Alkaline industrial by-product effects on plant growth in acidic-contaminated soil systems
by Joel Thomas Mehlenbacher

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University

Abstract:
In some regions of the United States the near proximity of alkaline industrial byproducts to acidic-contaminated landscapes in concert with low acquisition cost, make these by-products an attractive option for soil remediation projects. The objective of this research was to determine whether acidic-contaminated soil systems amended with alkaline industrial by-products enable plant growth equivalent to that attained with a commercial grade mixture of CaCO3 and CaO. In addition, it was determined whether an alkaline by-product dosage threshold existed, above which plant growth was impaired.

Three types of cement kiln dust (CKD), three types of lime kiln dust (LKD), and two other alkaline by-products (Dicalcium Silicate, Carbide Lime) were evaluated in this investigation. These alkaline by-products, and the standard treatment composed of a commercial grade CaCO3/CaO mixture, were applied to metalliferous tailings (pH 1.8), and metal contaminated soil (pH 5.0) and plant growth was evaluated.

All alkaline products produced a desired soil pH (7.0 - 8.4) in the root zone during plant growth tests. Following a 111 day plant growth period with Basin Wildrye and Redtop all alkaline industrial by-products tested had plant growth equal to-or greater than- the CaCO3/CaO mixture. This was the case in tailings and the contaminated soil for above ground plant biomass, plant height, root biomass, root depth, and number of roots at the 5 cm and 10 cm soil depths.

When alkaline by-products, including the CaCO3/CaO mixture, were added to the Plant Growth Center soil, the greater the application rate the less was plant growth. Across the alkaline product dosage range of 0 % to 12 % (soil dry weight basis) the loss in aboveground plant biomass was 65 % for Basin Wildrye and 88 % for Redtop.

ALKALINE INDUSTRIAL BY-PRODUCT EFFECTS ON PLANT GROWTH IN ACIDIC-CONTAMINATED SOIL SYSTEMS

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APPROVAL

of a thesis submitted by

Joel Thomas Mehlenbacher

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency and is ready for submission to the College of Graduate Studies.

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Abstract

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CHAPTER 1

INTRODUCTION

History has many lessons, not the least of which points to the importance of foresight. Mining practices that occurred in the United States prior to Federal and State legislation utilized all existing resources to extract the relevant mineral often without regard or respect for the land which harbored it. The advent of the industrial revolution in the United States brought with it the ability to strip the earth of resources crucial to the development, if not the integrity, of this nation.

The Butte-Anaconda region of Montana has a long history of mining, primarily hard rock mining. The processing required to extract and purify the relevant mineral produces a waste stream of material enriched in metals, primarily, Al, Cd, Cu, Pb, Zn, the metalloid As, and metal sulfides. The final processed ore is sent to a smelting operation where further impurities are volatilized. The waste or "mill tailings" are slurried into an impoundment where the excess water is extracted. Upon exposure to O_2 and H_2O, the metal sulfides present in the tailings produce hydrogen ions acidifying the soil and mobilizing metals that contaminate water resources and deter any vegetative establishment.

The waste impoundments cover many square kilometers and pose a health risk to both humans (U.S. EPA 1998) and wildlife (U.S. EPA, 1999). In addition to waste impoundments, many tens of square kilometers has been impacted by stack emissions emanating from the smelting process. It is assumed that dry deposition of metals and sulfates have decreased the pH of the soil impacting all but deeply rooted vegetation;

subsequently, erosion of the topsoil can be severe in these areas. The result is the largest Environmental Protection Agency (EPA) Superfund site in the country. Remedial strategies based upon the best available technology consist of a thin lime layer underlying a 46 cm coversoil cap and/or an in situ treatment of soil with a 60 %/40 % mixture of commercial grade $CaCO_3$/CaO respectively (RRU *et al*, 1987). The rationale depicted is establishing a suitable plant root zone and prevention of upward migration of contaminates and acidity into the coversoil and establishing a suitable plant root zone by raising the pH of the soil to a range of 9 – 11 s.u. to precipitate metals of concern after which plant growth can be established when pH falls below 8.5 s.u.. Regions in the state of Montana that require this type of reclamation are frequently limited by financial resources. The scale of the site and frequently, the lack of a responsible party, create a cost prohibitive scenario.

Alkaline Industrial By-Products

Due to absence of a market, many types of alkaline industrial by-products have historically been landfilled in the United States. Cement kiln dust (CKD) and lime kiln dust (LKD) are two of the most common alkaline by-products, but there are many others. In some regions of the United States, the near proximity of these alkaline by-products to acidic-contaminated landscapes in concert with low acquisition cost, make these by-products an attractive option for land reclamation projects. The U.S. EPA estimated that in 1990 the

cement industry produced approximately 14 million tons (12.7 metric tons) of cement kiln dust from 111 plants in 38 states (EPA, 1999). The industry disposed of 3.6 million metric tons of CKD in 1995 (EPA, 1999). Lime kiln dust, a by-product of calcium oxide production, is produced at 114 plants in 32 states (USGS, 1999).

Sources of Contamination

These alkaline products are in the strictest sense a waste stream and liability of the manufacturer. They are discarded due to impurities that are introduced via:

i) the type of fuel used in the kiln process

ii) the limestone ore body chemistry (or dolomite in the case of Dicalcium Silicate)

iii) chemical inputs required for the final product

iv) the degree of recirculation of the dust within the kiln

The type of fuel utilized in the kiln process can be coal, coke, petroleum, heat oil, natural gas or a combination of fuels. All fuel except natural gas leave an ash residue with an inherent metal and salt content. This "fly ash" becomes part of the kiln dust and directly affects the utility of the kiln dust for reclamation projects. Natural gas, which does not introduce new contaminants into the kiln can have the potential to concentrate the kiln dust relative to the burning of coal and coke. The introduction of coal and coke into the kiln is accomplished through forced air due to the extreme temperatures present. This input effectively dilutes the kiln dust several magnitudes by increasing the amount of kiln dust

created. A natural gas-fired kiln will not require this forced air input and relative to a coal and coke fueled kiln will have a increased concentration of contaminants (Holnam, 2000).

Companies that use kilns to produce burnt lime (CaO) typically input the highest grade of limestone available. Therefore, ore bodies associated with this industry are typically 95 % or greater limestone resulting in a low potential to introduce impurities into the LKD. Cement production in a kiln requires additional constituents to reach the desired output. The manufacturing of cement requires iron, aluminum and silica inputs in addition to limestone. When the ore body does not contain these materials, they must be added to the kiln. This has the potential to increase the metal and salt content of the resulting kiln dust compared to lime production.

Kiln dust, although impure, contains amounts of the original materials and can be recirculated into the kiln for continued processing. This results in highly enriched kiln dust but overall, the amount of kiln dust produced decreases which is beneficial to the manufacturer. A study by the Portland Cement Association (1992) chemically analyzed CKD at most cement manufacturing facilities in the United States. The only samples of CKD that failed to pass the Toxicity Characteristic Leaching Procedure (TCLP) test, which is used to determine whether a material is a hazardous waste, were those from kilns where the kiln dust was recirculated. The study concluded the single most important parameter in determining the level of trace metals in CKD is the degree of recirculation of the CKD in the kiln system.

Efforts to Characterize Kiln Dust Physicochemical Traits

Haynes and Kramer (1982) analyzed kiln dust samples from 102 cement plants in the United States. Concentrations of aluminum (Al), chloride (Cl^-), fluoride (F^-), sulfate (SO_4^{2-}), strontium (Sr), and titanium (Ti) were consistently greater than 500 mg/kg. Lead (Pb) concentrations ranged as high as 2500 mg/kg and 8000 mg/kg for zinc (Zn) while median values were 148 and 167 mg/kg, respectively. They determined CKD was not a hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA).

The Portland Cement Association (1992) sampled kiln dust from 79 plants in the United States. All but two samples passed the TCLP test used to identify a hazardous waste. Total concentrations of 12 metals were determined and enrichment was greatest for barium (Ba) (mean 280 mg/kg) followed by chromium (Cr), nickel (Ni), arsenic (As), and Pb.

Dollhopf (1996a, 1996b, 1997a,1997b) and Dollhopf and Juntunen (1995) analyzed both CKD and LKD from several facilities located in the northwest United States. All CKD and LKD evaluated had high calcium carbonate equivalence and contained desired compounds ($CaCO_3$, $Ca(OH)_2$, CaO) for neutralization of acidic-metalliferous mine waste. Some kiln dusts formed a notable quantity of coarse particles (>0.25 mm diameter) due to having been weathered in outdoor storage areas, a physical trait that is not desired for neutralization of acidic soil, but most materials were fine textured. Both LKD and CKD contained enriched levels of metals compared to concentrations present in natural soils in the United States. However, copper (Cu), manganese (Mn), Pb, Zn, and other metals were very enriched in some CKD samples. In addition, sodium adsorption ratio (SAR) in CKD

was typically very high (20 - 60) which could exacerbate a preexisting sodic condition in a soil. The soluble salt content in LKD was low but this trait was not analyzed in CKD. These investigators found both LKD and CKD were capable of neutralizing acidic-metalliferous mine waste, but did not have the opportunity to evaluate these industrial by-products with plant growth tests.

May (1999) evaluated whether representative trace metal data in CKD could be obtained from a single grab sample. More than 20,000 samples were collected from two cement kilns. Results indicated that variation between samples was sufficiently large that multiple samples should be collected to accurately determine chemical traits of CKD.

Kiln Dust use in the Soil – Plant System

Redente and Richard (1998) conducted plant (Redtop, *Agrostis alba*) growth tests in the greenhouse in acidic waste rock from the Summitville Superfund Site amended with LKD, quicklime (CaO), and limestone ($CaCO_3$). They found limestone supported significantly greater plant shoot and root biomass compared to LKD. This result was attributed to the high pH produced in the root zone when LKD was applied compared to that attained with limestone. However, the authors did not allow the LKD to attain a suitable pH <8.5 for plant establishment.

Gitt and Dollhopf (1991) treated acidic coal waste with agriculture grade limestone and CKD at a field site in central Montana that was seeded to a mixture of grasses and forbs. They found both amendments neutralized the acidic nature of the coal waste, but limestone treatment resulted in significantly more (3 fold) plant production compared to treatment with CKD.

Dollhopf and McDaniel (1997) studied alkaline industrial by-products (Dicalcium Silicate and Flux Bar Residue) produced from a kiln during the manufacture of magnesium from dolomite. Bench top column test indicated these alkaline by-products effectively neutralized acidic mine wastes and precipitated metals of concern. However, when these by-products were used to treat acidic wastes, above ground plant (*Agropyron intermedium*, Intermediate wheatgrass) production attained with a mixture of agriculture grade limestone and a commercially produced calcium hydroxide was 20-fold that produced with Dicalcium Silicate, and no plant growth was attained with Flux Bar Residue. Mine waste application rates for Dicalcium Silicate and Flux Bar Residue were very high, 190.6 t/1000t and 129 t/1000t respectively.

ARCO Environmental Remediation, L.L.C (1999) reported LKD had been used on eight sites in the Upper Clark Fork River Basin in Montana where the landscape had become acidic and contaminated with metals due to historical overland flooding containing mine waste and/or fallout from smelter emissions. These authors indicated vegetation measurements had not been completed on all sites, but some locations exhibited notable plant establishment and growth following treatment with LKD.

Winking and Dollhopf (2000) amended acidic-metalliferous tailings with LKD at an application rate of 9.8 % (dry weight basis), Dicalcium Silicate at an application rate of 9.5 %, and a mixture of commercial grade limestone with calcium hydroxide at a 8.5 % application rate. All amendments successfully neutralized the acid conditions in the tailings. Above and below ground growth of *Thinopyrum intermedium* (Intermediate wheatgrass, var. Tegmar) and *Elymus trachycaulum* (Slender wheatgrass, var. Pryor) were the same for tailings amended with the commercial grade limestone/calcium oxide mixture and LKD, but Dicalcium Silicate amended tailings had significantly less plant growth.

Investigators reported loss in plant growth when soils were treated with CKD. Saravanan and Appavu (1998) measured decreased root length, shoot length and seedling vigor index for crops grown in soils treated with CKD. Investigators determined plants grown in a solution treated with CKD had a decreased mitotic index which was related to plant chromosome damage and it was suggested CKD acted as a mutagen to the plant system (Ignacimuthu and Muraleytharan 1994, Kaushik 1996).

Numerous investigators reported deposition, i.e. dusting, of CKD onto plant leaves impaired growth of various plant species (Chitralekha and Dhakshinamoorthy 1998, Rao and Narayanan 1998, Durge and Phadnawis 1994, Durge and Phadnawis 1998, Hegazy 1996, Prasad and Inamdar 1990, Uma and Ramana 1994, Uma and Ramana 1993). This result may be a function of the caustic (pH >9 s.u.) nature of kiln dusts. It is likely that any caustic amendment (i.e. CKD, LKD, CaO or $Ca(OH)_2$) transferred by wind onto adjacent lands could cause impaired plant growth.

Gutenmann et al. (1994) found enriched levels of selenium in CKD resulted in significantly higher concentrations of this element in plant parts when the soil had been treated with CKD compared to commercial grade $CaCO_3$ and CaO.

Investigators reported LKD and CKD improved plant growth when applied to soils at rates comparable to fertilizer application or in combination with sewage sludge treatments (Simpson and Stopes 1991, Christie et al. 2001, Lafond and Simard 1999, Luo and Christie 1997).

Alkaline Industrial By-product Chemical Enrichment

Alkaline industrial by-products often contained metal contaminants at concentrations that may produce phytotoxic responses in plant growth. However, phytotoxic concentrations may be mitigated when applied to soils at an application rate of 2 - 10 % of the soil mass which facilitates dilution of the amendment metal chemistry, and the change in amendment pH from a range of 9.6 - 13.7 to the soil pH of 7.0 - 8.4 results in decreased contaminant solubility in the soil solution.

The water soluble metal content of an alkaline by-product at its pH, which ranged from 9.6 to 13.7, may be significantly different compared to an amended soil where the final pH will be in a target range of 7.0 - 8.4. It was predicted that water soluble metal concentration in alkaline by-products would be at lower concentration in an amended soil (pH 7.0 - 8.4) compared to its water soluble metal concentration at pH 9.6 - 13.7. As will be

discussed below, certain water soluble metal concentrations of alkaline industrial by-products had the potential for phytotoxicity, however, no toxicity appeared to be in the amended soil system having a pH of 7.0 - 8.4.

Alkaline industrial by-products will be applied to acidic-contaminated soil systems at various application rates ranging up to 10 %, i.e. 100 tons amendment/1000 tons soil. Often a by-product contained a total metal concentration that had the potential for phytotoxicity. However, amendment incorporation into the soil profile results in notable dilution that decreases the risk of a phytotoxic response.

By-product dilution during soil incorporation and a decrease in metal solubility following treatment implementation generally led to interpretations that these alkaline products would not produce phytotoxic symptoms in the plant root zone. Uncertainty associated with these interpretations is present, thus plant growth tests presented later in this thesis provide additional information regarding by-product phytotoxicity.

Vanadium

Vanadium (V) is a umbiquitous element and is naturally present in surface soils in the United States which are reported to contain 7 - 300 mg/kg V and sedimentary rocks such as limestone typically contain 10-45 mg/kg V (Kabata-Pendias and Pendias, 1984) Gough et al. (1979) reviewed the topic of V phytotoxicity and stated that there are no reports indicating V toxicity under field conditions. However, he stated under experimental conditions, V concentrations as high as 0.5 ppm in the nutrient solution, and 140 ppm in the soil solution,

may be toxic to plants. Kaplan et al. (1989) reported dosages of 3 and 6 mg/l V were applied in a hydroponic study that induced visual toxicity symptoms in beans that increased with V concentration. He stated part of the toxicity effect of V on plants was related to the depression of calcium and possibly manganese uptake by the plant which leads to nutrient deficiency. In 1990, Kaplan et al. reported on a study where both sand and loamy sand soils were prepared with 1, 20, 40, 60, 80, and 100 mg/kg total V. At the two highest concentration of V, the sand soil had significantly less plant biomass of *Brassica oleracea*, but the loamy sand soil showed no effect on plant growth. These investigators also evaluated seed germination as a function of V in soil solutions that ranged from 0-75 mg/l. Low concentrations of V (1 mg/l) stimulated radicle elongation while slightly greater concentration (3 mg/l) caused severe toxicity. These investigations suggest high concentrations of V in soil systems have potential to impair plant growth. The concentration of V that will cause impaired plant growth is dependent upon the plant species present and the soil physicochemical characteristics.

Aluminum

Natural soil solutions contain approximately 0.4 mg/l Al (Kabata-Pendias and Pendias (1984), and Munshower (1994) reported water extractable concentrations of 1 – 5 mg/kg may be phytotoxic. When Dicalcium Silicate is used as a soil amendment, all water soluble aluminum in Dicalcium Silicate (464 mg/l) must transform into a solid phase precipitate that is unavailable for plant uptake. If a portion of the by-product Al remains in solution in the plant root zone, phytotoxic conditions would likely be present.

Barium

Kabata-Pendias and Pendias (1984) indicate the total Ba content of surface soils in the United States average 400 to 835 mg/kg depending on soil type and range from 10 to 3000 mg/kg. In soil systems, Ba is relatively insoluble since it tends to form precipitates with sulfates and carbonates, and is strongly adsorbed by clays. Therefore, Ba enrichment measured in kiln dust is not expected to impair plant growth.

Boron

Kabata-Pendias and Pendias (1984) indicate total boron (B) content of surface soils in the United States average 20 - 55 mg/kg depending on soil type. Holnam (CH_4) CKD had a water extractable B concentration of 5 mg/l while all other alkaline products were below the detection limit. Soil water extractable B concentrations >5 mg/l may impair growth and reproduction of some plant species (Eaton 1944, Munshower 1994). The 5 mg/l B measured in the water extract from the Holnam CKD where the kiln was fired with natural gas (CH_4), was at a solution pH of 13.7. Adsorbed (or fixed) B, as opposed to B in the soil solution is highly pH dependent, with maximum adsorption occurring in a pH range of 7 - 9 (Barth et al. 1987). At soil pH > 9.2, $B(OH)_4^-$ predominates in solution and was likely the species measured in CKD. Nonionized $B(OH)_3$ predominates in soil solution in the pH range 7 to 9. Therefore, the amount of B in solution would be less in a pH range of 7.0 - 8.5 compared to a pH of 13.7. Given the solubility characteristics of B, and anticipated

alkaline product application rate of less than 10 % of the soil dry weight mass, the enriched levels of water soluble B measured at pH 13.7 are not expected to impair plant growth in an amended soil system having a pH in the range of 7.0 - 8.3.

Selenium

The primary concern with enriched soil Se levels is that it may facilitate enriched Se concentrations in plant tissues that cause toxic symptoms in livestock as a result of grazing on these plants. Munshower (1994) reported a soil water extractable Se concentration >0.5 μg/g is considered very enriched (Note 1 μg/g = [1 mg/l]/relative density). Certain plant species accumulate sufficient Se to be toxic to animals if soluble soil selenium (selenate, SeO_4^{2-}) concentrations were only a few tenths of a μg/g (Lakin, 1972). AB-DTPA extractable soil Se concentrations of < 0.2 μg/g produced plant tissue Se levels greater than levels recommended for prolonged consumption by livestock (Prodgers and Munshower 1991).

Selenate is the predominant form of Se in calcareous soils and selenite is the predominant form in acid soils (Sims et al. 1986). Selenate is highly mobile (i.e. soluble) in alkaline soils. Griffen and Shimp (1978) showed that selenite solubility decreased from a pH of 2 to 9. Therefore, use of CKD to treat acidic-metalliferous soil should be done with caution pertaining to use of selenium accumulating plant species and livestock grazing issues.

Zinc

The soil solution concentration of Zn that can cause a phytotoxic response is uncertain. Total Zn concentrations in soil that produce phytotoxic response are usually in the 250 to 650 mg/kg range (Munshower 1994). Kabata-Pendias and Pendias (1984) reviewed results from several investigations and found total soil Zn concentrations of 70 - 400 mg/kg caused phytotoxicity. Kiln dust application rates in the range of 2 - 10 % (dry weight basis) will increase the total Zn concentration in the tailings approximately 1 % to 50 % and in contaminated soil < 1 % to 15 %. It is not known whether increased Zn concentration in the soil system due to kiln dust application will exacerbate the phytotoxicity issue, but the risk of impaired plant growth is increased by producing a higher contaminant concentration in the soil system

Arsenic, Cadmium, Chromium, Copper, Lead, Manganese, Nickel

Although the degree of enrichment for these chemical elements in the by-products was often notable, the final concentration in an amended soil (assuming a 2 - 10 % amendment application rate, dry weight basis) would be relatively low and is not expected to produce a phytotoxic response. However, use of kiln dust will generally increase the level of these contaminants in the amended soil system and the impact, if any, to plant growth is not known. Given these circumstances, plant growth tests are appropriate to better understand phytotoxicity issues.

In summary, the toxicity of these elements when applied as an amendment to a soil system is nebulous. The texture of the soil, resulting pH of the root zone, and the plant species present greatly affect the degree of impairment. The literature cited for all elements reported that levels of plant growth impairment were less as a function of increased levels of calcium (Ca^{2+}) and magnesium (Mg^{2+}) present in the soil matrix. This indicates that, to a certain degree, the effects of introduced contaminants in the plant root zone can be mitigated by the alkaline inputs of these industrial by-products.

Objectives of Research

The goal of this research was to determine whether acidic-contaminated soil systems amended with alkaline industrial by-products enable plant growth equivalent to that attained with a commercial grade mixture of $CaCO_3$ and CaO.

Alkaline by-products with enriched concentrations of metals and/or soluble salts may provide the means for good plant growth when applied at low soil application rates, but a threshold dosage rate may exist that impairs plant growth. This investigation was conducted to better understand these concerns.

Three types of CKD, three types of LKD, and two other alkaline by-products (Dicalcium Silicate, Carbide Lime) were evaluated in this investigation. These alkaline by-products, and the standard treatment composed of a commercial grade $CaCO_3$/CaO

mixture, were applied to acidic-metalliferous soil matrices and an optimal soil matrix and plant growth was evaluated. Specific objectives of this investigation were as follows.

- Determine the physicochemical traits of alkaline industrial by-products.
- Determine plant growth characteristics in acidic-metalliferous soil matrices amended with alkaline by-products and a $CaCO_3/CaO$ mixture.
- Determine whether an alkaline by-product dosage thresholds exist, above which plant growth is impaired.
- Identify those alkaline by-products that are suitable for in-situ treatment of acid soil systems.

CHAPTER 2

METHODS AND MATERIALS

Tailings, Contaminated Soil, Plant Growth Center Soil Bulk Sample Collection

A bulk composite tailings sample of approximately 680 liters (180 gallons) was collected from the D-2 cell of the Opportunity pond site near Anaconda, MT. Stainless steel tools were used to place tailings into clean plastic cans. The sample was collected to a depth of 45 cm avoiding the initial 0 - 7 cm depth increment which contained some limestone. Similarly, a bulk composite contaminated soil sample of approximately 680 liters was collected from the east end of Stucky Ridge near Anaconda, Montana within the 0 - 10 cm depth increment. The MSU Plant Growth Center soil was composed of 33 % Bozeman silt-loam, 33 % sand and 33 % sphagnum peat (volume basis). This soil was sterilized with forced steam and used as an optimal potting medium to support maximum plant growth of the test species.

Alkaline Industrial By-Products Bulk Sample Collection

These following nine alkaline industrial products were collected for this investigation.

$CaCO_3/CaO$

Limestone ($CaCO_3$) was provided by Montana Limestone, Bridger, MT. Burnt lime (CaO) was provided by Greymont, Inc. (formerly Continental Lime Company), Townsend, MT.

Greymont LKD

This LKD was produced by Greymont, Inc. Townsend, MT. A composite bulk sample, consisting of 10 subsamples, was collected from a stockpile of this LKD located in Anaconda, Montana, owned by Atlantic Richfield Company. This LKD was produced in a kiln heated with a fuel mixture of 70 % coal and 30 % coke. The kiln process did not include recirculation of the LKD.

Tacoma LKD

This LKD was produced by Tacoma Lime, Inc. Tacoma, WA. The company referred to this LKD as "Econolime". Limestone is shipped to Tacoma where the kiln is located. Atlantic Richfield Company purchased this LKD and had it transported by rail to Rocker, Montana where it was stockpiled. A composite bulk sample, consisting of 6 subsamples, was collected from this stockpile in Rocker, MT.

MT Limestone LKD

This LKD was produced by Montana Limestone, Bridger, MT. The limestone pit and kiln are located in Frannie, WY. This LKD was produced in a kiln heated with a fuel mixture of coal and coke. Montana Limestone staff collected the bulk LKD sample and shipped it to Montana State University.

Holnam (CH_4) CKD

This CKD was produced by Holnam, Inc., Three Forks, MT. The limestone pit and kiln are located in Trident, MT. The CKD was produced in a kiln heated with methane gas (CH_4). In addition to limestone, amounts of shale, sand, glass and iron ore were placed in the kiln to produce cement. The kiln process did not include recirculation of the CKD. A single bulk sample of CKD was collected from the storage silo.

Holnam (Coal, Coke) CKD

This CKD was produced by Holnam, Inc., Three Forks, MT. The limestone pit and kiln are located in Trident, MT. The CKD was produced in a kiln heated with a mixture of 75 % coal and 25 % coke. In addition to limestone, amounts of shale, sand, glass and iron

ore were placed in the kiln to produce cement. The kiln process did not include recirculation of the CKD. A single bulk sample of CKD was collected from the storage silo.

Ash Grove CKD

This CKD was produced by Ash Grove Cement Company, Clancy, MT. The limestone pit and kiln are located in Montana City, MT. The CKD was produced in a kiln heated with a mixture of 70 % coal and 30 % coke. In addition to limestone, amounts of shale, silica, and slag iron were placed in the kiln to produce cement. Approximately one-third of the CKD was recirculated through the kiln. A single bulk sample of CKD was collected from the storage silo.

Dicalcium Silicate

This kiln dust was produced by Northwest Alloys, Addy, Washington., where magnesium is produced from dolomitic limestone. The limestone pit and kiln are located in Addy, WA. Staff from Northwest Alloys collected a bulk sample and shipped it to Montana State University.

Carbide Lime

This alkaline by-product was produced by Liquide Air, Missoula, MT. The by-product stockpile was located on Liquide Air properties in Missoula, MT. Carbide Lime is a by-product in the production of acetylene gas. Coke is combusted in the presence of calcium oxide to produce calcium carbide, which is then treated with water to yield acetylene and Carbide Lime. A composite bulk sample, consisting of 10 subsamples, was collected from a stockpile in Missoula, MT

Analytical Methods for Soil and Alkaline Industrial By-Products

The soil samples collected from the field (tailings and contaminated soil) were mechanically homogenized prior to analysis. Samples were placed in a rotating tractor driven cement mixer at the MSU Plant Growth Center for five minutes with the tractor set at 1200 rpm. Subsamples were then collected and dried for analysis of physicochemical parameters listed in Table 1.

In addition to the standard bench top pH glass electrode method, a stainless steel pH probe (Scientific Instruments Model IQ150) was used to measure root zone pH during the plant growth period. The probe was periodically pushed into the pot substrate to the 2.5 cm soil depth and pH measured with the calibrated instrument.

Table 1. Analytical testing methods for soil and alkaline industrial by-products.

Analysis	Note	Method
pH[2], s.u.		Agron. Soc. Amer., Monograph No. 9, Methods of Soil Analysis, 1965, Method 62-1.3.2.1, p. 935.
Electrical Conductivity[2], dS/m		Agron. Soc. Amer., Monograph No. 9, Methods of Soil Analysis, 1965, Method 62-2.2.3, p. 938.
Total Metals[1]	Ag, Al, As, Ba, Be, B, Ca, Cd, Cr, Cu, Fe, Hg, K, Mg, Mn, Ni, P, Pb, Se, Sn, V, Zn	Test Methods for Evaluating Solid Waste, 1986. Method 3050 (HNO_3 and H_2O_2 digestion).
Water Soluble Metals[1]	Al, As, B, Cd, Cl, Cu, Fe, Mn, Pb, Se, SO_4, Zn,	Agron. Soc. Amer., Monograph No. 9, Methods of Soil Analysis, 1965, Method 62-1.3.2.1, p. 935
Toxicity Characteristic Leaching Procedure (8 RCRA metals)[1]	As, Ba, Cd, Cr, Pb, Hg, Se, Ag	EPA, SW 846, Method 1311
Calcium Carbonate Equivalence (CCE)[1], %		Agron. Soc. Amer., Monograph No. 9, Methods of Soil Analysis, 1965, Method 91-4.2., p. 1387.
Loss on Ignition[1], %		ASTM (1980) C25-90, Section 21
Sodium Adsorption Ratio[2]	$[Na]/(([Ca] + [Mg])/2)^{1/2}$, meq/l	Agron. Soc. Amer., Monograph No. 9, Methods of Soil Analysis, 1965, Method 62-1.3.2.1, p. 935
Acid-Base Account[1]		Modified Sobek Method (RRU *et. al.*, 1987) (Sobek et al. 1978)
Lime Requirement (SMP Buffer)[1]	Lime requirement tons/1000 tons	Method 12-3 (ASA, 1982), Part 2
Particle Size Analysis [2]	% sand, silt and clay	Modified Day, Method 15-5 (ASA, 1982), Part 1
Textural Classification [2]	USDA Textural Triangle	Soil Survey Staff (1975)
% Rock Fragments [2]	$\geq$2 mm diameter	ASTM (1993) D421-85
% Saturation [2]		Method 27a (U.S. Salinity Lab Staff, 1969)

[1] Energy Laboratories, [2] RRU Laboratory

Table 2. Characteristics of plant species used in this investigation (Munshower, 1998).

Plant Specie	Plant Common Name	Salinity Tolerance	Acid Tolerance	Metal/Non-metal Tolerance	Seeding Depth (cm)
Leymus cinereus, Magnar	Basin Wildrye	good to very good	acid to alkaline	Elevated heavy metals, very tolerant of water soluble arsenic in soil	1.25
Agrostis alba, Streaker	Redtop	moderate	acid	some	1.25

Plant Species

Plant species selected for this investigation were based on their relevance to disturbed land reclamation and tolerance to saline and acidic-metalliferous soils. Perennial grasses selected are listed in Table 2.

Table 3. Alkaline amendment application rates for tailings, contaminated soil, and Plant Growth Center soil.

Treatment	Application Rate, Tons Amendment/ 1000 Tons Soil		
	Tailings	Contaminated Soil	Plant Growth Center
1) Control	0	0	0
2) $CaCO_3$/CaO	29.16 $CaCO_3$ + 11.23	4.36 $CaCO_3$ + 1.87 CaO	29.16 $CaCO_3$ + 11.23
3) Greymont LKD	75.15	12.55	75.15
4) Tacoma LKD	116.60	19.47	116.60
5) MT Limestone LKD	91.25	6.24	91.25
6) Holnam (CH_4) CKD	53.31	8.90	53.31
7) Holnam (Coal, Coke)	55.15	9.21	55.15
8) Ash Grove CKD	68.70	11.47	68.70
9) Dicalcium Silicate	42.35	7.07	42.35
10) Carbide Lime	73.84	12.33	73.84

Soil Treatments for Tailings, Contaminated Soil and Plant Growth Center Soil

Nine alkaline products were applied to three difference soil types (Table 3). The tailings had a lime requirement of 47.43 t $CaCO_3$/1000 t, the contaminated soil had a lime requirement of 7.92 t $CaCO_3$/1000 t, and the Plant Growth Center soil had no lime requirement and was included to evaluate the effects of the lime products in an optimal plant growth medium. The total lime requirement for these three soil types was calculated according to Equation 1.

t $CaCO_3$ /1000 t soil = (% HNO_3 Extractable S + % Residual S) 31.25 + 23.44 (% HCl Extractable S) + SMP Lime Requirement, t $CaCO_3$/1000 t soil [Equation 1]

A control treatment served to evaluate plant growth in each soil type without addition of an alkaline product. The application rate was different for each alkaline product for tailings and for the contaminated soil since physicochemical traits of each product are different. An alkaline product application rate for a soil was a function of the calcium carbonate equivalence, particle size < 60 mesh (0.25 mm), and gravimetric water content. The Plant Growth Center alkaline product application rate was set the same as that required for tailings as the contaminated soil requirement was very low and higher application rates would provide a better comparison. All treatments were replicated 8 times into a randomized complete block experimental design. This constituted 480 experimental pots (8 replications x 10 soil treatments x 3 substrates x 2 plant species). Plant growth containers

were round plastic pots with dimensions of approximately 15 cm in diameter and 15 cm deep. Plants were watered at a rate of 100 ml per day. The plant growth period was 111 days.

Soil Treatments for The Alkaline Product Dosage Sequence Plant Growth Tests

Nine alkaline products were applied to the Plant Growth Center soil at seven different application rates that ranged from 0 % (0 t alkaline amendment /1000 t) to 12 %

Table 4. Alkaline amendment application rates for variable dosage rate research using the Plant Growth Center soil.

Treatment	Alkaline Amendment Dosage Sequence						
	0 %	2 %	4 %	6 %	8 %	10 %	12 %
	Tons Amendment/ 1000 Tons Soil						
1) $CaCO_3/CaO$	0	20	40	60	80	100	120
2) Greymont LKD	0	20	40	60	80	100	120
3) Tacoma LKD	0	20	40	60	80	100	120
4) MT Limestone LKD	0	20	40	60	80	100	120
5) Holnam (CH_4) CKD	0	20	40	60	80	100	120
6) Holnam (Coal, Coke) CKD	0	20	40	60	80	100	120
7) Ash Grove CKD	0	20	40	60	80	100	120
8) Dicalcium Silicate	0	20	40	60	80	100	120
9) Carbide Lime	0	20	40	60	80	100	120

(120 t alkaline amendment /1000 t) in 20-ton increments (Table 4). All treatments were replicated 5 times a randomized complete block experimental design. This constituted 630 experimental pots (5 replications x 9 soil treatments x 7 application rates x 2 plant species).

Plant growth containers were square plastic pots with dimensions of approximately 11 cm in diameter and 10 cm deep. Plants were watered at a rate of 50 ml every other day. The plant growth period was 90 days.

Plant Growth Conditions

Initially, all soil materials treated with alkaline products had a pH >8.5 due to the presence of CaO and $Ca(OH)_2$. In order to reduce this pH, carbonation of these oxides and hydroxides of calcium was facilitated with CO_2 gas piped through each substrate in the presence of applied water. The carbonation treatment process required a several month period to complete. When all substrate pH levels were below 8.5, seeding was instituted. A seed stock viability test was performed to determine the percent live seed for Basin Wildrye and Redtop. Ten seeds of each species were placed on paper towels in a petri dish and kept moist. This procedure was replicated 4 times. Percent of the seeds that germinated was recorded. Live seed was 92.0±5.4 % for Basin Wildrye and 92.0±4.8 % for Redtop. Fifteen seeds of the same plant species were planted in each pot. Following 14 days of post-emergence plant growth, several growth characteristics were measured and then plants were thinned to five per pot. Plants were grown with 18 hours of light per day at 21° C (69.8° F). Night temperatures were maintained at 18° C (64° F).

Plant Growth Measurements

Nine types of plant growth measurements were made and are described in Table 5. Measurement of below ground biomass, i.e. root biomass, was facilitated with a water

Table 5. Plant Growth Measurements

Measurement	Procedure
Time To Emergence	Number of days for seedling to emerge from date of seeding.
14 Days After Emergence	
Germination	Given the 15 seeds per pot, the number that germinated and emerged.
Survival	Number of viable seedlings of those that emerged.
Shoot Height	Distance from ground to the end of the longest leaf for each plant.
Plant Harvest	
Aboveground Height	Distance from the ground to the end of the longest leaf for each plant.
Maximum Root Depth	The maximum root length in each growth pot measured a maximum of the depth of pot.
Root Distribution	The number of roots at 5 cm and 10 cm soil depth.
Aboveground Biomass	The aboveground biomass of all plants measured after drying at 50° C for a minimum of 48 hours.
Belowground Biomass	The belowground biomass of all plants measured after drying at 50° C for a minimum of 48 hours.

washing procedure that separated soil from the root. Maximum Root Depth and Root Distribution at 10 cm was not measured in plant growth tests associated with alkaline

product dosage sequence investigation.

Statistical Analyses

Plant growth measurements were statistically analyzed using Sigmastat® statistical software version 2.03 (SPSS 1997). Statistical analyses for soil pH were performed using $[H^+]$. Normally distributed data were analyzed using a two-way ANOVA to determine if treatment means were significantly different ($p < 0.05$). If treatment means were found to be significantly different, then the means were separated using the All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method). Data that were not normally distributed were transformed and analyzed using a two-way ANOVA to determine if treatment means were significantly different ($p < 0.05$). Data that were not normally distributed and could not be normalized through transformation were analyzed using the nonparametric one-way Kruskal-Wallis ANOVA on ranks to determine whether significant differences were present
($p < 0.05$).

Data Quality Control

Laboratory analyses were conducted on tailings, soil, and alkaline industrial products.

Statements pertaining to laboratory data accuracy, precision and completeness are presented in Appendix C.

CHAPTER 3

RESULTS AND DISCUSSION

Physicochemical Characteristics of Tailings and Contaminated Soil

Opportunity Tailings

Tailings material was collected from the D2 Opportunity Impoundment near Anaconda, MT. No plant growth was present at the field site. It contained no coarse fragments (> 2 mm diameter) and had a sandy loam particle size distribution (Table 6). Tailings were acidic (pH 1.8) and saline (electrical conductivity 9.7 ds/m) with a low sodium adsorption ratio of 0.03. Water soluble concentrations of aluminum were very enriched (976 mg/l), and associated concentrations of copper, manganese, and zinc were also enriched.

In tailings, 19.2 t $CaCO_3$ /1000 tons of tailings was required to neutralize the active acidity. Potential acidity emanating from sulfide minerals (0.51 %) required 15.9 t $CaCO_3$ /1000 tons of tailings to neutralize this source of acidity. It was assumed that relatively insoluble sulfate minerals were present, e.g. jarosite, which had the potential to produce acidity that required an additional 3.8 t $CaCO_3$ /1000 tons of tailings. The total $CaCO_3$ requirement was 47.43 t/1000 t (Table 6).

Table 6. Physicochemical characteristics of tailings and contaminated soil.

Sample Type	SMP Active Acidity analysis $tCaCO_3/1000t$	Lime Requirements (%)											Total Lime Requirement $tCaCO_3/1000t$
		HCl Extractable S	HNO_3 Extractable S	Residual S	H_2O Extractable S	Total S	Neut. Pot. t/1000t as $CaCO_3$	Acid Pot. t/1000t as $CaCO_3$	Acid Base Pot. as $CaCO_3$	Non-Sulfate Sulfur	H_2O by Weight	Substrate >2 mm	
Contaminated Soil	5.4	0	0.01	0.02	0.01	0.04	<1	1	-1	0.03	1.38	23.0	7.92
Tailings	19.2	0.12	0.44	0.07	0.51	1.14	<1	20	-20	0.63	6.01	0	47.43

Sample Type	pH	EC ds/m	Sodium Adsorption Ratio	Water Saturated Paste Extract (mg/l)								
				Ca meq/l	Mg meq/l	Na meq/l	Al	As	Cu	Pb	Mn	Zn
Contaminated Soil	5.0	0.60	0.32	2.84	0.48	0.42	1	0.36	22.5	<1	4.6	10.5
Tailings	1.8	9.7	0.03	27.6	23.3	0.14	976	6.8	99.0	<.01	183	81.4

Sample Type	Total Concentration (mg/kg)					
	Al	As	Cu	Pb	Mn	Zn
Contaminated Soil	11400	443	1400	138	241	311
Tailings	2680	76	162	273	93	94

Sample Type	% Passing Dry Sieve Size		Calcium Carbonate Equivalence	Loss on Ignition	Particle Size Analysis			Textural Class	Saturation Percentage %
	10 mesh 2.0 mm	60 mesh 0.25 mm			% Sand	% Silt	% Clay		
Contaminated Soil	77	ND	0.1	ND	73.4	16.6	10	sandy loam (sl)	24.1
Tailings	100	ND	0.1	ND	58.4	30	11.6	sandy loam (sl)	36.0

ND = Not Determined

Contaminated Soil

The contaminated soil was collected from the east end of Stucky Ridge near Anaconda, MT. Contamination in this natural soil emanated from smelter emissions of sulfates and metals. There was no grass growth at this field site, but Canadian thistle constituted approximately a 5% plant cover. This soil had a coarse fragment content of 23 %, i.e. particles not passing a sieve with 2 mm openings, and a sandy loam particle size distribution (Table 6). The contaminated soil was acidic (pH 5.0) but was neither saline nor sodic. Total soil concentrations of arsenic (443 mg/kg) and copper (1400 mg/kg) were very enriched while lead, manganese and zinc were enriched to a lesser degree. Water soluble concentrations of arsenic (0.36 mg/l) were low in the pH 5.0 soil matrix, while copper (22.5 mg/l) and zinc (10.5 mg/l) were the most enriched metals in the soil solution.

In order to neutralize the active acidity in this contaminated soil, 5.4 t $CaCO_3$ /1000 tons of soil would be required. Potential acidity emanating from sulfide minerals was small (0.03 %) and required 0.9 t $CaCO_3$ /1000 tons of soil to neutralize this source of acidity. The total $CaCO_3$ requirement was 7.92 t/1000 t (Table 6).

Physicochemical Characteristics of Alkaline Industrial By-Products, Calcium Carbonate and Calcium Oxide

That portion of an alkaline amendment passing a 60 mesh sieve (0.25 mm) is chemically reactive for neutralization of soil acidity (Tisdale et al, 1966). This is true for

$CaCO_3$. However, both CaO and $Ca(OH)_2$ are each approximately 100 times more soluble in water compared to $CaCO_3$. Thus the coarse particles (>60 mesh) of an alkaline amendment that pass a 60 mesh sieve following a 16 hour period of shaking in a beaker of water are considered reactive CaO and $Ca(OH)_2$.

All alkaline amendments passed the 60 mesh screen except for Greymont Lime Kiln Dust (LKD), Tacoma LKD, and Carbide Lime (Table 7). Following dry and wet sieving procedures, 19.2 % of the Greymont LKD failed to pass the 60 mesh sieve, while 55.1 % of

Table 7. Physicochemical Characteristics of Alkaline Industrial By-Products and Commercial Grade Lime.

Sample Type	% Passing Dry Sieve Size		% Passing Wet Sieve 60 mesh 0.25 mm	% 60 mesh minus material Wet + Dry	Calcium Carbonate Equivalence %	Loss on Ignition %
	10 mesh 2.0 mm	60 mesh 0.25 mm				
Greymont LKD	ND*	68.7	38.5	80.75	78.4	26.3
Tacoma LKD	ND	15.3	35.0	44.90	90.6	37.2
MT Limestone LKD	ND	100	ND	100	127	9.33
Holnam (CH_4) CKD	ND	100	ND	100	89	26.3
Holnam (Coal/Coke) CKD	ND	100	ND	100	86	21.7
Ash Grove CKD	ND	100	ND	100	69.1	23.3
Dicalcium Silicate	ND	100	ND	100	112	0.99
Carbide Lime	ND	30.2	52.0	66.49	96.6	38.3
$CaCO_3$	ND	100	ND	100	97.6	ND
CaO	ND	19.0	100	100	169	ND

ND = Not Determined

the Tacoma LKD failed and 33.5 % of the Carbide Lime failed. Portions of an alkaline amendment failing to pass a 60 mesh sieve are considered inert, and must be accounted for during calculation of an application rate to neutralize an acidic soil system.

