	6.2	6.8	6.7	6.7	6.8	6.8	6.8	6.8	6.7	6.5	6.6	6.5	6.9	3.5	4.0	4.2	3.9	3.9	3.9	3.8	3.8	3.8	4.0
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**6.0**	**6.5**	**6.4**	**5.3**	**6.8**	**6.4**	**6.9**	**6.8**	**7.0**	**6.9**	**6.9**	**6.8**	**6.8**	**6.8**	**6.7**	**6.7**	**6.7**	**7.0**	**5.3**	**5.6**	**5.7**	**5.5**	**5.2**	**5.3**	**5.2**	**5.2**	**5.1**	**5.3**
Count	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
St. Dev.	**0.3**	**0.3**	**0.1**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**	**0.4**	**0.1**	**0.1**	**0.0**	**0.1**	**0.1**	**0.3**	**0.1**	**0.2**	**0.1**	**2.5**	**2.2**	**2.1**	**2.2**	**1.8**	**2.0**	**1.9**	**1.9**	**1.8**	**1.8**
Survival	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**60%**	**40%**

Growth Medium:	SITE 5																											
Tree Specie:	CHOKECHERRY																											
Sample Number	Tree Height (cm)																											
	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	4.9	5.6	7.5	6.3	8.1	8.3	8.2	8.4	8.6	8.6	8.3	8.3	8.2	8.2	8.5	8.4	8.3	8.4	8.6	8.6	8.5	8.6	8.4	8.4	8.5	8.6	8.5	8.6
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	6.2	7.1	8.1	7.5	13.5	14.6	15.4	15.7	16.3	16.4	16.3	16.0	15.9	15.7	16.4	15.6	16.0	16.2	16.2	16.2	16.1	16.2	16.0	16.1	16.0	16.0	16.0	16.1
Average	**5.6**	**6.4**	**7.8**	**6.9**	**10.8**	**11.5**	**11.8**	**12.1**	**12.5**	**12.5**	**12.3**	**12.2**	**12.1**	**12.0**	**12.5**	**12.0**	**12.2**	**12.3**	**12.4**	**12.4**	**12.3**	**12.4**	**12.2**	**12.3**	**12.3**	**12.3**	**12.3**	**12.4**
Count	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
St. Dev.	**0.9**	**1.1**	**0.4**	**0.8**	**3.8**	**4.5**	**5.1**	**5.2**	**5.4**	**5.5**	**5.7**	**5.4**	**5.4**	**5.3**	**5.6**	**5.1**	**5.4**	**5.5**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.3**	**5.2**	**5.3**	**5.3**
Survival	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**

Growth Medium:	CONTROL																											
Tree Specie:	CHOKECHERRY																											
Sample Number	Tree Height (cm)																											
	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	8.2	8.1	8.3	7	9.1	9.2	9.1	9.2	9.2	9.2	9.2	9.1	9.1	9.0	9.0	9.0	9.0	9.0	8.8	9.3	9.2	9.5	9.4	9.4	9.3	9.4	9.4	9.4
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	6.8	7.6	7.9	6.4	8	7.9	8.1	8.0	8.0	8.0	8.0	8.1	8.0	8.0	8.0	8.3	8.1	8.1	7.4	7.5	7.5	7.6	7.5	7.6	7.5	7.5	7.4	7.4
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	6.5	6.5	8.1	5.8	8.2	9	10.4	10.5	10.9	10.6	10.5	10.5	10.2	10.6	10.7	10.7	10.5	10.6	10.6	10.6	10.9	10.9	11.0	11.1	11.0	11.1	11.2	11.0
Average	**7.2**	**7.4**	**8.1**	**6.4**	**8.4**	**8.7**	**9.2**	**9.2**	**9.4**	**9.3**	**9.2**	**9.2**	**9.1**	**9.2**	**9.2**	**9.3**	**9.2**	**9.2**	**8.9**	**9.1**	**9.2**	**9.3**	**9.3**	**9.4**	**9.3**	**9.3**	**9.3**	**9.3**
Count	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
St. Dev.	**0.9**	**0.8**	**0.2**	**0.6**	**0.6**	**0.7**	**1.2**	**1.3**	**1.5**	**1.3**	**1.3**	**1.2**	**1.1**	**1.3**	**1.4**	**1.2**	**1.2**	**1.3**	**1.6**	**1.6**	**1.7**	**1.7**	**1.8**	**1.8**	**1.8**	**1.8**	**1.9**	**1.8**
Survival	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**

