Using Organic Amendments to Restore Degraded Mineland Soils

A Thesis

Presented in Partial Fulfillment of the Requirement for the

Degree of Master of Science

with a

Major in Soil and Land Resources

in the

College of Agricultural and Life Sciences

University of Idaho

by

Monica R. Ott

Major Professor: Daniel G. Strawn, Ph.D.

Committee Members: Deborah S. Page-Dumroese, Ph.D.; Mark D. Coleman, Ph.D.

Department Administrator: Jodi L. Johnson-Maynard, Ph.D.

May 2017

Authorization to Submit Thesis

This thesis of Monica R. Ott, submitted for the degree of Master of Science with a Major in Soil and Land Resources and titled "**Using Organic Amendments to Restore Degraded Mineland Soils**," has been reviewed in final form. Permission, as indicated by signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: _________________________________ Date: _____________
Daniel G. Strawn, Ph.D.

Committee Members:_________________________________ Date: _____________
Deborah S. Page-Dumroese, Ph.D.

_________________________________ Date: _____________
Mark D. Coleman, Ph.D.

Department
Administrator: _________________________________ Date: _____________
Jodi L. Johnson-Maynard, Ph.D.

Abstract

With over 30,000 abandoned mines on USDA Forest Service land, efficient and affordable reclamation methods are needed to restore site productivity. Surface applied amendments, biochar, biosolids, and woodchips, provide cheap, sustainable solutions to promote re-vegetation. We investigated amendment effects on soil quality at a dredge tailings site in Northeast Oregon. Experimental plots of the three amendments were sampled bi-annually for two years to measure changes in soil properties and plant success. Available nutrients were analyzed by both field and laboratory methods. Soil moisture and temperature were monitored *in-situ*, and soil water holding capacity was measured. Results show increases in soil pH, cation exchange capacity (CEC), organic carbon, macronutrients, and plant growth. Although changes are pronounced in single amendment applications, the combination treatments induce more stable plant growth by providing a combination of soil quality improvements. Results suggest that surface amendment of biochar, woodchips, and biosolids for land reclamation of disturbed forest soils may be a promising method for remediation in droughty areas of the Pacific Northwest.

Acknowledgments

I would first like to thank my major professor Dr. Daniel Strawn for his encouragement, availability, and willingness to take on an inexperienced student. Even with setbacks and project changes, Professor Strawn continually found creative, reasonable ways to work through them. I could not have asked for a more knowledgeable mentor. I also want to thank my committee members, Dr. Deborah Page-Dumroese for providing the project and funding, and Dr. Mark Coleman for his guidance and support.

Second, I want to thank all the laboratory staff, both at the University of Idaho and the USFS Rocky Mountain Research Station. Specifically, I'd like to thank Anita Fallen, Joanne Tirocke, and Ian Leslie for providing their instrument knowledge, schedule flexibility, and for putting up with my constant questions.

There were many contributors to this thesis that require mention for their short but invaluable help: Dr. James Gustafson, who made me believe I could succeed; Dr. William Price, a statistical genius; Dr. Robert Heinse, who guided much of the physics; and all my fellow graduate students who served as a constant soundboard for ideas and discussions. I want to thank the Plant, Soil and Entymology department for providing funding, as well as the Iddings Research Fellowship and Robert E. McDole scholarship.

Lastly, I want to thank Samuel Conley for providing the fun times that were needed in order to persevere and complete this project.

Contents

Authorization to Submit Thesis .... **ii**

Abstract .... **iii**

Acknowledgments .... **iv**

List of Figures .... **vii**

List of Tables .... **viii**

Chapter 1: Introduction and Literature Review **1**

1.1 Abstract **1**
1.2 Introduction **1**
1.2.1 Number of Abandoned Mine Sites 2
1.2.2 Abandoned Mine Land Hazards 3
1.2.3 Cost of Reclamation 4
1.2.4 Methods of Reclamation 5
1.2.5 Constraints of Reclamation Methods 7
1.2.6 Organic Versus Inorganic Amendments 7
1.3 Experimental Site **8**
1.3.1 Site Background and Research Needs 8
1.3.2. Site Limitations 12
1.4 Amendment Properties **13**
1.4.1 Biochar as a Soil Amendment 13
1.4.2 Biosolids as a Soil Amendment 17
1.4.3 Woodchips as a Soil Amendment 19
1.5 Recent Biochar Use **20**
1.6 Research Objectives **22**
1.6.1 Project Objectives 22
1.6.2 Reuse of Forest Waste 22
1.6.3 Reuse of Municipal Waste 22
1.6.4 Thesis Objectives 23
1.7 Justification **25**
1.8 Literature Cited **26**