Gravimetric water content of alkaline by-products ranged from 0.0 - 34.3 % (Table 7). By-products stored in silos typically had a very low water content, while those stockpiled

outdoors and not covered had higher water contents and >60 mesh material.

The calcium carbonate equivalence (CCE) of an alkaline by-product is a measure of its acid neutralization capability compared to pure $CaCO_3$. The CCE of these alkaline by-products ranged from 69.1 – 127 % (Table 7). The loss on ignition test results ranged from 0.99 to 38.3 % (Table 7) which by calculation means the $CaCO_3$ content of these by-products ranged from 2.2 to 87.0 %. It was estimated that the CaO and $Ca(OH)_2$ content of these alkaline by-products ranged from 3.4 – 80.7 %.

The loss on ignition (LOI) laboratory test is used to determine the $CaCO_3$ content of a alkaline amendment. If a material is pure $CaCO_3$, it will lose 44 % of its mass after ignition in accordance with Reaction [1]. If the alkaline amendment loses less than 44 % of its mass after

$$CaCO_3 + \text{Heat} \rightarrow CaO + CO_{2(g)} \qquad \text{[Reaction 1]}$$

ignition, then proportionately less $CaCO_3$ is present. The interpretation of the LOI test can be complicated by the presence of $Ca(OH)_2$. If $Ca(OH)_2$ is present, the LOI test will remove its molecular bound water in accordance with Reaction 2. Therefore this loss in mass as water could mistakenly be interpreted as CO_2 loss [Reaction 1], which would cause

$$Ca(OH)_2 + \text{Heat} \rightarrow CaO + H_2O \qquad \text{Reaction 2]}$$

an overestimation of $CaCO_3$ content. Given the mass of $Ca(OH)_2$, it has the potential to lose 24 % of its weight during LOI. In the laboratory, ignition of these by-products was

performed in a furnace with an air atmosphere. In addition to error associated with water loss from $Ca(OH)_2$ during ignition, the air atmosphere in the furnace may cause analytical error. The CO_2 in air may contribute to carbonation of CaO instead of CO_2 release from $CaCO_3$ [Reaction 1], causing an overestimation of $CaCO_3$ content and associated underestimation of CaO and $Ca(OH)_2$ contents.

Data presented in Table 7 indicate each alkaline industrial by-product contained the compounds $CaCO_3$, $Ca(OH)_2$ and CaO which are important for treatment of acidic-metalliferous soil substrates. Additional neutralizing compounds may be present, such as MgO, but are assumed to be in very small concentrations. It is important that the hydroxide (OH) and oxide (O) compounds of calcium be present to raise the amended soil pH up into the 10 – 12 range such that metal contaminates can effectively precipitate out of the soil solution, and consequently not be available for plant uptake. Both $Ca(OH)_2$ and CaO in alkaline by-products must undergo carbonation [Reactions 3 - 7] to form $CaCO_3$ in the soil system to facilitate a suitable soil pH for plant growth. A soil system containing $CaCO_3$, as opposed to $Ca(OH)_2$ and/or CaO, will have a soil pH less than 8.4.

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \text{[Reaction 3]}$$

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- \qquad \text{[Reaction 4]}$$

$$OH^- + CO_2 \rightarrow HCO_3 \qquad \text{[Reaction 5]}$$

$$HCO_3^- + OH \rightarrow CO_3^{2-} + H_2O \qquad \text{[Reaction 6]}$$

$$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3 \qquad \text{[Reaction 7]}$$

All alkaline by-products passed the U.S.E.P.A. Toxicity Characteristic Leaching Procedure that determines whether a material fits the criteria for a hazardous waste (Table 8). The alkaline industrial by-products tested at this time passed the TCLP and therefore are not considered hazardous waste.

Table 8. Toxicity Characteristic Leaching Procedure for Alkaline Industrial By-Products and Commercial Grade Lime.

Sample Type	Toxicity Characteristic Leaching Procedure (TCLP) mg/l							
	As	Ba	Cd	Cr	Pb	Hg	Se	Ag
Greymont LKD	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
Tacoma LKD	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
MT Limestone LKD	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
Holnam (CH_4) CKD	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
Holnam (Coal/Coke) CKD	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
Ash Grove CKD	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
Dicalcium Silicate	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
Carbide Lime	<0.5	<10	<0.1	<0.5	<0.5	<0.02	<0.1	<0.5
$CaCO_3$	ND	ND	ND	ND	ND	ND	ND	ND
CaO	ND	ND	ND	ND	ND	ND	ND	ND
TCLP Regulatory Limit	5	100	1	5	5	0.2	1	5

ND = Not Determined

Alkaline Industrial By-Product Soluble Salt Content – Salinity and Sodicity

The soluble salt content of an alkaline by-product refers to the inorganic constituents that are appreciably soluble in water. In general, the growth of salt sensitive plant species may be impaired when the soil electrical conductivity is > 4 ds/m (Firman, 1955). Soil dispersion and associated loss of structure and decreased water permeability rate may occur

when the sodium adsorption ratio† is > 10 for fine textured soils and > 20 for coarse textured soils.

Cement kiln dust (CKD) samples were both saline (66.8 – 97.3 ds/m) and sodic (SAR 28.5 – 40.1) (Table 9). Conversely, lime kiln dust (LKD) samples, Dicalcium Silicate and Carbide Lime were neither saline (0.2 – 2.2 ds/m) nor sodic (0.02 – 1.8). CKD salinity may emanate from high concentrations of water soluble SO_4^{2-} (15300 – 48100 mg/l) and Cl^- (1070 – 1180 mg/l) in association with the cations Ca^{2+}, Mg^{2+}, Na^+ and K^+. These sulfate and chloride salts were either added during the manufacturing of cement or were a component of the fuel ash remaining in the kiln. CKD salinity is sufficiently high that an

Table 9. pH, salinity and sodicity characteristics of alkaline industrial by-products and commercial grade lime.

Sample Type	pH s.u.	EC ds/m	Ca meq/l	Mg meq/l	Na meq/l	SO_4 mg/l	Cl mg/l	SAR	H_2O by Weight %
Greymont LKD	9.6	2.2	69.8	<0.01	2.47	1380	160	0.41	0.32
Tacoma LKD	10.1	0.91	28.4	<0.01	6.8	7	22	1.8	15.5
MT Limestone LKD	10.0	1.2	81.3	<0.01	1.69	1680	279	0.26	0
Holnam (CH_4) CKD	13.7	97.3	3.35	<0.01	51.9	15300	1070	40.1	0.03
Holnam (Coal/Coke) CKD	13.7	66.8	12.1	<0.01	103	28100	1050	41.8	0
Ash Grove CKD	13.5	79.2	6.09	<0.01	49.9	48100	1180	28.5	0.1
Dicalcium Silicate	10.4	0.2	20	<0.01	0.14	<1	3	0.04	0
Carbide Lime	11.9	1.64	41.9	<0.01	0.09	5	87	0.02	34.3
$CaCO_3$	8.0	0.56	6.79	0.58	0.74	59	43	0.38	0
CaO	12.3	4.9	50.9	<0.01	0.57	134	6	0.11	0

†Sodium Adsorption Ratio = $[Na]/(([Ca]+[Mg])/2)^{1/2}$, meq/l.

Table 10. Electrical conductivity of Plant Growth Center potting soil as a function of alkaline amendment application rate.

Amendment	Soil Electrical Conductivity, ds/m						
	Alkaline Amendment Application Rate (dry weight basis)						
	0 %	2 %	4 %	6 %	8 %	10 %	12 %
Greymont LKD	0.94[1]	2.01	2.22	2.70	2.46	3.02	3.35
Tacoma LKD	0.87	0.94	1.55	2.03	1.20	1.32	1.70
MT Limestone LKD	0.65	2.38	2.75	2.78	3.74	2.72	3.00
Holnam (CH_4) CKD	0.89	1.38	1.87	2.68	4.45	5.82	7.08
Holnam (Coal, Coke) CKD	0.75	1.64	2.30	3.17	3.36	4.10	5.54
Ash Grove CKD	0.68	3.23	5.09	8.13	10.66	12.94	16.63
Dicalcium Silicate	0.54	1.24	1.02	1.39	0.86	1.35	0.98
Carbide Lime	0.76	1.71	1.53	2.22	1.30	2.63	1.10
$CaCO_3/CaO$	0.74	1.26	1.46	1.05	2.00	1.32	1.35

[1] n = 1. Plant Growth Center potting soil was analyzed in replication number five.

amended soil may be elevated into a range that could impair plant growth of salt sensitive species. Assuming the CKD field application rate will range from 2 - 10 % of the soil mass, the soil salinity could be increased 1.3 - 9.7 ds/m. Given these same assumptions, the soil sodium adsorption ratio (SAR) could be increased 0.4 - 4.0 units. Most acidic soils are not sodic, so an increase of 0.4 - 4.0 SAR units when CKD is applied may not notably impair either the soil physical condition or plant growth. However, the potential increase in soil salinity from CKD may be sufficient to impair plant growth during periods when water availability is not abundant. In plant growth tests discussed later in this document, alkaline amendments were mixed into Plant Growth Center potting soil at application rates that ranged from 0 % to 12 % (dry weight basis). Following a 90 day plant growth period the soil electrical conductivity was measured in one replication of the experiment (Table 10). All alkaline products increased soil salinity across the application rate range of 0 - 12 %. Soil

salinity increases associated with the amendments $CaCO_3/CaO$, Dicalcium Silicate and Carbide Lime ranged from 0.32 - 1.87 ds/m, while increases for LKD ranged from 0.07 - 3.09 ds/m, and increases for CKD ranged from 0.49 - 15.95 ds/m. The three CKD amendments elevated the soil EC to a range of 5.54 ds/m to 16.63 ds/m for the 12 % amendment application rate. Soil treatment with CKD resulted in a saline soil, defined as having an electrical conductivity > 4 ds/m, for application rates low as 4 % (40 tons CKD/1000 tons soil). Under conditions of abundant plant available water, these measured increases in soil salinity with alkaline amendment use will likely not impair plant growth. However, under conditions of plant water stress, these increases in soil salinity may impair plant growth due to the osmotic potential created between salt and water within the soil matrix. The plant has to expend greater energy to uptake water from the salt enriched soil matrix compared to a soil system not enriched in salt, which can cause a loss in plant growth.

Alkaline Industrial By-Product – Chemical Enrichment

CKD by-products were enriched 12.2 to 25.9 times for total zinc (Zn), while LKD enrichment was 1.3 to 3.8 compared to the control ($CaCO_3$ and CaO, Table 12). Dicalcium Silicate and Carbide Lime were not enriched in Zn. Ash Grove CKD contained the greatest concentration of total Zn (467 mg/kg), and had the highest water extractable concentration 1.9 mg/l at pH 13.5 (Table 11).

Total selenium (Se) was not enriched in alkaline industrial by-products, but the water extract from a saturated paste was enriched several hundred times in CKD compared to the

control. Holnam and Ash Grove CKD contained 3.31 and 1.30 mg/l Se, respectively,

Table 11. Water soluble metal concentrations of Alkaline Industrial By-Products and Commercial Grade Lime.

Sample Type	Water Saturated Paste Extract (mg/l)									
	Al	As	B	Cd	Cu	Fe	Pb	Mn	Se	Zn
Greymont LKD	<1	<0.01	<1	<0.01	<0.01	<0.1	<0.01	<0.01	0.05	<0.1
Tacoma LKD	<1	<0.01	<1	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.1
MT Limestone LKD	<1	<0.01	<1	<0.01	<0.01	<0.1	<0.01	<0.01	0.09	<0.1
Holnam (CH_4) CKD	<2	0.55	5	<0.01	<0.02	0.4	0.7	<0.02	3.31	1.3
Holnam (Coal,Coke)CKD	<2	0.03	<2	<0.01	<1	<1	0.02	<1	0.1	<1
Ash Grove CKD	<1	0.36	<1	<0.1	0.10	<0.1	0.2	<0.01	1.3	1.9
Dicalcium Silicate	464	<0.01	<1	<0.01	0.20	<0.1	<0.01	<0.01	0.01	<0.1
Carbide Lime	<1	<0.01	<1	<0.01	<0.1	<0.1	<0.01	<0.01	0.01	<0.1
$CaCO_3$	<1	<0.01	<1	<0.01	<0.1	0.2	<0.01	<0.01	<0.01	<0.1
CaO	<1	<0.01	<1	<0.01	<0.1	<0.1	<0.01	<0.01	<0.01	<0.1

compared to control materials ($CaCO_3$ and CaO) which had <0.01 mg/l Se (Table 11). At issue is whether 1.30 - 3.31 mg/l Se water extractable measured at a pH of 13.5 - 13.7 in CKD increases- or decreases- in concentration when applied to a soil system and a pH of 7.0 - 8.3 is produced in the plant root zone.

Total boron (B) was enriched in Greymont LKD (137 mg/kg) and Montana Limestone LKD (130 mg/kg) approximately 50 times compared to control materials ($CaCO_3$ and CaO, Table 12).

Total barium (Ba) was enriched in most kiln dusts by as much as 33 times compared to $CaCO_3$ and CaO (Table 12). Montana Limestone LKD had the greatest total Ba content, 862 mg/kg.

Table 12. Total Metal Concentration of Alkaline Industrial By-Products and Commercial Grade Lime.

Sample Type	Total Concentration (mg/kg)										
	Al	Ag	As	B	Ba	Be	Cd	Ca	Cr	Cu	Fe
Greymont LKD	16300	<5	5	137	475	<5	4	309000	<5	19	4290
Tacoma LKD	2810	<5	11	7	23	<5	<1	281000	<5	20	4210
MT Limestone LKD	16300	<5	<5	130	862	<5	1	416000	42	13	5310
Holnam (CH_4) CKD	12000	<5	13	16	77	<5	4	295000	59	11	10700
Holnam (Coal/Coke) CKD	11200	<5	9	<1	161	<5	2	294000	83	10	10100
Ash Grove CKD	9380	<5	15	20	131	<5	5	237000	33	45	7270
Dicalcium Silicate	67100	<5	<5	<5	24	<5	<1	345000	<5	<5	335
Carbide Lime	3070	<5	<5	6	11	<5	<1	272000	<5	<5	197
$CaCO_3$	794	<5	<5	<5	17	<5	<1	347000	<5	<5	1140
CaO	1100	<5	<5	<5	26	<5	<1	556000	78	5	856

Table 12. Total Metal Concentration of Alkaline Industrial By-Products and Commercial Grade Lime - Continued.

Sample Type	Total Concentration (mg/kg)										
	Hg	K	Mg	Mn	Ni	P	Pb	Se	Sn	V	Zn
Greymont LKD	<1	860	9700	325	129	280	107	5	<5	454	49
Tacoma LKD	<1	191	2790	96	7	179	18	<5	<5	15	68
MT Limestone LKD	<1	1720	13800	228	<5	414	9	<5	<5	18	23
Holnam (CH_4) CKD	<1	40600	7350	278	<5	131	205	<5	<5	25	219
Holnam (Coal/Coke) CKD	<1	25100	7920	276	11	219	94	<5	<5	60	115
Ash Grove CKD	<1	73200	9230	247	13	117	117	6	<5	43	467
Dicalcium Silicate	<1	39	29100	7	<5	94	<5	<5	<5	<5	<5
Carbide Lime	<1	<50	179	<5	<5	10	<5	<5	<5	5	<5
$CaCO_3$	<1	368	1470	85	<5	61	<5	<5	<5	7	10
CaO	<1	129	9590	159	<5	101	<5	<5	<5	6	18

Total aluminum (Al) was enriched 2-30 times in alkaline industrial by-products compared to the control ($CaCO_3$ and CaO). Dicalcium Silicate contained the greatest

concentration of total Al (67,100 mg/kg). The associated water saturated paste extract for Dicalcium Silicate contained 464 mg/l Al, while all other alkaline industrial by-products contained <2 mg/l (Table 11).

Following the 111 day plant growth period discussed later in this thesis, the 8 replicated pots amended with Dicalcium Silicate were composited for tailings, contaminated soil, and Plant Growth Center soil, and the extract from a water saturated soil paste was analyzed for Al (Table 13). Following the carbonation process (Reactions 3 - 7) that produced a soil pH in the range of 7.0 - 8.3 and 111 day plant growth period, the amount of Al in the soil solution was relatively low, ranging from < 0.5 - 2.0 mg/l. As will be discussed below, plant growth in these pots was good and was not impaired by an Al phytotoxicity issue.

Table 13. Water soluble concentrations of aluminum (Al) following a 111 day plant growth period in tailings, contaminated soil, and Plant Growth Center soil amended with Dicalcium Silicate.

Sample Type	Dicalcium Silicate Application Rate tons/1000 tons	Aluminum	
		Total Concentration mg/kg	Water Saturated Paste Extract mg/l
Tailings	42.35	ND	<0.5
Contaminated Soil	7.07	ND	1.3
Plant Growth Center Soil	42.35	ND	2.0

ND = Not Determined

Dicalcium Silicate will infuse a large quantity of Al into the soil solution when applied as an amendment. During the 4 - 12 month period following application the soil

pH will be > 8.5, i.e. during the "pH mellowing" or carbonation period, and the soil is expected to contain soluble Al at concentrations that are phytotoxic during this period. However, once the soil completes carbonation Reactions 3 - 7 (p. 30), the soil pH should be <8.5 and the quantity of Al in the soil solution should approach a low concentration that is not expected to impair plant growth. If the amended soil fails to carbonate over a period of months and the pH remains above 8.5, the soil solution will contain Al concentrations that would be expected to impair plant growth. Therefore, use of Dicalcium Silicate, or other alkaline product with notable concentrations of soluble Al, presents a risk that is not present in manufactured lime (CaO) or its hydroxide ($Ca(OH)_2$, or in mined limestone.

Total vanadium (V) was enriched 2-8 times in LKD and CKD compared to control materials. Control alkaline products were $CaCO_3$ (limestone) and CaO (quicklime). One notable exception was Greymont LKD which was enriched 65 times (454 mg/kg) greater than the control (7 mg/kg).

Table 14. Total and water soluble concentrations of vanadium (V) following a 111 day plant growth period in tailings, contaminated soil, and Plant Growth Center soil amended with Greymont LKD

Sample Type	Greymont LKD Application Rate tons/1000 tons	Vanadium	
		Total Concentration mg/kg	Water Saturated Paste Extract mg/l
Tailings	75.15	41	<0.5
Contaminated Soil	12.55	37	<0.5
Plant Growth Center Soil	75.15	66	<0.5

Greymont LKD was produced from a kiln fuel mixture of 70 % coal and 30 % coke. Ash from these fuels likely caused the highly enriched concentrations of V found in the LKD. Following the 90 day plant growth period, pots amended with Greymont LKD were composited and a subsample analyzed for total V in the soil matrix and in the extract from a water saturated paste extract (Table 14). At the Greymont LKD application rates used in this research (12.55 – 75.15 tons/1000 tons), neither the total nor the water extractable concentrations were at levels that would impair plant growth. It is likely that the V content of this LKD will vary over time as a function of fuel chemistry in the kiln, combustion efficiency and other processing variables. Total V should be periodically measured in LKD to ensure the concentration is not greatly exceeding 454 mg/kg total V measured in this research.

In general, both LKD and CKD had enrichment in arsenic, cadmium, chromium, copper, lead, manganese and nickel, compared to lime (CaO) and limestone, while Dicalcium Silicate and Carbide Lime were not enriched in these elements. The total and soluble metal concentrations that were inherent in the soils and the alkaline amendments greatly decreased as a result i) the change in soil pH from a range of 1.8 – 5.0 to 7.0 – 8.4 and ii) the change in pH of the alkaline product from a range of 9.6 – 13.7 to 7.0 – 8.4

Table 15. Soil pH in pots containing amended tailings, contaminated soil, and Plant Growth Center soil prior to seeding and during the plant growth period.

Amendment Type	pH (s.u.)					
	Basin Wildrye			Redtop		
	days after seeding			days after seeding		
	0	70	111	0	70	111
	Tailings					
Greymont LKD	7.7[1]	8.1 b[2]	7.9 bc	7.7	8.2 b	7.7 b
Tacoma LKD	7.9	8.1 b	7.8 bc	7.9	8.1 b	7.7 b
MT Limestone LKD	8.4	8.1 b	7.8 bc	8.4	8.0 b	7.8 b
Holnam (CH_4) CKD	8.1	8.0 b	7.8 bc	8.1	8.0 b	7.8 b
Holnam (Coal, Coke) CKD	7.5	8.2 b	7.8 bc	7.5	8.1 b	7.8 b
Ash Grove CKD	7.6	8.2 b	8.0 ac	7.6	8.2 b	8.0 b
Dicalcium Silicate	8.3	8.1 b	7.8 bc	8.3	8.1 b	7.9 b
Carbide Lime	8.2	8.0 b	7.7 b	8.2	8.1 b	7.8 b
$CaCO_3$/CaO	8.3	8.1 b	7.7 b	8.3	8.0 b	7.8 b
Control	2.0	1.9 a	1.9 a	2.0	2.0 a	1.9 a
	Contaminated Soil					
Greymont LKD	7.7	8.2 bc	7.7 bcd	7.7	8.2 bc	7.9 bc
Tacoma LKD	8.2	8.3 cd	7.8 bcd	8.2	8.4 d	7.7 b
MT Limestone LKD	8.4	8.5 d	8.0 d	8.4	8.3 cd	8.0 c
Holnam (CH_4) CKD	7.8	8.1 b	7.7 bc	7.8	8.1 bc	7.7 b
Holnam (Coal, Coke) CKD	8.1	8.1 b	7.7 bc	8.1	8.1 bc	7.7 b
Ash Grove CKD	8.3	8.1 b	7.6 b	8.3	8.1 bc	7.7 b
Dicalcium Silicate	8.3	8.1 b	7.9 cd	8.3	8.0 b	8.1 c
Carbide Lime	8.1	8.4 cd	7.9 cd	8.1	8.4 d	7.9 bc
$CaCO_3$/CaO	7.9	8.3 cd	7.6 b	7.9	8.3 cd	7.8 b
Control	5.0	5.1 a	5.0 a	5.0	4.9 a	5.0 a
	Plant Growth Center Soil					
Greymont LKD	7.8	8.1 a	7.9 b	7.8	8.3 a	7.9 b
Tacoma LKD	7.8	8.5 b	8.0 bc	7.8	8.5 a	8.3 c
MT Limestone LKD	8.1	8.3 b	8.2 bc	8.1	8.2 a	8.2 bc
Holnam (CH_4) CKD	7.7	8.5 b	8.4 d	7.7	8.4 a	8.3 c
Holnam (Coal, Coke) CKD	7.6	8.4 b	8.0 bc	7.6	8.4 a	8.0 bc
Ash Grove CKD	7.6	8.4 b	8.0 bc	7.6	8.5 a	8.0 bc
Dicalcium Silicate	8.3	8.6 b	8.0 bc	8.3	8.6 a	8.1 bc
Carbide Lime	7.8	8.4 b	8.0 bc	7.8	8.6 a	8.1 bc
$CaCO_3$/CaO	7.6	8.5 b	8.1 bc	7.6	8.3 a	8.1 bc
Control	7.6	8.3 b	7.1 a	7.6	8.2 a	7.3 a

[1] Measured pH values (n = 1) for time zero, i.e. prior to seeding, were taken in the bulk sample barrel used to prepare the substrate for greenhouse pots.

[2] Means (n = 8) followed by the same letter in the same column are not significantly different (P = 0.05).

Effect of Alkaline Industrial By-Products on Plant Growth in Acidic Contaminated Soil Systems

Soil pH Control During The Plant Growth Period

Addition of alkaline amendments initially raised the soil pH into a range of 9.0 to 12.0 which is not suitable for plant growth. Amended soils were treated with CO_2 gas and water for months to expedite carbonation Reactions [3] through [7], discussed above, to produce a soil with a pH suitable for plant growth (7.0 - 8.4). Once a suitable soil pH was attained and pots were seeded, pH was monitored during the 111 day plant growth period to determine whether the pH of these amended soils remained in the suitable range. Unamended tailings and the contaminated soil had pH levels of 1.9 - 2.0 and 5.0, respectively, both prior to seeding and after the 111 day plant growth period (Table 15). The unamended Plant Growth Center soil mean pH before and after the 111 day plant growth period ranged from 7.1 - 7.6.

Substrates amended with alkaline products were in a suitable range (7.0 - 8.4) during the 111 day plant growth period, with infrequent exceedences of 8.5 and 8.6 (Table 15). Amended soils had a mean pH range of 7.7 - 8.0 for tailings, 7.6 - 8.0 for contaminated soil, and 7.9 - 8.2 for Plant Growth Center soil. During the plant growth period, tailings pH was not significantly different when amended by the various types of alkaline products tested, with one exception. Ash Grove Cement Kiln Dust (CKD) produced a mean pH of 8.0 at the completion of the Basin Wildrye growth period which was greater than the $CaCO_3$/CaO and Carbide Lime treatments. This elevated pH may have been due to sodium hydrolysis

attributed to the presence of excess sodium in CKD (Reaction 8). Sodium on the clay (micelle) cation exchange undergoes hydrolysis to form hydroxide in the soil solution, a strong base that will raise the pH.

$$Na^{+}\boxed{\text{Micelle}} + HOH \rightarrow H^{+}\boxed{\text{Micelle}} + Na^{+} + OH^{-} \qquad \text{[Reaction 8]}$$

For the contaminated soil, MT Limestone LKD and Dicalcium Silicate produced significantly greater pH by 0.3 to 0.4 units, compared to $CaCO_3/CaO$, Holnam CKD and Ash Grove CKD for pots containing Basin Wildrye at the completion of the 111 day plant growth period. Similarly, for pots containing Redtop, MT Limestone LKD and Dicalcium Silicate treated soil had significantly higher pH values, 8.0 - 8.1 versus 7.7 - 7.8, compared to several alkaline by-products after the completion of he 111 day plant growth period. For each alkaline product the pH generally changed a few tenths of a unit during the course of the plant growth period, but remained in the suitable range for plant growth.

For the Plant Growth Center soil, alkaline industrial by-products had similar pH levels in plant growth pots at the completion of the 111 day plant growth period compared to $CaCO_3/CaO$. One exception was Holnam (CH_4) CKD, pH 8.4, which was greater than all other treatments. This elevated soil pH may lead to soil nitrogen, phosphorus and potassium deficiencies. As a result, plant growth may be greater in a soil matrix with a pH < 8.0 compared to those with pH >8.0.

Effect Of Alkaline Industrial By-Products On Initial 14 Days of Plant Growth

Percent seed germination for Basin Wildrye and Redtop was not significantly different between pots amended with different alkaline industrial products (Tables 16 and 17). Seeds did not germinate in tailings that were not amended with an alkaline product. In pots amended with alkaline products, Basin Wildrye had a mean percent germination of 69.8 $\pm$ 6.6 and Redtop 91.6 $\pm$ 4.7 in tailings and contaminated soil. Mean percent germination in amended pots containing Plant Growth Center soil was 77.6 $\pm$ 7.5 for Basin Wildrye and 91.0 $\pm$ 6.5 for Redtop.

The number of days required for seedlings to emerge for Basin Wildrye and Redtop was not significantly different between pots amended with different alkaline industrial products (Tables 16 and 17). Seedling emergence occurred within 5 to 8 days following planting in either tailings or contaminated soil. Time required for plant emergence in amended pots that had Plant Growth Center soil was similar to that for tailings and contaminated soil. Of the plant seedlings that emerged, all survived after 14 days of growth in tailings and contaminated soil when amended with alkaline products (Tables 16 and 17). Consequently, there were no significant differences between alkaline products regarding seedling survival for Basin Wildrye and Redtop.

After 14 days of growth, Basin Wildrye had a significantly greater plant shoot height in tailings amended with either of the Holnam CKD products compared to MT Limestone LKD, but these were not different compared to other alkaline products (Table 16). Greater shoot height after 14 days generally corresponds to greater root mass that can facilitate

Table 16. Effect of different alkaline products on growth of Basin Wildrye during the initial 14 days

Amendment Type	Time to Emergence (days)	Germination %	Survival %	Shoot Height (mm)
	Tailings			
Greymont LKD	7.1 a[1]	73.3 a	100.0 a	88.9 ab
Tacoma LKD	7.1 a	71.3 a	100.0 a	94.2 ab
MT Limestone LKD	7.1 a	65.3 a	100.0 a	78.4 b
Holnam (CH_4) CKD	6.5 a	78.7 a	100.0 a	100.5 a
Holnam (Coal,Coke)	7.0 a	64.0 a	100.0 a	103.5 a
Ash Grove CKD	8.0 a	74.7 a	100.0 a	85.1 ab
Dicalcium Silicate	6.5 a	65.3 a	100.0 a	86.5 ab
Carbide Lime	6.7 a	83.3 a	100.0 a	86.7 ab
$CaCO_3$/CaO	6.3 a	75.3 a	100.0 a	92.7 ab
Control	None	0.0 b	None	None
	Contaminated Soil			
Greymont LKD	6.6 a	70.0 a	100.0 a	99.8 a
Tacoma LKD	6.3 a	70.0 a	100.0 a	101.4 a
MT Limestone LKD	6.5 a	68.0 a	100.0 a	107.2 a
Holnam (CH_4) CKD	6.6 a	74.7 a	100.0 a	107.5 a
Holnam (Coal,Coke)	6.5 a	74.0 a	100.0 a	110.7 a
Ash Grove CKD	6.6 a	65.3 a	100.0 a	96.9 a
Dicalcium Silicate	6.3 a	68.0 a	100.0 a	111.7 a
Carbide Lime	6.6 a	58.7 a	100.0 a	109.7 a
$CaCO_3$/CaO	5.6 a	57.3 a	100.0 a	109.1 a
Control	7.2 a	64.7 a	100.0 a	38.1 b
	Plant Growth Center Soil			
Greymont LKD	5.8 ab	88.7 a	100.0 a	108.9 ab
Tacoma LKD	6.6 ab	80.0 a	100.0 a	122.2 a
MT Limestone LKD	6.3 ab	68.7 a	100.0 a	100.1 b
Holnam (CH_4) CKD	6.6 ab	76.7 a	100.0 a	112.6 ab
Holnam (Coal,Coke)	6.0 ab	82.0 a	100.0 a	99.4 b
Ash Grove CKD	6.6 ab	70.0 a	100.0 a	108.4 ab
Dicalcium Silicate	6.8 a	70.7 a	100.0 a	105.7 ab
Carbide Lime	5.7 ab	88.0 a	100.0 a	114.3 ab
$CaCO_3$/CaO	5.8 ab	74.0 a	100.0 a	124.2 a
Control	5.3 b	87.3 a	100.0 a	117.2 ab

[1] Means (n = 8) followed by the same letter in the same column for each substrate are not significantly different (P = 0.05).

Table 17. Effect of different alkaline products on growth of Redtop during the initial 14 days.

Amendment Type	Time to Emergence (days)	Germination %	Survival %	Shoot Height (mm)
	Tailings			
Greymont LKD	6.2 a[1]	91.3 a	100.0 a	24.2 a
Tacoma LKD	6.6 a	88.7 a	100.0 a	28.2 a
MT Limestone LKD	6.3 a	94.7 a	100.0 a	19.7 a
Holnam (CH_4) CKD	6.2 a	92.0 a	100.0 a	23.2 a
Holnam (Coal,Coke)CKD	5.8 a	94.0 a	100.0 a	29.8 a
Ash Grove CKD	6.3 a	92.0 a	100.0 a	21.7 a
Dicalcium Silicate	5.6 a	94.7 a	100.0 a	26.9 a
Carbide Lime	5.7 a	91.3 a	100.0 a	22.5 a
$CaCO_3$/CaO	5.7 a	92.0 a	100.0 a	28.3 a
Control	None	0.0 b	None	None
	Contaminated Soil			
Greymont LKD	5.8 b	86.0 a	100.0 a	31.1 a
Tacoma LKD	5.7 b	90.0 a	100.0 a	32.3 a
MT Limestone LKD	5.7 b	93.3 a	100.0 a	32.0 a
Holnam (CH_4) CKD	6.0 b	93.3 a	100.0 a	27.6 a
Holnam (Coal,Coke)CKD	6.3 b	76.6 a	100.0 a	28.6 a
Ash Grove CKD	5.8 b	92.0 a	100.0 a	36.3 a
Dicalcium Silicate	5.7 b	94.0 a	100.0 a	33.6 a
Carbide Lime	6.1 b	83.3 a	100.0 a	32.4 a
$CaCO_3$/CaO	6.0 b	90.6 a	100.0 a	27.7 a
Control	8.5 a	12.5 b	100.0 a	9.6 b
	Plant Growth Center Soil			
Greymont LKD	5.5 a	96.7 a	100.0 a	42.3 b
Tacoma LKD	5.5 a	94.0 a	100.0 a	52.8 a
MT Limestone LKD	5.7 a	84.0 a	100.0 a	31.3 cd
Holnam (CH_4) CKD	5.3 a	90.7 a	100.0 a	42.9 b
Holnam (Coal,Coke)CKD	6.1 a	94.0 a	100.0 a	29.6 d
Ash Grove CKD	5.8 a	77.3 a	100.0 a	44.9 b
Dicalcium Silicate	5.6 a	94.7 a	100.0 a	39.9 bc
Carbide Lime	5.6 a	90.7 a	100.0 a	38.6 bc
$CaCO_3$/CaO	5.5 a	97.3 a	100.0 a	58.5 a
Control	5.5 a	100.0 a	100.0 a	61.5 a

[1] Means (n = 8) followed by the same letter in the same column for each substrate are not significantly different (P = 0.05).

plant survival under harsh growing conditions. Conversely, a slow developing shoot will have less root development and may be more adversely affected by harsh environmental factors such as lack of water. In the contaminated soil, Basin Wildrye shoot height after 14 days was significantly greater for all pots amended with alkaline industrial products compared to no treatment (control). Apparently the acidic (pH 5.0) metal contaminated soil condition impaired seedling development. In the Plant Growth Center soil, the $CaCO_3/CaO$ and Tacoma LKD treatments had a significantly greater Basin Wildrye shoot height compared to the MT Limestone LKD treatment, but these were not different compared to other alkaline products. Basin Wildrye mean shoot height was numerically greatest for the Plant Growth Center soil (110.6 mm) compared to that for tailings (90.7 mm) and the contaminated soil (106.0 mm).

After 14 days of growth, Redtop shoot height was not significantly different in pots containing tailings amended with alkaline industrial products (Table 17). In pots containing the contaminated soil, Redtop shoot height was not significantly different for the various alkaline industrial products tested. However, pots containing the unamended contaminated soil had significantly less shoot length compared to all pots that were amended with alkaline products.

Apparently, this soil with pH 5.0 and enriched levels of metals caused decreases plant shoot development during the initial 14 days. The Plant Growth Center soil had significantly greater plant shoot height for the control, $CaCO_3/CaO$, and Tacoma LKD treatments compared to other alkaline products. Conversely, treatment with Holnam (Coke, Coal) CKD resulted in significantly less plant shoot height compared to all other alkaline

products. These results indicate nearly all alkaline by-products impaired growth of Redtop in the Plant Growth Center soil during the first 14 days of seedling development. Redtop mean shoot height was numerically greatest for the Plant Growth Center soil (42.3 mm) compared to that for tailings (24.9 mm) and the contaminated soil (31.3 mm).

In summary, when acidic-metalliferous tailings was not amended with an alkaline product, there was no plant growth. When acidic contaminated soil was not amended with an alkaline product, plant shoot height after 14 days was significantly impaired. Alkaline industrial products did not impair either seed germination, plant emergence or plant survival after 14 days of growth. In general, treatment of tailings and contaminated soil with any one of these alkaline products facilitated acceptable plant growth after 14 days. Initial plant growth in $CaCO_3$/CaO amended soil systems was similar to that attained by CKD and LKD products, Dicalcium Silicate, and Carbide Lime.

Effect of Alkaline Industrial By-Products After 111 Days of Plant Growth

Following a 111 day growth period, Basin Wildrye and Redtop were harvested and measurements were made for above ground plant biomass, plant height, root biomass, maximum root depth, and number of roots at the 5 cm and 10 cm soil depths. Representative above ground and below ground growth of Basin Wildrye and Redtop as a function of the different alkaline products tested are shown in Figures 1 and 2.

Above Ground Plant Biomass. In tailings, no plant growth was present when an alkaline product was not applied and the pH remained ≤ 2.0 (Tables 18 and 19). Two LKD products (Greymont, Tacoma) and Dicalcium Silicate produced the greatest numerical values for above ground Basin Wildrye biomass and were significantly greater compared to several alkaline products ($CaCO_3/CaO$, MT Limestone LKD, Ash Grove CKD, Carbide Lime). For Redtop, Tacoma LKD, Holnam (Coke, Coal) CKD, and Dicalcium Silicate had the greatest numerical values for above ground production and were significantly greater than several alkaline products ($CaCO_3/CaO$, MT Limestone LKD, Ash Grove CKD, Carbide Lime).

In contaminated soil, above ground biomass was generally increased by each alkaline product tested, indicating the unamended soil pH of 5.0 impaired plant growth. Above ground biomass for Basin Wildrye was numerically greatest for soil amended with the three LKD products but they were not significantly different compared to other alkaline industrial by-products. Treatment with two LKD products (Greymont and Tacoma) had significantly greater Basin Wildrye biomass compared to treatment with the $CaCO_3/CaO$ mixture.

Figure 1. Photos of Basin Wildrye (top) and Redtop (bottom) after a 111 day plant growth period in tailings as a function of different alkaline amendments.