Growth Medium:	**SITE 1**																																	
Tree Specie:	**ASPEN**																																	
Sample Number	**Tree Height (cm)**																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	0.9	1	0.9	1	0.9	1	0.9	0.8	1	0.7	0.8	0.7	0.8	0.9	1.0	1.0	0.9	1.0	1.0	0.8	1.0	0.8	0.9	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.8	0.8
2	1	1.3	1.1	1.5	1.5	1.1	1.3	1.5	1.3	1.2	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.6	1.7	1.6	1.6	1.7	1.6	1.5	1.5	1.5	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7
3	1.1	1.3	1.3	1.1	1.4	1.3	1.1	1.3	1.3	1	1.4	1.4	1.5	1.4	1.5	1.4	1.6	1.7	2.1	2.5	3.9	4.0	7.5	9.0	9.5	10.3	10.5	10.4	10.7	10.7	10.8	10.8	10.8	10.8
4	0.5	0.6	0.5	0.5	0.4	0.4	0.5	0.6	0.5	0.5	0.5	0.7	0.7	0.5	0.7	0.5	0.6	0.5	0.4	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.7	0.7
5	1.1	1.3	1.2	1.3	1.2	1.1	0.9	1.5	1.2	1.1	1.4	1.4	1.3	1.3	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.4	1.3	1.4	1.4	1.3	1.2	1.3	1.3
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	1.1	1.3	1.2	1.3	1.5	1.2	1.3	1.4	1.3	1.1	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.2	1.3	1.5	1.8	2.0	2.1	2.1	2.2	2.3	2.3	2.2	2.2	2.3
8	1.2	1.5	1.4	1.3	1.1	1.3	1.2	1.7	1.6	1	1.7	1.6	1.6	1.5	1.7	1.6	1.7	1.6	1.7	1.7	1.7	0.9	0.9	0.9	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0	1.0	0.9
9	1.1	1.2	1.1	0.8	1	1	1	0.8	0.8	0.5	0.7	0.7	0.8	1.7	2.2	3.0	3.5	4.6	7.0	7.9	9.0	9.2	10.8	10.4	10.4	10.2	7.0	6.8	-	-	-	-	-	-
10	1.4	1.7	1.5	2.2	2.2	2.2	2.1	2.1	2.1	1.6	1.9	2.1	2.2	2.1	2.1	2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.7	1.7	1.7	1.2	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5
Average	**1.0**	**1.2**	**1.1**	**1.2**	**1.2**	**1.2**	**1.1**	**1.3**	**1.2**	**1.0**	**1.3**	**1.3**	**1.33**	**1.389**	**1.5**	**1.6**	**1.6**	**1.8**	**2.1**	**2.2**	**2.5**	**2.4**	**3.0**	**3.1**	**3.2**	**3.2**	**2.9**	**2.9**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**
Count	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**8**	**8**	**8**	**8**	**8**	**8**
Survival	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**90%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**

Growth Medium:	**SITE 2**																																	
Tree Specie:	**ASPEN**																																	
Sample Number	**Tree Height (cm)**																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	0.5	0.7	0.9	1.4	1.9	1.9	1.8	1.7	2.5	2.2	2.6	2.9	2.8	2.8	2.7	2.7	2.7	2.7	2.9	2.6	2.7	2.6	2.8	2.5	2.8	2.6	2.7	2.7	2.5	2.6	2.5	2.5	2.5	2.3
2	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**0.4**	**0.7**	**0.9**	**1.4**	**1.9**	**1.9**	**1.8**	**1.7**	**2.5**	**2.2**	**2.6**	**2.9**	**2.8**	**2.8**	**2.7**	**2.7**	**2.7**	**2.7**	**2.9**	**2.6**	**2.7**	**2.6**	**2.8**	**2.5**	**2.8**	**2.6**	**2.7**	**2.7**	**2.5**	**2.6**	**2.5**	**2.5**	**2.5**	**2.3**
Count	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Survival	**20%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**