Chapter 2: Plant Survival on Dredge Mine Tailings After Applying Biochar, Biosolid, and Woodchip Soil Amendments **34**

2.1 Abstract **34**
2.2. Introduction **35**
2.3. Materials and Methods **40**
2.3.1. Experimental Site and Soil Characteristics 40
2.3.2. Experimental Design 42
2.3.3. Sampling 44
2.3.4. In Situ Measurements 44
2.3.5. Laboratory Chemical Methods 45
2.3.6. Soil Water Retention 47
2.3.7. Plant Density 48
2.3.8 Statistical Analysis 48

2.4. Results ... 48
2.4.1. Soil Properties ... 48
2.4.2. Nutrient Availability ... 53
2.4.2.1. Laboratory Nitrogen Results ... 53
2.4.2.2. In-Situ Nutrient Results ... 57
2.4.3. Available Water ... 61
2.4.4. Soil Temperature and Moisture ... 64
2.4.5. Plant Success ... 68
2.5. Discussion ... 70
2.5.1. Soil Properties ... 70
2.5.2. Nutrient Availability ... 73
2.5.3. Available Water ... 77
2.5.4 Plant Cover ... 78
2.5.5. Limitations ... 79
2.6. Conclusions ... 80
2.7. Literature Cited ... 82

Chapter 3: Broader Implications ... 89
3.1. Abstract ... 89
3.2. Introduction ... 90
3.3. Amendment Potential ... 90
3.3.1 Biochar ... 90
3.3.2. Biosolids ... 92
3.3.3. Woodchips ... 94
3.4. Conclusions ... 95
3.5. Literature Cited ... 96

Appendix A: Raw Data ... 98
Table A-1: 2015 Soil Properties ... 98
Table A-2: 2015 Nitrogen Measurements ... 99
Table A-3: 2015 Mehlich-3 Nutrient Results ... 100
Table A-4: 2015 Pressure Plate Results ... 101
Table A-4 Continued ... 102
Table A-5: 2016 Soil Properties ... 103
Table A-6: 2016 Nitrogen Measurements ... 104
Table A-7: 2016 Mehlich-3 Nutrient Results ... 105
Table A-8: 2016 Pressure Plate Results ... 106
Table A-8 Continued ... 107
Table A-9: 2015 Plant Counts ... 108
Table A-10: 2016 Plant Counts ... 109
Table A-11: Bulk Pre-treatment Soil Particle Size Analysis ... 110
Table A-12: Organic Matter LOI Reference Samples ... 110
Table A-15: Spring 2015 Resin Capsule Results ... 111
Table A-16: Fall 2015 Resin Capsule Results ... 112
Table A-17: Spring 2016 Resin Capsule Results ... 113

List of Figures

Figure 1.1: Map of Clear Creek experimental site location……………………………………………..9

Figure 1.2: Pre-treatment site photo………………………………………………………………………….10

Figure 1.3: Experimental site plot layout……………………………………………………………………11

Figure 2.1: Map of Clear Creek experimental site location…………………………………………..41

Figure 2.2: Graph of CEC results…………………………………………………………………………………51

Figure 2.3: Graph of organic carbon results 0-3cm…………………………………………………….52

Figure 2.4: Graph of organic carbon results over time 0-3cm……………………………………..53

Figure 2.5: Graph of inorganic nitrogen results 0-3cm………………………………………………..54

Figure 2.6: Graph of total nitrogen results 0-3cm……………………………………………………….56

Figure 2.7: Graph of available nitrogen from resin capsules for biosolids……………………..58

Figure 2.8: Graph of available phosphorus from resin capsules for biosolids………………..59