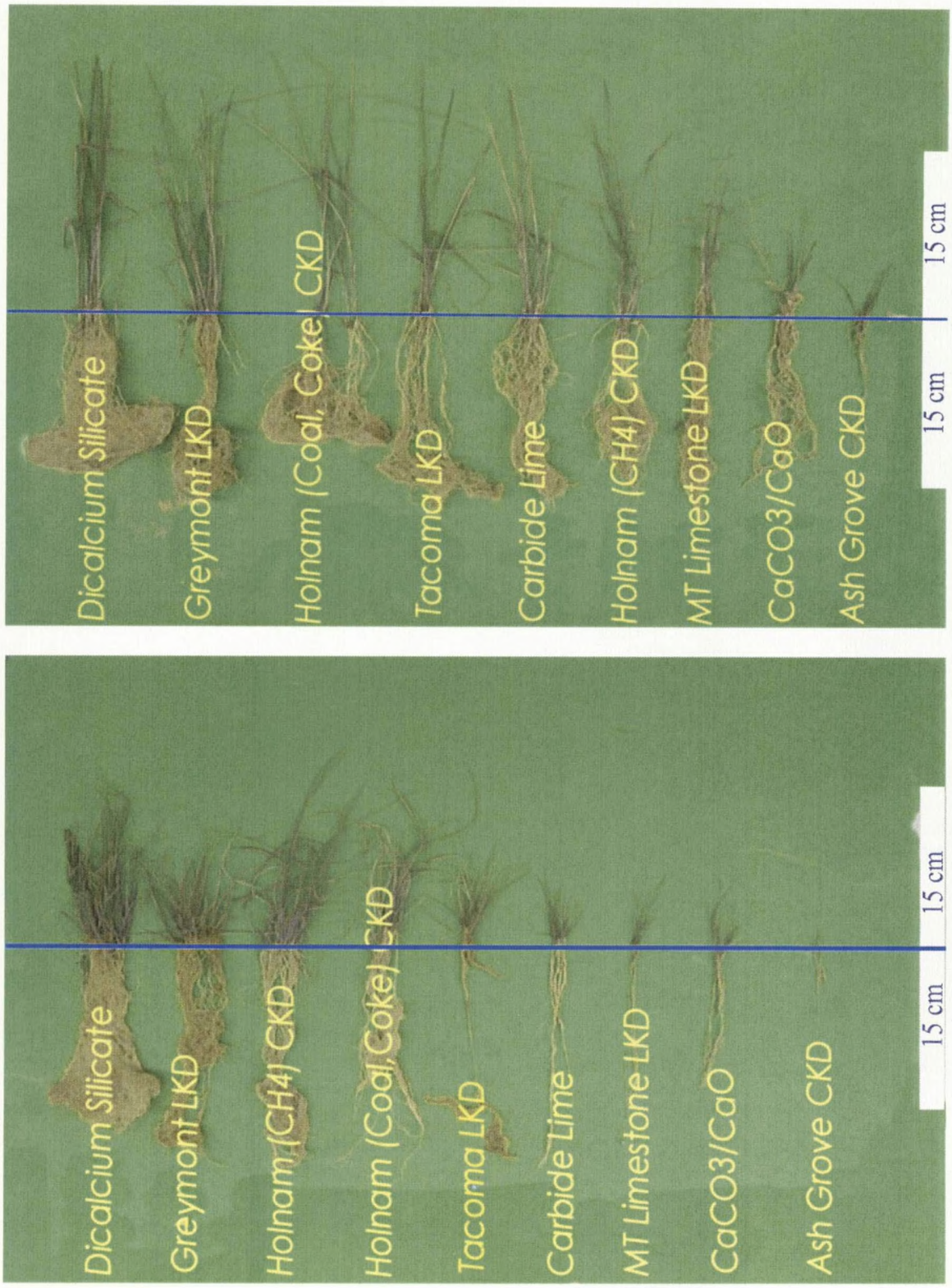


Figure 2. Photos of Basin Wildrye (top) and Redtop (bottom) after 111 day plant growth period in contaminated soil as a function of different alkaline amendments

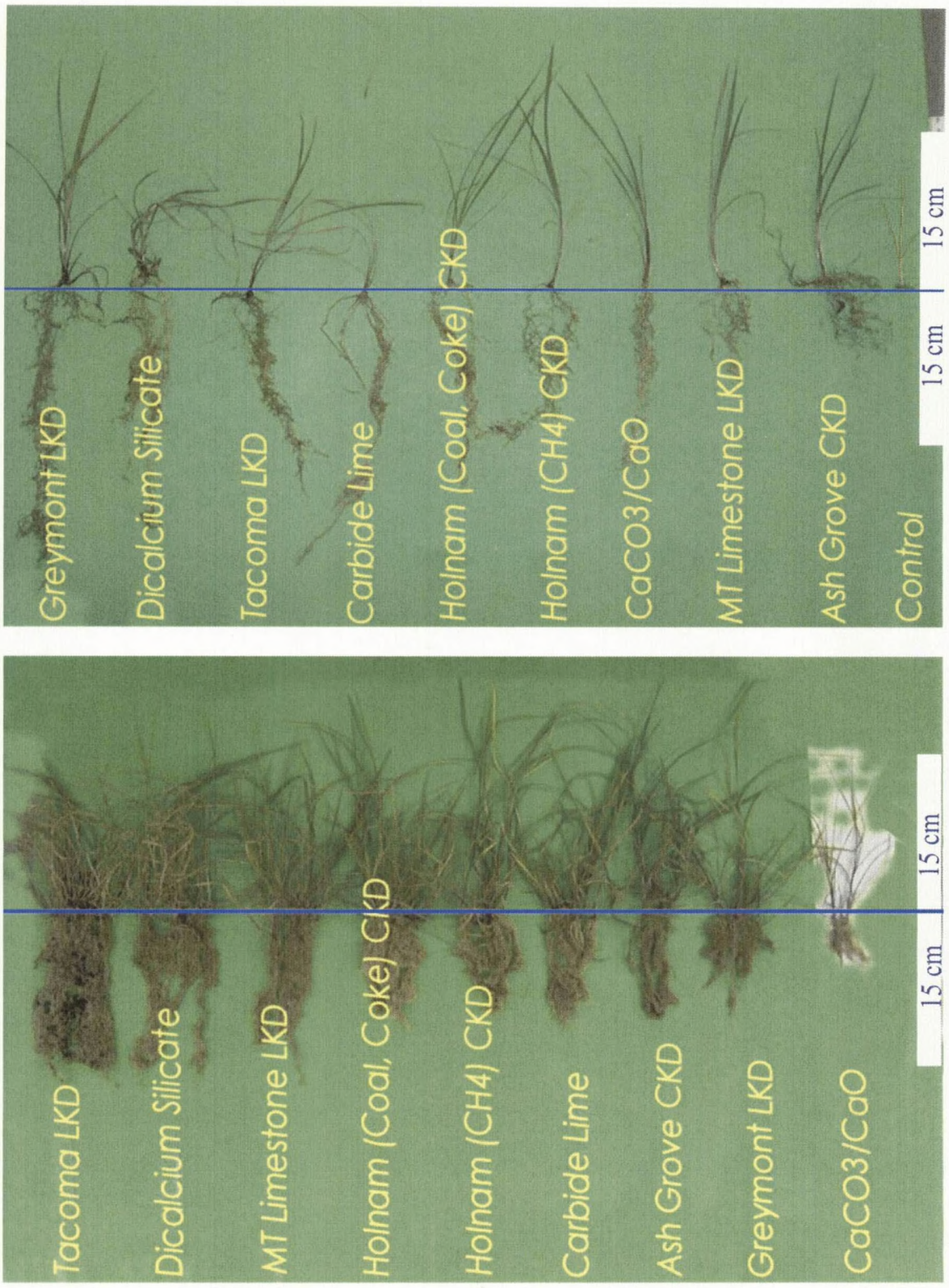


Table 18. Effect of different alkaline products on growth of Basin Wildrye 111 days after seeding

Amendment Type	Above Ground Height (mm)	Maximum Root Depth (mm)	Number of Roots		Above Ground Biomass (g)	Below Ground Biomass (g)
			5 cm Depth	10 cm Depth		
	Tailings					
Greymont LKD	254.5 ab[1]	116.2	15.2 bc	21.3 bc	0.492 a	0.969 ab
Tacoma LKD	293.0 a	126.5	21.8 ab	26.6 b	0.547 a	1.325 a
MT Limestone LKD	159.0 b	118.0	15.0 bc	19.7 bc	0.193 bc	0.526 b
Holnam (CH_4) CKD	224.1 ab	139.7	16.3 bc	28.3 b	0.31abc	0.467 b
Holnam (Coal,Coke)CKD	339.5 a	105.3	25.2 ab	37.0 b	0.397 ab	0.922 ab
Ash Grove CKD	157.0 b	109.6	9.6 c	8.6 c	0.143 bc	0.268 b
Dicalcium Silicate	319.1 a	121.7	55.8 a	74.3 a	0.566 a	1.482 a
Carbide Lime	172.7 b	109.5	15.1 bc	10.6 bc	0.152 bc	0.299 b
$CaCO_3$/CaO	141.4 b	109.7	8.8 c	10.8 bc	0.068 c	0.261 b
Control	None	None	None	None	None	None
	Contaminated Soil					
Greymont LKD	271.5 a	105.0	16.0 bc	12.0 ab	0.620 a	0.646 ab
Tacoma LKD	257.4 a	117.6	44.6 a	31.8 a	0.616 a	0.934 a
MT Limestone LKD	242.5 a	110.6	22.5 b	17.2 ab	0.530 a	0.717 ab
Holnam (CH_4) CKD	233.6 a	111.7	25.0 b	18.2 ab	0.495 a	0.844 ab
Holnam (Coal,Coke)CKD	212.7 a	113.3	24.7 b	19.7 ab	0.423 a	0.461 abc
Ash Grove CKD	174.0 a	103.1	19.5 bc	11.3 b	0.447 a	0.358 abc
Dicalcium Silicate	229.9 a	99.2	17.7 bc	14.3 ab	0.417 a	0.556 abc
Carbide Lime	190.9 a	97.3	17.7 bc	4.2 c	0.262 b	0.452 abc
$CaCO_3$/CaO	174.6 a	92.1	12.3 bc	2.1 c	0.232 b	0.258 c
Control	76.2 b	17.9	0.2 c	0.0 c	0.073 c	0.023 c
	Plant Growth Center Soil					
Greymont LKD	548.2 a	116.8	75.1 ab	84.6 b	2.248 a	4.829 ab
Tacoma LKD	591.8 a	103.0	62.5 b	95.6 b	2.809 a	4.645 ab
MT Limestone LKD	477.1 ab	118.6	51.8 b	80.6 b	1.192 b	3.307 abc
Holnam (CH_4) CKD	415.1 b	110.5	44.8 b	46.8 b	1.170 b	2.642 cd
Holnam (Coal,Coke)CKD	500.0 ab	122.6	43.5 b	87.7 b	1.992 ab	4.527 abc
Ash Grove CKD	414.2 b	114.2	36.2 b	52.5 b	1.147 b	2.132 d
Dicalcium Silicate	483.1 ab	106.8	53.1 b	96.8 b	1.230 b	3.114 c
Carbide Lime	505.6 ab	105.7	45.0 b	61.8 b	2.291 a	3.537 c
$CaCO_3$/CaO	520.9 ab	103.2	42.2 b	39.5 b	2.238 a	3.812 abc
Control	507.7 ab	113.0	98.7 a	159.3 a	2.204 a	6.715 a

[1] Means (n = 8) followed by the same letter in the same column for each substrate are not significantly different (P = 0.05).

Table 19. Effect of different alkaline products on growth of Redtop 111 days after seeding.

Amendment Type	Above-ground Height (mm)	Maximum Root Depth (mm)	Number of Roots		Above-ground Biomass (g)	Below-ground Biomass (g)
			5 cm Depth	10 cm Depth		
	Tailings					
Greymont LKD	148.8abc[1]	96.1	24.5 b	25.6 b	0.389 ab	0.566 c
Tacoma LKD	200.2 a	126.8	29.9 ab	38.5 b	0.935 a	1.793 a
MT Limestone LKD	120.3 bc	118.7	21.7 b	19.5 b	0.128 b	0.296 c
Holnam (CH_4) CKD	151.3 abc	117.7	21.1 b	21.2 b	0.310 ab	0.467 c
Holnam (Coal,Coke) CKD	210.5 a	110.2	29.1 ab	38.6 b	0.663 a	0.980 bc
Ash Grove CKD	108.0 c	111.0	12.2 b	6.6 b	0.106 b	0.150 c
Dicalcium Silicate	187.1 ab	119.1	47.9 a	74.5 a	0.621 a	1.385 ab
Carbide Lime	84.3 c	104.3	12.1 b	3.7 b	0.089 b	0.164 c
$CaCO_3/CaO$	102.1 c	105.7	11.7 b	6.8 b	0.180 b	0.108 c
Control	None	None	None	None	None	None
	Contaminated Soil					
Greymont LKD	197.8 bc	100.0	18.3 b	6.2 bcd	0.370 bc	0.424 b
Tacoma LKD	374.8 a	119.0	49.6 a	63.5 a	1.341 a	1.314 a
MT Limestone LKD	286.8 b	113.2	27.7 ab	25.8 ab	0.825 b	0.608 b
Holnam (CH_4) CKD	273.1 bc	105.5	35.0 ab	32.1 ab	0.630 bc	0.719 b
Holnam (Coal,Coke) CKD	230.6 bc	110.6	30.2 ab	35.1 ab	0.703 bc	0.837 b
Ash Grove CKD	223.6 bc	99.8	15.1 b	13.1 bc	0.460 bc	0.340 b
Dicalcium Silicate	252.1 bc	103.5	30.3 ab	23.8 ab	0.784 b	0.793 b
Carbide Lime	234.0 bc	111.5	34.7 ab	18.3 bc	0.365 bc	0.356 b
$CaCO_3/CaO$	160.1 c	71.2	12.7 b	5.1 cd	0.198 c	0.362 b
Control	7.7 d	14.8	0.0 c	0.0 d	0.031 c	0.021 b
	Plant Growth Center Soil					
Greymont LKD	345.3 a	119.1	48.8 a	67.5 bc	2.587 a	3.794 b
Tacoma LKD	335.0 a	105.3	70.6 a	102.5ab	2.763 a	3.276 b
MT Limestone LKD	355.8 a	131.8	65.0 a	63.1 bc	2.004 ab	3.013 b
Holnam (CH_4) CKD	284.5 ab	115.3	43.1 a	69.0 bc	1.573 ab	3.308 b
Holnam (Coal,Coke) CKD	298.7 ab	122.1	60.0 a	102.5ab	2.305 a	3.287 b
Ash Grove CKD	248.5 b	113.3	48.6 a	44.8 c	1.025 b	1.721 b
Dicalcium Silicate	285.0 ab	105.0	50.6 a	55.0 c	1.581 ab	2.732 b
Carbide Lime	327.2 a	111.2	48.7 a	32.2 c	2.561 a	2.004 b
$CaCO_3/CaO$	329.2 a	103.8	46.0 a	40.5 c	2.673 a	2.784 b
Control	301.7 ab	114.1	75.6 a	115.6 a	1.989 ab	6.395 a

[1] Means (n = 8) followed by the same letter in the same column for each substrate are not significantly different (P = 0.05).

Redtop biomass was greatest for soils amended with Tacoma LKD. Two alkaline by-products (MT Limestone LKD and Dicalcium Silicate) produced significantly greater biomass compared to the $CaCO_3/CaO$ mixture.

When alkaline products were applied to the Plant Growth Center soil, average above ground biomass of Basin Wildrye was 568 % greater than that for tailings and 404 % greater than that for contaminated soil. Redtop above ground biomass in amended Plant Growth Center soil was 535 % greater than that for tailings and 336 % greater than that for the contaminated soil. These results illustrate that raising the pH in tailings and the contaminated soil enables significantly improved plant growth, but these contaminated mediums will not provide optimum plant growth attained in a high quality soil medium. The Plant Growth Center soil was composed of 33 % Bozeman silt loam, 33 % sand, and 33 % sphagnum peat.

In summary, all alkaline industrial by-products tested resulted in above ground biomass equal to- or greater than- that attained with $CaCO_3/CaO$. Treatment with the mixture 60 % $CaCO_3$ and 40 % CaO (weight basis) has been the recommended approach to neutralize acidic-contaminated soil systems.

Above Ground Height. In tailings, three alkaline by-products (Tacoma LKD, Holnam (Coke,Coal) CKD, Dicalcium Silicate) produced the greatest numerical values for Basin Wildrye and Redtop height and each was significantly greater than treatment with three alkaline products ($CaCO_3/CaO$, Ash Grove CKD, Carbide Lime) (Tables 15 and 16).

In contaminated soil, all alkaline products produced significantly greater plant height compared to the unamended control which had a pH 5.0. Plant height for Basin Wildrye was not different between alkaline products tested. For Redtop, significantly greater plant height was attained with Tacoma LKD compared to all other treatments. Treatment with Tacoma LKD and MT Limestone LKD had significantly greater plant height compared to treatment with the $CaCO_3/CaO$ mixture.

In summary, all alkaline industrial by-products tested resulted in plant height equal to- or greater than- that attained with the $CaCO_3/CaO$ mixture.

Below Ground Biomass. In tailings, treatment with two alkaline by-products (Tacoma LKD, Dicalcium Silicate) resulted in numerically the largest Basin Wildrye root mass, and each was significantly greater than other alkaline products tested except for Greymont LKD and Holnam (Coke, Coal) CKD (Table 18). Tacoma LKD and Dicalcium Silicate also produced significantly more Redtop root biomass compared to other alkaline products, except Holnam (Coke, Coal) CKD (Table 19). In contaminated soil, all alkaline products had numerical values for root mass notably greater compared to the control which had a pH 5.0. Treatment with Tacoma LKD resulted in the greatest numerical value for Basin Wildrye root mass, but this was not significantly different compared to other alkaline industrial by-products. However, four of eight alkaline industrial by-products had significantly greater root mass compared to the $CaCO_3/CaO$ mixture. For Redtop, soil treatment with Tacoma LKD produced significantly greater root mass compared to other alkaline products.

When alkaline products were applied to the Plant Growth Center soil, average root biomass of Basin Wildrye was 500 % greater than that for tailings and 623 % greater than that for contaminated soil. Redtop above ground biomass in amended Plant Growth Center soil was 438 % greater than that for tailings and 450 % greater than that for the contaminated soil. These results illustrate that raising the pH in tailings and the contaminated soil enables significantly improved root development, but these contaminated mediums will not provide optimum root growth attained in a soil without contamination and a high organic matter content.

In summary, all alkaline industrial by-products tested resulted in root biomass equal to- or greater than- that attained with the $CaCO_3/CaO$ mixture. Application of Tacoma LKD consistently produced the largest root biomass values and the difference compared to other alkaline amendments was frequently significant.

Maximum Root Depth. In tailings and contaminated soil amended with alkaline products, root growth reached the depth of the growth medium. The Plant Growth Center soil had alkaline products applied at the rate required for tailings and root growth also reached the depth of the growth medium. Subsequently, the data was not analyzed for variance. However, in unamended tailings there was no root development and the roots that developed in unamended contaminated soil were, in every instance, less than the depth of the growth medium.

Number Of Roots. The greater the number of roots at the 5 cm and 10 cm soil depth the greater the opportunity for the plant to uptake water and nutrients. Also, abundant roots aid in soil structural development that facilitates stability and infiltration of surface water. Conversely, if the number of roots are few then plant growth and survival may be impaired.

In tailings, treatment with DiCalcium Silicate resulted in the largest number of Basin Wildrye roots at the 5 cm depth which was significantly greater than nearly all other alkaline products tested (Table 18). Similarly, the 10 cm soil depth, treatment with Dicalcium Silicate resulted in a significantly greater number of Basin Wildrye roots compared to other treatments. The number of Redtop roots at the 5 cm and 10 cm soil depth was significantly greater for Dicalcium Silicate compared to all other alkaline products (Table 19).

In contaminated soil, treatment with all alkaline products resulted in notably larger mean root count numbers at the 5 cm and 10 cm soil depths compared to the control which had a pH 5.0. Soil treatment with Tacoma LKD resulted in a significantly greater number of Basin Wildrye roots at the 5 cm and 10 cm soil depths compared to the $CaCO_3/CaO$ mixture, but was generally not different compared to other alkaline industrial by-products. At the 10 cm soil depth, the number of Basin Wildrye roots was significantly less when soil was amended with either $CaCO_3/CaO$ or Carbide Lime compared to other alkaline products. The number of Redtop roots at the 5 cm and 10 cm depth was significantly greater for soil treated with Tacoma LKD compared to Greymont LKD, Ash Grove CKD, and $CaCO_3/CaO$.

In summary, all alkaline industrial by-products tested resulted in development of plant root numbers at the 5 cm and 10 cm soil depths equal to- or greater than- that attained with the $CaCO_3$/CaO mixture. Tailings and contaminated soil treated with alkaline product had mean number of roots at the 5 cm and 10 cm depths greater than when these acidic substrates were not amended.

Effect Of Increasing Application Rate Of Alkaline Products On Plant Growth

It can be hypothesized that alkaline products have a threshold application rate above which plant growth is significantly impaired. As discussed above in previously, good plant growth resulted when acidic-metal contaminated tailings and soil were amended with Dicalcium Silicate. Previous reports indicated Dicalcium Silicate successfully increased acid soil pH and precipitated metal contaminants from solution (Dollhopf, et al. 1996; Dollhopf and McDaniel 1997), but plant growth failed in amended acid mine waste materials (Kelly 1997). All these investigations used acidic-metalliferous tailings from the Opportunity impoundment located near Anaconda, Montana. However, tailings material collected by Kelly (1997) required a Dicalcium Silicate application rate of 196 tons/1000 tons of tailings, while the required application rate in this investigation was 42.4 tons/1000 tons of tailings (Table 3). These results indicate that Dicalcium Silicate applied to a soil at a rate of 4.2 % (dry weight basis) enabled good plant growth, but an application rate of 19.6 % resulted in

very poor plant growth. This suggests there is a threshold application rate for Dicalcium Silicate below which plant growth is good and above which plant growth will fail.

Daniels et al. (1996) evaluated an industrial lime by-product and reported a threshold application rate for soil above which plant growth was impaired. The concept of a threshold application rate may be especially important for alkaline industrial by-products since they often contain soluble salts and/or metal contaminants that have potential to impair plant growth if present at a high concentration in the root zone. In order to better understand this threshold concept, plant growth was measured as a function of increasing application rates for each alkaline product. The Plant Growth Center soil was used in all pots and the dosage rate of each alkaline product was varied.

Soil pH Control During The Plant Growth Period

Addition of alkaline amendments initially raised the Plant Growth Center soil pH into a range of 9.0 to 12.0 which is not suitable for plant growth. Amended soils were treated with CO_2 gas and water for several months to expedite carbonation Reactions [3] through [7], (p. 30), to produce a soil with a pH suitable for plant growth (7.0 - 8.4).

Unamended Plant Growth Center soil pH before and after the 90 day plant growth period ranged from 7.5 to 7.9 (Table 20). Plant Growth Center soil amended with alkaline products were all in a suitable range (7.0 - 8.4) prior to seeding (Table 20). Following the 90 day plant growth period all treatments had a mean pH in the range 7.1 to 8.4, except for Holnam cement kiln dust (CKD) and Ash Grove CKD. These CKD materials had pH

values of 8.5 and 8.6 for soil treated at the 10 % and 12 % application rates. This increase in pH may have been due to sodium hydrolysis [Reaction 8 above] during the plant growth period and resultant formation of sodium hydroxide that will increase the soil solution pH. Both CKD products had a high content of sodium compared to other alkaline products tested.

Effect Of Increasing Alkaline Amendment Application Rate During The Initial 14 Day Plant Growth Period

Percent seed germination, time required for emergence and % survival for Basin Wildrye and Redtop were not significantly different as each alkaline product dosage rate was increased incrementally across the range 0 - 12 % (Tables 21 and 22). The one exception was number of days for Redtop emergence for treatment with Holnam (Coke, Coal) CKD where the 0 % rate required significantly more time compared to the 2 %, 4 %, 6 %, 8 %, and 12 % application rates. Basin Wildrye and Redtop mean shoot height consistently decreased across the 0 % to 12 % dosage range, and these decreases were frequently significant for each alkaline product tested.

Therefore, after only a 14 day growth period, plant shoot height was impaired with each 2 % increase in alkaline product dosage increase in the soil matrix across the range 0 % to 12 %. This was the case for all alkaline industrial by-products as well as the $CaCO_3/CaO$ mixture.

Table 20. Plant Growth Center soil pH[1] prior to seeding and during the plant growth period as a function of increasing application rates of alkaline amendments.

Amendment Type	pH (s.u.) pre-seeding							pH (s.u.) Basin Wildrye 90 days after seeding							pH (s.u.) Redtop 90 days after seeding						
	Amendment Application Rate[2] (%)							Amendment Application Rate (%)							Amendment Application Rate (%)						
	0	2	4	6	8	10	12	0	2	4	6	8	10	12	0	2	4	6	8	10	12
Greymont LKD	7.6	8.0	8.0	7.9	8.0	8.2	8.1	7.7	7.9	8.2	7.1	7.1	8.0	8.0	7.5	7.8	8.0	8.1	8.1	8.1	8.1
Tacoma LKD	7.7	7.5	7.9	7.9	8.0	7.9	7.8	7.7	7.6	7.9	8.0	8.2	8.1	8.0	7.8	7.6	8.2	8.0	8.1	7.9	8.2
MT Limestone LKD	7.7	8.0	7.6	7.6	7.7	7.6	7.8	7.7	8.1	8.1	8.1	8.1	8.0	8.1	7.7	8.1	8.0	7.9	7.9	8.0	8.0
Holnam (CH_4) CKD	7.6	7.6	8.2	8.4	7.9	8.2	8.3	7.7	8.1	8.3	8.4	8.4	8.6	8.5	7.5	7.9	8.3	8.4	8.4	8.5	8.4
Holnam (Coal, Coke) CKD	7.6	8.4	8.2	7.9	8.3	8.3	8.3	7.6	8.0	8.3	8.4	8.4	8.2	8.5	7.5	8.1	8.1	8.5	8.4	8.5	8.6
Ash Grove CKD	7.7	7.8	8.0	8.1	8.3	8.2	8.4	7.6	7.8	8.1	8.2	8.4	8.4	8.3	7.8	7.8	8.1	8.3	8.4	8.5	8.5
Dicalcium Silicate	7.7	8.4	8.4	8.3	7.8	7.9	7.9	7.8	7.9	8.1	8.1	8.2	8.2	8.3	7.7	8.1	8.2	8.2	8.3	8.3	8.3
Carbide Lime	7.7	7.6	7.9	8.0	8.1	8.0	8.1	7.9	7.9	7.9	8.0	8.1	8.1	8.2	7.6	8.2	7.9	7.8	8.0	8.1	8.1
$CaCO_3/CaO$	7.6	8.0	8.1	8.2	8.3	8.4	8.4	7.6	8.0	8.1	8.0	8.2	8.3	8.0	7.5	7.8	7.9	8.2	8.4	8.2	8.4

[1] Each pH value in the table is a mean of 5 replications following the 90 day growth period. Prior to seeding, each value in the table is the pH for a single value collected in within a bulk mixing container.

[2] Application rate is on a dry weight basis, i.e. 2 % is equivalent to 20 t amendment/1000 t soil.

Effect Of Increasing Alkaline Amendment Application Rates After a 90 Day Plant Growth Period

Aboveground biomass, plant height, belowground biomass and number of roots at the 5 cm soil depth, all tended to have largest values associated with the 0 % alkaline amendment dosage rate and progressively smaller values with increasing dosage rate up to 12 % (Tables 23 and 24). This loss in plant growth across the 0 - 12 % dosage range was generally significant for aboveground biomass, but not for belowground root biomass. Aboveground biomass for the $CaCO_3/CaO$ mixture did have significant differences across the dosage range for Basin Wildrye, and all alkaline industrial by products had significant differences across the same dosage range. This may indicate enriched metal and soluble salt content in some alkaline by-products cause a more rapid loss in plant growth as dosage rate increases. However, all alkaline products, including the $CaCO_3/CaO$ mixture, exhibited the trend where aboveground biomass values decrease with increasing dosage rate in the soil matrix.

The loss in plant growth as alkaline product dosage increased is illustrated in Figure 3. Above ground plant biomass when no alkaline product was applied to the Plant Growth

Table 21. Effect of increasing alkaline product application rate on growth of Basin Wildrye 14 days after emergence.

Amendment Dosage, Dry Weight Basis (%)	Time to Emergence (days)	Germination %	Survival %	Shoot Height (mm)
	Greymont LKD			
0	8.0 a[1]	82.7 a	100.0 a	205.0 a
2	7.4 a	92.0 a	100.0 a	160.5 bc
4	7.8 a	84.0 a	100.0 a	126.9 cd
6	7.8 a	89.3 a	100.0 a	135.2 cd
8	8.0 a	84.0 a	100.0 a	111.7 d
10	7.8 a	97.3 a	100.0 a	95.3 d
12	7.8 a	85.3 a	100.0 a	106.5 d
	Tacoma LKD			
0	7.4 a	89.3 a	100.0 a	174.1 a
2	7.8 a	85.3 a	100.0 a	144.7 a
4	7.8 a	94.7 a	100.0 a	140.9 a
6	7.8 a	94.7 a	100.0 a	143.7 a
8	8.0 a	77.3 a	100.0 a	140.2 a
10	7.8 a	84.0 a	100.0 a	141.7 a
12	7.6 a	89.3 a	100.0 a	132.8 a
	MT Limestone LKD			
0	8.2 a	78.7 a	100.0 a	165.2 a
2	7.4 a	80.0 a	100.0 a	148.9 ab
4	7.6 a	89.3 a	100.0 a	130.8 bc
6	8.0 a	68.0 a	100.0 a	113.6 c
8	7.8 a	82.7 a	100.0 a	104.0 c
10	7.4 a	92.0 a	100.0 a	97.5 c
12	7.8 a	84.0 a	100.0 a	98.5 c
	Holnam (CH_4) CKD			
0	7.8 a	78.7 a	100.0 a	187.9 a
2	7.4 a	82.7 a	100.0 a	153.5 ab
4	8.2 a	86.7 a	100.0 a	165.7 a
6	7.4 a	84.0 a	100.0 a	121.4 bc
8	8.2 a	78.7 a	100.0 a	128.9 bc
10	7.6 a	85.3 a	100.0 a	103.7 c
12	8.2 a	80.0 a	100.0 a	100.0 c
	Holnam (Coal, Coke) CKD			
0	7.2 a	90.7 a	100.0 a	176.7 a
2	7.6 a	89.3 a	100.0 a	140.4 a
4	7.4 a	86.7 a	100.0 a	155.7 a
6	8.0 a	85.3 a	100.0 a	127.3 a
8	7.6 a	88.0 a	100.0 a	140.6 a
10	7.6 a	89.3 a	100.0 a	129.9 a
12	8.0 a	81.3 a	100.0 a	117.3 a

Table 21. Effect of increasing alkaline product application rate on growth of Basin Wildrye 14 days after emergence – Continued.

Amendment Dosage, Dry Weight Basis (%)	Time to Emergence (days)	Germination %	Survival %	Shoot Height (mm)
	Ash Grove CKD			
0	7.2 a	89.3 a	100.0 a	177.7 a
2	8.0 a	81.3 a	100.0 a	175.6 a
4	8.0 a	86.7 a	100.0 a	155.1 a
6	8.0 a	82.7 a	100.0 a	113.0 b
8	8.0 a	78.7 a	100.0 a	115.4 b
10	8.4 a	86.7 a	100.0 a	104.6 b
12	8.8 a	64.0 a	100.0 a	92.2 b
	Dicalcium Silicate			
0	7.8 a	94.7 a	100.0 a	158.6 a
2	8.2 a	93.3 a	100.0 a	162.9 a
4	7.8 a	96.0 a	100.0 a	114.8 b
6	8.0 a	76.0 a	100.0 a	97.6 b
8	8.0 a	100.0 a	100.0 a	102.4 b
10	7.4 a	92.0 a	100.0 a	94.5 b
12	7.2 a	92.0 a	100.0 a	106.1 b
	Carbide Lime			
0	7.6 a	96.0 a	100.0 a	183.0 a
2	7.8 a	78.7 a	100.0 a	135.6 abc
4	7.8 a	88.0 a	100.0 a	151.7 ab
6	7.4 a	85.3 a	100.0 a	111.1 bc
8	7.6 a	85.3 a	100.0 a	118.5 bc
10	7.6 a	82.7 a	100.0 a	84.2 c
12	7.8 a	90.7 a	100.0 a	90.7 c
	$CaCO_3$/CaO			
0	7.8 a	93.3 a	100.0 a	180.3 a
2	7.6 a	90.7 a	100.0 a	145.9 ab
4	7.4 a	89.3 a	100.0 a	140.3 ab
6	7.8 a	81.3 a	100.0 a	118.0 b
8	7.6 a	96.0 a	100.0 a	109.1 b
10	7.4 a	86.7 a	100.0 a	96.1 b
12	7.8 a	77.3 a	100.0 a	100.7 b

[1] Means (n = 5) followed by the same letter in the same column are not significantly different (P = 0.05)

Table 22. Effect of increasing alkaline product application rate on growth of Redtop 14 days after emergence.

Amendment Dosage, Dry Weight Basis (%)	Time to Emergence (days)	Germination (%)	Survival (%)	Shoot Height (mm)
	Greymont LKD			
0	7.8 a[1]	72.0 a	100.0 a	96.4 a
2	7.0 a	100.0 a	100.0 a	79.5 a
4	7.0 a	100.0 a	100.0 a	77.7 a
6	7.2 a	93.3 a	100.0 a	55.4 ab
8	7.4 a	90.7 a	100.0 a	34.9 b
10	7.4 a	96.0 a	100.0 a	41.7 ab
12	7.6 a	100.0 a	100.0 a	36.3 b
	Tacoma LKD			
0	7.6 a	100.0 a	100.0 a	111.7 a
2	7.0 a	89.3 a	100.0 a	67.4 bc
4	7.4 a	100.0 a	100.0 a	77.8 bc
6	7.2 a	97.3 a	100.0 a	53.9 c
8	7.2 a	100.0 a	100.0 a	49.4 c
10	7.2 a	90.7 a	100.0 a	92.9 ab
12	7.2 a	100.0 a	100.0 a	51.4 c
	MT Limestone LKD			
0	7.2 a	85.3 a	100.0 a	114.6 a
2	7.2 a	80.0 a	100.0 a	52.3 b
4	7.2 a	100.0 a	100.0 a	41.5 b
6	7.0 a	100.0 a	100.0 a	29.6 b
8	7.2 a	96.0 a	100.0 a	42.2 b
10	7.0 a	96.0 a	100.0 a	33.9 b
12	7.6 a	100.0 a	100.0 a	27.3 b
	Holnam (CH_4) CKD			
0	8.0 a	84.0 a	100.0 a	95.6 a
2	7.2 a	90.7 a	100.0 a	75.8 ab
4	7.4 a	86.7 a	100.0 a	68.6 ab
6	7.2 a	86.7 a	100.0 a	50.9 bc
8	7.2 a	84.0 a	100.0 a	55.5 bc
10	7.6 a	92.0 a	100.0 a	44.3 bc
12	7.6 a	98.7 a	100.0 a	33.9 c
	Holnam (Coal, Coke) CKD			
0	7.8 a	92.0 a	100.0 a	89.9 a
2	6.8 b	100.0 a	100.0 a	78.0 ab
4	7.2 b	100.0 a	100.0 a	84.2 ab
6	7.0 b	97.3 a	100.0 a	72.4 ab
8	7.0 b	94.7 a	100.0 a	49.3 ab
10	7.4 ab	100.0 a	100.0 a	36.5 b
12	7.0 b	100.0 a	100.0 a	38.1 b

Table 22. Effect of increasing alkaline product application rate on growth of Redtop 14 days after emergence – Continued.

Amendment Dosage, Dry Weight Basis (%)	Time to Emergence (days)	Germination %	Survival %	Shoot Height (mm)
	Ash Grove CKD			
0	7.4 a	93.3 a	100.0 a	91.5 a
2	7.2 a	93.3 a	100.0 a	82.1 ab
4	7.6 a	93.3 a	100.0 a	67.3 abc
6	7.6 a	92.0 a	100.0 a	60.4 bc
8	7.8 a	100.0 a	100.0 a	47.8 c
10	8.2 a	89.3 a	100.0 a	36.5 c
12	8.2 a	100.0 a	100.0 a	39.7 c
	Dicalcium Silicate			
0	7.8 a	85.3 a	100.0 a	109.8 a
2	7.2 a	89.3 a	100.0 a	69.3 b
4	7.4 a	100.0 a	100.0 a	55.4 bc
6	7.4 a	90.7 a	100.0 a	44.9 bc
8	7.6 a	85.3 a	100.0 a	34.4 bc
10	7.0 a	100.0 a	100.0 a	27.3 c
12	7.0 a	100.0 a	100.0 a	33.4 bc
	Carbide Lime			
0	7.8 a	100.0 a	100.0 a	78.7 a
2	7.2 a	89.3 a	100.0 a	70.6 a
4	7.6 a	100.0 a	100.0 a	67.4 a
6	7.2 a	97.3 a	100.0 a	57.3 ab
8	7.6 a	97.3 a	100.0 a	45.2 ab
10	7.4 a	96.0 a	100.0 a	30.7 b
12	7.4 a	100.0 a	100.0 a	44.8 ab
	$CaCO_3$/CaO			
0	8.4 a	92.0 a	100.0 a	78.5 a
2	7.4 a	100.0 a	100.0 a	84.4 a
4	7.8 a	96.0 a	100.0 a	78.3 a
6	7.8 a	92.0 a	100.0 a	68.2 a
8	7.8 a	100.0 a	100.0 a	45.3 b
10	7.4 a	100.0 a	100.0 a	33.3 b
12	7.4 a	100.0 a	100.0 a	39.8 b

[1] Means (n = 5) followed by the same letter in the same column are not significantly different (P = 0.05)

Table 23. Effect of increasing alkaline product application rate on Basin Wildrye following a 90 day growth period.

Amendment Dosage, Dry Weight Basis (%)	Aboveground Height (mm)	Number of Roots 5 cm Depth	Aboveground Biomass (g)	Belowground Biomass (g)
	Greymont LKD			
0	300.6 a[1]	56.0 a	0.504 a	0.460 a
2	271.0 a	41.4 a	0.412 ab	0.431 a
4	215.0 ab	34.2 a	0.299 bc	0.288 a
6	226.2 ab	36.6 a	0.297 bc	0.429 a
8	269.2 a	34.6 a	0.271 bc	0.282 a
10	225.6 ab	34.0 a	0.191 c	0.338 a
12	167.8 b	33.0 a	0.184 c	0.231 a
	Tacoma LKD			
0	312.8 a	43.0 a	0.682 a	0.427 a
2	238.4 a	26.6 a	0.348 b	0.410 a
4	231.6 a	27.8 a	0.301 b	0.357 a
6	222.4 a	18.0 a	0.257 b	0.170 a
8	273.0 a	43.8 a	0.265 b	0.352 a
10	207.4 a	23.6 a	0.259 b	0.248 a
12	256.4 a	31.0 a	0.380 b	0.527 a
	MT Limestone LKD			
0	275.6 a	43.0 a	0.563 a	0.337 a
2	260.6 a	28.0 a	0.354 b	0.344 a
4	232.2 a	21.8 a	0.234 bc	0.371 a
6	211.4 a	42.8 a	0.169 c	0.233 a
8	201.2 a	40.6 a	0.187 c	0.253 a
10	153.4 a	24.8 a	0.114 c	0.207 a
12	161.2 a	22.2 a	0.099 c	0.147 a
	Holnam (CH_4) CKD			
0	290.4 a	42.0 a	0.532 a	0.288 a
2	220.2 a	23.2 a	0.248 b	0.297 a
4	252.2 a	21.6 a	0.287 b	0.282 a
6	239.0 a	38.4 a	0.298 b	0.366 a
8	212.6 a	43.0 a	0.256 b	0.335 a
10	201.2 a	35.4 a	0.155 b	0.208 a
12	184.0 a	28.4 a	0.165 b	0.255 a
	Holnam (Coal, Coke) CKD			
0	311.4 a	31.2 a	0.642 a	0.375 a
2	233.2 a	29.2 a	0.310 abc	0.323 a
4	274.8 a	49.4 a	0.346 ab	0.349 a
6	245.0 a	33.4 a	0.293 abc	0.389 a
8	250.4 a	36.0 a	0.337 abc	0.440 a
10	228.4 a	61.6 a	0.205 c	0.378 a
12	181.6 b	35.6 a	0.157 c	0.290 a

Table 23. Effect of increasing alkaline product application rate on Basin Wildrye following a 90 day growth period – Continued.

Amendment Dosage, Dry Weight Basis (%)	Aboveground Height (mm)	Number of Roots 5 cm Depth	Aboveground Biomass (g)	Belowground Biomass (g)
	Ash Grove CKD			
0	270.8 a	54.0 a	0.600 a	0.463 a
2	295.2 a	33.0 a	0.460 ab	0.412 a
4	247.8 abc	46.6 a	0.358 b	0.400 a
6	257.4 ab	21.2 a	0.272 b	0.335 a
8	176.4 c	23.6 a	0.263 b	0.252 a
10	182.8 bc	31.4 a	0.299 b	0.341 a
12	229.4 abc	26.4 a	0.292 b	0.255 a
	Dicalcium Silicate			
0	255.6 a	27.2 a	0.470 a	0.260 a
2	225.4 a	32.0 a	0.274 a	0.276 a
4	204.6 a	38.4 a	0.260 ab	0.183 a
6	195.4 a	28.6 a	0.163 ab	0.203 a
8	208.2 a	29.0 a	0.149 ab	0.214 a
10	171.0 a	32.0 a	0.109 b	0.231 a
12	142.8 a	20.8 a	0.112 b	0.194 a
	Carbide Lime			
0	244.2 a	20.8 a	0.283 a	0.180 a
2	243.6 a	27.2 a	0.301 a	0.262 a
4	220.2 a	30.4 a	0.172 ab	0.190 a
6	211.0 a	25.6 a	0.196 ab	0.273 a
8	148.8 a	28.4 a	0.120 b	0.164 a
10	190.0 a	37.2 a	0.181 ab	0.263 a
12	202.2 a	24.0 a	0.153 ab	0.177 a
	$CaCO_3$/CaO			
0	285.4 a	30.2 a	0.489 a	0.200 a
2	223.0 ab	22.2 a	0.311 b	0.285 a
4	205.6 ab	18.8 a	0.215 bc	0.236 a
6	199.4 ab	32.6 a	0.184 bc	0.271 a
8	162.2 b	42.8 a	0.153 bc	0.287 a
10	162.0 b	28.2 a	0.152 bc	0.240 a
12	132.2 b	27.4 a	0.123 c	0.211 a

[1] Means (n = 5) followed by the same letter in the same column are not significantly different (P = 0.05)

Table 24. Effect of increasing alkaline product application rate on growth of Redtop 90 days after emergence.

Amendment Dosage, Dry Weight Basis (%)	Aboveground Height (mm)	Number of Roots 5 cm Depth	Aboveground Biomass (g)	Belowground Biomass (g)
	Greymont LKD			
0	188.6 ab[1]	25.6 a	0.481 ab	0.147 a
2	202.2 ab	28.2 a	0.278 ab	0.112 a
4	196.4 ab	16.6 a	0.334 ab	0.136 a
6	211.6 a	22.2 a	0.223 ab	0.134 a
8	178.0 ab	17.4 a	0.143 bc	0.137 a
10	158.4 ab	15.4 a	0.174 bc	0.082 a
12	122.6 b	17.0 a	0.063 c	0.065 a
	Tacoma LKD			
0	197.2 a	34.2 a	0.375 a	0.203 a
2	174.8 a	11.4 b	0.311 ab	0.075 ab
4	176.8 a	12.2 b	0.219 ab	0.083 ab
6	136.0 a	23.8 a	0.180 ab	0.151 ab
8	146.8 a	16.8 b	0.128 ab	0.076 ab
10	158.4 a	26.0 a	0.176 ab	0.136 ab
12	135.8 a	15.2 b	0.076 b	0.067 b
	MT Limestone LKD			
0	191.0 a	25.6 a	0.288 a	0.140 a
2	176.4 a	18.0 a	0.304 ab	0.062 a
4	181.6 a	24.6 a	0.156 abc	0.105 a
6	141.2 a	13.6 a	0.105 bcd	0.055 a
8	127.6 a	15.8 a	0.042 d	0.098 a
10	128.8 a	20.2 a	0.071 cd	0.126 a
12	102.6 a	17.8 a	0.028 d	0.049 a
	Holnam (CH_4) CKD			
0	241.4 a	41.8 a	0.541 a	0.237 a
2	170.4 ab	18.4 a	0.199 b	0.104 a
4	169.2 ab	19.6 a	0.156 b	0.131 a
6	151.8 ab	24.0 a	0.139 b	0.124 a
8	144.6 ab	14.0 a	0.122 b	0.098 a
10	158.2 ab	19.6 a	0.101 b	0.102 a
12	124.0 b	24.2 a	0.084 b	0.119 a
	Holnam (Coal, Coke) CKD			
0	194.2 a	22.6 a	0.343 a	0.116 a
2	181.4 a	31.4 a	0.137 b	0.110 a
4	147.0 a	17.8 a	0.116 b	0.105 a
6	170.8 a	21.4 a	0.135 b	0.117 a
8	150.4 a	20.4 a	0.100 b	0.086 a
10	148.4 a	16.4 a	0.084 b	0.060 a
12	130.8 a	12.0 a	0.040 b	0.045 a

Table 24. Effect of increasing alkaline product application rate on growth of Redtop 90 days after emergence – Continued.