Growth Medium:	SITE 3																																	
Tree Specie:	ASPEN																																	
Sample Number	Tree Height (cm)																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	**6/27**	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.6	0.8	0.8	0.6	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	0.9	1.1	1.3	1.2	1.1	1	0.9	-	-	0.9	0.6	0.5	0.5	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.2	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.9	1.3	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	0.6	0.7	0.6	0.6	0.6	0.7	0.7	0.5	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0.7	0.8	0.4	0.5	0.7	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	0.7	1.2	0.6	0.8	0.6	0.6	0.6	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	0.8	1	1	0.9	0.8	1	0.9	0.9	0.9	0.7	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**0.8**	**1.0**	**0.8**	**0.7**	**0.8**	**0.7**	**0.8**	**0.6**	**0.8**	**0.8**	**0.7**	**0.5**	**0.5**	**0.6**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Count	**9**	**9**	**6**	**7**	**6**	**5**	**4**	**3**	**2**	**2**	**2**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Survival	**90%**	**90%**	**60%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**20%**	**20%**	**10%**	**10%**	**10%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

Growth Medium:	SITE 4																																	
Tree Specie:	ASPEN																																	
Sample Number	Tree Height (cm)																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	**6/27**	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	1.9	2.1	2.2	2.3	2.4	2.2	2.3	2.3	2.0	1.6	2.2	2.3	2.3	2.3	2.4	2.3	2.4	2.3	2.3	2.2	2.1	2.0	2.0	2.1	2.3	2.4	2.7	2.7	2.8	2.8	2.9	2.8	2.7	2.7
2	1.1	1.4	1.5	1.5	1.6	1.7	2.0	2.2	2.1	1.8	2.6	2.7	2.9	3.0	2.9	2.9	3.0	2.9	2.9	2.9	3.0	2.9	2.9	2.9	2.9	2.8	2.8	3.0	2.8	2.8	2.8	2.8	2.8	2.7
3	1.3	1.4	1.6	1.7	1.6	1.8	2.2	2.3	2.2	1.8	2.5	2.4	2.4	2.5	2.5	2.5	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4
4	2.4	2.5	3.2	3.5	4.1	3.7	3.9	4.0	3.5	3.2	4.0	3.8	3.6	3.8	3.7	3.8	3.7	3.7	3.9	3.7	3.7	3.7	3.5	3.5	3.6	3.8	3.7	3.8	3.5	3.6	3.7	3.6	3.5	3.7
5	1.6	1.9	1.1	1.1	1.1	1.1	0.9	1.8	-	0.5	-	-	7.0	7.3	7.5	7.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	1.2	1.5	1.5	1.5	1.6	1.8	1.7	1.5	1.7	1.3	1.7	1.8	0.8	0.8	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	1.3	1.6	1.2	1.8	1.9	1.9	1.7	2.6	1.8	3.8	4.5	4.6	1.8	1.8	1.8	1.8	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.7	1.7	1.7	1.6	1.6	1.7	1.7	1.7	1.7	1.3	1.2
8	0.6	0.7	0.6	0.7	0.7	0.7	0.7	1.3	1.1	1.0	1.5	1.0	7.2	7.7	7.7	7.8	7.9	7.8	7.9	7.7	7.8	7.9	7.8	7.0	7.3	7.0	5.4	5.7	5.7	6.4	6.5	6.4	6.5	6.5
9	1.8	2.1	2.5	2.1	3.3	3.6	4.0	4.2	4.0	2.9	4.0	3.8	1.2	1.5	1.5	2.0	2.7	3.4	4.9	5.3	6.9	6.9	7.1	7.2	8.1	7.2	4.8	4.5	4.5	4.5	4.5	4.4	4.4	4.3
10	2.4	3.0	3.9	5.0	6.6	6.9	6.7	7.0	6.5	4.7	6.5	7.0	3.7	3.6	3.5	3.6	3.6	3.7	3.5	3.5	3.4	3.3	3.3	3.4	3.5	3.5	3.2	3.3	2.8	2.9	2.8	2.9	2.0	1.8
Average	**1.6**	**1.8**	**1.9**	**2.1**	**2.5**	**2.5**	**2.6**	**2.9**	**2.8**	**2.3**	**3.3**	**3.3**	**3.3**	**3.4**	**3.4**	**3.8**	**3.4**	**3.5**	**3.7**	**3.7**	**3.9**	**3.9**	**3.9**	**3.8**	**4.0**	**3.9**	**3.3**	**3.4**	**3.3**	**3.4**	**3.4**	**3.4**	**3.2**	**3.2**
Count	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**9**	**10**	**9**	**9**	**10**	**10**	**10**	**9**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**90%**	**100%**	**90%**	**90%**	**100%**	**100%**	**100%**	**90%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**