Figure 2.9: Graph of plant available water results 0-3cm…………………………………………….63

Figure 2.10: Graph of plant available water results 3-12cm………………………………………..64

Figure 2.11: Soil moisture graph from data loggers……………………………………………………66

Figure 2.12: Soil temperature graph from data loggers………………………………………………67

Figure 2.13: Graph of plant growth in woodchip treatments……………………………………..69

Figure 2.14: Graph of planting strategy differences for 2015………………………………………70

Figure 2.15: Graph of nitrogen decrease vs plant growth……………………………………………75

Figure 2.16: Treatment comparison photo………………………………………………………………….81

Figure 3.1: Total N, P, K resin capsule results………………………………………………………………..93

List of Tables

Table 1.1: Cost of abandoned mine reclamation……………………………………………………………5
Table 1.2: Species and quantities of plants in seed mixture…………………………………………11
Table 1.3: Biochar chemical analysis results………………………………………………………………16
Table 1.4: Biosolid chemical analysis results………………………………………………………………18
Table 2.1: Pre-treatment soil analysis results……………………………………………………………42
Table 2.2: Biosolid chemical analysis results………………………………………………………………43
Table 2.3: Summary statistics for soil property results………………………………………………49
Table 2.4: Mean values of soil properties 0-3cm…………………………………………………………50
Table 2.5: Mean values of soil properties 3-12cm…………………………………………………………50
Table 2.6: Mean values of nitrogen measurements 0-3cm……………………………………………54
Table 2.7: Mean values of nitrogen measurements 3-12cm……………………………………………55
Table 2.8: Summary statistics for resin capsule results………………………………………………59
Table 2.9: Mean resin capsule results………………………………………………………………………60
Table 2.10: Summary statistics for water measurement results………………………………………61
Table 2.11: Mean values of water measurements 0-3cm…………………………………………………62
Table 2.12: Mean values of water measurements 3-12cm………………………………………………63
Table 2.13: Summary statistics for plant count results…………………………………………………68

Chapter 1: Introduction and Literature Review

1.1 Abstract

Abandoned mines on public land in the western USA are numerous, and hazardous to both humans and the environment. Efficient and affordable reclamation methods are needed to restore soil function and productivity. Current reclamation strategies are both expensive and time consuming. Surface applied organic amendments, biochar, biosolids, and woodchips, provide inexpensive, local, sustainable solutions that will improve soil function and promote re-vegetation. This project investigated amendment effects on soil physical and chemical properties at an abandoned dredge tailings site in the Umatilla National Forest of northeastern Oregon. Experimental plots of the three amendments, applied singly and in combination, were sampled bi-annually over the course of two years. Project objectives were 1) determine which amendment or combinations promoted planted grass or seeded re-vegetation by looking at water holding capacity and nutrient availability over time, and 2) determine which amendment or combinations promote planted grass or seeded re-vegetation by looking at plant survival. Field research is needed to better understand how unincorporated organic amendments affect soil function in a natural setting.

1.2 Introduction

Mining in the Pacific Northwest, USA has been a staple industry throughout the history of development in the region. Mineral exploration and exploitation resulted in numerous operational and abandoned mine sites. Effective and cost efficient reclamation of these sites is of national concern (Mittal, 2011). In this project, we investigated the effects of surface applied amendments to soil chemical and physical properties of capped mine tailings in northeast Oregon. This field study measured the effectiveness of biochar, biosolids, and woodchips as amendments to restore soil function for the purpose of vegetation recovery.

1.2.1 Number of Abandoned Mine Sites

Exact numbers of abandoned mines in the USA are difficult to estimate because mine sites are broadly distributed, sites are on both public and private land, and often exist in hard to access locations (Mittal, 2011). In addition, assessment of the number of mine sites is confounded by the fact that there are inconsistent definitions of abandoned mines, limited information reported about land ownership of mines, and that some managing agencies do not keep data on land used for mining (Mittal, 2011).

In 1995, the USDA Forest Service (USFS) estimated the total abandoned mines on National Forests to be 38,991 (USDA, 2012). In 2011, the House Committee on Natural Resources: Subcommittee on Energy and Mineral Resources held a hearing concerning the problem of public abandoned mine land and how best to remediate these sites (AGI, 2011). Numbers reported by various agencies during this hearing show little change from twenty years ago, and reflect either a lack of reclamation or a lack of accurate data collection. The Department of Interior Bureau of Land Management (BLM) reported 31,000 abandoned mines on their land. The USFS abandoned mine land program reported between 27,000 and 39,000 abandoned mines. The United States Geological Survey (USGS), and the Government

Accountability Office reported that in the 12 western states, 161,000 abandoned mines were on public land (AGI, 2016). Today, according to the USGS, in Idaho, Oregon and Washington alone, there are approximately 38,500 mine sites (USGS, 2015). However, this number may not be only public land, as the USGS does not collect land ownership data (Mitta,l 2011). Clearly, the numbers of AML sites are large, and the reclamation needs are great.