Amendment Dosage, Dry Weight Basis (%)	Aboveground Height (mm)	Number of Roots 5 cm Depth	Aboveground Biomass (g)	Belowground Biomass (g)
	Ash Grove CKD			
0	188.4 a	24.0 a	0.320 a	0.142 a
2	174.0 a	18.8 a	0.335 a	0.124 a
4	175.2 a	23.4 a	0.208 a	0.128 a
6	179.6 a	20.8 a	0.183 ab	0.107 a
8	159.0 a	17.0 a	0.126 ab	0.086 a
10	130.0 a	15.2 a	0.077 b	0.046 a
12	163.2 a	17.8 a	0.082 b	0.083 a
	Dicalcium Silicate			
0	201.0 a	32.2 a	0.414 a	0.172 a
2	170.2 a	20.4 a	0.178 ab	0.061 a
4	180.0 a	14.0 a	0.124 abc	0.099 a
6	151.8 a	22.2 a	0.076 bcd	0.087 a
8	137.0 a	25.0 a	0.056 bcd	0.109 a
10	93.8 a	14.6 a	0.025 d	0.047 a
12	138.4 a	14.8 a	0.047 cd	0.078 a
	Carbide Lime			
0	179.6 a	25.2 a	0.240 a	0.090 a
2	157.8 a	13.0 a	0.188 ab	0.092 a
4	133.8 a	19.4 a	0.092 ab	0.061 a
6	185.0 a	25.6 a	0.093 ab	0.096 a
8	113.2 a	24.0 a	0.049 b	0.122 a
10	128.0 a	31.4 a	0.052 ab	0.114 a
12	117.6 a	15.4 a	0.089 ab	0.058 a
	$CaCO_3$/CaO			
0	163.4 a	22.2 a	0.206 a	0.115 a
2	177.6 a	19.8 a	0.183 a	0.077 a
4	159.0 a	15.0 a	0.200 a	0.047 a
6	150.0 a	24.4 a	0.126 a	0.101 a
8	144.4 a	22.8 a	0.123 a	0.086 a
10	123.2 a	12.6 a	0.058 a	0.048 a
12	129.4 a	24.0 a	0.064 a	0.068 a

[1] Means (n = 5) followed by the same letter in the same column are not significantly different (P = 0.05)

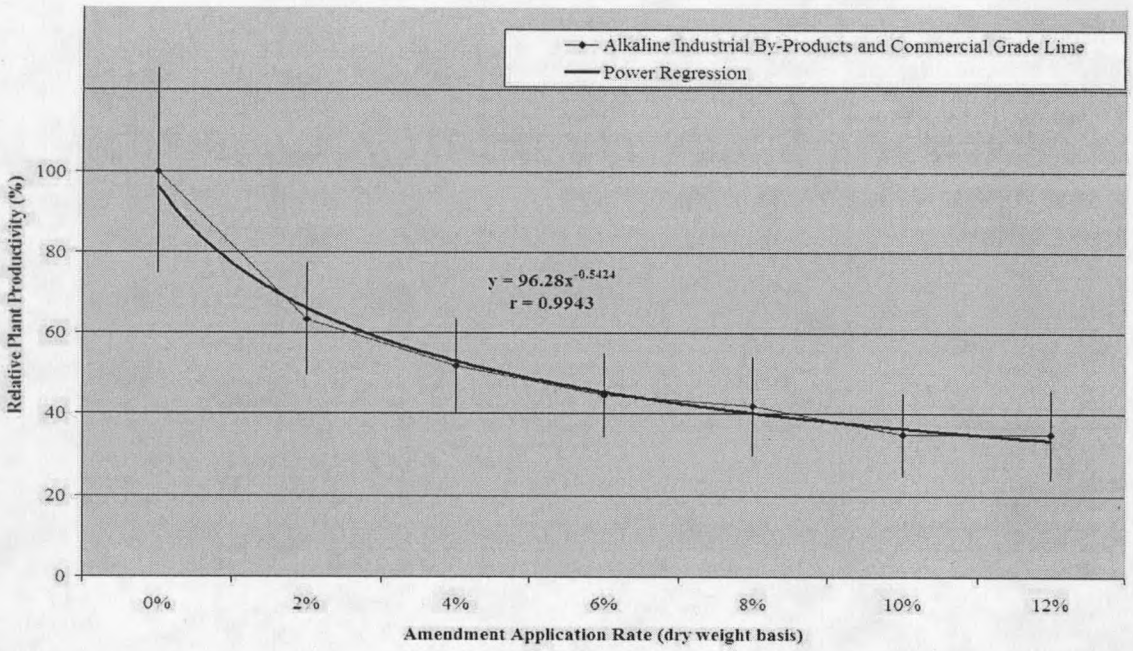
Center soil was assigned a relative value of 100 %, indicating optimal plant growth. Means presented in Figure 3 are calculated across data for all 9 alkaline products evaluated and the 5 replications. Incorporation of alkaline products into Plant Growth Center soil at a 2 % application rate (i.e. 20 tons amendment/1000 tons soil) resulted in approximately a 35 % loss in plant biomass. Each subsequent alkaline product application rate increase, i.e. 2 %, 4 %, 6 %, 8 %, 10 % and 12 %, produced incrementally less plant biomass. At the 12 % application rate, Basin Wildrye biomass decreased approximately 65 % and Redtop decreased approximately 88 %. All alkaline amendments tested, i.e. the $CaCO_3/CaO$ mixture, CKD and LKD materials, Dicalcium Silicate and Carbide Lime, had a similar result as indicated by the relatively narrow standard deviation bar on each mean in Figure 3. These results help explain plant growth failure with Dicalcium Silicate when the tailings application rate was 19.6 % (Kelly, 1997) and good plant growth attained in this investigation with a 4.2 % application rate. Apparently, the greater the excess of alkaline amendment residing in the soil matrix to address future potential acidity issues, the greater will be the loss in plant growth.

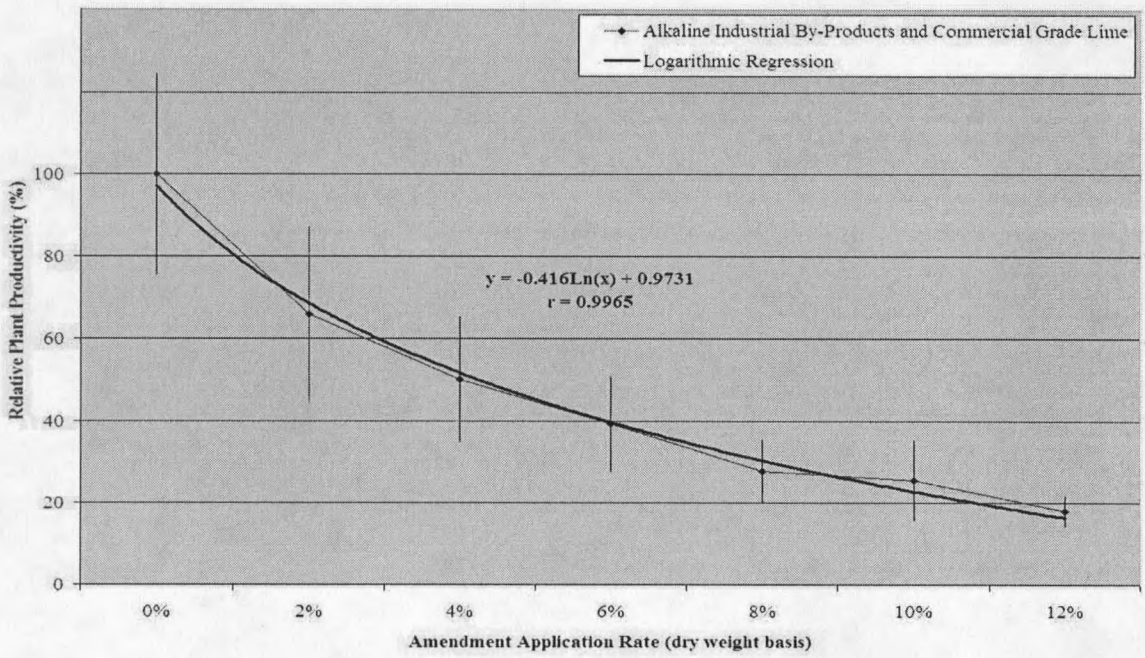
The progressive loss in plant biomass with increasing alkaline product application rate, illustrated in Figure 3, is not consistent with the threshold concept. A typical threshold would be expressed by similar plant biomass values with increasing alkaline product application, followed by an abrupt decline in plant biomass at the threshold application rate. The principle presented in Figure 3 is that for each alkaline product, the greater the application rate the less will be the plant growth, i.e. no threshold dosage was present.

However, these results should not be immediately interpreted to mean high application rates will result in plant growth failure for all alkaline products. Consider Tacoma LKD which was applied at a high rate of 11.6 % (116.6 tons/1000 tons tailings) to both tailings and the Plant Growth Center soil in the experiment discussed in previously. This application rate facilitated good above ground plant growth in tailings while growth in the Plant Growth Center soil was on the average 350 % greater. Clearly, the 11.6 % application rate is below a threshold value where plant growth fails, but results presented in Figure 3 indicate if a lower application rate could have been applied, more plant biomass would have been produced.

Therefore, when designing the alkaline amendment application rate for a project landscape, procedures should be used to apply the correct amount of alkaline material as opposed to a known excess. Excess applications emanate from insufficient data to account for variability across the landscape, thus more alkaline product is applied than required to insure the high rate captures this variability and soil acidification does not reappear in the future. Minimizing error of over application of alkaline material will increase plant growth and decrease treatment cost.

Figure 3. Loss in above ground biomass, Basin Wildrye (top) and Redtop (bottom), with increasing application of alkaline amendments. Each point is a mean of 45 observations (9 alkaline products, 5 replications and error bars represent plus or minus one standard deviation).





Correlation Of Soil pH And Electrical Conductivity To Increasing Amendment Application Rate And Loss In Plant Biomass

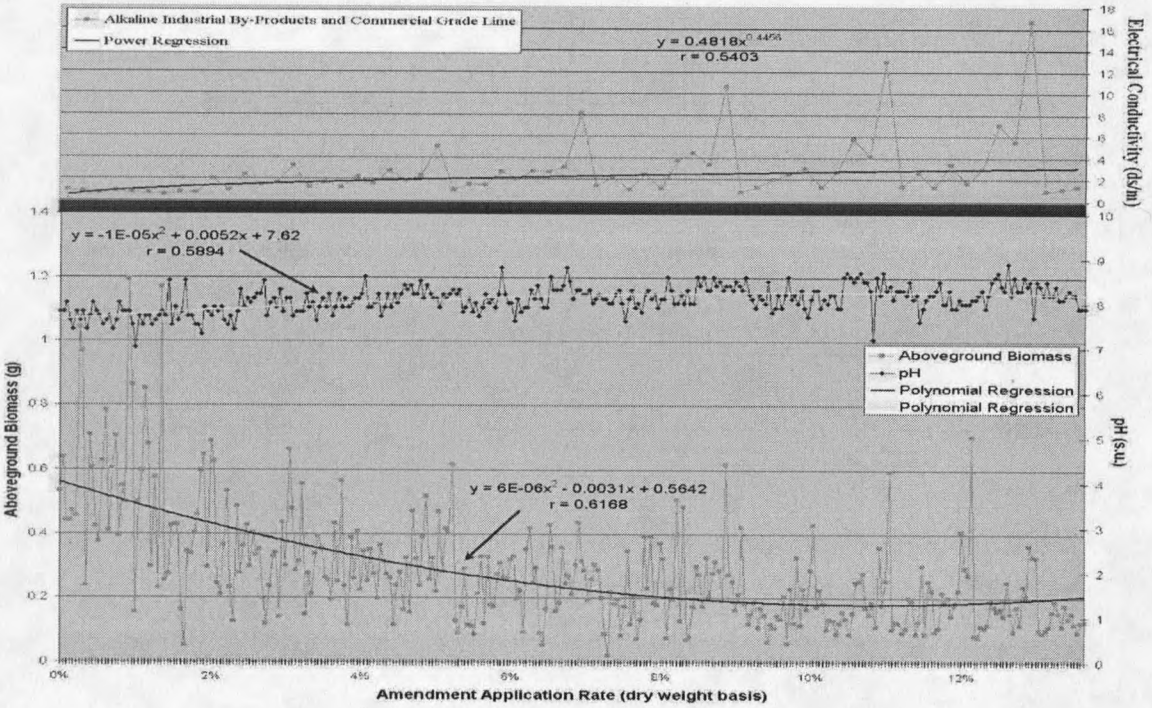
Loss in plant growth with increasing alkaline amendment dosage in relation to soil pH and electrical conductivity is shown in Figure 4. Loss in aboveground plant biomass was significantly correlated (r = 0.62 and 0.56) to increased amendment application rate. Increased soil pH associated with greater amendment application rates was significantly correlated (r = 0.59 and 0.54) to loss in above ground plant biomass. The pH increased from approximately 7.7 to 8.3 across the alkaline amendment application rate range of 0 % to 12 %. Similarly, increased soil electrical conductivity associated with greater amendment application rates was significantly correlated (r = 0.54) to loss in aboveground plant biomass.

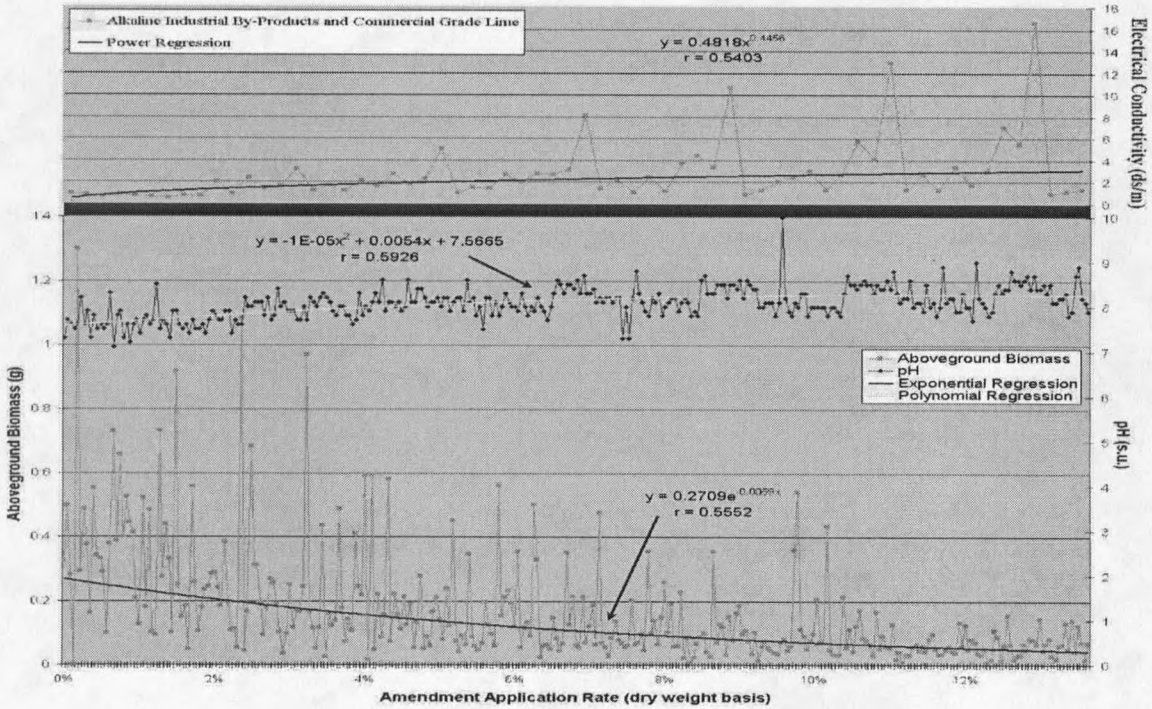
Table 25. Soil pH following a 90 day plant growth period for Basin Wildrye as a function of different alkaline amendments and application rates.

Amendment Type	Amendment Application Rate [1]						
	0 %	2 %	4 %	6 %	8 %	10 %	12 %
Greymont LKD	7.7 a[2]	7.8 ab	8.2 b	8.1 b	8.1 b	8.0 b	8.0 b
Tacoma LKD	7.7 a	7.6 a	7.9 b	8.0 b	8.2 b	8.1 b	8.0 b
MT Limestone LKD	7.7 a	8.1 b	8.1 b	8.1 b	8.1 b	8.0 b	8.1 b
Holnam (CH_4) CKD	7.7 a	8.1 b	8.3 bc	8.3 bc	8.4 c	8.6 c	8.5 c
Holnam (Coal, Coke) CKD	7.6 a	8.1 b	8.3 b	8.4 b	8.4 b	8.2 b	8.5 b
Ash Grove CKD	7.6 a	7.8 b	8.1 c	8.2 c	8.3 c	8.4 c	8.3 c
Dicalcium Silicate	7.8 a	7.9 a	8.1 a	8.1 a	8.2 a	8.2 a	8.3 a
Carbide Lime	7.9 a	8.0 a	7.9 a	8.0 a	8.1 a	8.1 a	8.2 a
$CaCO_3$/CaO	7.6 a	8.0 b	8.1 b	8.0 b	8.2 b	8.3 b	8.0 b

[1] Application rate is on a dry weight basis, i.e. 2 % is equivalent to 20 t amendment/1000 t soil.
[2] Means (n = 5) followed by the same letter in the same row are not significantly different (P =0.05).

Figure 4. Loss in above ground biomass, Basin Wildrye (top) and Redtop (bottom), in relation to increased soil pH, electrical conductivity and alkaline amendment application rate.





On the average, the soil electrical conductivity increased from approximately 0.8 ds/m to 4.5 ds/m across the alkaline amendment application rate range of 0 % to 12 %. These results suggest that elevated soil pH and soluble salts associated with increasing alkaline amendment application rates contributed to a loss in plant biomass. The mechanisms causing loss in plant growth may be i) lower availability of nitrogen, phosphorus, and potassium as pH increases, and ii) greater expenditure of energy by the plant root to uptake water due to a soluble salt induced increase in the osmotic potential between soil and water.

Table 26. Soil pH following a 90 day plant growth period for Redtop as a function of different alkaline amendments and application rates.

Amendment Type	Amendment Application Rate [1]						
	0 %	2 %	4 %	6 %	8 %	10 %	12 %
Greymont LKD	7.5 a[2]	7.8 b	8.0 b	8.1 b	8.1 b	8.1 b	8.1 b
Tacoma LKD	7.8 ab	7.6 a	8.2 c	8.0 bc	8.1 c	8.0 bc	8.2 c
MT Limestone LKD	7.7 a	8.1 b	8.0 b	8.0 b	8.0 b	8.0 b	8.0 b
Holnam (CH_4) CKD	7.5 a	7.9 b	8.3 c	8.4 c	8.4 c	8.5 c	8.4 c
Holnam (Coal, Coke) CKD	7.5 a	8.1 b	8.1 b	8.5 c	8.4 c	8.5 c	8.6 d
Ash Grove CKD	7.8 a	7.8 a	8.1 b	8.3 b	8.4 b	8.5 b	8.5 b
Dicalcium Silicate	7.7 a	8.1 b	8.2 b	8.2 b	8.3 b	8.3 b	8.3 b
Carbide Lime	7.6 a	8.0 b	7.9 b	7.8 ab	8.0 b	8.1 b	8.1 b
$CaCO_3$/CaO	7.5 a	7.8 ab	8.0 bc	8.2 c	8.4 c	8.2 c	8.4 c

[1] Application rate is on a dry weight basis, i.e. 2 % is equivalent to 20 t amendment/1000 t soil.
[2] Means (n = 5) followed by the same letter in the same row are not significantly different (P =0.05).

As shown in Tables 25 and 26, pH in the amended soil frequently increased significantly as the alkaline product application rate increased across the range of 0 % to 12 %. The equilibrium pH for a soil solution saturated with $CaCO_3$ is approximately 8.3. Therefore, pH values greater than 8.3 may have been caused by either i) applied CaO or $Ca(OH)_2$ that failed to carbonate during the "mellowing" time period or ii) NaOH produced

from the hydrolysis of excess sodium emanating from the applied alkaline product, especially CKD. Increased soil pH with increasing alkaline product application rate may have been a contributing factor to loss in plant biomass.

Linear correlation coefficients between soil pH and aboveground plant biomass for each alkaline product are presented in Table 27. Nearly all regressions were significant at the 10 % probability level and many were significant at the 5 % level ($P < 0.05$). These results indicate loss in plant biomass was correlated to increases in soil pH which were attributable

Table 27. Linear correlation coefficient (r) between above ground plant production and soil pH at time of harvest.

Amendment Type	Basin Wildrye		Redtop	
	r [1]	P value [2]	r [1]	P value [2]
Greymont LKD	0.38	0.02	0.23	0.18
Tacoma LKD	0.17	0.32	0.22	0.21
MT Limestone LKD	0.59	<0.01	0.14	0.42
Holnam (CH_4) CKD	0.65	<0.01	0.52	<0.01
Holnam (Coal, Coke) CKD	0.07	0.70	0.62	<0.01
Ash Grove CKD	0.53	<0.01	0.56	<0.01
Dicalcium Silicate	0.55	<0.01	0.40	0.02
Carbide Lime	0.25	0.10	0.12	0.50
$CaCO_3$/CaO	0.58	<0.01	0.40	<0.01

[1] Correlation coefficient (r) based on regression of 35 values, i.e. 5 replications x 7 amendment application rates.
[2] Linear correlation is significant (*) at $P < 0.05$.

to increasing alkaline amendment dosage (0 % to 12 %). The correlation coefficient squared (i.e. r^2) is the coefficient of determination which indicates the amount of the problem explained by the regression analysis. Most significant coefficient of determination values were well below 0.5 indicating increases in soil pH with increased amendment dosage was

only a part of the reason a loss in plant growth was measured. Other factors besides soil pH contributed to the loss in plant growth.

Linear correlation coefficients between soil electrical conductivity (EC) and aboveground plant biomass for each alkaline product are presented in Table 28. Nearly half of these regressions were significant at the 10 % probability level and a few were significant at the 5 % level ($P < 0.05$). These results indicate loss in plant biomass was correlated to increases in soil EC which were attributable to increasing alkaline amendment dosage for some alkaline products. The coefficient of determination (r^2) for significant regressions were relatively high indicating EC was a key factor contributing to loss in plant biomass as the amendment dosage rate was increased.

Table 28. Linear correlation coefficient (r) between above ground plant production and soil Electrical Conductivity at time of harvest.

Amendment Type	Basin Wildrye		Redtop	
	r [1]	P value [2]	r [1]	P value [2]
Greymont LKD	0.74[1]	0.06	0.93	0.01
Tacoma LKD	0.22	0.64	0.44	0.32
MT Limestone LKD	0.91	<0.01	0.79	0.03
Holnam (CH_4) CKD	0.73	0.06	0.70	0.08
Holnam (Coal, Coke) CKD	0.55	0.20	0.87	<0.01
Ash Grove CKD	0.43	0.34	0.86	<0.01
Dicalcium Silicate	0.35	0.44	0.61	0.14
Carbide Lime	0.32	0.49	0.44	0.32
$CaCO_3$/CaO	0.67	0.10	0.06	0.91

[1] Correlation coefficient (r) based on regression of 7 values, i.e. 1 replication x 7 amendment application rates.
[2] P = 0.05.

In summary, linear correlation analysis indicated increasing soil pH and electrical conductivity as alkaline amendment dosage rate increased contributed to loss in above

ground plant biomass. Loss in plant growth with increasing amendment dosage was due to other unidentified factors, which are presumed to be associated with alkaline amendment physicochemical characteristics.

Conclusion

Plant growth was evaluated in acidic-metalliferous tailings and acidic-metal contaminated soil after being neutralized with three lime kiln dust industrial by-products, three cement kiln dusts industrial by-products, industrial by-products Dicalcium Silicate and Carbide Lime, and a lime product mixture of $CaCO_3/CaO$. In addition, effects of increasing alkaline product dosage from 0 % to 12 % (soil dry weight basis) on plant growth in an optimal soil matrix were investigated.

Metals were often present in high concentrations in the alkaline by-product matrix which had a pH that ranged from 9.6 to 13.7. However, evidence indicated that plant growth issues may have been mitigated i) when diluted in the soil profile at a typical application rate of 2 % to 10% (soil dry weight basis) and ii) by an amended soil pH in the range of 7.0 – 8.4 when these metal contaminants were present at low concentrations in the soil solution. Treatment design risk is increased when alkaline by-products are used to amend soils. Additional metal contaminants are incorporated into the root zone and plant growth issues may arise if the soil pH migrates outside the 7.0 – 8.4 boundary condition in the future i.e. the soil re-acidifies.

All alkaline products produced a desired soil pH (7.0 – 8.4) in the root zone during plant growth test. Following a 111 day plant growth period for Basin Wildrye and Redtop, all alkaline industrial by-products tested had plant growth equal to- or greater than- the $CaCO_3/CaO$ mixture. This was the case in tailings and the contaminated soil for above ground plant biomass and root mass. These results indicate the use of alkaline industrial by-products is a viable low cost alternative to limestone, hydrate lime and CaO. However, each industrial by-product should undergo a screening process that includes chemical characterization, and plant growth tests. As economic conditions change for the companies that produce these by-products, low cost alternative fuels will be considered that have the potential to introduce contaminants. Subsequently, proper and thorough physicochemical characterization of the industrial by-products is strongly recommended.

For every alkaline product, including the $CaCO_3/CaO$ mixture, increasing the application rate resulted in an incremental decrease in plant growth. Starting with an ideal soil matrix (Plant Growth Center soil) for plant growth with an initial pH range of 7.6 – 7.7, each 2 % increase in the alkaline amendment application rate caused an incremental decrease in above ground plant biomass. Over the amendment application range of 0 % to 12 %, the loss in plant biomass was 65 % for Basin Wildrye and 88 % for Redtop. The greater the excess of alkaline amendment residing in the soil matrix, the greater was the loss in plant growth. This result was in-part attributed to both elevated pH and soluble salts in the soil matrix. Therefore, when designing the alkaline amendment application rate for a project landscape, procedures should be used to apply the correct amount of alkaline material as opposed to a known excess. Excess applications emanate from insufficient data to account

for variability across the landscape, thus more alkaline product is applied than required to insure the high rate captures this variability.

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APPENDICES

APPENDIX A

ANALYSIS OF VARIANCE RESULTS

Analysis of Variance for Emergence in Tailings, Contaminated Soil and Plant Growth Center Soil Amended with Alkaline Industrial By-Products.

Table 29. Number of days required for emergence in tailings: Basin Wildrye.

Two Way Analysis of Variance

General Linear Model (No Interactions)
Dependent Variable: rank(-DaysBWT-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	9750.500	1392.929	4.868	<0.001
Treat	8	2188.750	273.594	0.956	0.479
Residual	56	16022.250	286.112		
Total	71	27961.500	393.824		

Power of performed test with alpha = 0.0500: for Rep : 0.972
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 30. Number of days required for emergence in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: DaysBWCS
Normality Test: Passed (P = 0.071)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	27.487	3.927	4.330	<0.001
Treat	9	11.362	1.263	1.392	0.211
Residual	63	57.137	0.907		
Total	79	95.987	1.215		

Power of performed test with alpha = 0.0500: for Rep : 0.945
Power of performed test with alpha = 0.0500: for Treat : 0.177

Table 31. Number of days required for emergence in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: DaysBWPGC
Normality Test: Passed (P = 0.013)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	21.600	3.086	4.872	<0.001
Treat	9	17.300	1.922	3.035	0.004
Residual	63	39.900	0.633		
Total	79	78.800	0.997		

Power of performed test with alpha = 0.0500: for Rep : 0.974
Power of performed test with alpha = 0.0500: for Treat : 0.815

Table 32. Number of days required for emergence in tailings: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: DaysRTT
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	31.431	4.490	8.687	<0.001
Treat	8	7.944	0.993	1.921	0.075
Residual	56	28.944	0.517		
Total	71	68.319	0.962		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.380

Table 33. Number of days required for emergence in contaminated soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.090)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	52.220	7.460	4.308	<0.001
Treat	9	71.479	7.942	4.587	<0.001
Residual	60	103.893	1.732		
Total	76	219.270	2.885		

Power of performed test with alpha = 0.0500: for Rep : 0.942
Power of performed test with alpha = 0.0500: for Treat : 0.983

Table 34. Number of days required for emergence in Plant Growth Center soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: DaysRTPGC
Normality Test: Passed (P = 0.012)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	52.704	7.529	9.034	<0.001
Treat	9	3.203	0.356	0.427	0.916
Residual	63	52.507	0.833		
Total	79	108.415	1.372		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 35. Number of seedlings emerged of 15 seeds in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Emergence
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	73.487	10.498	1.638	0.141
Treat	9	916.813	101.868	15.890	<0.001
Residual	63	403.887	6.411		
Total	79	1394.188	17.648		

Power of performed test with alpha = 0.0500: for Rep : 0.249
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 36. Number of seedlings emerged of 15 seeds in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Emergence
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	113.400	16.200	2.194	0.047
Treat	9	66.300	7.367	0.998	0.451
Residual	63	465.100	7.383		
Total	79	644.800	8.162		

Power of performed test with alpha = 0.0500: for Rep : 0.467
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 37. Number of seedlings emerged of 15 seeds in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: emergenceBWPGC
Normality Test: Passed (P = 0.119)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	123.350	17.621	2.672	0.017
Treat	9	98.800	10.978	1.665	0.117
Residual	63	415.400	6.594		
Total	79	637.550	8.070		

Power of performed test with alpha = 0.0500: for Rep : 0.638
Power of performed test with alpha = 0.0500: for Treat : 0.293

Table 38. Number of seedlings emerged of 15 seeds in tailings: Redtop

Kruskal-Wallis One Way Analysis of Variance on Ranks
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	8	0	15.000	13.000	15.000
2.000	8	0	15.000	11.000	15.000
3.000	8	0	15.000	14.000	15.000
4.000	8	0	15.000	15.000	15.000
5.000	8	0	15.000	15.000	15.000
6.000	8	0	15.000	13.000	15.000
7.000	8	0	15.000	15.000	15.000
8.000	8	0	15.000	12.000	15.000
9.000	8	0	15.000	15.000	15.000
10.000	8	0	0.000	0.000	0.000

H = 34.225 with 9 degrees of freedom. (P = <0.001)

Table 39. Number of seedlings emerged of 15 seeds in contaminated soil: Redtop

Kruskal-Wallis One Way Analysis of Variance on Ranks
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	8	0	15.000	10.000	15.000
2.000	8	0	15.000	13.500	15.000
3.000	8	0	15.000	15.000	15.000
4.000	8	0	15.000	13.500	15.000
5.000	8	0	13.500	9.500	15.000
6.000	8	0	15.000	14.000	15.000
7.000	8	0	15.000	13.000	15.000
8.000	8	0	15.000	9.000	15.000
9.000	8	0	15.000	14.000	15.000
10.000	8	0	1.000	0.000	3.000

H = 29.579 with 9 degrees of freedom. (P = <0.001)

Table 40. Number of seedlings emerged of 15 seeds in Plant Growth Center soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Emergence
Normality Test: Passed (P = 0.012)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	3732.100	533.157	1.758	0.112
Treat	9	4364.938	484.993	1.599	0.135
Residual	63	19110.463	303.341		
Total	79	27207.500	344.399		

Power of performed test with alpha = 0.0500: for Rep : 0.295
Power of performed test with alpha = 0.0500: for Treat : 0.264

Table 41. Shoot height in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ShootHeightBWT
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	4792.910	684.701	3.961	0.001
Treat	9	63265.066	7029.452	40.670	<0.001
Residual	63	10889.039	172.842		
Total	79	78947.015	999.329		

Power of performed test with alpha = 0.0500: for Rep : 0.911
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 42. Shoot height in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ShootHeightBWCS
Normality Test: Passed (P = 0.148)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	509.179	72.740	0.444	0.870
Treat	9	34953.450	3883.717	23.720	<0.001
Residual	63	10315.045	163.731		
Total	79	45777.675	579.464		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 43. Shoot height in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ShootHeightBWPG
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	6945.819	992.260	6.536	<0.001
Treat	9	5143.008	571.445	3.764	<0.001
Residual	63	9564.125	151.812		
Total	79	21652.952	274.088		

Power of performed test with alpha = 0.0500: for Rep : 0.998
Power of performed test with alpha = 0.0500: for Treat : 0.935

Table 44. Shoot height in tailings: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ShootHeightRTT
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	406.327	58.047	1.461	0.198
Treat	9	5267.495	585.277	14.732	<0.001
Residual	63	2502.922	39.729		
Total	79	8176.744	103.503		

Power of performed test with alpha = 0.0500: for Rep : 0.185
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 45. Shoot height in contaminated soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(ShootRTCS)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	6234.100	890.586	2.635	0.019
Treat	9	15103.813	1678.201	4.966	<0.001
Residual	63	21290.588	337.946		
Total	79	42628.500	539.601		

Power of performed test with alpha = 0.0500: for Rep : 0.625
Power of performed test with alpha = 0.0500: for Treat : 0.992

Table 46. Shoot height in Plant Growth Center soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ShootHeightRTPG
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	655.086	93.584	1.765	0.110
Treat	9	8097.174	899.686	16.969	<0.001
Residual	63	3340.125	53.018		
Total	79	12092.385	153.068		

Power of performed test with alpha = 0.0500: for Rep : 0.298
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 47. Measured pH in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	9404.450	1343.493	4.779	<0.001
Treat	9	14657.438	1628.604	5.794	<0.001
Residual	63	17709.112	281.097		
Total	79	41771.000	528.747		

Power of performed test with alpha = 0.0500: for Rep : 0.971
Power of performed test with alpha = 0.0500: for Treat : 0.998

Table 48. Measured pH in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P = 0.033)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	679.950	97.136	0.400	0.899
Treat	9	25802.000	2866.889	11.820	<0.001
Residual	63	15280.550	242.548		
Total	79	41762.500	528.639		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 49. Measured pH in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	0.00000000314	0.000000000448	1.364	0.236
Treat	9	0.00000000804	0.000000000893	2.716	0.010
Residual	63	0.0000000207	0.000000000329		
Total	79	0.0000000319	0.000000000404		

Power of performed test with alpha = 0.0500: for Rep : 0.152
Power of performed test with alpha = 0.0500: for Treat : 0.727

Table 50. Measured pH in tailings: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	4459.450	.637.064	1.814	0.100
Treat	9	14955.500	1661.722	4.730	<0.001
Residual	63	22131.050	351.287		
Total	79	41546.000	525.899		

Power of performed test with alpha = 0.0500: for Rep : 0.317
Power of performed test with alpha = 0.0500: for Treat : 0.988

Table 51. Measured pH in contaminated soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P = 0.130)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	1371.750	195.964	0.735	0.643
Treat	9	23800.250	2644.472	9.918	<0.001
Residual	63	16798.500	266.643		
Total	79	41970.500	531.272		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 52. Measured pH in Plant Growth Center soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ln(-H+-)
Normality Test: Passed (P = 0.047)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	2.765	0.395	1.180	0.327
Treat	9	7.505	0.834	2.491	0.017
Residual	63	21.094	0.335		
Total	79	31.363	0.397		

Power of performed test with alpha = 0.0500: for Rep : 0.0948
Power of performed test with alpha = 0.0500: for Treat : 0.650

Analysis of Variance for Harvest Plant Response Variables in Tailings, Contaminated Soil and Plant Growth Center Soil Amended with Alkaline Industrial By-Products.

Table 53. Aboveground biomass in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.030)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	0.275	0.0393	0.831	0.566
Treat	8	2.294	0.287	6.071	<0.001
Residual	56	2.645	0.0472		
Total	71	5.215	0.0734		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.998

Table 54. Aboveground biomass in contaminated soil: Basin Wildrye.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Normality Test: Failed (P = 0.003)

Group	N	Missing	Median	25%	75%
1.000	8	0	0.485	0.449	0.744
2.000	8	0	0.484	0.433	0.846
3.000	8	0	0.530	0.437	0.696
4.000	8	0	0.489	0.284	0.734
5.000	8	0	0.311	0.134	0.639
6.000	8	0	0.290	0.246	0.565
7.000	8	0	0.408	0.246	0.575
8.000	8	0	0.249	0.178	0.328
9.000	8	0	0.220	0.161	0.291
10.000	8	0	0.0415	0.0130	0.101

H = 34.536 with 9 degrees of freedom. (P = <0.001)

Table 55. Aboveground biomass in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-Data-)
Normality Test: Passed (P = 0.043)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	1.852	0.265	4.393	<0.001
Treat	9	3.896	0.433	7.188	<0.001
Residual	63	3.794	0.0602		
Total	79	9.542	0.121		

Power of performed test with alpha = 0.0500: for Rep : 0.949
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 56. Aboveground biomass in tailings: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	2735.667	390.810	1.503	0.185
Treat	8	13793.938	1724.242	6.631	<0.001
Residual	56	14561.896	260.034		
Total	71	31091.500	437.908		

Power of performed test with alpha = 0.0500: for Rep : 0.197
Power of performed test with alpha = 0.0500: for Treat : 0.999

Table 57. Aboveground biomass in contaminated soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.104)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	5.428	0.775	7.528	<0.001
Treat	9	8.374	0.930	9.032	<0.001
Residual	58	5.975	0.103		
Total	74	19.798	0.268		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 58. Aboveground biomass in Plant Growth Center soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.050)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	17.949	2.564	3.492	0.003
Treat	9	23.858	2.651	3.610	0.001
Residual	63	46.259	0.734		
Total	79	88.066	1.115		

Power of performed test with alpha = 0.0500: for Rep : 0.843
Power of performed test with alpha = 0.0500: for Treat : 0.918

Table 59. Belowground biomass in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.017)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	5.309	0.758	2.306	0.039
Treat	8	13.943	1.743	5.298	<0.001
Residual	56	18.421	0.329		
Total	71	37.672	0.531		

Power of performed test with alpha = 0.0500: for Rep : 0.503
Power of performed test with alpha = 0.0500: for Treat : 0.992

Table 60. Belowground biomass in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.012)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	5.383	0.769	5.139	<0.001
Treat	9	5.455	0.606	4.051	<0.001
Residual	63	9.427	0.150		
Total	79	20.264	0.257		

Power of performed test with alpha = 0.0500: for Rep : 0.983
Power of performed test with alpha = 0.0500: for Treat : 0.959

Table 61. Belowground biomass in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: log10(-Data-)
Normality Test: Passed (P = 0.198)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	1.807	0.258	7.901	<0.001
Treat	9	1.795	0.199	6.102	<0.001
Residual	63	2.059	0.0327		
Total	79	5.661	0.0717		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.999

Table 62. Belowground biomass in tailings: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	5.123	0.732	2.204	0.047
Treat	8	23.205	2.901	8.737	<0.001
Residual	56	18.592	0.332		
Total	71	46.920	0.661		

Power of performed test with alpha = 0.0500: for Rep : 0.465
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 63. Belowground biomass in contaminated soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.160)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	7.978	1.140	6.442	<0.001
Treat	9	7.236	0.804	4.544	<0.001
Residual	57	10.085	0.177		
Total	73	25.404	0.348		

Power of performed test with alpha = 0.0500: for Rep : 0.998
Power of performed test with alpha = 0.0500: for Treat : 0.981

Table 64. Belowground biomass in Plant Growth Center soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: log10(-Data-)
Normality Test: Passed (P = 0.023)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	5.420	0.774	16.655	<0.001
Treat	9	1.793	0.199	4.285	<0.001
Residual	63	2.929	0.0465		
Total	79	10.142	0.128		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.972

Table 65. Aboveground height in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.136)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	51731.542	7390.220	0.915	0.502
Treat	8	368231.528	46028.941	5.701	<0.001
Residual	56	452109.583	8073.385		
Total	71	872072.653	12282.713		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.996

Table 66. Aboveground height in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.080)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	55784.188	7969.170	1.621	0.146
Treat	9	231355.513	25706.168	5.230	<0.001
Residual	63	309656.188	4915.178		
Total	79	596795.888	7554.378		

Power of performed test with alpha = 0.0500: for Rep : 0.243
Power of performed test with alpha = 0.0500: for Treat : 0.995

Table 67. Aboveground height in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	140915.200	20130.743	3.425	0.004
Treat	9	212254.450	23583.828	4.012	<0.001
Residual	63	370327.550	5878.215		
Total	79	723497.200	9158.192		

Power of performed test with alpha = 0.0500: for Rep : 0.830
Power of performed test with alpha = 0.0500: for Treat : 0.956

Table 68. Aboveground height in tailings: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: TRTHeight
Normality Test: Passed (P = 0.036)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	51083.111	7297.587	2.368	0.034
Treat	8	133239.361	16654.920	5.404	<0.001
Residual	56	172586.639	3081.904		
Total	71	356909.111	5026.889		

Power of performed test with alpha = 0.0500: for Rep : 0.526
Power of performed test with alpha = 0.0500: for Treat : 0.993

Table 69. Aboveground height in contaminated soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	29485.006	4212.144	0.752	0.629
Treat	9	392762.144	43640.238	7.793	<0.001
Residual	58	324800.161	5600.003		
Total	74	749285.180	10125.475		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 70. Aboveground height in Plant Growth Center soil: Redtop

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	16779.550	2397.079	7.967	<0.001
Treat	9	6905.812	767.312	2.550	0.014
Residual	63	18954.638	300.867		
Total	79	42640.000	539.747		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.672

Table 71. Number of roots (5 cm) in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.120)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	3323.722	474.817	1.949	0.079
Treat	8	14006.750	1750.844	7.187	<0.001
Residual	56	13642.028	243.608		
Total	71	30972.500	436.232		

Power of performed test with alpha = 0.0500: for Rep : 0.366
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 72. Number of roots (5 cm) in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	10561.900	1508.843	5.860	<0.001
Treat	9	15657.813	1739.757	6.757	<0.001
Residual	63	16221.788	257.489		
Total	79	42441.500	537.234		

Power of performed test with alpha = 0.0500: for Rep : 0.995
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 73. Number of roots (5 cm) in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.014)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	16114.750	2302.107	2.957	0.010
Treat	9	25891.550	2876.839	3.695	<0.001
Residual	63	49053.250	778.623		
Total	79	91059.550	1152.653		

Power of performed test with alpha = 0.0500: for Rep : 0.722
Power of performed test with alpha = 0.0500: for Treat : 0.928

Table 74. Number of roots (5 cm) in tailings: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.180)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	5242.875	748.982	3.021	0.009
Treat	8	8560.000	1070.000	4.316	<0.001
Residual	56	13884.000	247.929		
Total	71	27686.875	389.956		

Power of performed test with alpha = 0.0500: for Rep : 0.732
Power of performed test with alpha = 0.0500: for Treat : 0.959

Table 75. Number of roots (5 cm) in contaminated soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-Data-)
Normality Test: Passed (P = 0.047)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	162.990	23.284	7.918	<0.001
Treat	9	252.373	28.041	9.535	<0.001
Residual	63	185.273	2.941		
Total	79	600.637	7.603		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 76. Number of roots (5 cm) in Plant Growth Center soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	4110.700	587.243	1.146	0.347
Treat	9	6061.313	673.479	1.314	0.248
Residual	63	32287.988	512.508		
Total	79	42460.000	537.468		

Power of performed test with alpha = 0.0500: for Rep : 0.0855
Power of performed test with alpha = 0.0500: for Treat : 0.147

Table 77. Number of roots (10 cm) in tailings: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	3686.944	526.706	2.160	0.052
Treat	8	13662.438	1707.805	7.005	<0.001
Residual	56	13653.618	243.815		
Total	71	31003.000	436.662		

Power of performed test with alpha = 0.0500: for Rep : 0.448
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 78. Number of roots (10 cm) in contaminated soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	6494.850	927.836	4.308	<0.001
Treat	9	22125.063	2458.340	11.415	<0.001
Residual	63	13567.588	215.359		
Total	79	42187.500	534.019		

Power of performed test with alpha = 0.0500: for Rep : 0.943
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 79. Number of roots (10 cm) in Plant Growth Center soil: Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.032)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	52015.788	7430.827	3.398	0.004
Treat	9	85842.063	9538.007	4.362	<0.001
Residual	63	137767.837	2186.791		
Total	79	275625.688	3488.933		

Power of performed test with alpha = 0.0500: for Rep : 0.825
Power of performed test with alpha = 0.0500: for Treat : 0.976

Table 80. Number of roots (10 cm) in tailings: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: data
Normality Test: Passed (P = 0.039)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	12867.278	1838.183	2.941	0.011
Treat	8	31751.111	3968.889	6.349	<0.001
Residual	56	35004.222	625.075		
Total	71	79622.611	1121.445		

Power of performed test with alpha = 0.0500: for Rep : 0.711
Power of performed test with alpha = 0.0500: for Treat : 0.999

Table 81. Number of roots (10 cm) in contaminated soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	11576.750	1653.821	8.161	<0.001
Treat	9	16621.750	1846.861	9.114	<0.001
Residual	63	12767.000	202.651		
Total	79	40965.500	518.551		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 82. Number of roots (10 cm) in Plant Growth Center soil: Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.027)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	7	21799.487	3114.213	3.217	0.006
Treat	9	59161.262	6573.474	6.790	<0.001
Residual	63	60989.638	968.089		
Total	79	141950.388	1796.840		

Power of performed test with alpha = 0.0500: for Rep : 0.787
Power of performed test with alpha = 0.0500: for Treat : 1.000

Analysis of Variance for Emergence Plant Response Variables in Plant Growth Center Soil With Increasing Application Rate of Alkaline Industrial By-Products.