Growth Medium:	**SITE 5**																																	
Tree Specie:	**ASPEN**																																	
Sample Number	**Tree Height (cm)**																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	**6/27**	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	0.7	0.7	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	0.2	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	2.3	2.5	2.3	2.5	2.9	3	2.6	2.8	2.8	2.3	3	2.9	2.9	3.0	3.0	2.9	2.7	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.3	2.3	2.0	1.0	1.0	1.0
6	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	0.4	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**0.9**	**1.0**	**1.4**	**2.5**	**2.9**	**3.0**	**2.6**	**2.8**	**2.8**	**2.3**	**3.0**	**2.9**	**2.9**	**3.0**	**3.0**	**2.9**	**2.7**	**2.6**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.3**	**2.3**	**2.0**	**1.0**	**1.0**	**1.0**
Count	**8**	**6**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Survival	**80%**	**60%**	**20%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**

Growth Medium	**SITE 1**																																	
Tree Specie:	**SAGE BRUSH**																																	
Location:																																		
Sample No.	**Tree Height (cm)**																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	0.6	0.7	0.6	0.7	0.6	0.7	0.7	0.5	0.7	0.6	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.9	1.1	1.7	1.8	1.9	2	1.9	1.6	2.1	1.8	2	1.8	2.4	2.4	2.4	2.6	2.8	2.8	3.2	3.2	3.4	3.3	3.2	3.0	3.0	2.7	2.5	1.7	1.1	1.1	-	-	-	-
3	0.9	1.1	0.6	1.2	1	1.1	0.9	0.8	1.2	0.9	1	1.1	1.2	1.0	1.1	1.0	1.0	1.0	1.1	1.0	1.0	0.9	0.9	0.8	0.9	0.9	0.8	0.9	1.0	1.0	1.1	1.2	1.1	1.2
4	0.6	0.6	0.9	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1.7	1.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.5	0.9	1.1	1.1	1	1.1	1	0.9	1	0.8	1	1	1.0	1.0	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	0.9	1.6	1.2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	1.1	1.1	1.3	1.2	1.3	1.5	1.4	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.4	1.6	1.1	1	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	1.1	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**1.0**	**1.2**	**1.1**	**1.1**	**1.1**	**1.3**	**1.2**	**0.9**	**1.3**	**1.0**	**1.1**	**1.1**	**1.3**	**1.2**	**1.3**	**1.4**	**1.9**	**1.9**	**2.2**	**2.1**	**2.2**	**2.1**	**2.1**	**1.9**	**2.0**	**1.8**	**1.7**	**1.3**	**1.1**	**1.1**	**1.1**	**1.2**	**1.1**	**1.2**
Count	**10**	**10**	**8**	**8**	**7**	**5**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**
Survival	**####**	**####**	**80%**	**80%**	**70%**	**50%**	**50%**	**50%**	**40%**	**40%**	**40%**	**40%**	**40%**	**40%**	**30%**	**30%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**20%**	**10%**	**10%**	**10%**	**10%**

Growth Medium:	SITE 2																																	
Tree Specie:	SAGE BRUSH																																	
Location:																																		
Sample	Tree Height (cm)																																	
Number	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average																																		
Count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Survival	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Growth Medium:	SITE 3																																	
Tree Specie:	SAGE BRUSH																																	
Location:																																		
Sample	Tree Height (cm)																																	
Number	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	0.5	0.6	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.6	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	0.7	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1.3	1.4	1.1	1.1	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.6	1	0.7	0.6	0.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	1	0.7	0.4	1	0.9	1	0.9	0.6	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0.5	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	0.6	0.7	0.2	0.8	0.9	0.9	0.7	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	0.7	0.8	0.7	0.9	0.8	0.8	0.8	0.5	0.9																									
Count	9	9	5	5	4	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Survival	90%	90%	50%	50%	40%	30%	20%	20%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Growth Medium:	SITE 4																																	
Tree Specie:	SAGE BRUSH																																	
Location:																																		
Sample Number	Tree Height (cm)																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	0.9	1.1	1.1	1.5	1.5	1.3	1.7	2.2	2.5	2.5	3.5	4	3.5	4.4	4.5	5.0	5.3	6.0	6.0	6.2	6.7	6.7	6.7	6.7	7.3	7.1	7.3	7.3	6.9	7.1	7.3	7.4	7.5	8.0
2	1.8	1.5	1.6	1.6	1.6	1.8	1.6	1.4	1.5	1.3	1.7	1.8	1.6	1.9	2.2	2.4	2.9	2.9	3.0	3.0	3.2	3.3	3.4	3.5	3.6	3.7	3.5	3.6	3.7	3.7	3.7	3.7	3.7	3.7
3	1.1	1.3	1.8	2.1	2.5	2.4	2.4	2.1	2.4	1.9	2.3	1.9	1.9	2.3	3.0	2.8	3.2	3.4	3.5	3.4	3.5	3.5	3.9	3.8	4.4	4.9	5.0	5.1	5.2	5.2	5.2	5.2	5.0	4.6
4	1.9	2.1	2	1.9	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	2.4	2.4	1.7	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	1.4	1.5	1.4	-	-	-	-	-	-	-	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0.8	1	0.7	-	-	-	-	-	-	0.4	-	-	-	0.5	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.7	1.8	2.1	2.1	1.9	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	1.2	1.7	1.7	1.6	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**1.4**	**1.6**	**1.6**	**1.7**	**1.7**	**1.8**	**1.9**	**1.9**	**2.1**	**1.5**	**2.5**	**2.6**	**2.3**	**2.3**	**2.6**	**3.4**	**3.8**	**4.1**	**4.2**	**4.2**	**4.5**	**4.5**	**4.7**	**4.7**	**5.1**	**5.2**	**5.3**	**5.3**	**5.3**	**5.3**	**5.4**	**5.4**	**5.4**	**5.4**
Count	**10**	**9**	**9**	**7**	**6**	**4**	**3**	**3**	**3**	**4**	**3**	**3**	**3**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Survival	**100%**	**90%**	**90%**	**70%**	**60%**	**40%**	**30%**	**30%**	**30%**	**40%**	**30%**	**30%**	**30%**	**50%**	**50%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**