1.2.2 Abandoned Mine Land Hazards

The hazards associated with public abandoned mine land are both physical and environmental (such as risks from the presence of toxic elements). Estimates have been made that eighty percent of mines pose physical hazards, and the other twenty percent pose both physical and environmental threats (AGI, 2016). Physical dangers to the public include concealed shafts and holes, decayed and unstable structures, and explosives. (Newton et al., 2000; AGI, 2016).

Environmental hazards include, but are not limited to, toxic soil, air, and water. The contaminants are introduced into the environment from both mining activities and chemicals used in the extraction and processing of ores. The contaminants degrade ecosystem stability and present toxicity risks to wildlife and humans. There are numerous examples of mining activity posing risks to humans, even long after the mines are shut down or abandoned (Grayson and Scott, 2003; Holzman, 2011; Koberstein, 2000). Areas surrounding abandoned mines are often barren of vegetation due to degraded or contaminated soils from tailings and extraction processes. Erosion often carries toxic elements off site and into surface and ground water (Duruibe et al., 2007). Site-point mining contamination easily and quickly becomes large scale. For example, the Bunker Hill Mine in Shoshone County of northern Idaho exhibits severe lead contamination has spread across a 21 square mile area (EPA, 2016).

1.2.3 Cost of Reclamation

Four government agencies (BLM, USFS, the Environmental Protection Agency (EPA), and the Office of Surface Mining (OSM)) have developed AML programs to mitigate both the hazards and cleanup costs of AML (BLM, 2014). According to the USFS, reclamation is defined as,

> "Returning disturbed land to a useful state, i.e., resource production, and limiting environmental impacts" (USFSc, 2015).

In 1977, the Surface Mining Control and Reclamation Act put in place laws that required reclamation bonds from operators before coal permits are obtained (OSMRE, 2015). Eventually, reclamation bonds and/or assurances were required for all types of mining on public land, with amounts varying based on product, period of operation, period of clean-up, and direct and indirect costs (USDA, 2004). Often, however, these assurances are not enough to cover the enormous cost of reversing mining damage done to site resources. If the operator cannot pay for full reclamation, the cost of reclamation falls to the government agencies, and ultimately the taxpayers. In the ten-year period from 1997 to 2008, the BLM, USFS, USGS, and OSM spent $2.6 billion dollars on hardrock mine reclamation (Mittal, 2011). This amount does not include all other types of mining reclamation, such as industrial and aggregate mining.

The Government Accountability Office and the Mineral Policy Center estimate that the cost of reclamation of abandoned mines (not already under reclamation) in the western 13 states, is between $9.6 and $21 billion (Weiss, 2015). These dollar amounts were determined by dividing abandoned mines into categories based on their respective cleanup costs, then multiplying by the amount of those types of abandoned mines (Table 1.1).

Table 1.1. Average cleanup cost by abandoned mine type nationally. Adapted from Center for Western Priorities Report, 2015.

Type of contamination	**Average cleanup cost**	**Number of sites**
Reclaimed and/or benign	$0	194,500
Landscape disturbance	$7,245	231,900
Safety hazard	$32,100	116,300
Surface water contamination	$1,646,678 - $4,940,035	14,400
Groundwater contamination	$8,233,391 - $24,700,173	500
Superfund	$411,699,550 - $576,337,370	50

In the Pacific Northwest, abandoned mine sites on National Forest lands cause a decrease in natural resources and profit generation for the USFS because site and vegetation production are reduced. Thus, it is imperative to develop efficient and affordable reclamation methods.

1.2.4 Methods of Reclamation

There are many mine land reclamation tools available, but their uses are site specific. Mining can affect water, air, soil and vegetation. Soil is a vital part of any disturbed site that interconnects other resources and is the foundation for plant growth (Sheoran et al., 2010). For example, contaminated air and wind can deposit undesirable elements onto the soil where soil water may leach these contaminants into groundwater or be taken up by plants. In the case of mine tailings and abandoned mine-land, re-vegetation is a main goal of reclamation, which requires healthy soil.