Table 83. Number of days required for emergence (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	2.457	0.614	1.856	0.151
Treat	6	1.200	0.200	0.604	0.724
Residual	24	7.943	0.331		
Total	34	11.600	0.341		

Power of performed test with alpha = 0.0500: for Rep : 0.227
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 84. Number of days required for emergence (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.132)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5.257	1.314	2.199	0.099
Treat	6	1.086	0.181	0.303	0.929
Residual	24	14.343	0.598		
Total	34	20.686	0.608		

Power of performed test with alpha = 0.0500: for Rep : 0.311
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 85. Number of days required for emergence (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.971	0.243	0.829	0.520
Treat	6	2.686	0.448	1.528	0.212
Residual	24	7.029	0.293		
Total	34	10.686	0.314		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.173

Table 86. Number of days required for emergence (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.122)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	3.829	0.957	1.534	0.224
Treat	6	4.171	0.695	1.115	0.383
Residual	24	14.971	0.624		
Total	34	22.971	0.676		

Power of performed test with alpha = 0.0500: for Rep : 0.153
Power of performed test with alpha = 0.0500: for Treat : 0.0720

Table 87. Number of days required for emergence (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.106)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.886	0.471	0.521	0.721
Treat	6	2.571	0.429	0.474	0.821
Residual	24	21.714	0.905		
Total	34	26.171	0.770		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 88. Number of days required for emergence (Ash Grove): Basin Wildrye.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	8.000	6.500	8.000
2.000	5	0	8.000	8.000	8.000
3.000	5	0	8.000	7.750	8.250
4.000	5	0	8.000	7.750	8.250
5.000	5	0	8.000	8.000	8.000
6.000	5	0	8.000	7.750	9.250
7.000	5	0	9.000	8.000	9.250

H = 8.264 with 6 degrees of freedom. (P = 0.219)

Table 89. Number of days required for emergence (Dicalcium Silicate): Basin Wildrye.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	8.000	7.250	8.500
2.000	5	0	8.000	8.000	8.250
3.000	5	0	8.000	7.750	8.000
4.000	5	0	8.000	8.000	8.000
5.000	5	0	8.000	7.750	8.250
6.000	5	0	7.000	7.000	7.500
7.000	5	0	7.000	7.000	7.250

H = 10.191 with 6 degrees of freedom. (P = 0.117)

Table 90. Number of days required for emergence (Carbide Lime): Basin Wildrye.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	8.000	7.500	8.000
2.000	5	0	8.000	7.500	8.250
3.000	5	0	8.000	7.500	8.250
4.000	5	0	8.000	6.750	8.000
5.000	5	0	8.000	7.500	8.000
6.000	5	0	8.000	7.500	8.000
7.000	5	0	8.000	7.750	8.000

H = 1.567 with 6 degrees of freedom. (P = 0.955)

Table 91. Number of days required for emergence ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.010)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	17.029	4.257	10.045	<0.001
Treat	6	0.971	0.162	0.382	0.883
Residual	24	10.171	0.424		
Total	34	28.171	0.829		

Power of performed test with alpha = 0.0500: for Rep : 0.998
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 92. Number of days required for emergence (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.111)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.314	0.329	0.663	0.623
Treat	6	2.686	0.448	0.904	0.508
Residual	24	11.886	0.495		
Total	34	15.886	0.467		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 93. Number of days required for emergence (Tacoma): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	8.000	7.000	8.000
2.000	5	0	7.000	6.750	7.250
3.000	5	0	7.000	7.000	8.000
4.000	5	0	7.000	7.000	7.250
5.000	5	0	7.000	7.000	7.250
6.000	5	0	7.000	7.000	7.250
7.000	5	0	7.000	7.000	7.250

H = 4.042 with 6 degrees of freedom. (P = 0.671)

Table 94. Number of days required for emergence (MT Limestone): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	7.000	7.000	7.250
2.000	5	0	7.000	6.750	8.000
3.000	5	0	7.000	7.000	7.250
4.000	5	0	7.000	7.000	7.000
5.000	5	0	7.000	7.000	7.250
6.000	5	0	7.000	7.000	7.000
7.000	5	0	7.000	7.000	8.250

H = 3.321 with 6 degrees of freedom. (P = 0.768)

Table 95. Number of days required for emergence (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.118)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.971	0.243	0.646	0.635
Treat	6	2.686	0.448	1.190	0.345
Residual	24	9.029	0.376		
Total	34	12.686	0.373		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0881

Table 96. Number of days required for emergence (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.041)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.400	0.1000	0.750	0.568
Treat	6	3.371	0.562	4.214	0.005
Residual	24	3.200	0.133		
Total	34	6.971	0.205		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.846

Table 97. Number of days required for emergence (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.857	0.214	0.647	0.634
Treat	6	4.343	0.724	2.187	0.080
Residual	24	7.943	0.331		
Total	34	13.143	0.387		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.370

Table 98. Number of days required for emergence (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.071)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5.029	1.257	2.966	0.040
Treat	6	2.686	0.448	1.056	0.415
Residual	24	10.171	0.424		
Total	34	17.886	0.526		

Power of performed test with alpha = 0.0500: for Rep : 0.499
Power of performed test with alpha = 0.0500: for Treat : 0.0603

Table 99. Number of days required for emergence (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	3.257	0.814	1.966	0.132
Treat	6	1.486	0.248	0.598	0.729
Residual	24	9.943	0.414		
Total	34	14.686	0.432		

Power of performed test with alpha = 0.0500: for Rep : 0.254
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 100. Number of days required for emergence ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.198)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.429	0.357	0.622	0.651
Treat	6	3.943	0.657	1.145	0.367
Residual	24	13.771	0.574		
Total	34	19.143	0.563		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0784

Table 101. Number of seedlings emerged of 15 seeds (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.140)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	68.400	17.100	3.128	0.033
Treat	6	19.371	3.229	0.591	0.735
Residual	24	131.200	5.467		
Total	34	218.971	6.440		

Power of performed test with alpha = 0.0500: for Rep : 0.537
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 102. Number of seedlings emerged of 15 seeds (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.145)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	37.257	9.314	1.928	0.138
Treat	6	25.771	4.295	0.889	0.518
Residual	24	115.943	4.831		
Total	34	178.971	5.264		

Power of performed test with alpha = 0.0500: for Rep : 0.245
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 103. Number of seedlings emerged of 15 seeds (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	19.829	4.957	0.707	0.595
Treat	6	41.543	6.924	0.988	0.455
Residual	24	168.171	7.007		
Total	34	229.543	6.751		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 104. Number of seedlings emerged of 15 seeds (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.018)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1413.071	353.268	4.839	0.005
Treat	6	79.200	13.200	0.181	0.979
Residual	24	1752.229	73.010		
Total	34	3244.500	95.426		

Power of performed test with alpha = 0.0500: for Rep : 0.829
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 105. Number of seedlings emerged of 15 seeds (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.175)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	34.171	8.543	1.251	0.316
Treat	6	6.743	1.124	0.165	0.984
Residual	24	163.829	6.826		
Total	34	204.743	6.022		

Power of performed test with alpha = 0.0500: for Rep : 0.0943
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 106. Number of seedlings emerged of 15 seeds (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	17.886	4.471	0.494	0.740
Treat	6	48.400	8.067	0.891	0.517
Residual	24	217.314	9.055		
Total	34	283.600	8.341		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 107. Number of seedlings emerged of 15 seeds (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.183)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	28.171	7.043	1.786	0.165
Treat	6	38.800	6.467	1.640	0.179
Residual	24	94.629	3.943		
Total	34	161.600	4.753		

Power of performed test with alpha = 0.0500: for Rep : 0.211
Power of performed test with alpha = 0.0500: for Treat : 0.204

Table 108. Number of seedlings emerged of 15 seeds (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.183)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	83.429	20.857	3.027	0.037
Treat	6	21.200	3.533	0.513	0.793
Residual	24	165.371	6.890		
Total	34	270.000	7.941		

Power of performed test with alpha = 0.0500: for Rep : 0.514
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 109. Number of seedlings emerged of 15 seeds ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	16.971	4.243	0.659	0.627
Treat	6	29.371	4.895	0.760	0.608
Residual	24	154.629	6.443		
Total	34	200.971	5.911		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 110. Number of seedlings emerged of 15 seeds (Greymont): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	5.250	15.000
2.000	5	0	15.000	15.000	15.000
3.000	5	0	15.000	15.000	15.000
4.000	5	0	15.000	13.750	15.000
5.000	5	0	15.000	13.250	15.000
6.000	5	0	15.000	14.250	15.000
7.000	5	0	15.000	15.000	15.000

H = 6.011 with 6 degrees of freedom. (P = 0.422)

Table 111. Number of seedlings emerged of 15 seeds (Tacoma): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	15.000	15.000
2.000	5	0	15.000	13.000	15.000
3.000	5	0	15.000	15.000	15.000
4.000	5	0	15.000	14.500	15.000
5.000	5	0	15.000	15.000	15.000
6.000	5	0	15.000	13.250	15.000
7.000	5	0	15.000	15.000	15.000

H = 4.256 with 6 degrees of freedom. (P = 0.642)

Table 112. Number of seedlings emerged of 15 seeds (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.017)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	510.286	127.571	5.165	0.004
Treat	6	218.900	36.483	1.477	0.228
Residual	24	592.814	24.701		
Total	34	1322.000	38.882		

Power of performed test with alpha = 0.0500: for Rep : 0.863
Power of performed test with alpha = 0.0500: for Treat : 0.159

Table 113. Number of seedlings emerged of 15 seeds (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.027)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	151.314	37.829	13.374	<0.001
Treat	6	18.686	3.114	1.101	0.390
Residual	24	67.886	2.829		
Total	34	237.886	6.997		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.0692

Table 114. Number of seedlings emerged of 15 seeds (Holnam coal,coke): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	13.500	15.000
2.000	5	0	15.000	15.000	15.000
3.000	5	0	15.000	15.000	15.000
4.000	5	0	15.000	14.500	15.000
5.000	5	0	15.000	14.000	15.000
6.000	5	0	15.000	15.000	15.000
7.000	5	0	15.000	15.000	15.000

H = 4.256 with 6 degrees of freedom. (P = 0.642)

Table 115. Number of seedlings emerged of 15 seeds (Ash Grove): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	13.750	15.000
2.000	5	0	15.000	13.750	15.000
3.000	5	0	15.000	13.750	15.000
4.000	5	0	15.000	13.500	15.000
5.000	5	0	15.000	15.000	15.000
6.000	5	0	15.000	11.500	15.000
7.000	5	0	15.000	15.000	15.000

H = 3.544 with 6 degrees of freedom. (P = 0.738)

Table 116. Number of seedlings emerged of 15 seeds (Dicalcium Silicate): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	12.250	15.000
2.000	5	0	15.000	13.000	15.000
3.000	5	0	15.000	15.000	15.000
4.000	5	0	15.000	13.250	15.000
5.000	5	0	15.000	12.250	15.000
6.000	5	0	15.000	15.000	15.000
7.000	5	0	15.000	15.000	15.000

H = 3.305 with 6 degrees of freedom. (P = 0.770)

Table 117. Number of seedlings emerged of 15 seeds (Carbide Lime): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	15.000	15.000
2.000	5	0	15.000	13.000	15.000
3.000	5	0	15.000	15.000	15.000
4.000	5	0	15.000	14.500	15.000
5.000	5	0	15.000	14.250	15.000
6.000	5	0	15.000	15.000	15.000
7.000	5	0	15.000	15.000	15.000

H = 4.256 with 6 degrees of freedom. (P = 0.642)

Table 118. Number of seedlings emerged of 15 seeds ($CaCO_3$/CaO): Redtop.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Data source: Data 1 in Notebook
Normality Test: Failed (P = <0.001)

Group	N	Missing	Median	25%	75%
1.000	5	0	15.000	13.500	15.000
2.000	5	0	15.000	15.000	15.000
3.000	5	0	15.000	14.250	15.000
4.000	5	0	15.000	13.500	15.000
5.000	5	0	15.000	15.000	15.000
6.000	5	0	15.000	15.000	15.000
7.000	5	0	15.000	15.000	15.000

H = 4.255 with 6 degrees of freedom. (P = 0.642)

Table 119. Shoot height (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.063)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	24818.438	6204.610	8.619	<0.001
Dosage	6	42736.475	7122.746	9.894	<0.001
Residual	24	17277.182	719.883		
Total	34	84832.095	2495.062		

Power of performed test with alpha = 0.0500: for Rep : 0.992
Power of performed test with alpha = 0.0500: for Dosage : 1.000

Table 120. Shoot height (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.079)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	4048.733	1012.183	1.216	0.330
Treat	6	5232.496	872.083	1.048	0.420
Residual	24	19977.455	832.394		
Total	34	29258.684	860.550		

Power of performed test with alpha = 0.0500: for Rep : 0.0876
Power of performed test with alpha = 0.0500: for Treat : 0.0587

Table 121. Shoot height (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5145.547	1286.387	3.280	0.028
Treat	6	21025.951	3504.325	8.935	<0.001
Residual	24	9412.761	392.198		
Total	34	35584.259	1046.596		

Power of performed test with alpha = 0.0500: for Rep : 0.570
Power of performed test with alpha = 0.0500: for Treat : 0.999

Table 122. Shoot height (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	8803.073	2200.768	4.448	0.008
Treat	6	32388.462	5398.077	10.910	<0.001
Residual	24	11874.275	494.761		
Total	34	53065.810	1560.759		

Power of performed test with alpha = 0.0500: for Rep : 0.780
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 123. Shoot height (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	18477.644	4619.411	4.736	0.006
Treat	6	11818.615	1969.769	2.019	0.102
Residual	24	23410.028	975.418		
Total	34	53706.287	1579.597		

Power of performed test with alpha = 0.0500: for Rep : 0.817
Power of performed test with alpha = 0.0500: for Treat : 0.318

Table 124. Shoot height (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.068)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	13314.247	3328.562	7.060	<0.001
Treat	6	37391.116	6231.853	13.218	<0.001
Residual	24	11315.053	471.461		
Total	34	62020.416	1824.130		

Power of performed test with alpha = 0.0500: for Rep : 0.968
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 125. Shoot height (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	8879.018	2219.755	11.863	<0.001
Treat	6	25084.023	4180.670	22.343	<0.001
Residual	24	4490.806	187.117		
Total	34	38453.847	1130.995		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 126. Shoot height (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	8543.070	2135.768	2.169	0.103
Treat	6	36343.150	6057.192	6.152	<0.001
Residual	24	23631.002	984.625		
Total	34	68517.222	2015.212		

Power of performed test with alpha = 0.0500: for Rep : 0.304
Power of performed test with alpha = 0.0500: for Treat : 0.977

Table 127. Shoot height ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	22373.153	5593.288	7.285	<0.001
Treat	6	27097.974	4516.329	5.882	<0.001
Residual	24	18426.283	767.762		
Total	34	67897.410	1996.983		

Power of performed test with alpha = 0.0500: for Rep : 0.974
Power of performed test with alpha = 0.0500: for Treat : 0.970

Table 128. Shoot height (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.025)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	431.929	107.982	1.763	0.169
Treat	6	1667.300	277.883	4.536	0.003
Residual	24	1470.271	61.261		
Total	34	3569.500	104.985		

Power of performed test with alpha = 0.0500: for Rep : 0.205
Power of performed test with alpha = 0.0500: for Treat : 0.884

Table 129. Shoot height (Tacoma): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5937.010	1484.252	5.486	0.003
Treat	6	16618.823	2769.804	10.238	<0.001
Residual	24	6493.182	270.549		
Total	34	29049.015	854.383		

Power of performed test with alpha = 0.0500: for Rep : 0.891
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 130. Shoot height (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	3397.106	849.276	2.072	0.116
Treat	6	27470.096	4578.349	11.170	<0.001
Residual	24	9836.718	409.863		
Total	34	40703.920	1197.174		

Power of performed test with alpha = 0.0500: for Rep : 0.280
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 131. Shoot height (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.129)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	2723.604	680.901	2.118	0.110
Treat	6	13199.678	2199.946	6.842	<0.001
Residual	24	7717.208	321.550		
Total	34	23640.490	695.309		

Power of performed test with alpha = 0.0500: for Rep : 0.291
Power of performed test with alpha = 0.0500: for Treat : 0.990

Table 132. Shoot height (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	2449.894	612.474	1.017	0.419
Treat	6	14963.787	2493.965	4.141	0.005
Residual	24	14455.850	602.327		
Total	34	31869.531	937.339		

Power of performed test with alpha = 0.0500: for Rep : 0.0523
Power of performed test with alpha = 0.0500: for Treat : 0.836

Table 133. Shoot height (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.023)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1702.461	425.615	1.453	0.247
Treat	6	13201.551	2200.258	7.511	<0.001
Residual	24	7030.415	292.934		
Total	34	21934.427	645.130		

Power of performed test with alpha = 0.0500: for Rep : 0.135
Power of performed test with alpha = 0.0500: for Treat : 0.995

Table 134. Shoot height (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.016)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	2960.003	740.001	1.795	0.163
Treat	6	24772.899	4128.816	10.015	<0.001
Residual	24	9894.561	412.273		
Total	34	37627.463	1106.690		

Power of performed test with alpha = 0.0500: for Rep : 0.213
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 135. Shoot height (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	3473.682	868.420	2.299	0.088
Treat	6	8729.916	1454.986	3.852	0.008
Residual	24	9064.658	377.694		
Total	34	21268.256	625.537		

Power of performed test with alpha = 0.0500: for Rep : 0.336
Power of performed test with alpha = 0.0500: for Treat : 0.791

Table 136. Shoot height ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.073)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5430.833	1357.708	6.607	<0.001
Treat	6	13324.127	2220.688	10.806	<0.001
Residual	24	4932.007	205.500		
Total	34	23686.967	696.675		

Power of performed test with alpha = 0.0500: for Rep : 0.954
Power of performed test with alpha = 0.0500: for Treat : 1.000

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Table 137. Aboveground biomass (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.148)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.101	0.0251	2.542	0.066
Treat	6	0.400	0.0667	6.748	<0.001
Residual	24	0.237	0.00989		
Total	34	0.738	0.0217		

Power of performed test with alpha = 0.0500: for Rep : 0.397
Power of performed test with alpha = 0.0500: for Treat : 0.988

Table 138. Aboveground biomass (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.127)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.231	0.0578	1.904	0.143
Treat	6	0.687	0.115	3.775	0.009
Residual	24	0.728	0.0303		
Total	34	1.646	0.0484		

Power of performed test with alpha = 0.0500: for Rep : 0.239
Power of performed test with alpha = 0.0500: for Treat : 0.777

Table 139. Aboveground biomass (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.052)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0597	0.0149	1.451	0.248
Treat	6	0.802	0.134	12.998	<0.001
Residual	24	0.247	0.0103		
Total	34	1.109	0.0326		

Power of performed test with alpha = 0.0500: for Rep : 0.135
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 140. Aboveground biomass (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.120)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0292	0.00730	0.737	0.576
Treat	6	0.472	0.0786	7.935	<0.001
Residual	24	0.238	0.00991		
Total	34	0.739	0.0217		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.997

Table 141. Aboveground biomass (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	364.857	91.214	1.334	0.286
Treat	6	1564.400	260.733	3.814	0.008
Residual	24	1640.743	68.364		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.111
Power of performed test with alpha = 0.0500: for Treat : 0.784

Table 142. Aboveground biomass (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.134	0.0334	2.084	0.114
Treat	6	0.466	0.0776	4.848	0.002
Residual	24	0.384	0.0160		
Total	34	0.984	0.0289		

Power of performed test with alpha = 0.0500: for Rep : 0.283
Power of performed test with alpha = 0.0500: for Treat : 0.913

Table 143. Aboveground biomass (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.199)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	332.857	83.214	1.358	0.278
Treat	6	1766.000	294.333	4.802	0.002
Residual	24	1471.143	61.298		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.115
Power of performed test with alpha = 0.0500: for Treat : 0.909

Table 144. Aboveground biomass (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.121	0.0303	5.071	0.004
Treat	6	0.134	0.0224	3.751	0.009
Residual	24	0.143	0.00597		
Total	34	0.399	0.0117		

Power of performed test with alpha = 0.0500: for Rep : 0.854
Power of performed test with alpha = 0.0500: for Treat : 0.773

Table 145. Aboveground biomass ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.015)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.105	0.0263	2.901	0.043
Treat	6	0.497	0.0828	9.145	<0.001
Residual	24	0.217	0.00906		
Total	34	0.819	0.0241		

Power of performed test with alpha = 0.0500: for Rep : 0.484
Power of performed test with alpha = 0.0500: for Treat : 0.999

Table 146. Aboveground biomass (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.038)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1046.571	261.643	5.094	0.004
Treat	6	1290.800	215.133	4.189	0.005
Residual	24	1232.629	51.360		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.856
Power of performed test with alpha = 0.0500: for Treat : 0.842

Table 147. Aboveground biomass (Tacoma): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.085)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1438.571	359.643	7.586	<0.001
Treat	6	993.600	165.600	3.493	0.013
Residual	24	1137.829	47.410		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.980
Power of performed test with alpha = 0.0500: for Treat : 0.723

Table 148. Aboveground biomass (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	146.571	36.643	0.677	0.615
Treat	6	2123.600	353.933	6.535	<0.001
Residual	24	1299.829	54.160		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.985

Table 149. Aboveground biomass (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.065)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.118	0.0295	3.923	0.014
Treat	6	0.752	0.125	16.653	<0.001
Residual	24	0.181	0.00753		
Total	34	1.051	0.0309		

Power of performed test with alpha = 0.0500: for Rep : 0.697
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 150. Aboveground biomass (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.169)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.103	0.0258	5.961	0.002
Treat	6	0.282	0.0470	10.846	<0.001
Residual	24	0.104	0.00433		
Total	34	0.489	0.0144		

Power of performed test with alpha = 0.0500: for Rep : 0.923
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 151. Aboveground biomass (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1051.143	262.786	5.950	0.002
Treat	6	1458.800	243.133	5.505	0.001
Residual	24	1060.057	44.169		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.923
Power of performed test with alpha = 0.0500: for Treat : 0.955

Table 152. Aboveground biomass (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.138)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	189.143	47.286	0.941	0.457
Treat	6	2175.200	362.533	7.217	<0.001
Residual	24	1205.657	50.236		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.993

Table 153. Aboveground biomass (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.136)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	423.071	105.768	1.381	0.270
Treat	6	1308.200	218.033	2.847	0.031
Residual	24	1837.729	76.572		
Total	34	3569.000	104.971		

Power of performed test with alpha = 0.0500: for Rep : 0.120
Power of performed test with alpha = 0.0500: for Treat : 0.566

Table 154. Aboveground biomass ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.074)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0956	0.0239	1.868	0.149
Treat	6	0.114	0.0190	1.487	0.225
Residual	24	0.307	0.0128		
Total	34	0.517	0.0152		

Power of performed test with alpha = 0.0500: for Rep : 0.230
Power of performed test with alpha = 0.0500: for Treat : 0.161

Table 155. Belowground biomass (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1429.714	357.429	5.237	0.004
Treat	6	502.400	83.733	1.227	0.327
Residual	24	1637.886	68.245		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.870
Power of performed test with alpha = 0.0500: for Treat : 0.0964

Table 156. Belowground biomass (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.131)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.391	0.0978	2.408	0.077
Treat	6	0.417	0.0696	1.712	0.161
Residual	24	0.975	0.0406		
Total	34	1.784	0.0525		

Power of performed test with alpha = 0.0500: for Rep : 0.364
Power of performed test with alpha = 0.0500: for Treat : 0.225

Table 157. Belowground biomass (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.126)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.310	0.0774	4.909	0.005
Treat	6	0.204	0.0341	2.160	0.083
Residual	24	0.379	0.0158		
Total	34	0.893	0.0263		

Power of performed test with alpha = 0.0500: for Rep : 0.837
Power of performed test with alpha = 0.0500: for Treat : 0.362

Table 158. Belowground biomass (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.233	0.0582	3.904	0.014
Treat	6	0.0791	0.0132	0.884	0.522
Residual	24	0.358	0.0149		
Total	34	0.670	0.0197		

Power of performed test with alpha = 0.0500: for Rep : 0.694
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 159. Belowground biomass (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.051)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.574	0.144	6.396	0.001
Treat	6	0.0704	0.0117	0.523	0.785
Residual	24	0.539	0.0224		
Total	34	1.183	0.0348		

Power of performed test with alpha = 0.0500: for Rep : 0.945
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 160. Belowground biomass (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.015)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.562	0.140	3.720	0.017
Treat	6	0.189	0.0316	0.837	0.554
Residual	24	0.906	0.0377		
Total	34	1.657	0.0487		

Power of performed test with alpha = 0.0500: for Rep : 0.660
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 161. Belowground biomass (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.136)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.198	0.0496	3.970	0.013
Treat	6	0.0357	0.00595	0.476	0.819
Residual	24	0.300	0.0125		
Total	34	0.534	0.0157		

Power of performed test with alpha = 0.0500: for Rep : 0.705
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 162. Belowground biomass (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.269	0.0672	8.209	<0.001
Treat	6	0.0500	0.00833	1.018	0.437
Residual	24	0.196	0.00818		
Total	34	0.515	0.0152		

Power of performed test with alpha = 0.0500: for Rep : 0.988
Power of performed test with alpha = 0.0500: for Treat : 0.0532

Table 163. Belowground biomass ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.305	0.0762	6.774	<0.001
Treat	6	0.0367	0.00611	0.544	0.770
Residual	24	0.270	0.0112		
Total	34	0.611	0.0180		

Power of performed test with alpha = 0.0500: for Rep : 0.960
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 164. Belowground biomass (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.129	0.0323	5.073	0.004
Treat	6	0.0290	0.00484	0.761	0.607
Residual	24	0.153	0.00636		
Total	34	0.311	0.00914		

Power of performed test with alpha = 0.0500: for Rep : 0.854
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 165. Belowground biomass (Tacoma): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.163)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.201	0.0501	11.500	<0.001
Treat	6	0.0791	0.0132	3.024	0.024
Residual	24	0.105	0.00436		
Total	34	0.384	0.0113		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.613

Table 166. Belowground biomass (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.032)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0989	0.0247	3.674	0.018
Treat	6	0.0387	0.00645	0.959	0.473
Residual	24	0.161	0.00673		
Total	34	0.299	0.00879		

Power of performed test with alpha = 0.0500: for Rep : 0.651
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 167. Belowground biomass (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.118	0.0294	5.651	0.002
Treat	6	0.0701	0.0117	2.247	0.073
Residual	24	0.125	0.00520		
Total	34	0.312	0.00919		

Power of performed test with alpha = 0.0500: for Rep : 0.903
Power of performed test with alpha = 0.0500: for Treat : 0.389

Table 168. Belowground biomass (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.081)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0885	0.0221	12.185	<0.001
Treat	6	0.0243	0.00405	2.230	0.075
Residual	24	0.0436	0.00182		
Total	34	0.156	0.00460		

Power of performed test with alpha = 0.0500: for Rep : 1.000
Power of performed test with alpha = 0.0500: for Treat : 0.383

Table 169. Belowground biomass (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1581.429	395.357	6.022	0.002
Treat	6	412.800	68.800	1.048	0.420
Residual	24	1575.771	65.657		
Total	34	3570.000	105.000		

Power of performed test with alpha = 0.0500: for Rep : 0.927
Power of performed test with alpha = 0.0500: for Treat : 0.0587

Table 170. Belowground biomass (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.036)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.101	0.0252	4.610	0.007
Treat	6	0.0491	0.00819	1.498	0.221
Residual	24	0.131	0.00546		
Total	34	0.281	0.00827		

Power of performed test with alpha = 0.0500: for Rep : 0.801
Power of performed test with alpha = 0.0500: for Treat : 0.164

Table 171. Belowground biomass (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.010)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0817	0.0204	3.347	0.026
Treat	6	0.0174	0.00291	0.477	0.819
Residual	24	0.146	0.00610		
Total	34	0.246	0.00722		

Power of performed test with alpha = 0.0500: for Rep : 0.585
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 172. Belowground biomass ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.091)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0686	0.0172	8.248	<0.001
Treat	6	0.0193	0.00321	1.545	0.207
Residual	24	0.0499	0.00208		
Total	34	0.138	0.00405		

Power of performed test with alpha = 0.0500: for Rep : 0.989
Power of performed test with alpha = 0.0500: for Treat : 0.177

Table 173. Aboveground height (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.052)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	26723.029	6680.757	2.684	0.056
Treat	6	58593.086	9765.514	3.923	0.007
Residual	24	59743.771	2489.324		
Total	34	145059.886	4266.467		

Power of performed test with alpha = 0.0500: for Rep : 0.432
Power of performed test with alpha = 0.0500: for Treat : 0.803

Table 174. Aboveground height (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	45201.429	11300.357	3.644	0.019
Treat	6	37771.486	6295.248	2.030	0.101
Residual	24	74435.371	3101.474		
Total	34	157408.286	4629.655		

Power of performed test with alpha = 0.0500: for Rep : 0.645
Power of performed test with alpha = 0.0500: for Treat : 0.321

Table 175. Aboveground height (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.182)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	31727.029	7931.757	1.570	0.214
Treat	6	64636.686	10772.781	2.132	0.087
Residual	24	121252.171	5052.174		
Total	34	217615.886	6400.467		

Power of performed test with alpha = 0.0500: for Rep : 0.161
Power of performed test with alpha = 0.0500: for Treat : 0.353

Table 176. Aboveground height (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	25898.457	6474.614	1.706	0.181
Treat	6	37753.943	6292.324	1.658	0.175
Residual	24	91076.343	3794.848		
Total	34	154728.743	4550.845		

Power of performed test with alpha = 0.0500: for Rep : 0.192
Power of performed test with alpha = 0.0500: for Treat : 0.209

Table 177. Aboveground height (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	23852.971	5963.243	2.011	0.125
Treat	6	48734.000	8122.333	2.740	0.036
Residual	24	71157.429	2964.893		
Total	34	143744.400	4227.776		

Power of performed test with alpha = 0.0500: for Rep : 0.265
Power of performed test with alpha = 0.0500: for Treat : 0.536

Table 178. Aboveground height (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.018)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	16872.400	4218.100	2.277	0.091
Treat	6	58650.743	9775.124	5.278	0.001
Residual	24	44452.400	1852.183		
Total	34	119975.543	3528.692		

Power of performed test with alpha = 0.0500: for Rep : 0.331
Power of performed test with alpha = 0.0500: for Treat : 0.943

Table 179. Aboveground height (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.026)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	15964.857	3991.214	1.381	0.270
Treat	6	39788.171	6631.362	2.294	0.068
Residual	24	69367.543	2890.314		
Total	34	125120.571	3680.017		

Power of performed test with alpha = 0.0500: for Rep : 0.120
Power of performed test with alpha = 0.0500: for Treat : 0.403

Table 180. Aboveground height (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	56539.143	14134.786	5.591	0.003
Treat	6	32978.171	5496.362	2.174	0.081
Residual	24	60671.257	2527.969		
Total	34	150188.571	4417.311		

Power of performed test with alpha = 0.0500: for Rep : 0.899
Power of performed test with alpha = 0.0500: for Treat : 0.366

Table 181. Aboveground height ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.094)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	20094.686	5023.671	1.866	0.149
Treat	6	75966.343	12661.057	4.704	0.003
Residual	24	64596.514	2691.521		
Total	34	160657.543	4725.222		

Power of performed test with alpha = 0.0500: for Rep : 0.230
Power of performed test with alpha = 0.0500: for Treat : 0.901

Table 182. Aboveground height (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	30403.257	7600.814	4.369	0.009
Treat	6	27994.743	4665.790	2.682	0.039
Residual	24	41757.543	1739.898		
Total	34	100155.543	2945.751		

Power of performed test with alpha = 0.0500: for Rep : 0.768
Power of performed test with alpha = 0.0500: for Treat : 0.519

Table 183. Aboveground height (Tacoma): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	27098.686	6774.671	3.998	0.013
Treat	6	16093.771	2682.295	1.583	0.195
Residual	24	40670.514	1694.605		
Total	34	83862.971	2466.558		

Power of performed test with alpha = 0.0500: for Rep : 0.710
Power of performed test with alpha = 0.0500: for Treat : 0.188

Table 184. Aboveground height (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	9607.257	2401.814	0.960	0.447
Treat	6	33259.143	5543.190	2.216	0.077
Residual	24	60031.143	2501.298		
Total	34	102897.543	3026.398		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.379

Table 185. Aboveground height (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.079)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	25232.743	6308.186	2.468	0.072
Treat	6	40991.886	6831.981	2.673	0.039
Residual	24	61333.257	2555.552		
Total	34	127557.886	3751.703		

Power of performed test with alpha = 0.0500: for Rep : 0.379
Power of performed test with alpha = 0.0500: for Treat : 0.517

Table 186. Aboveground height (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.083)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	49464.571	12366.143	4.125	0.011
Treat	6	14956.571	2492.762	0.831	0.557
Residual	24	71955.429	2998.143		
Total	34	136376.571	4011.076		

Power of performed test with alpha = 0.0500: for Rep : 0.731
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 187. Aboveground height (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	22557.314	5639.329	2.485	0.071
Treat	6	10901.886	1816.981	0.801	0.579
Residual	24	54454.686	2268.945		
Total	34	87913.886	2585.703		

Power of performed test with alpha = 0.0500: for Rep : 0.383
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 188. Aboveground height (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	24815.543	6203.886	2.320	0.086
Treat	6	36519.371	6086.562	2.276	0.070
Residual	24	64172.057	2673.836		
Total	34	125506.971	3691.382		

Power of performed test with alpha = 0.0500: for Rep : 0.342
Power of performed test with alpha = 0.0500: for Treat : 0.398

Table 189. Aboveground height (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.029)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	20261.429	5065.357	3.961	0.013
Treat	6	25687.200	4281.200	3.348	0.015
Residual	24	30689.371	1278.724		
Total	34	76638.000	2254.059		

Power of performed test with alpha = 0.0500: for Rep : 0.704
Power of performed test with alpha = 0.0500: for Treat : 0.692

Table 190. Aboveground height ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	33166.000	8291.500	5.251	0.003
Treat	6	10974.971	1829.162	1.158	0.361
Residual	24	37897.600	1579.067		
Total	34	82038.571	2412.899		

Power of performed test with alpha = 0.0500: for Rep : 0.871
Power of performed test with alpha = 0.0500: for Treat : 0.0812

Table 191. Number of roots (5 cm) (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.152)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5405.829	1351.457	4.395	0.008
Treat	6	2012.286	335.381	1.091	0.396
Residual	24	7380.571	307.524		
Total	34	14798.686	435.255		

Power of performed test with alpha = 0.0500: for Rep : 0.772
Power of performed test with alpha = 0.0500: for Treat : 0.0671

Table 192. Number of roots (5 cm) (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1010.857	252.714	3.140	0.033
Treat	6	614.800	102.467	1.273	0.306
Residual	24	1931.343	80.473		
Total	34	3557.000	104.618		

Power of performed test with alpha = 0.0500: for Rep : 0.539
Power of performed test with alpha = 0.0500: for Treat : 0.107

Table 193. Number of roots (5 cm) (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	3084.971	771.243	2.411	0.077
Treat	6	2897.143	482.857	1.509	0.218
Residual	24	7677.429	319.893		
Total	34	13659.543	401.751		

Power of performed test with alpha = 0.0500: for Rep : 0.364
Power of performed test with alpha = 0.0500: for Treat : 0.168

Table 194. Number of roots (5 cm) (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.021)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	4909.429	1227.357	3.752	0.017
Treat	6	2314.686	385.781	1.179	0.350
Residual	24	7850.171	327.090		
Total	34	15074.286	443.361		

Power of performed test with alpha = 0.0500: for Rep : 0.666
Power of performed test with alpha = 0.0500: for Treat : 0.0858

Table 195. Number of roots (5 cm) (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-).
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1247.357	311.839	4.533	0.007
Treat	6	649.100	108.183	1.573	0.198
Residual	24	1651.043	68.793		
Total	34	3547.500	104.338		

Power of performed test with alpha = 0.0500: for Rep : 0.791
Power of performed test with alpha = 0.0500: for Treat : 0.185

Table 196. Number of roots (5 cm) (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.056)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	419.143	104.786	1.125	0.368
Treat	6	830.200	138.367	1.486	0.225
Residual	24	2235.157	93.132		
Total	34	3484.500	102.485		

Power of performed test with alpha = 0.0500: for Rep : 0.0709
Power of performed test with alpha = 0.0500: for Treat : 0.161

Table 197. Number of roots (5 cm) (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1678.500	419.625	8.542	<0.001
Treat	6	639.500	106.583	2.170	0.082
Residual	24	1179.000	49.125		
Total	34	3497.000	102.853		

Power of performed test with alpha = 0.0500: for Rep : 0.991
Power of performed test with alpha = 0.0500: for Treat : 0.365

Table 198. Number of roots (5 cm) (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1687.029	421.757	4.537	0.007
Treat	6	819.886	136.648	1.470	0.230
Residual	24	2230.971	92.957		
Total	34	4737.886	139.350		

Power of performed test with alpha = 0.0500: for Rep : 0.792
Power of performed test with alpha = 0.0500: for Treat : 0.157

Table 199. Number of roots (5 cm) ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	4485.829	1121.457	3.674	0.018
Treat	6	1791.143	298.524	0.978	0.461
Residual	24	7326.571	305.274		
Total	34	13603.543	400.104		

Power of performed test with alpha = 0.0500: for Rep : 0.651
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 200. Number of roots (5 cm) (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1965.886	491.471	4.295	0.009
Treat	6	755.486	125.914	1.100	0.391
Residual	24	2746.514	114.438		
Total	34	5467.886	160.820		

Power of performed test with alpha = 0.0500: for Rep : 0.757
Power of performed test with alpha = 0.0500: for Treat : 0.0691

Table 201. Number of roots (5 cm) (Tacoma): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.016)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1427.886	356.971	3.637	0.019
Treat	6	2060.571	343.429	3.499	0.013
Residual	24	2355.714	98.155		
Total	34	5844.171	171.887		

Power of performed test with alpha = 0.0500: for Rep : 0.644
Power of performed test with alpha = 0.0500: for Treat : 0.724

Table 202. Number of roots (5 cm) (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.091)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	404.457	101.114	1.095	0.381
Treat	6	586.171	97.695	1.058	0.414
Residual	24	2215.543	92.314		
Total	34	3206.171	94.299		

Power of performed test with alpha = 0.0500: for Rep : 0.0656
Power of performed test with alpha = 0.0500: for Treat : 0.0607

Table 203. Number of roots (5 cm) (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.040)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1007.314	251.829	1.543	0.222
Treat	6	2405.543	400.924	2.457	0.054
Residual	24	3915.886	163.162		
Total	34	7328.743	215.551		

Power of performed test with alpha = 0.0500: for Rep : 0.155
Power of performed test with alpha = 0.0500: for Treat : 0.453

Table 204. Number of roots (5 cm) (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.064)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1410.000	352.500	3.876	0.014
Treat	6	1100.343	183.390	2.016	0.103
Residual	24	2182.800	90.950		
Total	34	4693.143	138.034		

Power of performed test with alpha = 0.0500: for Rep : 0.689
Power of performed test with alpha = 0.0500: for Treat : 0.317

Table 205. Number of roots (5 cm) (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-Data-)
Normality Test: Passed (P = 0.082)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	873.071	218.268	2.114	0.110
Treat	6	160.400	26.733	0.259	0.951
Residual	24	2477.529	103.230		
Total	34	3511.000	103.265		

Power of performed test with alpha = 0.0500: for Rep : 0.290
Power of performed test with alpha = 0.0500: for Treat : 0.0500

Table 206. Number of roots (5 cm) (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.116)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1966.114	491.529	4.261	0.010
Treat	6	1347.886	224.648	1.947	0.114
Residual	24	2768.686	115.362		
Total	34	6082.686	178.903		

Power of performed test with alpha = 0.0500: for Rep : 0.752
Power of performed test with alpha = 0.0500: for Treat : 0.296

Table 207. Number of roots (5 cm) (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.027)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	2064.857	516.214	4.259	0.010
Treat	6	1234.400	205.733	1.698	0.165
Residual	24	2908.743	121.198		
Total	34	6208.000	182.588		

Power of performed test with alpha = 0.0500: for Rep : 0.752
Power of performed test with alpha = 0.0500: for Treat : 0.221

Table 208. Number of roots (5 cm) ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Data
Normality Test: Passed (P = 0.082)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1701.257	425.314	5.489	0.003
Treat	6	638.743	106.457	1.374	0.265
Residual	24	1859.543	77.481		
Total	34	4199.543	123.516		

Power of performed test with alpha = 0.0500: for Rep : 0.891
Power of performed test with alpha = 0.0500: for Treat : 0.132

Table 209. Measured pH (Greymont): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P = 0.019)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	5.066E-016	1.266E-016	4.670	0.006
Treat	6	7.126E-016	1.188E-016	4.379	0.004
Residual	24	6.509E-016	2.712E-017		
Total	34	1.870E-015	5.500E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.809
Power of performed test with alpha = 0.0500: for Treat : 0.866

Table 210. Measured pH (Tacoma): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	4.623E-016	1.156E-016	4.976	0.005
Treat	6	1.830E-015	3.050E-016	13.129	<0.001
Residual	24	5.575E-016	2.323E-017		
Total	34	2.850E-015	8.381E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.844
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 211. Measured pH (MT Limestone): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.960E-016	4.901E-017	3.952	0.013
Treat	6	6.202E-016	1.034E-016	8.335	<0.001
Residual	24	2.976E-016	1.240E-017		
Total	34	1.114E-015	3.276E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.702
Power of performed test with alpha = 0.0500: for Treat : 0.998

Table 212. Measured pH (Holnam CH_4): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: ln(-H+-)
Normality Test: Passed (P = 0.061)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.039	0.260	1.750	0.172
Treat	6	14.524	2.421	16.306	<0.001
Residual	24	3.563	0.148		
Total	34	19.126	0.563		

Power of performed test with alpha = 0.0500: for Rep : 0.202
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 213. Measured pH (Holnam coal,coke): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: log10(-H+-)
Normality Test: Passed (P = 0.052)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.054	0.264	3.558	0.020
Treat	6	3.028	0.505	6.813	<0.001
Residual	24	1.778	0.0741		
Total	34	5.860	0.172		

Power of performed test with alpha = 0.0500: for Rep : 0.629
Power of performed test with alpha = 0.0500: for Treat : 0.989

Table 214. Measured pH (Ash Grove): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P = 0.013)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.253E-016	3.133E-017	2.035	0.121
Treat	6	1.820E-015	3.033E-016	19.700	<0.001
Residual	24	3.695E-016	1.540E-017		
Total	34	2.315E-015	6.808E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.271
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 215. Measured pH (Dicalcium Silicate): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P = 0.090)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	331.071	82.768	1.069	0.394
Treat	6	1296.900	216.150	2.791	0.033
Residual	24	1858.529	77.439		
Total	34	3486.500	102.544		

Power of performed test with alpha = 0.0500: for Rep : 0.0610
Power of performed test with alpha = 0.0500: for Treat : 0.551

Table 216. Measured pH (Carbide Lime): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P = 0.036)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	3.718E-016	9.294E-017	2.892	0.044
Treat	6	2.412E-016	4.021E-017	1.251	0.316
Residual	24	7.712E-016	3.213E-017		
Total	34	1.384E-015	4.071E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.482
Power of performed test with alpha = 0.0500: for Treat : 0.102

Table 217. Measured pH ($CaCO_3$/CaO): Basin Wildrye.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-H+-)
Normality Test: Passed (P = 0.012)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.00000000410	0.00000000102	2.315	0.087
Treat	6	0.0000000272	0.00000000453	10.237	<0.001
Residual	24	0.0000000106	0.000000000442		
Total	34	0.0000000419	0.00000000123		

Power of performed test with alpha = 0.0500: for Rep : 0.340
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 218. Measured pH (Greymont): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: Col 4
Normality Test: Passed (P = 0.020)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.432E-016	3.580E-017	1.128	0.367
Treat	6	1.898E-015	3.163E-016	9.963	<0.001
Residual	24	7.619E-016	3.175E-017		
Total	34	2.803E-015	8.243E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.0713
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 219. Measured pH (Tacoma): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.0000000101	0.00000000254	3.465	0.023
Treat	6	0.0000000227	0.00000000378	5.173	0.002
Residual	24	0.0000000176	0.000000000732		
Total	34	0.0000000504	0.00000000148		

Power of performed test with alpha = 0.0500: for Rep : 0.610
Power of performed test with alpha = 0.0500: for Treat : 0.937

Table 220. Measured pH (MT Limestone): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-H+-)
Normality Test: Passed (P = 0.015)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.00000000410	0.00000000102	2.155	0.105
Treat	6	0.0000000106	0.00000000176	3.701	0.010
Residual	24	0.0000000114	0.000000000476		
Total	34	0.0000000261	0.000000000767		

Power of performed test with alpha = 0.0500: for Rep : 0.300
Power of performed test with alpha = 0.0500: for Treat : 0.764

Table 221. Measured pH (Holnam CH_4): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	159.357	39.839	0.941	0.457
Treat	6	2332.900	388.817	9.187	<0.001
Residual	24	1015.743	42.323		
Total	34	3508.000	103.176		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.999

Table 222. Measured pH (Holnam coal,coke): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	292.714	73.179	5.504	0.003
Treat	6	2881.700	480.283	36.124	<0.001
Residual	24	319.086	13.295		
Total	34	3493.500	102.750		

Power of performed test with alpha = 0.0500: for Rep : 0.893
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 223. Measured pH (Ash Grove): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P = 0.015)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	6.719E-017	1.680E-017	0.744	0.572
Treat	6	1.322E-015	2.204E-016	9.756	<0.001
Residual	24	5.422E-016	2.259E-017		
Total	34	1.932E-015	5.682E-017		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 1.000

Table 224. Measured pH (Dicalcium Silicate): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: sqrt(-H+-)
Normality Test: Passed (P >0.200)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	0.00000000179	0.000000000446	0.817	0.527
Treat	6	0.0000000222	0.00000000371	6.786	<0.001
Residual	24	0.0000000131	0.000000000546		
Total	34	0.0000000371	0.00000000109		

Power of performed test with alpha = 0.0500: for Rep : 0.0500
Power of performed test with alpha = 0.0500: for Treat : 0.989

Table 225. Measured pH (Carbide Lime): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: H+
Normality Test: Passed (P = 0.180)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	1.420E-015	3.550E-016	5.037	0.004
Treat	6	1.990E-015	3.317E-016	4.706	0.003
Residual	24	1.692E-015	7.048E-017		
Total	34	5.101E-015	1.500E-016		

Power of performed test with alpha = 0.0500: for Rep : 0.851
Power of performed test with alpha = 0.0500: for Treat : 0.901

Table 226. Measured pH ($CaCO_3$/CaO): Redtop.