Growth Medium:	SITE 5																																	
Tree Specie:	SAGE BRUSH																																	
Location:																																		
Sample Number	Tree Height (cm)																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	0.7	1.9	1.8	1.9	2.1	3.2	4	4.3	5.2	4.3	6.4	6.9	7.2	7.5	7.6	7.6	7.8	8.0	8.2	8.3	8.5	8.8	8.9	9.0	9.2	9.0	9.3	9.1	7.7	7.8	7.8	8.0	7.9	8.0
2	1	1.4	1.9	2.4	2.8	3.7	4.6	4.9	5.6	4.6	5.5	5.9	6.3	6.7	6.9	7.4	8.1	8.7	9.5	10.2	10.5	11.0	11.4	11.5	11.5	11.4	11.5	11.6	11.6	11.7	11.8	11.8	11.6	11.8
3	1.2	1.3	1.7	1.9	2.6	3.7	3.9	4.2	5.5	4.7	6	6.4	7.1	7.2	7.7	7.7	7.6	7.7	7.7	7.7	7.7	7.7	7.8	7.8	7.9	7.8	7.9	7.8	9.2	9.2	9.5	9.5	9.5	9.5
4	0.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1.5	2	2.6	3.2	4.1	4.7	5.9	5.4	6	4.5	6.2	6.4	7.4	7.8	8.3	9.2	8.9	9.6	9.8	10.1	10.0	9.9	10.1	10.2	10.3	9.9	10.0	10.0	9.9	9.8	10.0	10.0	9.9	10.0
6	1.4	1.7	1.2	1.3	1.8	2.5	3.2	3.6	4.5	3.8	4.4	5.4	5.4	2.5	5.7	5.9	6.2	6.6	6.8	7.0	7.3	7.5	7.5	7.8	7.7	7.7	7.8	7.8	7.6	7.7	7.8	7.8	7.9	7.9
7	1.2	1.3	1.1	1.1	1.2	1.1	1.2	1.1	1.3	1.1	1.2	1	1.1	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	1.1	1.2	1.6	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	2.6	2.7	2	2.5	2.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	0.3	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	**1.2**	**1.5**	**1.7**	**2.0**	**2.4**	**3.2**	**3.8**	**3.9**	**4.7**	**3.8**	**5.0**	**5.3**	**5.8**	**5.5**	**7.2**	**7.6**	**7.7**	**8.1**	**8.4**	**8.7**	**8.8**	**9.0**	**9.1**	**9.3**	**9.3**	**9.2**	**9.3**	**9.3**	**9.2**	**9.2**	**9.4**	**9.4**	**9.4**	**9.4**
Count	**10**	**10**	**8**	**8**	**7**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
Survival	**100%**	**100%**	**80%**	**80%**	**70%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**60%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**