Common methods for reclaiming mine land and mitigating pollution include phytoremediation/revegetation, applying soil caps, adding amendments (organic or commercial), and removal/relocation of contaminated soil (EPA, 2000). Soil caps are frequently used as containment barriers for landfills (Handel et al., 1997), waste piles, and mine tailings (Hauser et al., 2001). If possible, topsoil is removed in the initial mining process, stockpiled, and reapplied after operations cease (Sheoran et al., 2010); otherwise a non-native soil cap is acquired. Availability of topsoil to cover the vast area of sites needing reclamation is limited. An interesting case occurred at the Superfund Site in Shoshone County, ID, where local farmers could no longer produce crops after selling 35-85 acres of their topsoil to cap contaminated mine waste, causing need for reclamation of the farmland (Silverman, 2001). To address limited topsoil availability, Brown et al. (2003) researched alternative methods, such as manufactured topsoil, to cap mine sites.

Sewage sludge (Asensio et al., 2013; Fosberg and Ledin, 2005), manure (Shrestha and Lal, 2009), and biosolids (Haering et al., 2000) have been shown to be effective on mine soils to increase organic matter content, neutralize soil acidity (pH), and increase N availability. Vegetative cover has been shown to increase organic matter and N through annual inputs of plant debris over a long period (Bendfeldt et al., 2000). Commercial fertilizers have also been used to alleviate nutrient deficiencies (, Steiner et al., 2007; Walsh and Redente, 2011).

1.2.5 Constraints of Reclamation Methods

Key concerns to be addressed when choosing or developing a reclamation method are time and money. Reclamation methods need to be both relatively fast acting and financially feasible for land managers to reclaim soil function to increase site productivity. Because many mine sites include massive amounts of tailings, natural pedogenesis and re-vegetation on rock material takes too long. Application of topsoil can be used to build a layer of soil conducive to plant growth. However, top dressed soil is often negatively impacted by the underlying tailings (such as acidity, heavy metals, or lack of water retention), and thus requires amendments to counter these factors.

1.2.6 Organic Versus Inorganic Amendments

Both organic and inorganic fertilizers have been used on mineland reclamation sites to increase soil chemical properties (Steiner et al., 2007; Walsh and Redente, 2011). In recent studies, inorganic fertilizers were effective at increasing nutrient concentrations, but needed yearly applications, whereas the organic fertilizers, chicken manure and compost, kept nutrient levels and organic matter elevated for the length of the study (4 years) (Steiner et al., 2007). Schoenholtz et al. (1992) found that although inorganic fertilizers increased biomass production on mine soils by 87% in the first year, measurements in subsequent years showed no significant biomass increase or long lasting effects. Steiner et al (2007) found that the application of inorganic fertilizers with charcoal derived from secondary forest wood doubled grain yields for four consecutive years, but soil nutrient levels were only elevated the first growing season. The same study found that application of chicken manure and charcoal not only increased crop production every year, but nutrient levels stayed elevated throughout the four-year study.

Some inorganic fertilizers must be tilled into the soil to avoid volatilization, and many need reapplications annually because they quickly degrade, mobilize, and leach. Even slow release commercial fertilizers, such as methylene urease, degrade within months, and are the most expensive (USDA, 2013; Kopec, 1994). Organic amendments are often waste materials (e.g., biosolids or manure) and are cheaper, typically environmentally healthy, and can be surface applied, thus eliminating incorporation costs. Manures, sewage sludge, sawdust, woodchips, and biochar have all been shown to be effective amendments that increase the rate of re-vegetation through changes in soil physical, chemical or biological enhancement (Brendfeldt et al., 2000; Forsberg and Ledin 2005; Tammeorg et al., 2013). Although mixing amendments into the soil may speed up changes to the soil, accessibility and getting equipment to most mine sites often makes this cost-prohibitive.

1.3 Experimental Site

1.3.1 Site Background and Research Needs

A mine tailings re-vegetation study is being conducted by the USFS Rocky Mountain Research Facility in Moscow, Idaho at an abandoned mine site on the Umatilla National Forest, Oregon. The Granite mining district of the Umatilla National Forest, on the eastern edge of Grant County, is part of the larger "Oregon Gold District" which produced millions of ounces of gold in the 19^{th} and 20^{th} centuries. Extensive hydraulic, lode, and dredge mining left tailings piles lining dredged waterways for miles (EOMA, 1999). Dredge gold mining is conducted by scooping rock and sediment up from the bottom of waterways and separating out gold from the waste materials. Large rocks and gravel that get carried through the dredge are then deposited on the shore in big rock heaps (Yannopoulos, 1991).