Two Way Analysis of Variance
General Linear Model (No Interactions)
Dependent Variable: rank(-H+-)
Normality Test: Passed (P = 0.080)
Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Rep	4	510.929	127.732	3.014	0.038
Treat	6	1993.000	332.167	7.838	<0.001
Residual	24	1017.071	42.378		
Total	34	3521.000	103.559		

Power of performed test with alpha = 0.0500: for Rep : 0.511
Power of performed test with alpha = 0.0500: for Treat : 0.997

Linear Regression Results for Harvest Plant Response Variables in Plant Growth Center Soil With Increasing Application Rate of Alkaline Industrial By-Products.

Table 227. Measured soil pH vs. aboveground biomass (Greymont): Basin Wildrye.

Linear Regression
AboveGBW = 0.217 + (7618400.663 * H+)
N = 35.000
R = 0.383 Rsqr = 0.147 Adj Rsqr = 0.121
Standard Error of Estimate = 0.138

	Coefficient	Std. Error	t	P
Constant	0.217	0.0447	4.863	<0.001
H+	7618400.663	3194638.177	2.385	0.023

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.109	0.109	5.687	0.023
Residual	33	0.630	0.0191		
Total	34	0.738	0.0217		

Normality Test: Passed (P = 0.043)
Constant Variance Test: Passed (P = 0.139)
Power of performed test with alpha = 0.050: 0.628

Table 228. Measured soil pH vs. aboveground biomass (Tacoma): Basin Wildrye.

Linear Regression
rank(-AboveTBW- = 15.313 + (194247529.313 * H+)
N = 35.000
R = 0.174 Rsqr = 0.0301 Adj Rsqr = 0.000727
Standard Error of Estimate = 10.243

	Coefficient	Std. Error	t	P
Constant	15.313	3.169	4.831	<0.001
H+	194247529.313	191888582.073	1.012	0.319

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	107.519	107.519	1.025	0.319
Residual	33	3462.481	104.924		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.336)
Constant Variance Test: Passed (P = 0.776)
Power of performed test with alpha = 0.050: 0.166

Table 229. Measured soil pH vs. aboveground biomass (MT Limestone): Basin Wildrye.

Linear Regression
AboveMTBW = 0.0529 + (18746798.863 * H+)
N = 35.000
R = 0.594 Rsqr = 0.353 Adj Rsqr = 0.334
Standard Error of Estimate = 0.147

	Coefficient	Std. Error	t	P
Constant	0.0529	0.0518	1.022	0.314
H+	18746798.863	4416941.448	4.244	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.391	0.391	18.014	<0.001
Residual	33	0.717	0.0217		
Total	34	1.109	0.0326		

Normality Test: Passed (P = 0.040)
Constant Variance Test: Passed (P = 0.293)
Power of performed test with alpha = 0.050: 0.972

Table 230. Measured soil pH vs. aboveground biomass (Holnam CH_4): Basin Wildrye.

Linear Regression
AboveH1BW = 0.190 + (12087682.211 * H+)
N = 35.000
R = 0.651 Rsqr = 0.424 Adj Rsqr = 0.407
Standard Error of Estimate = 0.114

	Coefficient	Std. Error	t	P
Constant	0.190	0.0261	7.298	<0.001
H+	12087682.211	2450528.043	4.933	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.314	0.314	24.331	<0.001
Residual	33	0.425	0.0129		
Total	34	0.739	0.0217		

Normality Test: Passed (P = 0.043)
Constant Variance Test: Passed (P = 0.133)
Power of performed test with alpha = 0.050: 0.993

Table 231. Measured soil pH vs. aboveground biomass (Holnam coal,coke): Basin Wildrye.

Linear Regression
rank(-AboveH2BW = 18.414 - (36225517.955 * H+)
N = 35.000
R = 0.0675 Rsqr = 0.00456 Adj Rsqr = 0.000
Standard Error of Estimate = 10.377

	Coefficient	Std. Error	t	P
Constant	18.414	2.052	8.975	<0.001
H+	-36225517.955	93143688.852	-0.389	0.700

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	16.289	16.289	0.151	0.700
Residual	33	3553.711	107.688		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.835)
Constant Variance Test: Passed (P = 0.052)
Power of performed test with alpha = 0.050: 0.057

Table 232. Measured soil pH vs. aboveground biomass (Ash Grove): Basin Wildrye.

Linear Regression
AboveABW = 0.253 + (10946856.352 * H+)
N = 35.000
R = 0.531 Rsqr = 0.282 Adj Rsqr = 0.260
Standard Error of Estimate = 0.146

	Coefficient	Std. Error	t	P
Constant	0.253	0.0395	6.401	<0.001
H+	10946856.352	3040978.320	3.600	0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.277	0.277	12.958	0.001
Residual	33	0.706	0.0214		
Total	34	0.984	0.0289		

Normality Test: Passed (P = 0.204)
Constant Variance Test: Passed (P = 0.457)
Power of performed test with alpha = 0.050: 0.917

Table 233. Measured soil pH vs. aboveground biomass (Dicalcium Silicate): Basin Wildrye.

Linear Regression
rank(-AboveDBW- = 9.724 + (864251010.779 * H+)
N = 35.000
R = 0.548 Rsqr = 0.300 Adj Rsqr = 0.279
Standard Error of Estimate = 8.703

	Coefficient	Std. Error	t	P
Constant	9.724	2.648	3.673	<0.001
H+	864251010.779	229925687.767	3.759	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	1070.254	1070.254	14.129	<0.001
Residual	33	2499.746	75.750		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.227)
Constant Variance Test: Passed (P = 0.314)
Power of performed test with alpha = 0.050: 0.936

Table 234. Measured soil pH vs. aboveground biomass (Carbide Lime): Basin Wildrye.

Linear Regression
AboveCLBW = 0.148 + (4745720.665 * H+)
N = 35.000
R = 0.280 Rsqr = 0.0782 Adj Rsqr = 0.0503
Standard Error of Estimate = 0.106

	Coefficient	Std. Error	t	P
Constant	0.148	0.0365	4.049	<0.001
H+	4745720.665	2836037.201	1.673	0.104

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0312	0.0312	2.800	0.104
Residual	33	0.367	0.0111		
Total	34	0.399	0.0117		

Normality Test: Passed (P = 0.185)
Constant Variance Test: Passed (P = 0.018)
Power of performed test with alpha = 0.050: 0.369

Table 235. Measured soil pH vs. aboveground biomass ($CaCO_3$/CaO): Basin Wildrye.

Linear Regression
AboveCCBW = 0.121 + (9614847.551 * H+)
N = 35.000
R = 0.578 Rsqr = 0.334 Adj Rsqr = 0.314
Standard Error of Estimate = 0.129

	Coefficient	Std. Error	t	P
Constant	0.121	0.0348	3.488	0.001
H+	9614847.551	2361770.499	4.071	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.274	0.274	16.573	<0.001
Residual	33	0.546	0.0165		
Total	34	0.819	0.0241		

Normality Test: Passed (P = 0.054)
Constant Variance Test: Passed (P = 0.572)
Power of performed test with alpha = 0.050: 0.962

Table 236. Measured soil pH vs. aboveground biomass (Greymont): Redtop.

Linear Regression
rank(-AboveGRT- = 14.521 + (261022962.367 * H+)
N = 35.000
R = 0.231 Rsqr = 0.0535 Adj Rsqr = 0.0248
Standard Error of Estimate = 10.119

	Coefficient	Std. Error	t	P
Constant	14.521	3.069	4.732	<0.001
H+	261022962.367	191141633.918	1.366	0.181

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	190.953	190.953	1.865	0.181
Residual	33	3379.047	102.395		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.866)
Constant Variance Test: Passed (P = 0.928)
Power of performed test with alpha = 0.050: 0.265

Table 237. Measured soil pH vs. aboveground biomass (Tacoma): Redtop.

Linear Regression
rank(-AboveTRT- = 15.049 + (222130637.410 * H+)
N = 35.000
R = 0.217 Rsqr = 0.0471 Adj Rsqr = 0.0183
Standard Error of Estimate = 10.153

	Coefficient	Std. Error	t	P
Constant	15.049	2.877	5.230	<0.001
H+	222130637.410	173859754.327	1.278	0.210

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	168.269	168.269	1.632	0.210
Residual	33	3401.731	103.083		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.389)
Constant Variance Test: Passed (P = 0.970)
Power of performed test with alpha = 0.050: 0.238

Table 238. Measured soil pH vs. aboveground biomass (MT Limestone): Redtop.

Linear Regression
rank(-AboveMTRT = 15.385 + (211500577.929 * H+)
N = 35.000
R = 0.141 Rsqr = 0.0200 Adj Rsqr = 0.000
Standard Error of Estimate = 10.297

	Coefficient	Std. Error	t	P
Constant	15.385	3.631	4.237	<0.001
H+	211500577.929	257745209.458	0.821	0.418

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	71.388	71.388	0.673	0.418
Residual	33	3498.612	106.019		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.630)
Constant Variance Test: Passed (P = 0.540)
Power of performed test with alpha = 0.050: 0.124

Table 239. Measured soil pH vs. aboveground biomass (Holnam CH_4): Redtop.

Linear Regression
rank(-AboveH1RT = 14.471 + (352511648.726 * H+)
N = 35.000
R = 0.522 Rsqr = 0.272 Adj Rsqr = 0.250
Standard Error of Estimate = 8.872

	Coefficient	Std. Error	t	P
Constant	14.471	1.805	8.018	<0.001
H+	352511648.726	100289452.799	3.515	0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	972.481	972.481	12.355	0.001
Residual	33	2597.519	78.713		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.455)
Constant Variance Test: Passed (P = 0.239)
Power of performed test with alpha = 0.050: 0.906

Table 240. Measured soil pH vs. aboveground biomass (Holnam coal,coke): Redtop.

Linear Regression
AboveH2RT = 0.0814 + (6060361.013 * H+)
N = 35.000
R = 0.621 Rsqr = 0.385 Adj Rsqr = 0.366
Standard Error of Estimate = 0.096

	Coefficient	Std. Error	t	P
Constant	0.0814	0.0202	4.031	<0.001
H+	6060361.013	1333240.637	4.546	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.188	0.188	20.662	<0.001
Residual	33	0.301	0.00912		
Total	34	0.489	0.0144		

Normality Test: Passed (P = 0.029)
Constant Variance Test: Passed (P = 0.071)
Power of performed test with alpha = 0.050: 0.984

Table 241. Measured soil pH vs. aboveground biomass (Ash Grove): Redtop.

Linear Regression
rank(-AboveART- = 11.481 + (760572788.219 * H+)
N = 35.000
R = 0.559 Rsqr = 0.313 Adj Rsqr = 0.292
Standard Error of Estimate = 8.621

	Coefficient	Std. Error	t	P
Constant	11.481	2.225	5.160	<0.001
H+	760572788.219	196142050.210	3.878	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	1117.478	1117.478	15.036	<0.001
Residual	33	2452.522	74.319		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.294)
Constant Variance Test: Passed (P = 0.114)
Power of performed test with alpha = 0.050: 0.947

Table 242. Measured soil pH vs. aboveground biomass (Dicalcium Silicate): Redtop.

Linear Regression
rank(-AboveDRT- = 13.751 + (475322679.157 * H+)
N = 35.000
R = 0.395 Rsqr = 0.156 Adj Rsqr = 0.131
Standard Error of Estimate = 9.554

	Coefficient	Std. Error	t	P
Constant	13.751	2.358	5.831	<0.001
H+	475322679.157	192250481.203	2.472	0.019

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	557.945	557.945	6.113	0.019
Residual	33	3012.055	91.274		
Total	34	3570.000	105.000		

Normality Test: Passed (P = 0.627)
Constant Variance Test: Passed (P = 0.486)
Power of performed test with alpha = 0.050: 0.657

Table 243. Measured soil pH vs. aboveground biomass (Carbide Lime): Redtop.

Linear Regression
rank(-AboveCLRT = 16.517 + (99312658.366 * H+)
N = 35.000
R = 0.119 Rsqr = 0.0141 Adj Rsqr = 0.000
Standard Error of Estimate = 10.326

	Coefficient	Std. Error	t	P
Constant	16.517	2.776	5.950	<0.001
H+	99312658.366	144572636.910	0.687	0.497

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	50.316	50.316	0.472	0.497
Residual	33	3518.684	106.627		
Total	34	3569.000	104.971		

Normality Test: Passed (P = 0.581)
Constant Variance Test: Passed (P = 0.767)
Power of performed test with alpha = 0.050: 0.099

Table 244. Measured soil pH vs. aboveground biomass ($CaCO_3$/CaO): Redtop.

Linear Regression
rank(-AboveCCRT = 11.204 + (526506398.578 * H+)
N = 35.000
R = 0.476 Rsqr = 0.226 Adj Rsqr = 0.203
Standard Error of Estimate = 9.148

	Coefficient	Std. Error	t	P
Constant	11.204	2.678	4.183	<0.001
H+	526506398.578	169417711.080	3.108	0.004

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	808.158	808.158	9.658	0.004
Residual	33	2761.342	83.677		
Total	34	3569.500	104.985		

Normality Test: Passed (P = 0.765)
Constant Variance Test: Passed (P = 0.536)
Power of performed test with alpha = 0.050: 0.833

Table 245. Measured soil EC vs. aboveground biomass (Greymont): Basin Wildrye.

Linear Regression
Col 5 = 0.538 - (0.107 * Col 6)
N = 7.000
R = 0.741 Rsqr = 0.549 Adj Rsqr = 0.459
Standard Error of Estimate = 0.083

	Coefficient	Std. Error	t	P
Constant	0.538	0.108	4.971	0.004
Col 6	-0.107	0.0434	-2.469	0.057

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0424	0.0424	6.094	0.057
Residual	5	0.0348	0.00695		
Total	6	0.0771	0.0129		

Normality Test: Passed (P = 0.759)
Constant Variance Test: Passed (P = 0.545)
Power of performed test with alpha = 0.050: 0.478

Table 246. Measured soil EC vs. aboveground biomass (Tacoma): Basin Wildrye.

Linear Regression
Col 5 = 0.611 - (0.0997 * Col 6)
N = 7.000
R = 0.216 Rsqr = 0.0467 Adj Rsqr = 0.000
Standard Error of Estimate = 0.206

	Coefficient	Std. Error	t	P
Constant	0.611	0.287	2.127	0.087
Col 6	-0.0997	0.201	-0.495	0.642

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0104	0.0104	0.245	0.642
Residual	5	0.212	0.0423		
Total	6	0.222	0.0370		

Normality Test: Passed (P = 0.576)
Constant Variance Test: Passed (P = 0.720)
Power of performed test with alpha = 0.050: 0.064

Table 247. Measured soil EC vs. aboveground biomass (MT Limestone): Basin Wildrye.

Linear Regression
Col 5 = 0.882 - (0.229 * Col 6)
N = 7.000
R = 0.906 Rsqr = 0.821 Adj Rsqr = 0.785
Standard Error of Estimate = 0.111

	Coefficient	Std. Error	t	P
Constant	0.882	0.130	6.770	0.001
Col 6	-0.229	0.0479	-4.786	0.005

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.282	0.282	22.904	0.005
Residual	5	0.0616	0.0123		
Total	6	0.344	0.0573		

Normality Test: Passed (P = 0.553)
Constant Variance Test: Passed (P = 0.150)
Power of performed test with alpha = 0.050: 0.853

Table 248. Measured soil EC vs. aboveground biomass (Holnam CH_4): Basin Wildrye.

Linear Regression
Col 5 = 0.436 - (0.0409 * Col 6)
N = 7.000
R = 0.728 Rsqr = 0.529 Adj Rsqr = 0.435
Standard Error of Estimate = 0.100

	Coefficient	Std. Error	t	P
Constant	0.436	0.0706	6.172	0.002
Col 6	-0.0409	0.0173	-2.372	0.064

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0565	0.0565	5.624	0.064
Residual	5	0.0502	0.0100		
Total	6	0.107	0.0178		

Normality Test: Passed (P = 0.621)
Constant Variance Test: Passed (P = 0.073)
Power of performed test with alpha = 0.050: 0.455

Table 249. Measured soil EC vs. aboveground biomass (Holnam coal,coke): Basin Wildrye.

Linear Regression
Col 6 = 0.534 - (0.0604 * Col 7)
N = 7.000
R = 0.547 Rsqr = 0.299 Adj Rsqr = 0.158
Standard Error of Estimate = 0.161

	Coefficient	Std. Error	t	P
Constant	0.534	0.138	3.883	0.012
Col 7	-0.0604	0.0414	-1.459	0.204

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0555	0.0555	2.130	0.204
Residual	5	0.130	0.0261		
Total	6	0.186	0.0310		

Normality Test: Passed (P = 0.260)
Constant Variance Test: Passed (P = 0.438)
Power of performed test with alpha = 0.050: 0.232

Table 250. Measured soil EC vs. aboveground biomass (Ash Grove): Basin Wildrye.

Linear Regression
Col 5 = 0.529 - (0.00911 * Col 6)
N = 7.000
R = 0.426 Rsqr = 0.181 Adj Rsqr = 0.0177
Standard Error of Estimate = 0.120

	Coefficient	Std. Error	t	P
Constant	0.529	0.0841	6.293	0.001
Col 6	-0.00911	0.00866	-1.053	0.341

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0158	0.0158	1.108	0.341
Residual	5	0.0714	0.0143		
Total	6	0.0872	0.0145		

Normality Test: Passed (P = 0.599)
Constant Variance Test: Passed (P = 0.905)
Power of performed test with alpha = 0.050: 0.147

Table 251. Measured soil EC vs. aboveground biomass (Dicalcium Silicate): Basin Wildrye.

Linear Regression
Col 6 = 0.404 - (0.153 * Col 7)
N = 7.000
R = 0.350 Rsqr = 0.123 Adj Rsqr = 0.000
Standard Error of Estimate = 0.135

	Coefficient	Std. Error	t	P
Constant	0.404	0.200	2.024	0.099
Col 7	-0.153	0.183	-0.836	0.441

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0128	0.0128	0.699	0.441
Residual	5	0.0912	0.0182		
Total	6	0.104	0.0173		

Normality Test: Passed (P = 0.582)
Constant Variance Test: Passed (P = 0.181)
Power of performed test with alpha = 0.050: 0.110

Table 252. Measured soil EC vs. aboveground biomass (Carbide Lime): Basin Wildrye.

Linear Regression
Col 5 = 0.192 + (0.0585 * Col 6)
N = 7.000
R = 0.315 Rsqr = 0.0991 Adj Rsqr = 0.000
Standard Error of Estimate = 0.125

	Coefficient	Std. Error	t	P
Constant	0.192	0.135	1.419	0.215
Col 6	0.0585	0.0788	0.741	0.492

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.00857	0.00857	0.550	0.492
Residual	5	0.0779	0.0156		
Total	6	0.0865	0.0144		

Normality Test: Passed (P = 0.726)
Constant Variance Test: Passed (P = 0.181)
Power of performed test with alpha = 0.050: 0.095

Table 253. Measured soil EC vs. aboveground biomass ($CaCO_3$/CaO): Basin Wildrye.

Linear Regression
Col 5 = 0.734 - (0.324 * Col 6)
N = 7.000
R = 0.667 Rsqr = 0.445 Adj Rsqr = 0.335
Standard Error of Estimate = 0.153

	Coefficient	Std. Error	t	P
Constant	0.734	0.220	3.336	0.021
Col 6	-0.324	0.162	-2.004	0.101

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0941	0.0941	4.016	0.101
Residual	5	0.117	0.0234		
Total	6	0.211	0.0352		

Normality Test: Passed (P = 0.376)
Constant Variance Test: Passed (P = 0.843)
Power of performed test with alpha = 0.050: 0.364

Table 254. Measured soil EC vs. aboveground biomass (Greymont): Redtop.

Linear Regression
Col 6 = 1.616 - (0.492 * Col 7)
N = 7.000
R = 0.930 Rsqr = 0.864 Adj Rsqr = 0.837
Standard Error of Estimate = 0.168

	Coefficient	Std. Error	t	P
Constant	1.616	0.217	7.434	<0.001
Col 7	-0.492	0.0872	-5.640	0.002

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.893	0.893	31.807	0.002
Residual	5	0.140	0.0281		
Total	6	1.033	0.172		

Normality Test: Passed (P = 0.345)
Constant Variance Test: Passed (P = 0.388)
Power of performed test with alpha = 0.050: 0.912

Table 255. Measured soil EC vs. aboveground biomass (Tacoma): Redtop.

Linear Regression
Col 6 = 0.961 - (0.341 * Col 7)
N = 7.000
R = 0.444 Rsqr = 0.198 Adj Rsqr = 0.0370
Standard Error of Estimate = 0.314

	Coefficient	Std. Error	t	P
Constant	0.961	0.438	2.193	0.080
Col 7	-0.341	0.307	-1.109	0.318

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.121	0.121	1.231	0.318
Residual	5	0.493	0.0986		
Total	6	0.614	0.102		

Normality Test: Passed (P = 0.658)
Constant Variance Test: Passed (P = 0.905)
Power of performed test with alpha = 0.050: 0.158

Table 256. Measured soil EC vs. aboveground biomass (MT Limestone): Redtop.

Linear Regression
Col 6 = 0.476 - (0.116 * Col 7)
N = 7.000
R = 0.792 Rsqr = 0.627 Adj Rsqr = 0.552
Standard Error of Estimate = 0.093

	Coefficient	Std. Error	t	P
Constant	0.476	0.109	4.385	0.007
Col 7	-0.116	0.0400	-2.896	0.034

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0720	0.0720	8.389	0.034
Residual	5	0.0429	0.00858		
Total	6	0.115	0.0192		

Normality Test: Passed (P = 0.620)
Constant Variance Test: Passed (P = 0.545)
Power of performed test with alpha = 0.050: 0.576

Table 257. Measured soil EC vs. aboveground biomass (Holnam CH_4): Redtop.

Linear Regression
Col 5 = 0.429 - (0.0374 * Col 6)
N = 7.000
R = 0.701 Rsqr = 0.491 Adj Rsqr = 0.390
Standard Error of Estimate = 0.099

	Coefficient	Std. Error	t	P
Constant	0.429	0.0696	6.155	0.002
Col 6	-0.0374	0.0170	-2.198	0.079

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0472	0.0472	4.830	0.079
Residual	5	0.0488	0.00977		
Total	6	0.0960	0.0160		

Normality Test: Passed (P = 0.789)
Constant Variance Test: Passed (P = 0.014)
Power of performed test with alpha = 0.050: 0.412

Table 258. Measured soil EC vs. aboveground biomass (Holnam coal,coke): Redtop.

Linear Regression
Col 5 = 0.460 - (0.0783 * Col 6)
N = 7.000
R = 0.870 Rsqr = 0.757 Adj Rsqr = 0.708
Standard Error of Estimate = 0.077

	Coefficient	Std. Error	t	P
Constant	0.460	0.0660	6.963	<0.001
Col 6	-0.0783	0.0199	-3.942	0.011

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0933	0.0933	15.536	0.011
Residual	5	0.0300	0.00600		
Total	6	0.123	0.0205		

Normality Test: Passed (P = 0.690)
Constant Variance Test: Passed (P = 0.038)
Power of performed test with alpha = 0.050: 0.759

Table 259. Measured soil EC vs. aboveground biomass (Ash Grove): Redtop.

Linear Regression
Col 6 = 0.847 - (0.0509 * Col 7)
N = 7.000
R = 0.861 Rsqr = 0.741 Adj Rsqr = 0.689
Standard Error of Estimate = 0.186

	Coefficient	Std. Error	t	P
Constant	0.847	0.131	6.485	0.001
Col 7	-0.0509	0.0134	-3.781	0.013

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.493	0.493	14.297	0.013
Residual	5	0.172	0.0345		
Total	6	0.665	0.111		

Normality Test: Passed (P = 0.484)
Constant Variance Test: Passed (P = 0.843)
Power of performed test with alpha = 0.050: 0.736

Table 260. Measured soil EC vs. aboveground biomass (Dicalcium Silicate): Redtop.

Linear Regression
Col 6 = 0.979 - (0.664 * Col 7)
N = 7.000
R = 0.613 Rsqr = 0.376 Adj Rsqr = 0.251
Standard Error of Estimate = 0.282

	Coefficient	Std. Error	t	P
Constant	0.979	0.417	2.346	0.066
Col 7	-0.664	0.383	-1.736	0.143

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.240	0.240	3.013	0.143
Residual	5	0.398	0.0796		
Total	6	0.638	0.106		

Normality Test: Passed (P = 0.745)
Constant Variance Test: Passed (P = 0.096)
Power of performed test with alpha = 0.050: 0.297

Table 261. Measured soil EC vs. aboveground biomass (Carbide Lime): Redtop.

Linear Regression
Col 6 = 0.463 - (0.140 * Col 7)
N = 7.000
R = 0.438 Rsqr = 0.192 Adj Rsqr = 0.0304
Standard Error of Estimate = 0.204

	Coefficient	Std. Error	t	P
Constant	0.463	0.221	2.097	0.090
Col 7	-0.140	0.129	-1.090	0.325

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.0494	0.0494	1.188	0.325
Residual	5	0.208	0.0416		
Total	6	0.257	0.0429		

Normality Test: Passed (P = 0.649)
Constant Variance Test: Passed (P = 0.438)
Power of performed test with alpha = 0.050: 0.154

Table 262. Measured soil EC vs. aboveground biomass ($CaCO_3$/CaO): Redtop.

Linear Regression
Col 5 = 0.204 + (0.0216 * Col 6)
N = 7.000
R = 0.0555 Rsqr = 0.00308 Adj Rsqr = 0.000
Standard Error of Estimate = 0.164

	Coefficient	Std. Error	t	P
Constant	0.204	0.236	0.865	0.427
Col 6	0.0216	0.174	0.124	0.906

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	0.000417	0.000417	0.0154	0.906
Residual	5	0.135	0.0271		
Total	6	0.136	0.0226		

Normality Test: Passed (P = 0.586)
Constant Variance Test: Passed (P = 0.905)
Power of performed test with alpha = 0.050: 0.032

Table 263. Measured soil pH vs. aboveground biomass (all amendments): Basin Wildrye

Linear Regression
rank(-AboveBW-) = 131.552 + (2451423484.289 * (H+)BW)
N = 315.000
R = 0.261 Rsqr = 0.0679 Adj Rsqr = 0.0649
Standard Error of Estimate = 88.071

	Coefficient	Std. Error	t	P
Constant	131.552	7.437	17.689	<0.001
(H+)BW	2451423484.289	513429577.104	4.775	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	176825.034	176825.034	22.797	<0.001
Residual	313	2427801.466	7756.554		
Total	314	2604626.500	8294.989		

Normality Test: Passed (P = 0.200)
Constant Variance Test: Passed (P = 0.011)
Power of performed test with alpha = 0.050: 0.997

Table 264. Measured soil pH vs. aboveground biomass (all amendments): Redtop

Linear Regression
rank(-AboveRT-) = 127.890 + (2619923540.986 * (H+)RT)
N = 315.000
R = 0.303 Rsqr = 0.0915 Adj Rsqr = 0.0886
Standard Error of Estimate = 86.948

	Coefficient	Std. Error	t	P
Constant	127.890	7.263	17.608	<0.001
(H+)RT	2619923540.986	466562756.454	5.615	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	238381.049	238381.049	31.532	<0.001
Residual	313	2366240.951	7559.875		
Total	314	2604622.000	8294.975		

Normality Test: Passed (P = 0.472)
Constant Variance Test: Passed (P = 0.014)
Power of performed test with alpha = 0.050: 1.000

Table 265. Aboveground biomass vs. application rate (all amendments): Basin Wildrye

Linear Regression
rank(-AboveBW-) = 230.200 - (11.907 * Rate)
N = 315.000
R = 0.536 Rsqr = 0.287 Adj Rsqr = 0.285
Standard Error of Estimate = 77.008

	Coefficient	Std. Error	t	P
Constant	230.200	7.754	29.687	<0.001
Rate	-11.907	1.060	-11.234	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	748452.112	748452.112	126.209	<0.001
Residual	313	1856174.388	5930.270		
Total	314	2604626.500	8294.989		

Normality Test: Passed (P = 0.688)
Constant Variance Test: Passed (P = 0.393)
Power of performed test with alpha = 0.050: 1.000

Table 266 Aboveground biomass vs. application rate (all amendments): Redtop

Linear Regression
rank(-AboveRT-) = 232.045 - (12.212 * Rate)
N = 315.000
R = 0.550 Rsqr = 0.302 Adj Rsqr = 0.300
Standard Error of Estimate = 76.200

	Coefficient	Std. Error	t	P
Constant	232.045	7.673	30.242	<0.001
Rate	-12.212	1.049	-11.643	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	787187.319	787187.319	135.570	<0.001
Residual	313	1817434.681	5806.501		
Total	314	2604622.000	8294.975		

Normality Test: Passed (P = 0.884)
Constant Variance Test: Passed (P = 0.779)
Power of performed test with alpha = 0.050: 1.000

Table 267. Measured soil pH vs. application rate (all amendments): Basin Wildrye

Linear Regression
rank(-(H+)BW-) = 225.861 - (11.192 * Rate)
N = 315.000
R = 0.507 Rsqr = 0.257 Adj Rsqr = 0.254
Standard Error of Estimate = 78.224

	Coefficient	Std. Error	t	P
Constant	225.861	7.877	28.674	<0.001
Rate	-11.192	1.077	-10.395	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	661183.652	661183.652	108.054	<0.001
Residual	313	1915244.348	6118.992		
Total	314	2576428.000	8205.185		

Normality Test: Passed (P = 0.070)
Constant Variance Test: Passed (P = 0.313)
Power of performed test with alpha = 0.050: 1.000

Table 268. Measured soil pH vs. application rate (all amendments): Redtop

Linear Regression
rank(-(H+)RT-) = 229.501 - (11.792 * Rate)
N = 315.000
R = 0.533 Rsqr = 0.284 Adj Rsqr = 0.282
Standard Error of Estimate = 76.854

	Coefficient	Std. Error	t	P
Constant	229.501	7.739	29.656	<0.001
Rate	-11.792	1.058	-11.148	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	734019.147	734019.147	124.273	<0.001
Residual	313	1848732.853	5906.495		
Total	314	2582752.000	8225.325		

Normality Test: Passed (P = 0.098)
Constant Variance Test: Passed (P = 0.092)
Power of performed test with alpha = 0.050: 1.000

APPENDIX B

RAW DATA

Table 269. Number of days required for emergence in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	5	6	5	7	5	6	5	6	5	5	5	6	5	5	5	5	5	6	ND	ND
Contaminated Soil	5	8	5	5	5	6	5	6	6	5	5	7	5	5	5	7	5	6	8	5
PGC Soil	5	6	5	6	5	5	5	6	5	7	5	6	5	5	5	6	5	5	5	6
Replication 2																				
Tailings	6	6	5	6	6	10	5	6	5	7	5	6	5	6	5	7	5	6	ND	ND
Contaminated Soil	5	7	5	6	5	5	5	6	5	7	5	6	5	5	5	5	7	6	9	7
PGC Soil	5	6	5	7	5	6	5	7	5	5	5	5	5	7	5	6	5	6	5	5
Replication 3																				
Tailings	7	8	6	6	6	6	5	6	5	6	6	5	5	7	6	8	5	6	ND	ND
Contaminated Soil	5	5	5	6	5	6	5	5	7	5	5	6	5	6	5	5	5	5	7	7
PGC Soil	5	5	5	5	5	5	5	7	5	5	5	5	5	8	5	5	5	5	5	5
Replication 4																				
Tailings	6	9	8	7	8	7	8	8	7	8	6	9	7	6	5	6	7	8	ND	ND
Contaminated Soil	6	6	6	7	6	8	7	8	7	7	7	8	6	7	7	7	6	6	ND	7
PGC Soil	5	6	5	7	5	6	5	7	7	5	8	9	6	7	6	5	5	5	6	5
Replication 5																				
Tailings	7	6	9	8	6	7	6	7	6	7	7	7	6	7	6	7	5	6	ND	ND
Contaminated Soil	6	6	6	6	6	7	8	7	7	8	7	6	6	7	7	7	6	5	8	8
PGC Soil	6	6	6	6	6	6	5	5	9	6	5	6	5	6	5	6	5	7	5	5
Replication 6																				
Tailings	7	8	7	8	7	7	7	7	7	9	8	7	5	7	6	7	6	6	ND	ND
Contaminated Soil	6	7	6	7	6	7	5	7	6	7	6	7	6	7	6	7	5	2	ND	7
PGC Soil	5	6	5	7	6	8	5	6	5	6	5	7	5	7	6	5	5	6	5	5
Replication 7																				
Tailings	6	7	7	7	7	7	6	5	6	6	7	7	6	7	6	7	6	6	ND	ND
Contaminated Soil	7	6	7	7	6	6	6	7	6	6	5	7	6	7	6	7	7	7	ND	7
PGC Soil	6	6	6	7	6	7	6	7	6	7	6	7	6	7	6	7	7	6	6	5
Replication 8																				
Tailings	6	7	6	8	6	7	8	7	6	8	7	17	6	7	7	8	7	7	ND	ND
Contaminated Soil	7	8	6	7	7	7	7	7	7	7	7	6	7	7	8	8	7	8	10	10
PGC Soil	7	6	7	8	8	8	7	8	7	7	8	8	8	8	7	6	7	7	7	7

ND = No Data

Table 270. Germination (number of seedlings emerged/15 seeds, 14 day post-emergence) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	15	11	15	10	15	9	15	12	15	13	15	14	15	13	15	12	15	9	0	0
Contaminated Soil	15	4	15	10	15	11	15	11	1	14	15	12	15	9	15	1	15	8	7	7
PGC Soil	15	13	15	12	13	10	14	7	15	9	9	13	15	14	8	11	12	9	15	14
Replication 2																				
Tailings	15	12	15	11	15	4	15	12	15	2	15	11	15	9	15	12	15	8	0	0
Contaminated Soil	15	8	15	8	15	11	15	12	15	6	15	9	15	9	9	3	6	9	3	6
PGC Soil	15	12	15	14	15	11	15	13	15	13	8	11	15	8	14	11	15	12	15	15
Replication 3																				
Tailings	15	13	15	11	15	13	15	14	15	14	11	11	15	2	12	10	6	15	0	0
Contaminated Soil	15	11	15	9	15	13	15	11	15	12	15	9	14	12	15	11	15	6	1	11
PGC Soil	15	13	14	11	10	8	9	11	12	12	11	5	15	2	15	15	15	13	15	13
Replication 4																				
Tailings	11	12	12	13	11	11	6	11	8	13	15	11	9	12	15	14	15	10	0	0
Contaminated Soil	10	12	15	12	7	10	15	10	12	10	7	11	15	10	7	14	15	3	0	10
PGC Soil	15	12	9	9	15	11	15	12	13	11	11	3	15	6	15	13	15	8	15	13
Replication 5																				
Tailings	9	13	10	12	15	12	15	8	15	11	15	10	15	10	11	15	15	15	0	0
Contaminated Soil	10	13	6	12	15	11	10	13	8	13	13	12	15	9	15	12	15	8	3	11
PGC Soil	15	12	15	11	15	15	11	14	13	12	15	15	13	11	15	13	15	11	15	14
Replication 6																				
Tailings	15	7	15	8	15	9	15	12	15	5	10	13	15	8	15	15	15	10	0	0
Contaminated Soil	15	14	15	15	15	6	15	11	15	11	15	10	15	10	15	13	15	15	0	13
PGC Soil	15	15	15	13	15	6	15	13	15	15	15	15	15	15	15	15	15	15	15	14
Replication 7																				
Tailings	15	12	10	9	13	9	15	15	15	12	15	10	15	14	15	13	15	13	0	0
Contaminated Soil	8	14	12	13	15	12	12	8	11	13	15	5	12	12	15	8	15	7	0	7
PGC Soil	11	15	15	15	15	12	15	14	15	15	15	11	15	15	15	13	15	9	15	11
Replication 8																				
Tailings	15	8	15	12	15	12	15	11	15	7	15	10	15	11	12	9	15	11	0	0
Contaminated Soil	15	9	15	13	15	8	15	14	15	10	15	11	12	11	9	9	13	13	1	13
PGC Soil	15	15	15	11	3	10	15	8	15	12	9	11	11	14	12	15	15	12	15	11

Table 271. Survival (number of seedlings survived/emerged, 14 day post-emergence) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	15	11	15	10	15	9	15	12	15	13	15	14	15	13	15	12	15	9	ND	ND
Contaminated Soil	15	4	15	10	15	11	15	11	1	14	15	12	15	9	15	1	15	8	7	7
PGC Soil	15	13	15	12	13	10	14	7	15	9	9	13	15	14	8	11	12	9	15	14
Replication 2																				
Tailings	15	12	15	11	15	4	15	12	15	2	15	11	15	9	15	12	15	8	ND	ND
Contaminated Soil	15	8	15	8	15	11	15	12	15	6	15	9	15	9	9	3	6	9	3	6
PGC Soil	15	12	15	14	15	11	15	13	15	13	8	11	15	8	14	11	15	12	15	15
Replication 3																				
Tailings	15	13	15	11	15	13	15	14	15	14	11	11	15	2	12	10	6	15	ND	ND
Contaminated Soil	15	11	15	9	15	13	15	11	15	12	15	9	14	12	15	11	15	6	1	11
PGC Soil	15	13	14	11	10	8	9	11	12	12	11	5	15	2	15	15	15	13	15	13
Replication 4																				
Tailings	11	12	12	13	11	11	6	11	8	13	15	11	9	12	15	14	15	10	ND	ND
Contaminated Soil	10	12	15	12	7	10	15	10	12	10	7	11	15	10	7	14	15	3	ND	10
PGC Soil	15	12	9	9	15	11	15	12	13	11	11	3	15	6	15	13	15	8	15	13
Replication 5																				
Tailings	9	13	10	12	15	12	15	8	15	11	15	10	15	10	11	15	15	15	ND	ND
Contaminated Soil	10	13	6	12	15	11	10	13	8	13	13	12	15	9	15	12	15	8	3	11
PGC Soil	15	12	15	11	15	15	11	14	13	12	15	15	13	11	15	13	15	11	15	14
Replication 6																				
Tailings	15	7	15	8	15	9	15	12	15	5	10	13	15	8	15	15	15	10	ND	ND
Contaminated Soil	15	14	15	15	15	6	15	11	15	11	15	10	15	10	15	13	15	15	ND	13
PGC Soil	15	15	15	13	15	6	15	13	15	15	15	15	15	15	15	15	15	15	15	14
Replication 7																				
Tailings	15	12	10	9	13	9	15	15	15	12	15	10	15	14	15	13	15	13	ND	ND
Contaminated Soil	8	14	12	13	15	12	12	8	11	13	15	5	12	12	15	8	15	7	ND	7
PGC Soil	11	15	15	15	15	12	15	14	15	15	15	11	15	15	15	13	15	9	15	11
Replication 8																				
Tailings	15	8	15	12	15	12	15	11	15	7	15	10	15	11	12	9	15	11	ND	ND
Contaminated Soil	15	9	15	13	15	8	15	14	15	10	15	11	12	11	9	9	13	13	1	13
PGC Soil	15	15	15	11	3	10	15	8	15	12	9	11	11	14	12	15	15	12	15	11