Growth Medium:	**CONTROL**																																	
Tree Specie:	**SAGE BRUSH**																																	
Location:																																		
Sample Number	**Tree Height (cm)**																																	
	2/14	2/21	3/7	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/7	6/12	6/20	6/27	7/3	7/11	7/18	7/25	8/1	8/8	8/15	8/22	8/29	9/5	9/12	9/20	9/26	10/4	10/10
1	1.5	2	3.1	3.1	3.6	4.1	4.9	5.1	5.5	4.4	5.5	5.6	5.8	6.0	6.4	6.3	6.2	6.5	6.9	6.8	6.5	6.9	6.9	7.4	6.9	7.0	7.2	7.5	7.8	8.6	8.9	9.3	9.2	9.4
2	2.7	3.2	4.6	5.4	6.7	8.8	10.1	11.1	13.3	10.5	13.2	13.4	13.3	14.0	14.4	14.4	14.9	15.0	15.1	15.1	15.3	15.5	15.7	15.5	15.5	15.9	17.4	18.1	18.6	19.0	18.9	18.9	18.8	18.9
3	1.8	2.3	3	3.4	3.9	4.4	5.6	6.3	7.6	7.2	10	10.6	11.1	11.5	11.5	11.7	11.6	11.7	11.5	11.6	11.4	12.0	11.8	11.0	12.1	12.5	12.0	12.3	12.5	12.7	13.1	13.2	13.3	13.6
4	1.7	2.2	3.2	4.1	5	5.5	6.7	7.5	8.9	7.5	10.9	12.1	12.5	12.8	13.0	13.2	13.2	13.0	13.2	13.4	13.2	13.8	13.6	13.6	14.0	14.1	14.1	14.0	14.2	14.8	14.4	14.1	14.5	14.4
5	2.9	3	3.4	4.3	4.7	6	7.2	7.3	8.5	7	9.3	9.7	9.6	9.5	9.6	9.8	9.5	9.5	9.6	9.5	10.3	10.6	10.3	10.5	9.6	10.6	12.2	13.1	14.3	14.7	14.9	14.9	15.2	15.3
6	2.5	2.5	4.2	4.6	4.7	5.3	5.8	5.9	6.5	5.5	6.9	7.1	7.6	7.8	8.0	8.0	8.0	8.0	8.1	8.1	8.4	8.2	8.4	8.0	8.0	8.7	8.5	8.4	8.4	8.6	8.5	8.5	8.5	8.5
7	1.9	2.2	3	4	4.2	5.2	6.4	6.6	7.4	6.2	7.9	7.7	7.8	8.0	8.3	8.3	7.5	8.4	8.4	8.0	8.3	8.3	8.3	8.0	7.9	7.9	8.1	8.3	8.4	8.3	8.6	8.4	8.5	8.5
8	1.9	2.3	3.7	4.1	5.1	5.7	6.3	6.9	7.4	6	7.7	7.8	8.0	8.0	8.1	8.1	8.3	8.4	8.4	8.3	8.5	8.4	8.8	8.8	8.9	8.8	8.8	9.1	9.1	9.5	9.8	10.0	10.0	10.3
9	1.9	2.2	3.1	3.6	4.3	4.9	5.2	5.2	6.6	5.7	8.4	9.4	10.5	10.5	10.8	11.0	11.1	11.1	11.1	11.3	11.3	11.5	11.5	11.4	11.5	11.6	11.5	11.7	11.7	12.1	12.2	12.2	12.3	12.2
10	2.4	2.5	2.2	2.9	3.3	3.9	4.3	5.5	6.6	5.7	9.5	11.5	12.5	12.5	12.8	13.1	13.1	13.2	13.4	13.5	13.9	13.4	13.5	13.5	13.5	13.6	13.5	13.4	13.6	13.7	13.5	13.6	13.7	13.7
Average	**2.12**	**2.44**	**3.35**	**3.95**	**4.55**	**5.38**	**6.25**	**6.74**	**7.83**	**6.57**	**8.93**	**9.49**	**9.87**	**10.06**	**10.29**	**10.39**	**10.34**	**10.48**	**10.57**	**10.56**	**10.71**	**10.86**	**10.88**	**10.77**	**10.79**	**11.07**	**11.33**	**11.59**	**11.86**	**12.2**	**12.28**	**12.31**	**12.4**	**12.5**
Count	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**
Survival	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

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This is to certify that the thesis prepared by Francis Inkoom entitled "Developing Tree Species Tolerant to Degraded Mine Soils" has been examined and approved for acceptance by the Department of Mining Engineering, Montana Technological University, on this 18th day of April, 2019.

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