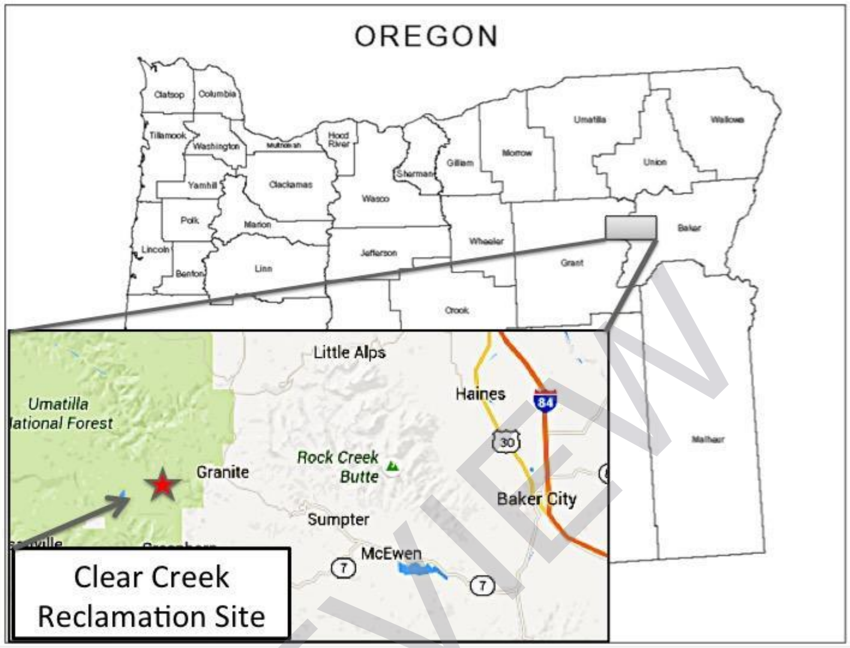

Figure 1.1. Map of Clear Creek experimental site

Clear Creek is a dredged waterway and is located approximately three miles west/southwest of the town of Granite, Oregon on Grant County Road 24 at an elevation of 1,439 meters above sea level. The site is a flattened tailings pile lining the north side of Clear Creek, leftover from dredging activities dating back as far as 1862 (EOMA, 1999). The tailings pile was capped in the 1970’s with roughly six inches of loam topsoil of unknown origin. Between 2001 and 2007, restoration work was done by USFS, including planting of shrubs, hardwoods, conifers, and the use of native plant seeding (Granite Creek Watershed EIS, 2015). These re-vegetation attempts had limited success. A few young ponderosa pines and few volunteer forbs are visible, but the overwhelming majority of the tailings cap is barren (Figure 1.2).

Figure 1.2. Pre-treatment Clear Creek reclamation site, Oct 2014 (USFS)

The Granite Creek Watershed, in which Clear Creek is a tributary, has been designated a “High Risk, High Value” area by the USFS because it provides habitat to steelhead and Chinook salmon, both of which are threatened species under the Endangered Species Act (NOAA Fisheries, 2016). Clear Creek specifically is home to steelhead, Chinook salmon, and bull trout (EIS 2015). In October 2014, experimental plots were installed, marked, and three soil amendments (biochar, biosolids, and woodchips) were surface applied. Application rates were as follows: Biochar- 11.2 Mg/ha, biosolids- 16.8 Mg/ha and woodchips- 22.7 Mg/ha. The plots are 10 x 10 feet with 3 replicates of each single amendment and combinations, plus controls, totaling 24 plots (Figure 1.3).