ND = No Data

Table 272. Shoot Height (height from soil to longest leaf (mm), 14 day post-emergence) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	32	100	37	104.3	20.2	101	18.3	107.4	27.1	108.7	22	110	25	120	27.3	111.2	26.8	118.2	ND	ND
Contaminated Soil	30	70	40	105.6	37.1	105	35.1	96.6	42	124.8	32.1	75	38.5	96	25	130	33	129.5	9	29.4
PGC Soil	32.6	122.3	46.4	146.2	30.8	120.6	32	114.2	29	126.3	55	117.6	42	130	37.1	142.7	40.2	135	57.1	116
Replication 2																				
Tailings	23	101	25.3	105	13	38	15.8	98	31	99.5	19.2	90	15.2	90	23	92.5	30.1	63.7	ND	ND
Contaminated Soil	30	92.3	37	92	36.6	101.2	30.6	125.2	35	94.5	28	101	37	115	30	115	18	120	8	40.3
PGC Soil	37.1	107.1	49	145.8	35.1	105.2	46.2	116.3	37	105	40	125	45	99.8	32	112.3	56.2	146.1	49.6	139.2
Replication 3																				
Tailings	25	68.2	28.3	97	19.6	70	27.5	86	31	100	17.5	91.6	27	57.5	16	67.2	18	99	ND	ND
Contaminated Soil	27	105	35	96	31.2	92	25	107	27.5	115	32	97	30	105.2	33	92.4	30	110	10	40.8
PGC Soil	37	113.2	41	92.3	25	80	56.6	125	33	88.4	45	70.6	45.2	91	35.2	120.2	52	126	60.2	110.5
Replication 4																				
Tailings	30	93	17	95	22	68.5	24.2	120.5	21.8	99.5	21.5	82.5	23.5	87.5	18	97.8	26.3	63.7	ND	ND
Contaminated Soil	33	100	43.3	80	26.6	128.7	30.5	111.2	20	88.8	91	104.7	29	118.8	46	105.5	31.7	126	ND	47.3
PGC Soil	35	120	58	123.3	35	102	37	93.8	19.5	85	53.7	73.6	43.6	81.5	43.7	101.3	64	115	59.5	112.6
Replication 5																				
Tailings	13.8	97.5	13	78.7	27.5	75	27	96.3	30	92	22.8	72.5	33.5	88.8	28.6	82.5	23	115	ND	ND
Contaminated Soil	36.6	118.3	24.3	94.2	26.2	113.8	23	91.3	19.8	111.2	40.8	97.5	34	122.5	26.3	95	21.7	86.6	9	43.7
PGC Soil	45	92.5	62	110	29.2	111.2	45.3	117	25	106.4	48.8	123.3	34.1	113.7	36.3	119.7	65	107.5	65	115
Replication 6																				
Tailings	18.2	82	31	103.2	18.5	96	26	115.5	18.2	109	15	91.6	31	82.2	28.3	82.5	30	97.3	ND	ND
Contaminated Soil	29.2	98	26	117.5	26.2	98.7	26.4	108.7	29	117.5	28	98.5	33	111.2	35.2	128	35.2	81.3	ND	28.7
PGC Soil	45	105	50	126.7	28.3	99.5	32	115.1	31.3	97	45.1	122.5	35	116.2	36	98.6	53	125.3	55	135
Replication 7																				
Tailings	15	94.2	40	79	18.2	87.2	25	69.2	51	102.7	27.3	51	28.5	74	20	75	30.3	87.5	ND	ND
Contaminated Soil	30.1	115	25.5	111	30.1	110	22	100.7	22.4	109.7	22	98.5	32.5	101.5	36.3	110.5	23.5	113.5	ND	40
PGC Soil	50	101	55.2	107.5	42.3	87	48.7	116.5	29.3	77.5	39.7	110.7	27.5	94.2	40.3	100.5	70.2	109.5	76.3	91
Replication 8																				
Tailings	36.8	76	34.5	91.4	19	92.1	21.3	111.2	28.8	117	29	92.3	31.5	92	19.2	85	42	97.5	ND	ND
Contaminated Soil	33	100.2	27.3	115.2	42.5	108.7	28.5	119.5	33.7	124.2	36	103.5	35.5	124	28	101.2	29.2	106.5	10	35.2
PGC Soil	56.7	110.5	61.5	126	25	96	45.7	103	33.2	109.7	32	124	47	119.2	48.5	119.5	67.5	129.5	69.5	118.5

ND = No Data

Table 273. Measured pH (s.u., 70 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	8.2	8.1	8.1	8.2	8.0	8.0	8.0	8.3	8.0	8.4	8.3	8.3	8.7	8.1	7.8	7.9	8.0	8.3	2.1	2.0
Contaminated Soil	8.2	8.3	8.5	8.4	8.3	8.5	8.1	8.0	8.0	7.9	8.2	8.2	7.6	8.0	8.5	8.3	8.4	8.5	5.0	5.1
PGC Soil	8.2	8.4	8.6	8.6	8.0	8.5	8.6	8.6	8.4	8.6	8.7	8.6	8.5	8.5	8.5	8.5	8.1	8.4	8.6	8.5
Replication 2																				
Tailings	8.2	8.1	8.1	8.1	8.1	8.3	8.2	8.3	8.5	8.4	8.3	8.6	8.3	8.3	8.2	8.4	8.3	8.5	2.0	2.1
Contaminated Soil	8.3	8.5	8.4	8.2	8.5	8.6	8.5	8.3	8.4	8.3	8.1	8.0	8.4	8.3	8.4	8.5	8.0	7.9	5.0	5.2
PGC Soil	8.5	7.8	8.5	8.4	8.3	8.2	8.4	8.8	8.3	8.5	8.4	8.7	8.8	8.9	8.6	8.6	8.8	8.5	8.6	8.4
Replication 3																				
Tailings	8.3	8.1	8.4	8.2	8.1	8.2	7.8	7.5	8.4	8.5	8.3	8.5	7.9	8.4	8.4	8.3	8.0	8.2	2.3	1.9
Contaminated Soil	8.2	8.3	8.5	8.4	8.3	8.5	8.1	8.0	8.0	7.9	8.1	8.2	7.9	8.0	8.5	8.6	8.5	8.4	5.1	5.0
PGC Soil	8.3	8.6	8.4	8.5	8.5	8.5	8.7	8.4	8.2	8.7	8.6	8.5	8.8	9.1	8.6	8.9	8.4	8.4	7.7	8.3
Replication 4																				
Tailings	8.4	8.2	8.1	8.3	8.1	8.1	7.7	8.3	7.9	8.1	7.9	9.3	7.8	8.2	8.0	8.3	8.1	8.0	2.1	2.0
Contaminated Soil	8.1	8.2	8.4	8.4	8.0	8.4	8.1	8.2	8.5	8.3	8.1	8.3	8.2	8.3	8.1	8.3	8.4	8.4	5.0	5.3
PGC Soil	8.5	7.9	8.6	8.1	8.0	8.1	8.4	8.5	8.5	8.6	8.4	8.3	8.4	8.7	8.7	8.4	8.1	8.5	8.2	8.4
Replication 5																				
Tailings	8.2	8.2	8.1	8.0	8.1	7.9	8.2	8.0	8.1	8.3	8.1	8.2	8.1	7.8	8.2	8.1	8.1	8.1	2.0	1.8
Contaminated Soil	8.2	8.3	8.5	8.4	8.3	8.5	8.1	8.0	8.0	7.9	8.1	8.2	7.9	8.0	8.5	8.6	8.5	8.4	4.9	5.0
PGC Soil	8.4	7.6	8.6	8.5	8.2	8.3	7.4	8.5	8.5	8.3	8.5	8.1	9.0	8.5	8.7	8.3	8.6	9.1	8.7	8.5
Replication 6																				
Tailings	8.2	8.2	8.0	8.1	7.9	8.0	7.8	8.2	7.9	8.4	8.1	8.2	8.3	8.2	8.4	7.8	8.1	8.0	1.9	2.1
Contaminated Soil	8.1	8.2	8.4	8.5	8.1	8.2	7.3	8.4	8.4	8.6	8.5	8.3	8.2	8.3	8.1	8.3	8.4	8.4	5.0	5.3
PGC Soil	8.4	8.4	8.4	9.0	8.6	8.2	8.9	8.2	8.5	8.1	8.9	8.8	8.6	8.7	8.6	8.1	8.7	8.7	8.2	8.1
Replication 7																				
Tailings	7.9	7.8	8.0	8.2	8.1	8.0	8.2	7.9	8.1	7.7	8.7	8.0	7.9	7.8	8.1	7.8	8.0	8.1	2.0	1.9
Contaminated Soil	8.1	8.2	8.4	8.4	8.0	8.4	8.1	8.2	8.5	8.3	8.1	7.9	7.9	8.0	8.5	8.4	8.5	8.5	5.0	5.2
PGC Soil	8.2	8.4	8.4	8.6	8.4	8.6	8.7	8.5	8.3	8.5	8.5	8.5	8.6	8.5	8.6	8.4	8.1	8.3	7.9	8.3
Replication 8																				
Tailings	8.2	8.1	8.0	8.1	8.0	8.3	8.3	8.1	8.2	8.0	8.1	8.2	8.2	8.2	8.1	8.1	8.1	8.1	2.0	2.0
Contaminated Soil	8.2	8.3	8.5	8.4	8.3	8.5	8.1	8.0	8.0	7.9	8.1	8.2	7.9	8.0	8.5	8.6	8.5	8.4	4.9	4.9
PGC Soil	8.4	8.4	8.6	8.3	7.8	8.6	8.5	8.8	8.5	8.3	8.3	8.4	8.3	8.5	8.5	8.6	8.3	8.4	7.9	8.6

Table 274. Aboveground height (height from soil to longest leaf (mm), 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	210	110	225	332	235	160	195	321	330	390	213	205	230	485	112	314	140	200	ND	ND
Contaminated Soil	220	95	335	345	330	320	95	230	160	230	273	145	150	122	258	137	125	310	ND	124
PGC Soil	522	544	415	720	600	590	380	529	320	655	305	550	340	486	430	569	360	500	350	521
Replication 2																				
Tailings	285	300	175	175	75	90	62	228	244	480	185	130	200	260	60	285	120	117	ND	ND
Contaminated Soil	255	217	440	302	150	260	280	277	175	133	294	120	345	320	214	165	174	190	0.5	65
PGC Soil	470	600	465	600	393	675	312	310	322	570	293	431	310	525	345	550	271	235	430	555
Replication 3																				
Tailings	46	330	237	365	65	80	160	339	224	310	130	180	242	440	80	80	93	150	ND	ND
Contaminated Soil	182	560	452	226	425	310	306	340	240	205	164	185	400	215	235	171	117	175	0.5	62
PGC Soil	310	530	296	490	302	563	245	546	254	452	305	410	325	640	372	580	444	562	410	540
Replication 4																				
Tailings	189	140	253	225	116	330	80	122	145	222	90	80	185	230	225	147	60	151	ND	ND
Contaminated Soil	135	211	470	212	342	225	229	286	285	276	47	237	150	235	172	245	183	171	40	55
PGC Soil	174	540	310	605	305	427	240	401	383	460	190	330	330	625	310	550	329	590	241	532
Replication 5																				
Tailings	156	144	233	343	63	101	150	227	131	290	82	220	136	481	42	65	100	116	ND	ND
Contaminated Soil	145	292	307	176	245	190	345	114	325	160	277	240	230	210	283	208	116	107	ND	85
PGC Soil	306	550	302	602	403	420	240	405	264	485	305	343	258	445	306	335	335	455	251	470
Replication 6																				
Tailings	30	368	185	304	197	216	150	167	245	295	35	168	168	246	66	87	110	142	ND	ND
Contaminated Soil	115	306	400	395	373	240	310	244	195	350	130	167	190	362	245	210	245	115	ND	54
PGC Soil	270	571	281	468	272	499	332	320	345	567	215	400	236	354	260	493	368	506	261	494
Replication 7																				
Tailings	153	334	206	357	132	145	150	159	165	394	83	203	166	91	20	74	104	135	ND	ND
Contaminated Soil	221	261	290	145	190	230	290	198	220	142	333	109	247	183	220	184	100	144	ND	70
PGC Soil	253	600	286	650	209	295	237	345	263	336	180	440	251	295	290	529	260	539	265	404
Replication 8																				
Tailings	122	310	88	243	80	150	264	230	200	335	46	70	170	320	70	330	90	120	ND	ND
Contaminated Soil	310	230	305	274	240	165	330	180	245	206	271	189	305	192	245	207	221	185	ND	95
PGC Soil	258	451	325	600	363	348	290	465	239	475	195	410	230	495	305	439	267	480	206	546

ND = No Data

Table 275. Maximum root depth (length of longest root (mm), 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	130	110	130	125	120	123	125	321	115	110	110	110	113	120	115	104	125	115	ND	ND
Contaminated Soil	90	70	105	115	115	125	80	105	70	90	85	60	95	90	105	85	25	105	ND	1
PGC Soil	120	120	105	100	125	115	125	112	120	130	101	119	103	110	103	96	103	100	118	115
Replication 2																				
Tailings	115	120	128	105	115	100	130	121	110	105	125	110	125	135	100	118	114	105	ND	ND
Contaminated Soil	110	90	110	115	87	110	80	110	80	105	113	100	110	105	93	102	76	90	1	1
PGC Soil	122	120	105	95	115	130	105	115	130	115	110	115	115	105	110	110	100	90	125	110
Replication 3																				
Tailings	40	120	127	120	100	120	112	125	106	97	120	97	120	104	115	102	102	110	ND	ND
Contaminated Soil	100	150	120	116	117	120	124	120	125	140	100	115	100	100	120	110	71	110	1	30
PGC Soil	123	120	100	96	230	120	110	107	130	125	110	114	100	105	117	100	115	108	105	109
Replication 4																				
Tailings	120	110	131	115	120	128	120	110	116	105	115	105	120	120	120	119	90	95	ND	ND
Contaminated Soil	105	90	125	125	123	105	120	114	135	117	1	105	105	105	97	107	95	95	2	2
PGC Soil	114	95	105	103	110	120	115	120	122	120	110	105	90	115	115	105	110	111	120	115
Replication 5																				
Tailings	112	110	120	127	120	125	110	116	100	126	108	105	110	120	75	110	95	105	ND	ND
Contaminated Soil	105	110	127	110	115	110	100	110	110	110	100	120	112	97	112	100	103	54	ND	0
PGC Soil	125	120	120	115	115	112	127	110	115	120	112	125	100	110	114	105	100	105	105	115
Replication 6																				
Tailings	5	120	134	125	135	123	120	105	110	100	95	115	115	110	115	103	110	120	ND	ND
Contaminated Soil	115	115	120	110	120	110	110	110	120	120	160	120	105	97	120	95	100	108	ND	54
PGC Soil	115	125	103	105	130	125	115	100	124	121	122	95	103	95	110	110	113	97	120	105
Replication 7																				
Tailings	125	120	125	125	120	120	110	100	105	100	100	115	130	115	90	120	105	103	ND	ND
Contaminated Soil	70	100	130	120	119	105	120	105	130	110	125	105	96	100	140	85	55	105	48	55
PGC Soil	109	115	100	110	120	120	106	105	121	125	112	111	120	115	111	100	90	110	105	120
Replication 8																				
Tailings	122	120	120	170	120	105	110	120	120	100	115	120	120	150	105	100	105	125	ND	ND
Contaminated Soil	105	115	115	130	110	100	110	120	115	115	115	100	105	100	105	95	45	70	ND	2
PGC Soil	125	120	105	100	110	107	120	115	115	125	130	130	109	100	110	120	100	105	115	115

ND = No Data

Table 276. Root distribution (number of roots at 5 cm depth, 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	40	17	12	25	10	15	27	30	40	35	20	11	40	35	28	27	7	13	ND	ND
Contaminated Soil	7	6	30	13	7	6	7	8	7	23	5	2	10	3	5	1	2	8	0	0
PGC Soil	35	125	100	75	100	80	70	25	50	50	45	25	30	32	15	35	30	48	100	50
Replication 2																				
Tailings	25	15	30	15	3	3	0	11	20	5	6	3	13	50	8	16	9	1	ND	ND
Contaminated Soil	5	3	7	30	10	15	3	30	3	5	9	1	20	9	18	6	20	10	0	0
PGC Soil	50	150	60	60	60	65	25	125	25	71	40	70	80	95	80	48	75	38	120	25
Replication 3																				
Tailings	49	15	23	30	40	15	15	18	17	20	50	10	25	22	7	7	10	10	ND	ND
Contaminated Soil	60	12	80	25	25	35	40	20	30	25	7	20	38	30	40	5	1	35	0	6
PGC Soil	55	45	115	30	100	25	35	34	55	25	25	40	40	25	20	25	45	35	40	115
Replication 4																				
Tailings	25	5	35	12	15	36	10	10	12	18	2	8	25	25	30	40	10	6	ND	ND
Contaminated Soil	2	15	50	30	40	20	15	35	40	30	0	8	20	6	20	30	10	5	0	0
PGC Soil	44	26	90	25	100	35	25	25	80	40	74	10	20	45	60	40	46	32	50	40
Replication 5																				
Tailings	5	12	25	25	5	12	5	15	5	35	1	12	30	45	4	12	5	12	ND	ND
Contaminated Soil	3	18	25	20	5	25	15	11	15	17	5	35	10	12	5	35	5	3	0	0
PGC Soil	40	35	25	70	40	60	25	40	90	50	80	18	20	45	60	50	60	25	50	85
Replication 6																				
Tailings	3	20	45	13	45	15	37	15	45	19	3	10	60	45	5	5	12	13	ND	ND
Contaminated Soil	30	30	45	109	45	30	100	37	72	35	20	35	35	50	35	35	60	10	0	1
PGC Soil	47	70	45	55	30	70	45	25	20	47	40	27	5	35	65	55	35	50	50	175
Replication 7																				
Tailings	19	30	49	35	20	18	25	12	50	30	10	19	90	25	4	10	25	12	ND	ND
Contaminated Soil	10	25	60	30	40	35	40	35	20	13	45	15	60	13	20	5	4	6	0	1
PGC Soil	50	80	70	80	50	20	20	35	60	0	50	40	120	70	30	47	30	70	120	150
Replication 8																				
Tailings	30	8	20	20	36	6	50	20	44	40	6	4	100	200	11	4	16	4	ND	ND
Contaminated Soil	30	19	100	100	50	14	60	24	55	50	30	40	50	19	135	25	0	22	0	0
PGC Soil	70	70	60	105	40	60	100	50	100	65	35	60	90	78	60	60	47	40	75	150

ND = No Data

Table 277. Root distribution (number of roots at 10 cm depth, 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	20	2	9	30	5	25	16	25	50	40	10	9	55	100	2	23	15	30	ND	ND
Contaminated Soil	0	0	3	9	2	6	0	2	6	19	3	0	0	0	2	0	0	7	0	0
PGC Soil	50	150	125	50	70	100	90	35	100	100	39	30	45	115	20	40	40	38	150	60
Replication 2																				
Tailings	30	20	40	19	6	5	0	19	5	9	8	5	26	60	0	14	5	0	ND	ND
Contaminated Soil	0	5	15	27	0	20	0	35	0	6	10	1	25	13	0	3	0	0	0	0
PGC Soil	60	70	80	120	65	130	60	75	90	157	40	75	70	80	40	30	50	15	210	100
Replication 3																				
Tailings	0	25	10	40	30	10	20	25	31	0	20	0	30	35	5	5	2	10	ND	ND
Contaminated Soil	18	5	90	20	10	13	25	25	15	21	1	12	40	5	0	2	0	1	0	0
PGC Soil	60	50	140	45	60	50	40	50	70	35	10	55	50	50	11	60	30	20	50	150
Replication 4																				
Tailings	30	10	60	9	10	35	5	10	12	20	4	7	45	40	15	10	1	2	ND	ND
Contaminated Soil	2	10	60	20	50	10	12	30	30	25	0	6	6	10	0	11	1	1	0	0
PGC Soil	70	22	110	80	115	40	47	35	80	60	60	10	30	65	50	20	40	30	70	35
Replication 5																				
Tailings	5	13	45	27	0	13	1	15	5	37	5	15	50	70	0	3	7	5	ND	ND
Contaminated Soil	0	30	35	12	20	20	5	3	10	15	1	35	5	20	10	3	1	0	0	0
PGC Soil	60	50	50	60	50	40	40	60	80	75	50	30	20	85	30	50	35	18	100	200
Replication 6																				
Tailings	0	47	49	13	60	25	48	15	60	30	0	6	80	50	2	5	6	13	ND	ND
Contaminated Soil	15	15	55	100	30	40	75	25	40	25	10	27	40	45	20	15	40	5	0	0
PGC Soil	70	160	100	150	30	150	65	40	30	110	55	0	5	0	25	80	40	0	75	250
Replication 7																				
Tailings	20	45	85	55	20	25	30	18	75	100	4	25	110	40	0	10	10	12	ND	ND
Contaminated Soil	0	15	50	17	55	20	30	16	15	7	30	7	45	12	15	0	0	3	0	0
PGC Soil	100	70	150	100	70	15	100	30	180	100	55	100	130	200	17	150	0	150	170	300
Replication 8																				
Tailings	100	9	10	20	25	20	50	100	71	60	2	2	200	200	6	15	9	15	ND	ND
Contaminated Soil	15	16	200	50	40	9	110	10	165	40	50	3	30	10	100	0	0	0	0	0
PGC Soil	70	105	65	160	45	120	110	50	190	65	50	120	90	180	65	65	89	45	100	180

ND = No Data

Table 278. Aboveground biomass (weight of aboveground production (g), 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Lime LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	0.871	0.114	0.170	0.537	0.067	0.028	0.128	0.279	1.138	0.166	0.233	0.236	0.611	0.931	0.034	0.148	0.925	0.008	ND	ND
Contaminated Soil	0.138	1.174	0.447	0.437	0.141	0.130	0.137	0.013	0.038	0.212	0.112	1.162	0.133	0.383	0.021	0.039	0.116	0.123	ND	0.133
PGC Soil	1.795	0.504	0.601	2.823	2.826	0.080	2.688	0.846	1.820	0.831	0.467	1.712	0.438	0.839	1.422	1.333	0.035	2.062	0.378	1.025
Replication 2																				
Tailings	0.812	0.417	1.152	0.175	0.062	0.105	0.150	0.451	0.655	0.331	0.193	0.091	0.557	0.551	0.096	0.334	0.043	0.077	ND	ND
Contaminated Soil	0.312	0.464	0.744	0.517	0.143	0.515	0.085	0.932	0.111	0.028	0.466	0.215	1.182	0.495	0.209	0.266	0.023	0.240	ND	0.023
PGC Soil	4.790	3.726	3.573	3.876	3.244	1.744	0.759	1.504	2.117	2.332	0.913	1.301	1.889	1.542	3.288	2.241	4.683	1.933	3.570	2.020
Replication 3																				
Tailings	0.009	0.781	0.789	0.662	0.029	0.068	0.398	0.693	0.715	0.330	0.292	0.159	0.813	0.340	0.191	0.028	0.169	0.083	ND	ND
Contaminated Soil	0.430	0.753	1.662	0.757	1.025	0.773	1.487	0.654	1.275	0.651	0.201	0.303	0.880	0.654	0.650	0.292	0.443	0.390	0.119	0.088
PGC Soil	3.830	2.514	3.044	3.268	2.644	1.452	1.353	2.557	3.705	1.357	0.866	1.444	1.736	1.050	2.733	3.387	3.786	3.288	2.987	2.333
Replication 4																				
Tailings	0.678	0.053	2.187	0.396	0.005	0.680	0.112	0.232	0.092	0.244	0.044	0.029	0.418	0.464	0.193	0.018	0.001	0.078	ND	ND
Contaminated Soil	0.052	0.481	2.143	0.428	1.030	0.546	0.441	0.814	1.025	0.626	0.003	0.277	0.260	0.433	0.253	0.364	0.042	0.236	0.001	0.009
PGC Soil	2.051	1.577	4.226	2.496	1.858	1.045	0.839	0.886	2.041	2.581	0.650	0.426	0.979	2.208	3.156	2.619	1.996	2.114	1.378	1.998
Replication 5																				
Tailings	0.185	0.130	0.665	0.953	0.090	0.080	0.030	0.189	0.115	0.335	0.003	0.254	0.396	0.806	0.020	0.040	0.080	0.003	ND	ND
Contaminated Soil	0.068	0.489	1.271	0.418	0.548	0.783	0.421	0.180	0.744	0.141	0.183	0.789	0.592	0.219	0.127	0.198	0.121	0.150	0.010	0.060
PGC Soil	2.783	1.910	3.141	3.536	1.743	1.482	1.297	0.601	2.083	2.106	1.684	1.124	1.420	0.843	3.131	2.203	3.040	2.015	1.736	4.115
Replication 6																				
Tailings	0.041	0.854	1.181	0.499	0.598	0.339	0.612	0.176	1.114	0.580	0.063	0.191	0.689	0.539	0.131	0.129	0.176	0.179	ND	ND
Contaminated Soil	1.234	0.734	1.237	0.984	1.553	0.484	0.990	0.523	0.822	1.193	0.703	0.341	0.853	0.664	0.486	0.543	0.586	0.204	ND	0.263
PGC Soil	2.346	2.847	2.639	2.454	1.471	2.029	1.774	0.623	1.949	1.869	1.136	0.846	1.564	0.837	1.754	2.117	3.866	2.425	2.301	2.736
Replication 7																				
Tailings	0.050	0.789	1.240	0.707	0.150	0.057	0.442	0.120	1.122	0.527	0.020	0.163	0.612	0.056	0.001	0.030	0.041	0.023	ND	ND
Contaminated Soil	0.220	0.433	1.115	0.450	1.111	0.619	0.690	0.454	0.619	0.126	1.248	0.272	1.119	0.256	0.506	0.232	0.075	0.172	ND	0.016
PGC Soil	1.721	3.143	2.532	3.601	1.238	0.743	0.599	0.532	3.160	2.952	1.485	1.328	3.397	1.285	2.136	1.799	2.070	2.801	2.036	1.837
Replication 8																				
Tailings	0.463	0.798	0.092	0.447	0.022	0.190	0.612	0.373	0.350	0.664	0.001	0.022	0.869	0.844	0.046	0.490	0.008	0.093	ND	ND
Contaminated Soil	0.510	0.434	2.107	0.935	1.047	0.389	0.792	0.388	0.987	0.409	0.766	0.219	1.255	0.236	0.671	0.158	0.176	0.342	ND	0.010
PGC Soil	1.383	1.760	2.345	2.421	1.012	0.960	3.276	1.813	1.566	1.910	1.003	0.998	1.225	1.233	2.866	2.628	1.911	1.266	1.529	1.564

ND = No Data

Table 279. Belowground biomass (weight of belowground production (g), 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Lime LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	0.682	0.031	0.485	0.769	0.112	0.075	0.042	0.414	1.301	0.188	0.004	0.411	0.652	0.352	0.024	0.274	0.037	0.154	ND	ND
Contaminated Soil	0.134	1.175	0.428	0.239	0.054	0.010	0.287	0.069	0.175	0.112	0.186	0.097	0.110	0.336	0.100	0.269	0.221	0.055	ND	0.149
PGC Soil	0.084	5.066	2.161	2.179	0.314	1.928	1.451	1.420	0.337	0.771	0.537	0.390	0.653	1.792	1.252	0.999	1.168	1.879	3.335	2.190
Replication 2																				
Tailings	1.129	0.868	4.112	0.495	0.262	0.117	0.076	0.513	0.971	0.629	0.302	0.090	1.134	2.157	0.084	0.470	0.048	0.321	ND	ND
Contaminated Soil	0.284	0.150	0.451	0.377	0.180	0.503	0.178	1.014	0.237	0.192	0.155	0.190	0.867	0.485	0.013	0.163	0.004	0.366	ND	0.001
PGC Soil	2.483	4.686	2.769	3.599	2.282	4.984	1.331	2.230	2.389	6.237	0.562	1.855	1.402	5.304	1.468	1.683	1.993	2.330	8.129	3.329
Replication 3																				
Tailings	0.124	0.406	1.079	1.592	0.133	0.121	0.344	0.993	1.202	0.770	0.587	0.190	1.319	0.691	0.279	0.071	0.119	0.163	ND	ND
Contaminated Soil	0.369	0.599	1.754	1.174	0.537	1.049	1.003	1.358	1.896	0.484	0.101	0.320	0.709	1.218	0.318	0.262	0.299	0.159	0.001	0.032
PGC Soil	4.111	4.104	2.209	5.415	2.033	4.124	2.500	5.606	4.814	2.945	1.081	3.866	1.848	1.667	1.949	3.856	2.529	4.590	3.762	6.877
Replication 4																				
Tailings	0.750	0.180	1.855	0.678	0.051	1.512	0.082	0.234	0.332	0.457	0.048	0.148	1.219	1.454	0.435	0.190	0.011	0.049	ND	ND
Contaminated Soil	0.051	0.573	1.905	0.421	0.939	1.121	0.183	0.882	0.580	0.652	0.001	0.558	0.213	0.405	0.234	0.838	0.039	0.194	0.001	0.001
PGC Soil	3.782	4.464	1.929	3.455	3.228	2.505	2.646	2.191	3.186	4.918	1.344	0.606	1.649	2.826	1.346	4.193	2.019	4.033	9.159	4.659
Replication 5																				
Tailings	0.135	0.223	0.763	2.352	0.085	0.148	0.050	0.285	0.262	0.885	0.035	0.595	1.047	1.839	0.040	0.012	0.180	0.142	ND	ND
Contaminated Soil	0.062	0.752	1.420	0.565	0.576	0.806	0.351	0.080	0.507	0.200	0.144	0.605	0.676	0.301	0.038	0.216	0.229	0.060	ND	0
PGC Soil	2.445	3.204	3.220	6.902	1.763	2.273	2.170	1.063	1.848	5.220	1.547	2.338	1.457	3.025	2.001	2.149	1.947	3.096	3.775	13.57
Replication 6																				
Tailings	0.075	1.899	2.627	1.029	1.460	0.914	1.611	0.350	1.044	1.208	0.170	0.443	1.664	1.380	0.322	0.233	0.234	0.524	ND	ND
Contaminated Soil	1.945	0.695	1.411	3.173	0.805	0.896	1.182	2.263	1.117	1.184	0.939	0.404	0.667	0.833	0.554	1.308	1.908	0.513	ND	0.001
PGC Soil	2.703	4.958	2.347	4.006	1.501	3.876	2.124	1.415	1.557	4.383	1.796	1.853	1.309	2.115	2.579	3.190	3.375	3.754	4.145	5.232
Replication 7																				
Tailings	0.266	2.318	3.022	2.491	0.203	0.613	0.787	0.187	2.316	1.710	0.054	0.190	2.236	0.343	0.001	0.145	0.201	0.234	ND	ND
Contaminated Soil	0.204	0.606	1.072	0.612	0.939	0.860	1.350	0.517	0.327	0.155	0.862	0.223	1.434	0.388	0.670	0.289	0.081	0.241	ND	0.001
PGC Soil	7.864	5.720	4.432	5.822	3.681	2.904	4.387	2.218	6.167	7.085	2.929	3.452	6.224	5.162	1.947	4.184	2.077	5.277	5.155	7.897
Replication 8																				
Tailings	1.370	1.826	0.402	1.198	0.064	0.707	0.744	0.756	0.416	1.526	0.001	0.079	1.806	3.638	0.124	0.998	0.037	0.504	ND	ND
Contaminated Soil	0.340	0.614	2.072	0.912	0.883	0.487	1.219	0.571	1.854	0.710	0.332	0.466	1.664	0.485	0.918	0.270	0.114	0.476	ND	0.001
PGC Soil	6.882	6.433	7.138	5.780	9.302	3.859	9.851	4.991	5.994	4.659	3.971	2.694	7.316	3.024	3.491	8.042	7.167	5.534	13.69	9.960

ND = No Data

Table 280. Measured pH (s.u., 111 day growth) in tailings, contaminated soil and Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO		Control	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																				
Tailings	8.0	8.0	7.8	7.8	7.8	8.0	7.8	7.9	7.9	7.8	8.3	7.9	7.9	7.7	7.7	7.5	7.8	7.7	2.0	1.9
Contaminated Soil	7.6	7.7	7.8	7.7	8.0	8.0	7.2	7.7	7.5	7.7	7.3	7.4	8.0	7.7	7.8	7.9	7.5	7.6	5.1	5.2
PGC Soil	8.1	8.0	8.2	8.1	8.3	8.0	8.2	8.3	8.2	8.1	7.9	8.0	8.1	7.9	8.0	7.7	8.0	7.9	7.2	7.0
Replication 2																				
Tailings	8.1	8.0	8.0	7.9	7.8	7.5	7.8	7.8	7.9	7.9	8.0	7.9	8.0	8.1	8.0	7.9	7.7	7.6	1.9	2.0
Contaminated Soil	8.1	7.5	7.8	8.0	8.3	8.0	7.9	7.8	7.7	7.9	7.7	7.8	8.2	8.2	8.0	7.9	7.7	7.6	4.9	5.1
PGC Soil	8.0	8.2	8.4	8.4	7.9	8.3	8.7	8.3	7.8	8.3	8.3	8.2	8.1	8.1	8.1	8.1	8.2	8.1	7.6	7.2
Replication 3																				
Tailings	7.7	7.9	7.7	8.0	7.8	7.8	7.9	7.9	7.8	7.7	7.7	8.0	8.0	7.6	8.2	7.7	7.9	7.6	2.0	2.1
Contaminated Soil	7.7	7.7	7.7	7.7	7.8	7.9	7.6	7.1	7.5	7.3	7.5	7.5	8.2	7.9	7.5	7.9	7.5	7.3	5.0	5.0
PGC Soil	8.0	8.0	8.3	8.1	8.3	8.2	8.4	8.5	7.9	8.0	8.2	8.3	8.2	7.8	8.0	7.9	8.2	8.0	7.3	7.1
Replication 4																				
Tailings	6.5	7.8	7.7	7.8	7.9	7.7	7.7	7.8	7.8	7.6	8.1	8.0	8.0	7.9	8.0	7.7	7.7	7.9	2.1	1.8
Contaminated Soil	7.8	7.7	8.0	7.9	8.1	8.1	8.0	7.5	7.5	7.6	8.0	8.0	7.8	8.2	8.2	8.0	7.7	7.4	5.1	4.9
PGC Soil	7.8	8.0	8.2	8.1	8.1	8.2	7.8	8.3	8.0	7.9	7.9	8.0	8.2	7.7	8.4	7.9	8.3	8.2	7.6	7.1
Replication 5																				
Tailings	8.0	7.8	7.9	7.7	7.7	7.8	7.7	7.9	7.8	7.8	8.0	8.0	7.8	8.0	7.9	7.7	7.6	7.8	1.8	2.2
Contaminated Soil	7.8	7.7	7.6	8.0	7.9	7.8	7.8	7.6	7.7	7.7	7.4	7.6	7.7	8.0	7.9	7.9	7.9	8.0	5.1	4.8
PGC Soil	8.0	7.8	7.9	8.3	8.0	8.1	8.1	8.5	8.1	8.2	8.1	8.0	8.0	8.4	7.8	8.2	8.1	8.2	7.3	7.3
Replication 6																				
Tailings	7.9	7.8	7.7	7.6	7.8	7.7	7.6	7.6	7.8	7.6	8.0	7.9	8.1	7.7	7.6	7.8	8.0	7.8	2.0	2.0
Contaminated Soil	7.6	7.7	7.4	7.8	8.0	7.8	7.1	7.8	7.7	7.5	7.9	7.5	8.2	7.7	7.2	8.1	7.5	7.5	5.2	5.0
PGC Soil	7.9	7.8	8.2	8.0	8.1	8.1	8.2	8.5	8.0	7.9	7.9	8.0	8.2	8.3	8.0	8.1	8.0	8.2	7.3	7.3
Replication 7																				
Tailings	7.9	7.7	8.0	7.8	8.1	7.9	8.0	7.8	8.2	8.1	8.3	8.2	8.1	8.0	7.9	7.8	8.0	7.8	1.9	2.0
Contaminated Soil	8.0	8.1	8.0	8.0	8.3	8.3	7.9	8.1	8.0	7.9	7.8	7.8	8.3	8.3	8.2	8.1	8.0	7.8	4.9	5.0
PGC Soil	7.7	8.0	8.3	8.1	8.5	8.2	8.6	8.4	8.2	8.0	8.1	8.2	8.4	8.4	8.1	8.3	8.3	8.1	7.1	7.2
Replication 8																				
Tailings	8.1	8.4	7.1	8.1	8.0	8.2	7.9	7.9	7.9	8.1	8.0	8.6	7.5	7.9	7.8	8.0	7.9	8.1	2.1	1.9
Contaminated Soil	8.4	8.2	7.8	8.0	8.3	8.2	8.4	7.8	8.3	8.1	8.2	7.5	8.4	7.6	8.5	7.5	8.8	7.8	5.2	5.0
PGC Soil	8.4	7.4	8.8	7.2	8.4	8.6	8.8	8.7	8.3	8.1	8.3	8.0	8.1	7.6	8.6	8.0	8.2	8.1	7.6	7.1

Table 281. Number of days required for emergence in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3/CaO$	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	8	8	8	8	7	9	8	8	8	8	7	8	7	8	8	8	9	9
2%	6	8	6	8	6	7	6	7	6	7	6	8	6	8	6	9	6	8
4%	7	7	7	8	7	8	7	8	7	7	7	9	7	8	7	8	7	7
6%	7	8	7	8	7	7	8	7	7	8	7	8	7	8	7	7	7	7
8%	7	9	7	9	7	7	7	9	7	8	8	8	7	8	7	8	8	8
10%	7	8	7	9	7	7	7	7	7	7	9	9	7	9	7	8	7	8
12%	7	7	8	9	8	8	7	7	7	7	8	10	7	7	7	8	8	8
Replication 2																		
0%	7	8	7	7	7	8	7	8	8	8	8	7	7	8	7	8	7	8
2%	7	7	7	7	7	7	8	8	7	7	7	8	7	8	8	8	8	8
4%	7	8	8	8	7	8	8	9	7	7	8	8	8	8	8	8	8	8
6%	7	8	8	8	7	8	7	7	7	8	8	9	7	8	7	8	8	10
8%	8	8	7	7	7	8	7	9	7	8	7	8	7	9	7	8	9	8
10%	7	8	7	7	7	8	7	8	8	8	8	7	7	7	7	8	8	8
12%	8	9	7	7	9	8	8	9	7	9	9	9	7	7	8	8	8	8
Replication 3																		
0%	8	7	7	9	7	8	8	7	7	7	7	8	7	8	8	8	8	8
2%	8	7	7	8	7	8	7	7	7	7	7	8	8	8	7	8	7	8
4%	7	8	8	7	8	7	7	7	8	8	8	8	8	8	8	9	8	8
6%	6	8	7	8	7	9	7	8	7	9	8	8	8	8	7	8	8	8
8%	7	7	7	8	7	8	8	8	7	7	8	8	9	8	9	8	8	8
10%	7	8	7	8	7	8	8	7	7	8	8	8	7	7	7	8	8	8
12%	9	8	7	7	7	8	8	10	7	9	8	8	7	8	8	8	7	8

Continued →

Table 281. Number of days required for emergence in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	8	9	8	5	8	8	9	8	8	5	8	5	8	5	8	6	8	6
2%	7	8	8	8	8	7	8	8	7	10	8	8	7	9	7	6	8	6
4%	7	8	7	8	7	8	7	9	7	8	7	8	7	8	8	6	8	6
6%	8	8	7	8	7	8	7	8	7	8	7	8	7	8	7	6	8	6
8%	8	8	7	8	8	8	7	8	7	8	8	8	7	7	7	6	7	6
10%	7	8	7	8	7	7	8	9	7	8	8	8	7	7	7	6	7	6
12%	7	8	7	8	7	8	7	7	7	7	8	9	7	7	7	7	7	8
Replication 5																		
0%	8	8	8	8	7	8	8	8	8	8	7	8	10	10	8	8	10	8
2%	7	7	7	8	8	8	7	7	7	7	8	8	8	8	8	8	8	8
4%	7	8	7	8	7	7	8	8	7	7	8	7	7	7	7	8	8	8
6%	8	7	7	7	7	8	7	7	7	7	8	7	8	8	8	8	8	8
8%	7	8	8	8	7	8	7	7	7	7	8	8	8	8	8	8	7	8
10%	9	7	8	7	7	7	8	7	8	7	8	10	7	7	9	8	7	7
12%	7	7	7	7	7	7	8	8	7	8	8	8	7	7	7	8	7	7

Table 282. Germination (number of seedlings emerged/15 seeds, 14 day post-emergence) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	15	15	15	15	15	9	15	11	15	15	15	12	15	15	15	12	15	15
2%	15	15	15	11	15	15	15	9	15	15	15	15	15	15	15	7	15	10
4%	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
6%	15	15	15	15	15	15	15	13	15	10	15	12	15	8	15	15	15	15
8%	15	9	15	10	15	9	15	11	15	10	15	9	15	15	15	15	15	12
10%	15	15	15	15	15	15	15	10	15	15	15	13	15	15	15	15	15	15
12%	15	10	15	15	15	12	15	11	15	15	15	9	15	12	15	10	15	15
Replication 2																		
0%	15	14	15	15	15	15	15	15	15	10	15	10	15	15	15	15	15	15
2%	15	15	15	12	15	15	15	15	15	15	15	15	15	15	15	15	15	15
4%	15	11	15	15	15	11	15	15	15	10	15	15	15	15	15	15	15	15
6%	15	15	15	15	15	10	15	15	15	15	15	9	15	15	15	11	15	10
8%	15	12	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	10
10%	15	15	15	11	15	15	15	15	15	15	15	15	15	10	15	15	15	13
12%	15	15	15	15	15	13	15	12	15	15	15	11	15	12	15	15	15	15
Replication 3																		
0%	15	15	15	15	15	12	15	15	15	15	15	15	15	15	15	15	15	7
2%	15	15	15	15	15	10	15	15	15	15	15	9	15	15	15	15	15	15
4%	15	10	15	15	15	15	15	15	15	14	15	15	15	13	15	12	15	12
6%	10	15	13	15	15	10	15	15	15	15	15	15	15	12	13	14	15	13
8%	15	15	15	15	15	12	15	15	15	13	15	12	15	15	15	15	15	15
10%	15	15	15	13	15	13	15	15	15	15	15	12	15	15	15	9	15	13
12%	15	15	15	12	15	13	15	8	15	12	15	9	15	15	15	15	15	15

Continued →

Table 282. Germination (number of seedlings emerged/15 seeds, 14 day post-emergence) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	3	6	15	15	15	15	7	7	15	15	10	15	15	15	15	15	15	10
2%	15	9	15	11	6	8	8	8	15	7	15	13	15	15	15	7	15	15
4%	15	12	15	11	15	11	11	11	15	15	15	8	15	15	15	9	15	15
6%	15	9	15	11	15	10	11	11	15	9	9	15	15	15	15	9	15	15
8%	15	15	15	10	15	14	7	7	15	13	15	8	15	15	15	10	15	15
10%	15	13	15	12	15	15	13	13	15	10	10	13	15	15	15	8	15	12
12%	15	9	15	13	15	10	14	14	15	10	15	4	15	15	15	13	15	15
Replication 5																		
0%	6	12	15	7	4	8	11	11	9	13	15	15	4	11	15	15	9	11
2%	15	15	7	15	9	12	15	15	15	15	10	9	7	10	7	15	15	10
4%	15	15	15	15	15	15	9	9	15	11	10	12	15	14	15	15	12	15
6%	15	13	15	15	15	6	9	9	13	15	15	11	8	7	15	15	9	8
8%	8	12	15	8	12	12	11	11	11	15	15	15	4	15	12	9	15	15
10%	12	15	8	12	12	11	11	11	15	12	12	12	15	14	15	15	15	15
12%	15	15	15	12	15	15	15	15	15	9	15	15	15	15	15	15	15	10

Table 283. Survival (number of seedlings survived/emerged, 14 day post-emergence) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	15	15	15	15	15	9	15	11	15	15	15	12	15	15	15	12	15	15
2%	15	15	15	11	15	15	15	9	15	15	15	15	15	15	15	7	15	10
4%	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
6%	15	15	15	15	15	15	15	13	15	10	15	12	15	8	15	15	15	15
8%	15	9	15	10	15	9	15	11	15	10	15	9	15	15	15	15	15	12
10%	15	15	15	15	15	15	15	10	15	15	15	13	15	15	15	15	15	15
12%	15	10	15	15	15	12	15	11	15	15	15	9	15	12	15	10	15	15
Replication 2																		
0%	15	14	15	15	15	15	15	15	15	10	15	10	15	15	15	15	15	15
2%	15	15	15	12	15	15	15	15	15	15	15	15	15	15	15	15	15	15
4%	15	11	15	15	15	11	15	15	15	10	15	15	15	15	15	15	15	15
6%	15	15	15	15	15	10	15	15	15	15	15	9	15	15	15	11	15	10
8%	15	12	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	10
10%	15	15	15	11	15	15	15	15	15	15	15	15	15	10	15	15	15	13
12%	15	15	15	15	15	13	15	12	15	15	15	11	15	12	15	15	15	15
Replication 3																		
0%	15	15	15	15	15	12	15	15	15	15	15	15	15	15	15	15	15	7
2%	15	15	15	15	15	10	15	15	15	15	15	9	15	15	15	15	15	15
4%	15	10	15	15	15	15	15	15	15	14	15	15	15	13	15	12	15	12
6%	10	15	13	15	15	10	15	15	15	15	15	15	15	12	13	14	15	13
8%	15	15	15	15	15	12	15	15	15	13	15	12	15	15	15	15	15	15
10%	15	15	15	13	15	13	15	15	15	15	15	12	15	15	15	9	15	13
12%	15	15	15	12	15	13	15	8	15	12	15	9	15	15	15	15	15	15

Continued →

Table 283. Survival (number of seedlings survived/emerged, 14 day post-emergence) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	3	6	15	15	15	15	7	7	15	15	10	15	15	15	15	15	15	10
2%	15	9	15	11	6	8	8	8	15	7	15	13	15	15	15	7	15	15
4%	15	12	15	11	15	11	11	11	15	15	15	8	15	15	15	9	15	15
6%	15	9	15	11	15	10	11	11	15	9	9	15	15	15	15	9	15	15
8%	15	15	15	10	15	14	7	7	15	13	15	8	15	15	15	10	15	15
10%	15	13	15	12	15	15	13	13	15	10	10	13	15	15	15	8	15	12
12%	15	9	15	13	15	10	14	14	15	10	15	4	15	15	15	13	15	15
Replication 5																		
0%	6	12	15	7	4	8	11	11	9	13	15	15	4	11	15	15	9	11
2%	15	15	7	15	9	12	15	15	15	15	10	9	7	10	7	15	15	10
4%	15	15	15	15	15	15	9	9	15	11	10	12	15	14	15	15	12	15
6%	15	13	15	15	15	6	9	9	13	15	15	11	8	7	15	15	9	8
8%	8	12	15	8	12	12	11	11	11	15	15	15	4	15	12	9	15	15
10%	12	15	8	12	12	11	11	11	15	12	12	12	15	14	15	15	15	15
12%	15	15	15	12	15	15	15	15	15	9	15	15	15	15	15	15	15	10

Table 284. Shoot height (height from soil to longest leaf (mm), 14 day post-emergence) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	145	256.2	132.2	204	109.2	185	126	187	102	206.5	118	170.5	135	175	66.5	210.7	79	203
2%	50.7	177	52.5	157.7	17.5	164.7	48.2	194.2	51	191.2	61	205	35	185	72	140	100	193
4%	73.7	178.2	67.7	141.7	28	155.5	97.5	193	115	177.2	79	192	67	157	100	170	87	193
6%	60.2	198.2	65	192	34	146.7	44.5	139	93	110	77	144	54	133	85	131	89	169
8%	32.7	161.2	50	156.2	34	111	52	153.5	58	126	47	132	43	116	46	146	66	138
10%	68	105	99	133	55	80	75	110	60	185	50	107	36	95	49	123	43	109
12%	56	149	79	159	31	91.2	56	160	61	177	61	121	37.5	126	39	115	47	116
Replication 2																		
0%	80.5	217	127.5	201.7	149.2	164	114.5	182.2	127.5	233.5	121.2	216.7	138.2	184.7	95.2	208.7	86.2	204.2
2%	78.7	162.5	55	128.7	86.7	147.2	98.7	152	64.2	182.5	85	177.5	137	178.7	71.5	155	104.2	165
4%	93.5	98.2	67.2	150.7	45.2	113	72	135.2	88	155.5	66.2	163.7	54.5	121.2	51.2	147.7	97.2	183
6%	44.5	125	63.2	145.7	20	133.5	67.2	102	96	124.5	45	82.2	43.2	105	51	91.2	84.2	94.7
8%	30.7	102.5	52.2	140	49.5	141.2	55.2	112.7	57.2	127.5	63.2	154	42	128	72	105	50.2	111.5
10%	39.5	137.5	103.2	124.2	16	97	38.2	104.2	30.2	161.5	31	145.2	28.3	111.7	25	89.5	34	107.2
12%	23.7	89.5	56	153.2	28.2	88.2	19.2	84.5	29	116.7	33.5	81.5	33.2	107.7	34	77.7	46.5	88
Replication 3																		
0%	67.2	187.7	96	180.2	98	144.5	96.5	194.5	96	194.5	91.5	186.7	96.2	148.5	80	136.5	85.8	180.5
2%	55.2	198.2	75.5	145	42.2	180	67.7	136	48.5	141	71.8	179.2	42.2	160.8	77	152.5	98.7	155.5
4%	62	138	71.2	147.2	28	137	57.2	171.5	58.2	149.2	65.8	129	43.8	87.5	35.8	95	49	127.8
6%	28.8	130.2	51.2	109.8	31	98.2	28.8	140.2	80.5	152.8	59.5	110	43.3	88	28.5	90.2	51.5	91.5
8%	29	117.2	57	140.7	21.2	101.5	42.8	121.5	33	137.2	45	78.5	25	92.5	38.2	97.8	27.5	106.7
10%	30	102.7	82	110.8	45	114.7	29.2	99	40.8	138.5	41.2	66.5	28.8	93.7	24.5	78.8	33	113.5
12%	27.5	95.5	56.5	129.5	26.5	94.2	21	80.7	25	93.2	33.8	101	42	102.8	36.2	85.5	28.5	97.2

Continued →

Table 284. Shoot height (height from soil to longest leaf (mm), 14 day post-emergence) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3/CaO$	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	19.5	112	69.5	128.5	59.3	140.5	54.4	128	47.3	97	30.3	140.5	53.3	121.3	42.8	192	48.3	123.7
2%	86.8	95.5	34.9	101.3	38.3	100	85.5	113	132.8	64.5	91.3	152.3	54.8	123.7	26.3	64	25.5	50.8
4%	97.5	92.8	64.3	136.3	36	101	34.7	168.8	67.3	113	68.3	108.2	59.5	85.2	61.5	109.8	67	50.8
6%	65	119.8	32.3	117.5	38.5	81	51.8	97	32.8	113.2	47.7	93.3	45.3	75.8	59.3	101.8	41.3	80.8
8%	47.2	72.5	36.7	105.2	51.3	85.8	57.5	139.8	76.3	129.3	46.3	72.5	33	87	43.5	155.5	36.5	72.8
10%	39	36.3	82.3	214.5	15.8	91	46.5	102.5	28.5	83.5	30.2	73	22.3	101	26	64.2	20.5	76.3
12%	28	108.3	23.7	120.5	25	95.4	29.5	76.6	36.3	103.2	30.2	65.2	26.2	85.5	52.5	91.3	44	122.5
Replication 5																		
0%	170	252.2	133.2	156.2	157.5	192	88	248	77	152.2	96.5	174	126.5	163.7	109.2	167.2	93.2	190
2%	126	169.5	119	190.7	77	152.5	79	172.2	93.7	123	101.2	164.2	77.5	166.5	106.2	166.5	93.7	165.2
4%	58.7	127.5	118.7	128.5	70.5	147.7	81.5	160	92.5	183.5	57	182.5	52.2	123.2	88.5	236.2	91.2	147
6%	78.7	103	58.2	153.7	24.7	108.7	62.2	128.7	59.7	136.2	73	135.7	38.7	86	62.7	141.2	75	154
8%	34.7	105.2	51.2	159	55.2	80.7	70.2	117.2	22	183	37.5	140	29.2	88.7	26.2	88	46.5	116.5
10%	32	95	98	126.2	37.5	105.2	32.5	102.7	23	81	30	131.2	21	71.2	28.8	65.5	36.2	74.7
12%	46.5	90.3	42	102	26	123.5	43.7	98.2	39.2	96.5	40.2	92.5	28.3	108.5	62.2	84.2	33	79.7

Table 285. Aboveground height (height from soil to longest leaf (mm), 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Lime LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	184	235	240	300	201	340	213	300	230	365	235	249	210	300	191	370	135	305
2%	273	305	180	257	154	330	179	255	315	225	120	370	155	245	90	335	197	280
4%	459	255	120	240	186	200	190	245	95	282	135	211	145	250	135	205	127	190
6%	247	226	105	260	161	236	166	335	165	185	130	257	141	335	133	210	161	175
8%	197	305	125	215	90	140	200	290	180	240	163	210	195	195	121	175	131	200
10%	126	170	135	270	155	131	130	195	155	315	172	165	100	166	143	205	144	160
12%	113	205	125	200	205	135	130	220	210	245	114	235	165	160	133	300	135	173
Replication 2																		
0%	212	350	253	409	145	215	178	277	175	340	239	305	242	340	177	315	187	278
2%	176	300	112	309	196	280	152	196	174	302	125	315	217	244	145	205	125	285
4%	200	265	204	205	203	261	226	296	141	332	128	304	145	190	145	235	198	315
6%	233	195	133	194	85	285	160	259	255	325	173	275	210	155	295	269	122	186
8%	178	411	176	355	208	455	125	234	155	219	185	252	100	138	116	194	160	171
10%	235	311	185	264	99	150	160	170	174	300	149	240	95	180	139	212	165	185
12%	125	200	178	330	110	135	138	205	65	158	167	230	192	139	120	195	178	125
Replication 3																		
0%	144	310	147	390	214	230	365	240	135	381	121	337	176	195	165	146	160	245
2%	186	353	194	177	132	270	190	245	55	175	145	228	99	198	159	220	215	216
4%	95	195	130	210	209	330	100	175	96	300	200	210	135	121	95	165	127	145
6%	202	255	114	150	135	174	95	181	130	235	170	177	150	125	135	115	145	113
8%	105	210	102	320	77	120	78	145	207	230	175	130	220	224	110	110	134	190
10%	200	165	162	158	100	155	89	120	97	180	100	210	59	250	100	122	112	200
12%	110	135	137	225	111	205	47	180	106	135	170	205	160	130	100	108	132	103

Continued →

Table 285. Aboveground height (height from soil to longest leaf (mm), 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Lime LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	128	300	145	200	145	289	171	320	136	226	95	211	172	218	130	150	185	209
2%	136	192	93	169	235	194	131	215	162	244	210	293	130	195	175	203	86	164
4%	193	190	155	223	170	140	135	305	180	210	203	304	140	240	99	214	103	153
6%	146	220	143	200	110	117	113	130	88	205	145	298	88	112	122	211	106	215
8%	170	200	161	175	98	137	90	249	90	208	142	160	40	259	97	130	62	100
10%	111	227	110	180	80	101	202	126	91	197	109	179	95	129	142	151	95	145
12%	100	149	114	192	37	151	155	165	83	155	115	227	90	110	80	273	52	140
Replication 5																		
0%	275	308	201	265	250	304	280	315	295	245	252	252	205	225	235	240	150	390
2%	240	205	295	280	165	229	200	190	270	220	270	270	250	245	220	255	265	170
4%	235	170	275	280	140	230	195	240	210	250	210	210	335	222	195	282	240	225
6%	230	235	185	308	215	245	225	290	280	275	280	280	170	250	240	245	216	308
8%	240	220	170	300	165	154	230	145	130	355	130	130	130	225	120	135	235	150
10%	120	255	200	165	210	230	210	395	120	150	120	120	120	130	116	260	100	120
12%	165	150	125	335	50	180	150	150	250	215	250	250	85	175	155	135	150	120

Table 286. Root distribution (number of roots at 5 cm, 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	30	70	70	30	30	25	45	50	35	35	20	150	40	30	45	30	30	30
2%	70	40	8	35	20	30	25	20	60	30	10	40	30	50	3	50	38	20
4%	20	50	9	46	35	40	40	40	20	55	15	130	20	20	30	30	30	20
6%	20	70	30	12	13	65	50	100	30	20	15	26	45	40	50	20	50	90
8%	20	40	10	90	9	20	10	100	20	60	10	30	30	45	40	50	20	100
10%	30	50	20	30	40	35	15	50	10	130	18	7	20	32	60	50	30	30
12%	28	50	20	25	20	25	40	30	10	90	12	30	10	20	25	30	30	50
Replication 2																		
0%	40	80	40	50	50	80	38	45	20	60	50	40	65	50	28	36	25	28
2%	28	40	15	45	30	30	15	40	43	37	20	35	26	30	15	30	15	50
4%	18	50	20	20	25	23	15	25	20	45	15	35	20	80	20	55	20	28
6%	30	30	25	28	10	80	18	30	45	60	19	20	20	35	4	31	20	20
8%	18	28	28	25	20	100	25	20	30	40	15	20	53	30	40	28	25	30
10%	15	50	40	30	13	20	25	40	28	60	20	50	10	50	35	30	7	50
12%	13	22	15	40	14	12	19	30	8	30	20	20	22	30	15	22	30	30
Replication 3																		
0%	14	80	18	100	18	50	80	70	18	23	15	35	29	18	18	15	16	30
2%	7	100	10	17	9	25	20	15	10	30	11	20	18	20	18	13	23	16
4%	10	30	8	40	20	4	16	8	19	100	50	30	13	21	17	17	10	10
6%	13	35	18	16	12	25	6	16	10	31	10	15	10	16	15	19	14	15
8%	5	50	14	40	8	20	9	50	21	30	20	22	21	20	15	22	8	50
10%	12	20	15	14	20	20	15	30	15	30	19	30	5	20	27	21	9	30
12%	4	30	11	17	28	30	13	20	8	15	20	25	19	20	14	20	22	25

Continued →

Table 286. Root distribution (number of roots at 5 cm, 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	4	30	14	18	12	30	26	25	15	18	10	15	13	18	10	5	25	35
2%	18	12	4	16	16	28	11	20	18	31	18	30	13	30	15	23	5	8
4%	15	14	10	18	13	24	12	20	15	20	19	20	13	33	18	20	5	20
6%	28	18	10	14	24	18	18	18	8	28	10	25	9	23	14	28	10	22
8%	21	37	12	16	27	29	11	30	8	12	25	16	8	25	15	14	14	16
10%	10	30	10	18	10	21	16	30	8	48	6	30	13	30	12	35	9	16
12%	10	33	15	13	19	23	13	26	10	20	10	30	13	14	10	30	20	15
Replication 5																		
0%	40	20	29	17	18	30	20	20	25	20	25	30	14	20	25	18	15	28
2%	18	15	20	20	15	27	21	21	26	18	35	40	15	30	14	20	18	17
4%	20	27	14	15	30	18	15	15	15	27	18	18	4	38	12	30	10	16
6%	20	30	30	20	9	26	28	28	14	28	50	20	27	29	45	30	28	16
8%	23	18	20	48	15	34	15	15	23	38	15	30	13	25	10	28	47	18
10%	10	20	45	26	18	28	27	27	21	40	13	40	25	28	23	50	8	15
12%	30	30	15	60	8	21	36	36	24	23	27	27	10	20	13	18	18	17

Table 287. Aboveground biomass (weight of aboveground production (g), 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	0.3250	0.5332	0.2930	0.4563	0.3414	0.6072	0.7310	0.4087	0.4449	0.4985	0.1823	0.5976	0.2753	0.2295	0.2523	0.4270	0.2604	0.3376
2%	0.2846	0.2958	0.1960	0.3655	0.0448	0.2769	0.1948	0.3344	0.1925	0.3289	0.1184	0.6624	0.1680	0.1471	0.0269	0.3560	0.1803	0.2522
4%	0.2462	0.2604	0.0474	0.3507	0.0733	0.2736	0.1252	0.1610	0.0513	0.2380	0.1432	0.2188	0.0750	0.6180	0.0871	0.1150	0.1277	0.1208
6%	0.2143	0.3104	0.0561	0.1977	0.3300	0.2448	0.1483	0.4303	0.1281	0.2439	0.0699	0.3159	0.0703	0.2877	0.0775	0.1803	0.0647	0.1178
8%	0.0992	0.2293	0.1013	0.3218	0.0226	0.1272	0.0885	0.2990	0.0691	0.2768	0.0773	0.2727	0.0759	0.1813	0.0763	0.1671	0.0700	0.143
10%	0.5410	0.1217	0.0972	0.2881	0.0476	0.0999	0.0538	0.1551	0.0829	0.2513	0.0504	0.1090	0.0187	0.1014	0.0558	0.2006	0.0803	0.0876
12%	0.0466	0.2160	0.0590	0.2230	0.0356	0.0832	0.1080	0.1892	0.0636	0.2506	0.0487	0.2361	0.0432	0.0993	0.0605	0.1906	0.0425	0.1508
Replication 2																		
0%	0.4978	0.6383	0.4876	1.0416	0.3333	0.4224	0.388	0.6040	0.4126	1.1945	0.4832	0.8519	0.4394	1.1706	0.1522	0.4302	0.1060	0.4012
2%	0.2903	0.6881	0.1077	0.5327	0.1687	0.3623	0.094	0.3517	0.1035	0.3411	0.1725	0.4803	0.1156	0.2758	0.1605	0.2644	0.0746	0.5642
4%	0.2202	0.4080	0.2218	0.2758	0.2225	0.2629	0.1918	0.3263	0.0904	0.3918	0.0803	0.4695	0.0419	0.1279	0.0605	0.1127	0.0988	0.3292
6%	0.2341	0.2627	0.1168	0.2240	0.0235	0.2931	0.0833	0.3586	0.2153	0.2688	0.1209	0.2863	0.0567	0.1992	0.0689	0.1958	0.0693	0.2020
8%	0.1390	0.3940	0.1921	0.0753	0.0867	0.4856	0.0991	0.2731	0.1270	0.3128	0.1638	0.2508	0.0349	0.1205	0.0542	0.1458	0.0817	0.1340
10%	0.1126	0.3284	0.2080	0.4291	0.0346	0.1324	0.1127	0.1333	0.0755	0.2769	0.0926	0.3604	0.0398	0.1251	0.0642	0.1903	0.0951	0.2514
12%	0.0571	0.1831	0.1264	0.4068	0.0293	0.0780	0.0876	0.1708	0.0161	0.1503	0.0813	0.2062	0.0663	0.0904	0.0643	0.1509	0.1236	0.1183
Replication 3																		
0%	0.2825	0.4404	0.3761	0.9690	0.2909	0.3756	0.6591	0.7042	0.2096	0.8653	0.1031	0.6789	0.3337	0.2533	0.1848	0.1620	0.1823	0.4595
2%	0.2437	0.6247	0.1135	0.2313	0.6860	0.4252	0.1800	0.1987	0.0367	0.1403	0.1683	0.2859	0.0519	0.2120	0.1238	0.2553	0.1444	0.236
4%	0.5940	0.2265	0.0878	0.1982	0.1582	0.1163	0.0542	0.1542	0.0603	0.5180	0.2404	0.2809	0.0921	0.0906	0.0479	0.0866	0.0597	0.1783
6%	0.1949	0.2593	0.1347	0.0934	0.0603	0.0890	0.0445	0.1576	0.0610	0.2124	0.1876	0.1941	0.0283	0.0871	0.0558	0.0831	0.0950	0.0730
8%	0.0657	0.1831	0.0575	0.2286	0.0099	0.0696	0.0393	0.1738	0.1207	0.2865	0.1854	0.1611	0.1009	0.1488	0.0447	0.0634	0.0439	0.2032
10%	0.0898	0.1131	0.0723	0.1714	0.0290	0.1299	0.0429	0.0852	0.0647	0.1669	0.0583	0.1764	0.0073	0.1222	0.0433	0.0878	0.0503	0.2229
12%	0.0413	0.1998	0.0483	0.2944	0.0509	0.1122	0.0127	0.1581	0.0277	0.0955	0.0771	0.3633	0.0809	0.0995	0.1318	0.1114	0.0700	0.0947

Continued →

Table 287. Aboveground biomass (weight of aboveground production (g), 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	0.0011	0.4386	0.1630	0.2370	0.0990	0.6262	0.3989	0.3935	0.1270	0.1542	0.0946	0.2966	0.1014	0.2734	0.0507	0.0524	0.2357	0.5980
2%	0.1866	0.2442	0.0546	0.1267	0.3109	0.2984	0.2703	0.1195	0.0986	0.4351	0.2448	0.3153	0.1178	0.3405	0.1405	0.1939	0.1074	0.1145
4%	0.0161	0.3456	0.1569	0.3660	0.1121	0.2405	0.1337	0.4720	0.1687	0.2586	0.1221	0.4175	0.0648	0.1701	0.0680	0.2130	0.5620	0.1712
6%	0.1205	0.3199	0.0923	0.3541	0.0635	0.0521	0.0684	0.1830	0.0546	0.3029	0.0632	0.2573	0.0859	0.0223	0.0625	0.1746	0.0463	0.1310
8%	0.1494	0.1770	0.0609	0.1943	0.0242	0.0785	0.0264	0.3285	0.0312	0.1934	0.0957	0.2096	0.0129	0.1885	0.0374	0.1179	0.585	0.0576
10%	0.0498	0.2279	0.0701	0.2258	0.0321	0.0872	0.1210	0.1512	0.0292	0.1483	0.0549	0.2535	0.0307	0.0916	0.0599	0.1250	0.0310	0.0930
12%	0.0386	0.1447	0.0796	0.2714	0.0087	0.1076	0.0593	0.1659	0.0304	0.1706	0.0630	0.3290	0.0276	0.1119	0.0508	0.1779	0.0456	0.1238
Replication 5																		
0%	1.3006	0.4716	0.5529	0.7079	0.3778	0.7823	0.5258	0.5497	0.5221	0.4992	0.7353	0.5773	0.9195	0.4251	0.5577	0.3455	0.2460	0.6471
2%	0.3853	0.2093	1.0849	0.4863	0.3110	0.4053	0.2567	0.2364	0.2525	0.3024	0.9709	0.5548	0.4358	0.3943	0.4883	0.4142	0.4098	0.3872
4%	0.5923	0.2525	0.5805	0.3163	0.2128	0.2787	0.2775	0.3222	0.2108	0.3260	0.4516	0.4013	0.3481	0.2918	0.1969	0.3304	0.1543	0.2737
6%	0.3534	0.3304	0.5006	0.4166	0.0490	0.1637	0.3518	0.3580	0.2143	0.4363	0.4755	0.3056	0.1387	0.2197	0.2035	0.3478	0.3556	0.3941
8%	0.2602	0.3708	0.2295	0.5069	0.0683	0.1738	0.3552	0.2066	0.1523	0.6168	0.1076	0.4214	0.0580	0.1076	0.034	0.1062	0.3603	0.2267
10%	0.0767	0.1644	0.4332	0.1817	0.2144	0.1215	0.1724	0.2485	0.1681	0.1835	0.1287	0.5950	0.0304	0.1046	0.0414	0.3014	0.0337	0.1047
12%	0.1367	0.1773	0.0693	0.7029	0.0165	0.1159	0.1564	0.1408	0.0655	0.1164	0.1439	0.3270	0.0189	0.1567	0.1406	0.1355	0.0684	0.1252

Table 288. Belowground biomass (weight of belowground production (g), 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	0.5973	0.1514	0.3946	0.5074	0.1775	0.3879	0.3667	0.3605	0.2063	0.5354	0.1108	1.1616	0.2026	0.2569	0.1567	0.4718	0.1943	0.2609
2%	0.5054	0.1574	0.1864	0.6900	0.0236	0.6232	0.1468	0.4257	0.1590	0.7000	0.0661	0.7499	0.0864	0.4359	0.0068	0.5458	0.1545	0.3067
4%	0.3156	0.3156	0.1607	0.6601	0.1660	0.5367	0.2974	0.2888	0.1680	0.4835	0.2626	0.8099	0.1533	0.1343	0.1265	0.2723	0.0967	0.3078
6%	1.0320	0.1566	0.4308	0.1774	0.1461	0.5789	0.2934	0.7001	0.2257	0.4675	0.0980	0.5649	0.1983	0.3352	0.2789	0.2860	0.2032	0.3976
8%	0.3803	0.4005	0.1540	0.6183	0.2935	0.1623	0.1596	0.4892	0.1212	0.5494	0.1067	0.2975	0.2280	0.3028	0.1593	0.3282	0.1887	0.5839
10%	0.2558	0.2362	0.2432	0.3375	0.4016	0.3370	0.1487	0.2582	0.0924	0.6115	0.0535	0.0949	0.0885	0.3693	0.2643	0.3778	0.1265	0.2942
12%	0.4044	0.1099	0.1497	0.3835	0.0863	0.2293	0.1998	0.3753	0.1234	0.5410	0.1129	0.2999	0.1158	0.1683	0.1162	0.2245	0.0854	0.3845
Replication 2																		
0%	0.2573	0.9050	0.3646	0.6794	0.3635	0.4897	0.2875	0.4518	0.1957	0.7420	0.4278	0.5301	0.4706	0.6702	0.0679	0.2049	0.2561	0.2234
2%	0.1869	0.5476	0.0287	0.4278	0.0856	0.4110	0.0548	0.4957	0.2590	0.2949	0.1971	0.3800	0.0676	0.2907	0.2300	0.1815	0.0492	0.5586
4%	0.0695	0.4110	0.0965	0.4822	0.1198	0.3385	0.2450	0.4928	0.0980	0.3136	0.0613	0.3778	0.0599	0.1552	0.0634	0.2258	0.0844	0.3943
6%	0.2836	0.2491	0.1153	0.2041	0.0455	0.2844	0.0843	0.2688	0.2063	0.5318	0.0963	0.2978	0.10002	0.4043	0.0333	0.1877	0.1138	0.4903
8%	0.0459	0.2696	0.1147	0.0761	0.0688	0.6790	0.1410	0.3069	0.1439	0.4432	0.1363	0.2935	0.2093	0.3415	0.3718	0.1356	0.0511	0.1888
10%	0.1028	0.8801	0.1849	0.4829	0.0426	0.1795	0.1293	0.2548	0.0835	0.5780	0.0631	0.4605	0.0842	0.2778	0.1267	0.4724	0.0568	0.3838
12%	0.0873	0.2051	0.0611	0.7985	0.0583	0.0558	0.1168	0.2560	0.0338	0.4183	0.1548	0.2498	0.1442	0.2134	0.0620	0.2323	0.1245	0.2265
Replication 3																		
0%	0.0473	0.4486	0.0693	0.5324	0.0629	0.2708	0.3436	0.2824	0.0425	0.3751	0.0218	0.2350	0.0882	0.1126	0.0588	0.548	0.354	0.1708
2%	0.0970	0.7053	0.0383	0.3393	0.0185	0.2350	0.1244	0.2969	0.0130	0.2275	0.0419	0.2274	0.0344	0.1526	0.0998	0.2803	0.1231	0.1945
4%	0.0255	0.3051	0.0925	0.2225	0.0907	0.3810	0.0511	0.0891	0.0593	0.4948	0.1690	0.2319	0.0560	0.1075	0.0134	0.0810	0.0131	0.2265
6%	0.0482	0.2433	0.0378	0.0794	0.0340	0.1119	0.0337	0.2089	0.0759	0.1728	0.1411	0.1648	0.0152	0.1063	0.0642	0.0665	0.0547	0.0940
8%	0.1018	0.2485	0.0345	0.4488	0.0038	0.1168	0.0194	0.3684	0.0765	0.3165	0.1254	0.1640	0.0525	0.1872	0.0438	0.1066	0.0138	0.2256
10%	0.0425	0.1454	0.0905	0.0830	0.0586	0.2414	0.0925	0.1246	0.0281	0.2485	0.0268	0.2241	0.0101	0.2785	0.0958	0.0770	0.0407	0.2249
12%	0.0636	0.1852	0.0529	0.2737	0.0721	0.1711	0.1019	0.2902	0.0188	0.1765	0.0744	0.2465	0.0985	0.2223	0.0475	0.1157	0.0770	0.1492

Continued →

Table 288. Belowground biomass (weight of belowground production (g), 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/ CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	0.0095	0.2497	0.0296	0.2116	0.0176	0.2340	0.0865	0.1992	0.0152	0.0785	0.0090	0.1284	0.0115	0.1093	0.0099	0.0453	0.0508	0.1752
2%	0.0731	0.2679	0.0103	0.0986	0.0866	0.1069	0.1549	0.0358	0.0339	0.2659	0.0525	0.2132	0.0179	0.2465	0.0402	0.1250	0.0004	0.0491
4%	0.1260	0.2079	0.0136	0.2576	0.0281	0.3033	0.0264	0.3714	0.0822	0.2351	0.0347	0.3431	0.0385	0.2252	0.0642	0.1274	0.0175	0.1535
6%	0.0666	0.2047	0.0202	0.2550	0.0387	0.0524	0.0197	0.2335	0.0299	0.3452	0.0301	0.3269	0.0767	0.0096	0.0181	0.2156	0.0312	0.2013
8%	0.0868	0.1848	0.0464	0.1736	0.0842	0.1033	0.0396	0.4192	0.0649	0.1741	0.0263	0.1899	0.0355	0.1043	0.0189	0.1138	0.0457	0.0356
10%	0.0175	0.1846	0.0267	0.1992	0.0071	0.1165	0.0427	0.1814	0.0236	0.2914	0.0220	0.2145	0.0285	0.1391	0.0373	0.1122	0.0165	0.1423
12%	0.0177	0.1266	0.0487	0.1760	0.0202	0.1261	0.0370	0.1635	0.0073	0.1788	0.0213	0.2320	0.0245	0.1372	0.0312	0.1795	0.0197	0.1562
Replication 5																		
0%	0.2653	0.1000	0.1572	0.2050	0.0782	0.3011	0.0985	0.1481	0.1198	0.1415	0.1412	0.2593	0.0872	0.1508	0.1589	0.1244	0.0385	0.1699
2%	0.0449	0.1275	0.1129	0.4922	0.0979	0.3420	0.0371	0.2311	0.0864	0.1272	0.2635	0.4879	0.1004	0.2540	0.0873	0.1780	0.0592	0.3163
4%	0.1436	0.1982	0.0532	0.1648	0.1193	0.2975	0.0344	0.1676	0.1172	0.2199	0.1133	0.2382	0.1872	0.2924	0.0386	0.2437	0.0260	0.1002
6%	0.1141	0.4147	0.1529	0.1353	0.0122	0.1396	0.1913	0.4203	0.0477	0.4276	0.1702	0.3208	0.0484	0.1587	0.0893	0.3372	0.1032	0.1704
8%	0.0505	0.3269	0.0302	0.4440	0.0436	0.2023	0.1303	0.0896	0.0282	0.7186	0.0357	0.3172	0.0178	0.1346	0.0150	0.1373	0.1308	0.4035
10%	0.0149	0.2247	0.1326	0.1373	0.1214	0.1607	0.0964	0.2224	0.0764	0.1615	0.0668	0.7131	0.0262	0.0891	0.0464	0.2741	0.0033	0.1543
12%	0.0475	0.2322	0.0262	1.0047	0.0082	0.1529	0.1393	0.1918	0.0443	0.1371	0.0536	0.2468	0.0110	0.2308	0.0333	0.1327	0.0337	0.1370

Table 289. Measured pH (s.u., 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 1																		
0%	7.3	7.8	8.2	7.8	7.5	8.0	7.1	7.7	7.2	7.8	7.8	7.5	7.7	7.7	7.6	7.9	7.5	7.7
2%	7.9	7.8	7.9	7.6	8.2	8.3	8.1	8.2	8.4	8.1	7.9	8.1	8.2	8.2	8.2	8.1	8.0	8.2
4%	8.3	8.1	8.3	7.9	8.1	8.2	8.6	8.4	8.2	8.5	8.0	8.1	8.2	8.3	8.2	8.1	8.2	8.2
6%	8.3	8.8	8.3	8.1	8.2	8.1	8.3	8.6	8.5	8.8	8.3	8.2	8.1	8.2	8.2	8.2	8.8	8.3
8%	8.2	8.3	8.1	8.1	8.2	8.2	8.6	8.6	8.5	8.6	8.5	8.4	8.5	8.6	8.1	8.1	10.0	8.2
10%	8.0	8.2	8.0	8.1	8.0	8.0	8.7	8.6	8.6	8.7	8.4	8.6	8.3	8.1	8.0	8.5	8.0	8.1
12%	8.1	8.0	8.3	8.1	8.2	8.1	8.3	8.5	8.8	8.9	8.7	8.6	8.5	8.4	8.2	8.4	8.7	8.2
Replication 2																		
0%	7.7	7.8	7.6	7.6	7.6	7.8	7.8	7.4	7.6	7.8	7.6	7.7	7.6	7.8	7.5	7.6	7.5	7.5
2%	7.8	7.7	7.4	7.5	8.0	7.9	7.8	8.2	8.0	7.9	7.7	7.7	8.1	7.9	8.1	7.9	7.8	7.9
4%	7.8	8.1	8.1	8.0	8.0	7.9	8.1	8.3	8.0	8.1	8.2	7.9	8.2	8.2	7.8	7.8	7.8	8.0
6%	8.1	8.2	8.0	7.8	8.0	8.4	8.6	8.3	8.4	8.5	8.3	8.2	8.2	8.1	7.3	8.3	8.3	7.9
8%	8.1	8.1	8.2	8.6	8.1	8.0	8.7	8.4	8.5	8.4	8.4	8.3	8.4	8.2	8.1	8.0	8.2	7.9
10%	8.3	8.0	8.0	8.3	8.0	8.2	8.5	8.7	8.5	8.5	8.4	8.2	8.1	8.3	8.1	8.1	8.1	8.2
12%	8.2	8.0	8.0	8.0	8.1	8.2	8.5	8.6	8.6	8.2	8.4	8.4	8.3	8.2	8.2	8.1	8.9	8.2
Replication 3																		
0%	7.6	8.0	7.9	7.8	7.5	7.7	7.9	7.6	7.7	7.5	7.7	7.7	7.3	7.7	7.6	7.8	7.6	7.5
2%	7.7	7.9	7.7	7.7	8.0	8.1	8.2	8.5	8.1	8.3	7.7	7.8	8.0	8.0	7.9	8.2	7.8	8.1
4%	8.0	8.2	8.6	8.2	8.1	8.2	8.1	8.4	8.1	8.4	8.2	8.2	7.9	8.3	8.0	8.0	8.1	8.1
6%	8.0	8.0	7.8	7.9	7.9	8.1	8.5	8.3	8.6	8.1	8.4	8.3	8.2	8.1	8.0	8.0	8.1	8.0
8%	8.3	8.2	8.2	8.3	7.8	8.3	8.3	8.6	8.5	8.5	8.6	8.5	8.4	8.1	8.1	8.5	7.9	8.2
10%	8.3	8.3	8.0	8.3	7.9	8.2	8.5	8.6	8.5	8.5	8.6	8.7	8.2	8.3	8.1	8.2	7.8	8.2
12%	8.2	8.3	8.0	8.0	8.0	8.3	8.3	8.7	8.6	8.6	8.7	8.5	8.5	8.5	8.3	8.1	8.2	7.9

Continued →

Table 289. Measured pH (s.u., 90 day growth) in Plant Growth Center soil amended with alkaline industrial by-products and commercial grade lime – Continued.

	Greymont LKD		Tacoma LKD		MT Limestone LKD		Holnam (CH_4) CKD		Holnam (Coal, Coke) CKD		Ash Grove CKD		Dicalcium Silicate		Carbide Lime		$CaCO_3$/CaO	
	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW	RT	BW
Replication 4																		
0%	7.5	7.6	7.3	7.4	7.6	7.5	7.3	8.0	7.4	7.0	8.5	7.5	7.9	8.5	7.4	8.5	7.4	7.3
2%	7.7	7.8	7.6	7.4	8.1	8.0	7.7	7.7	7.9	7.8	8.0	7.8	8.2	7.6	7.8	7.7	7.6	7.9
4%	7.9	8.6	7.9	7.7	7.9	8.0	8.4	8.2	8.1	8.2	7.9	8.1	8.6	7.8	7.5	7.7	7.8	7.9
6%	8.0	8.0	8.0	7.9	7.7	7.9	8.3	8.3	8.3	8.3	8.1	8.0	8.1	8.0	7.3	7.6	7.9	7.8
8%	7.8	7.9	7.9	8.0	7.9	8.0	8.3	8.3	8.2	8.3	8.2	8.4	8.0	7.9	7.8	7.8	7.8	8.6
10%	7.8	7.9	8.0	7.9	7.8	7.9	8.4	8.5	8.3	8.3	8.4	8.3	8.2	8.3	7.9	7.6	8.0	8.3
12%	7.9	7.9	7.7	8.0	7.8	7.9	8.4	8.4	8.5	8.3	8.4	7.7	8.1	8.2	7.8	8.2	8.1	7.9
Replication 5																		
0%	7.6	7.4	7.8	7.7	8.3	7.6	7.6	7.8	7.7	7.7	7.5	7.6	7.9	7.7	7.7	7.7	7.7	7.9
2%	7.9	7.9	7.6	7.8	8.1	8.1	7.8	8.0	7.9	8.2	7.7	7.8	8.3	7.9	8.0	7.9	7.7	8.0
4%	8.1	7.9	8.1	7.9	8.0	8.2	8.4	8.2	8.2	8.2	8.1	8.2	8.1	7.9	8.2	7.9	8.0	8.2
6%	7.8	7.6	7.9	8.3	8.0	7.9	8.5	8.4	8.7	8.3	8.2	8.1	8.2	8.1	8.2	8.1	7.8	8.2
8%	8.0	8.1	8.1	8.0	7.8	8.0	8.3	8.3	8.5	8.4	8.6	8.3	8.0	7.9	8.1	7.9	8.1	8.1
10%	8.0	7.7	7.8	8.1	8.3	7.9	8.5	8.6	8.5	7.2	8.8	8.4	8.6	7.9	8.5	7.9	8.9	8.5
12%	7.9	7.9	9.0	8.1	7.9	8.2	8.4	8.3	8.6	8.3	8.4	8.5	8.1	8.3	7.9	8.3	7.9	7.9

APPENDIX C

DATA QUALITY CONTROL

DATA QA/QC STATEMENT

Contract Laboratory Analyses

Several separate sample batches associated with this project were submitted for laboratory analyses by Energy Laboratories, Billings, MT. With one minor exception, all laboratory QA/QC parameters were within control limits and there is no associated limits (data flags) to the use of the resulting data. Sample batches are summarized below.

Batch 00-57442 -1-11 (11 samples). This batch was submitted September 01, 2000 for saturated paste analyses for Ca, Mg, Na, Al, As, B, Cd, Cu, Fe, Pb, Mn, Se, Zn, SO_4, and Cl; and for sulphur fractionation acid base account (ABA) for 3 of the 11 samples. One field duplicate (DS-001, duplicate of SR-001) was included in this batch. All laboratory quality control samples (duplicates, spikes, and blanks) associated with this batch were within control limits except for Na (used to determine SAR). The RPD for Na analysis of OP-001 was 33 percent. Although the Na concentration in this sample was low (3.2 mg/l), it was above 5 times the detection limit. The resulting calculated SAR values were 0.02 and 0.03 for the duplicate and natural sample respectively. The usability of the SAR data should not be affected. Laboratory spike recoveries ranged from 90 to 102 percent and duplicate relative percent differences (RPD) ranged from 0 to 8.7 percent except for Na as noted above.

Batch 00-57442 -1 (total of 13 samples). This batch was analyzed for total analyses of Al, As, Ba, Be, B, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Sn, P, V, and Zn. Three samples were analyzed for only Al, As, Cu, Pb, Mn, and Zn while additional TCLP

analyses for As, Ba, Cd, Cr, Pb, Hg, Se, and Ag were performed for 9 of the samples. All laboratory QA/QC parameters associated with these samples were within control limits. Maximum RPD for the field duplicate (DS-001) was 7.7 percent.

- Batch 00-58053-1-2 (2 samples). This batch was submitted September 19, 2000 for saturated paste analyses for Ca, Mg, Na, Al, As, B, Cd, Cu, Fe, Pb, Mn, Se, Zn, SO_4, Cl, and lime as $CaCO_3$. All laboratory QA/QC parameters associated with these samples were within control limits. No field QA/QC samples submitted with these two samples.

- Batch 01-56507 (5 samples). These samples were submitted August 01, 2001 for saturated paste analyses of aluminum and vanadium. All laboratory QA/QC parameters associated with these samples were within control limits. No applicable field QA/QC samples submitted with these samples.

- Batch 01-56735 (D-02, G-02). These samples were submitted August 07, 2001 for total analyses of aluminum and vanadium respectively. All laboratory QA/QC parameters associated with these samples were within control limits. No field QA/QC samples submitted with these two samples.

- Batch 00-59133 (3 samples). These kiln dust samples were submitted for analysis of calcium carbonate equivalence (lab report dated November 2, 2000). All laboratory

QA/QC parameters associated with these samples were within control limits. No field QA/QC samples submitted with these samples.

Soil Electrical Conductivity And pH Measurements At MSU

Electrical conductivity and pH (both Fisher glass and Scientific Instruments stainless steel electrodes) measurements were made for substrates used to grow plants during this investigation. These measurements were made utilizing 3 point (pH 4, 7, and 10) calibrations for the Fisher glass electrode, and 2 point (either pH 4, 7 or pH 7, 10) calibrations for the Scientific Instruments stainless steel electrode, and a continuing calibration check for each batch of 20 natural samples. The meter was recalibrated if off more than 0.1 standard units (SU).

Relative percent difference (RPD) was determined for pH using sample splits of the contaminated soil collected from Stucky Ridge, Anaconda, MT. The RPD for pH using the Fisher glass electrode was 1.29 %. Standard reference material (SRM) was obtained from the Reclamation Research Laboratory, Montana State University, in order to evaluate accuracy of pH measurements. Recovery tests for SRM ranged from 97 % to 99 %. Using this SRM, the relative percent difference for soil pH was 0.26 % for the Scientific Instruments stainless steel electrode, and ranged from 0.37 % to 0.50 % for the Fisher glass electrode.

Electrical conductivity (EC) measurements were also made utilizing 3 point calibrations. Linear regression of conductivity bridge output and standard values were used to determine actual sample values. Standard reference material (SRM) was obtained from

the Reclamation Research Laboratory, Montana State University, in order to evaluate accuracy of EC measurements. The difference between the established SRM value (3.3 ds/m) and the measurement (3.16) was 0.14 ds/m. The RPD for samples SR-001 and DS-001 was 18 %.

Analyses of EC in soils amended with alkaline products included 3 field duplicate samples. These were treatments identified as Ash Grove CKD 12 %, Holnam (CH_4) CKD 2 %, and MT Limestone LKD 2 %. The RPD for these samples were 24.1 %, 35.3 %, and 19.4 % percent, respectively.