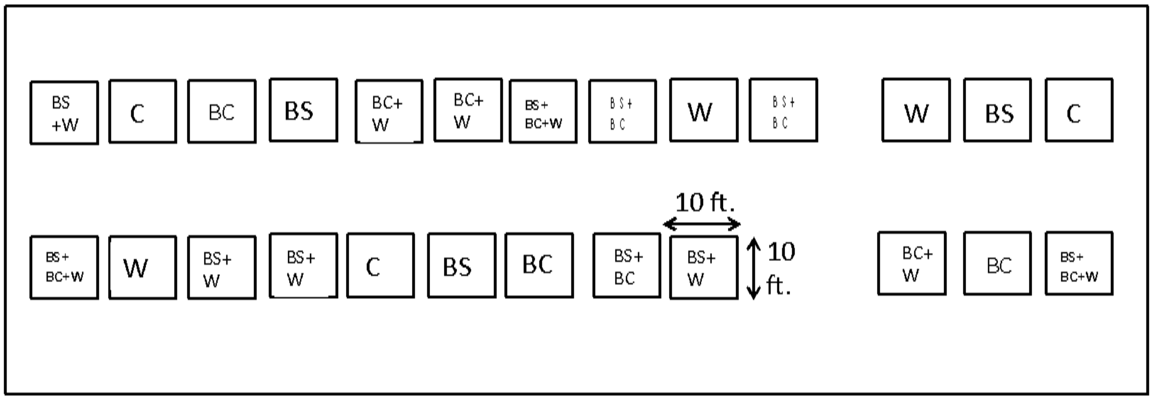

Figure 1.3. Clear Creek plot layout; bottom of figure faces south, runs parallel and is in close proximity to Clear Creek. C=control, BS=biosolid, BC=biochar, W=woodchip, BS+BC=biosolid + biochar, BS+W=biosolid+woodchip, BC+W=biochar+woodchip, and BS+BC+W=biosolid +biochar + woodchip.

At the time of application, half of each plot was seeded with a mixture of perennial grasses and native forbs (Table 1.2).

Table 1.2. Species and percentages of plants in seed mixture

Common name	**Scientific name**	**Relative percentage**
Western yarrow	*Achillea millefolium* L.	1.2%
Mountain brome	*Bromus marginatus* Nees es Steud.	35%
Bottlebrush squirreltail	*Elymus elymoide*s (Raf.) Swezey	9.4%
Blue wildrye	*Elymus glaucus* Buckley	25.9%
Idaho fescue	*Festuca idahoensis* Elmer	4.7%
Prairie junegrass	*Koeleria macrantha* (Ledeb.) Schult.	7.1%
Sandberg's bluegrass	*Poa secunda* J. Presl	4.7%
Bluebunch wheatgrass	*Pseudoroegneria spicata* (Pursh) A. Love	11.8%

These species are used by the National Resource Conservation Service in reclamation projects in the Pacific Northwest (NRCS, 2005), and known for their tolerance of degraded soils among other benefits. The other half of each plot was planted in April 2015 with greenhouse grown seedlings of the same grass species.

1.3.2. Site Limitations

The Clear Creek dredge site is located in Climate Division 8 (NOAA), with an average annual precipitation of 62.8 cm (averaged from the last 100 years). According to the Palmer Drought Severity Index (PDSI), the site is in a region of moderate drought (NIDIS), and according to the U.S. Drought Monitor is in a region of severe to extreme drought during 6 months of the year. Plant available water is likely a limiting soil factor at this location. Extending the growing season of plants by keeping moisture in the soil for a longer period could greatly aid re-vegetation attempts. Soil structure and soil texture are the two main components responsible for soil water retention and plant available water (Or, Tuller, and Wraith, 2009). The soil resting on top of the Clear Creek tailings is classified as a loam, with a rock content ranging from 28% to 52%, increasing from the surface down to 20 cm. As this soil cap is only 15.5 cm thick, it is important to maximize water retention quantity because water will quickly drain as soon as it percolates below the cap. Increasing silt and clay sized particles, organic matter, or particles with water retention characteristics (such as biochar) can aid in maximizing plant available water.

The second limiting factor on the experimental site is a commonly found issue at many tailing sites, a lack of plant-available nutrients (Hossner and Hons, 1992). Typical deficient soil nutrients in forest environments are N, P, and occasionally K, sulfur (S) and boron (B) (Coleman et al., 2014, Lehto et al., 2010, Kishchuk et al., 2002). Although this site is barren and not technically a forest environment, it is assumed that it was at one point and will be in the future following revegetation. Organic matter content, a major source of plant nutrients, is below typical percentages due to limited additions from vegetation litter and few soil organisms. Organic matter is also responsible for replenishing nutrients in soil solution, and organic C is positively correlated with P and K in the soil (Sheoran et al., 2010). Fifty to ninety percent of the CEC of mineral soils is from humus colloids found in soil organic matter (Brady and Weil, 1996). At Clear Creek, nutrients in the soil cap are either not sufficient for plant needs, or the combination of limited water and nutrients hinder growth. Once vegetation is established, additions of nutrients, mainly N, can meet plant demand over time. Establishing that vegetation requires soil amendments to get started.

1.4 Amendment Properties

1.4.1 Biochar as a Soil Amendment

In this study, three specific amendments were tested (biosolids, biochar woodchips). Biochar as an amendment has seen intensive research interests over the last few years (Atkinson et al., 2010; Beasley et al., 2007; Jeffery et al., 2011). The main applications of biochar have been to increase agricultural yield (Major et al., 2010; Sinclair et al., 2008), reduce risks at polluted sites (Fellet et al., 2011; Murano et al. 2009), sequester C in soils (Galinato et al., 2011; Steinbeiss et al., 2009) and restore degraded soils (Anawar et al., 2015; Stavi, 2012). Current interests in biochar can be traced to the Amazonian Terra Preta soils studied by Glaser (2001). Although the biochar of Terra Preta is not identical to pyrolysis-produced biochar, the soil quality enhancements from Terra Preta have promoted many researchers to test biochar as a soil amendment.

Biochar has been shown to influence soil chemical and physical properties by increasing soil nutrient retention and plant growth (Lehmann et al., 2003; Tammeorg et al., 2014), increasing soil water-holding capacity, and decreasing soil contaminant availability, usually heavy metals (Ojeda et al., 2015; Rodriguez-Vila et al., 201; Uchimiya et al., 2010). Particular nutrients that are found to be more bioavailable in biochar are P, K, calcium (Ca), magnesium (Mg), and molybdenum (Mo) (Atkinson et al., 2010). Biochar has also been shown to increase cation exchange capacity, which increases retention of cationic nutrients (namely K, Mg, Ca, NH_4) (Lehman, 2007; Liang, 2006), increases total organic C (Tammeorg et al., 2014; Unger et al., 2011), and increases soil pH (Chan et al., 2009).

Some studies have shown detrimental effects of biochar on soil health and plant growth. Kookana et al. (2011) found that biochar's sorption properties can hinder nutrient availability to plants by hindering N mineralization and increasing N immobilization. Yao et al. (2011) found that biochar absorbs phosphate, and when not applied with other nutrients can reduce already limited plant-available nutrients. There is also evidence suggesting that the pore space in biochar, one of its main benefits, becomes clogged over time (on a 100-year scale) with organic C and other adsorbed substances, reducing its sorption capacity by limiting the surface area of the inner pores (Hammes and Schmidt, 2012).

Properties of biochar that make it useful as a soil amendment are high macro- and micro-pore space, which are associated with its large surface area (Kookana et al., 2011; Lehman et al., 2012). Pore space is responsible for the high surface area and sponge-like characteristics of biochar. Although surface area is a physical property, it is directly related to chemical properties because increased surface area increases the solid solution interface, providing more exchange sites to accumulate nutrients for later use.

Biochar's surface charge allows for adsorption of water molecules and cation (NH_4^+, K^+) and anion nutrients (NO_3^-, PO_4^{3-}) (Downie et al., 2012). Different feedstocks and pyrolysis temperatures as well as how long the char has been in the soil greatly affect its surface charge (Uchimiya et al., 2010). Freshly produced biochar has less of an ability to adsorb ions because it has less surface charge. After aging and oxidation begins, which has been found to be a main component of biochar aging, the surface charge becomes increasingly negative due to formation of carbonyl, carboxyl, and phenolic groups (Cheng et al., 2006). These groups are believed to be the main sites of cation adsorption (Cheng et al., 2006; Pittman et al., 1999).

A second benefit of a more negative surface charge is water retention. Water molecules are polar, and therefore their slightly positive hydrogen atoms are attracted to the negatively charged functional groups on the surface of the char. Water retention is also a function of soil organic carbon content. Rawles et al. (2003) found that water retention increased in sandy soils specifically with increased additions of organic carbon. Biochar is composed of primarily organic carbon left over from pyrolysis (Kookana et al., 2011). However, some studies show that biochar does not increase soil water holding capacity. Recent studies show that rate of application and hydrophobicity of each biochar amendment, according to its original biomass, influences whether it will increase soil water retention (Hardie et al., 2013; Ojeda et al., 2014). Ojeda et al. (2014) found no change in water holding capacity in greenhouse studies of biochar, and Hardie et al. (2013) found that any change in water retention was dependent on the original feedstock of the biochar.