The evaluation of seven acid tolerant plant species grown on acidic, limed and unlimed tailings in South-western Montana
by Tonia Carr Torrence

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Land Rehabilitation
Montana State University

Abstract:
Mining operations are often located in forested areas at high elevations. Reclaiming these sites may be difficult because of extremely acidic spoil or tailings which result from the mining or milling processes and harsh environmental conditions. Liming increases pH, reduces levels of potentially phytotoxic metals and increases availability of plant nutrients. It is assumed that liming of extremely acidic mine material is necessary to facilitate plant establishment. This theory is tested in this study by planting seven acid tolerant species on limed and unlimed acidic tailings on the Champion mine site which is located in Deerlodge County, Mt. Species planted were Alopecuris arundiaceus, A. pratensis, Agrostis tenuis, A. alba. Festuca ovina, Poa Compressa, and Lotus corniculatus. Plant growth was measured at the seedling and mature stages. Success of the species planted on the unlimed versus limed tailings was used to evaluate the suitability of the unlimed tailings as a plant growth medium. Success of individual species was also evaluated. All species exibited superior growth on the limed tailings compared to that of the unlimed tailings. Two species Festuca ovina. and Alopecurls pratensis grew better than the other species on the limed tailings. It was concluded that liming was necessary for the establishment of all of these species on the Champion mine tailings. Results of species growth are considered to be preliminary and may not be indicative of the species success over time.

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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

Mining operations are often located in forested areas at high elevations. Reclaiming these sites may be difficult because of extremely acidic spoil or tailings which result from the mining or milling processes and harsh environmental conditions. Liming increases pH, reduces levels of potentially phytotoxic metals and increases availability of plant nutrients. It is assumed that liming of extremely acidic mine material is necessary to facilitate plant establishment. This theory is tested in this study by planting seven acid tolerant species on limed and unlimed acidic tailings on the Champion mine site which is located in Deerlodge County, Mt. Species planted were _Alopecuris arundinaceus_, _A. pratensis_, _Agrostis tenuis_, _A. alba_, _Festuca ovina_, _Poa compressa_, and _Lotus corniculatus_. Plant growth was measured at the seedling and mature stages. Success of the species planted on the unlimed versus limed tailings was used to evaluate the suitability of the unlimed tailings as a plant growth medium. Success of individual species was also evaluated. All species exibited superior growth on the limed tailings compared to that of the unlimed tailings. Two species _Festuca ovina_, and _Alopecuris pratensis_ grew better than the other species on the limed tailings. It was concluded that liming was necessary for the establishment of all of these species on the Champion mine tailings. Results of species growth are considered to be preliminary and may not be indicative of the species success over time.

INTRODUCTION

There are thousands of acres of land previously and currently being disturbed by mining in the western United States. The 1977 Surface Mining Control and Reclamation Act (Public Law 95-87) and individual state laws require that these lands be reclaimed. Many mining sites are located in forested areas at high elevations. As a result reclamation of these sites is made difficult by numerous factors, some of which are:

1) scarcity of topsoil;
2) steep slopes and the high erodibility of some soils;
3) the presence of extremely acidic spoils or tailings and the oxidation potential or acid producing capabilities of these materials;
4) toxic levels of metals in the material;
5) lack of essential plant nutrients;
6) the short growing season; and
7) non-availability of commercial seed and plant materials of species adapted to these areas.

These factors exemplify the problems associated with reclamation of many hard rock mine sites.

The Champion mine is an inactive silver mine located 39 km northwest of Butte, Montana (Figure 1). It lies at an elevation of approximately 1965 meters and is surrounded by the Deerlodge National Forest. This mine site exhibits many of these characteristics and is the site at which this study was carried out.

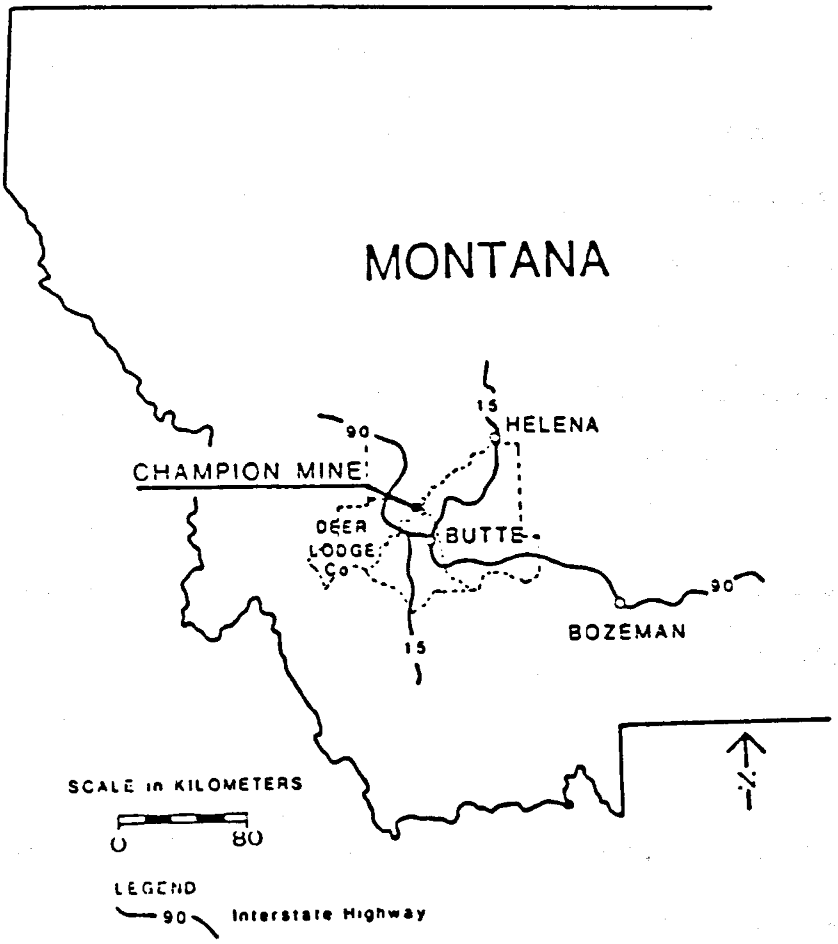

Figure 1. Location of Champion Mine Site.

Champion mine was last active in 1926 and there has been little regrowth of vegetation on the tailings in the intervening sixty years. This is thought to be a result primarily of the extreme acidity of the tailings and attendant phytotoxic levels of aluminum (Russell 1984). Therefore, successful reclamation of this site may lie in the ability to reduce the acidity of the tailings. Applying lime to the material will raise the tailings pH and result in precipitation of aluminum ions in a form unavailable to plants (Foy, 1984). The determination of lime application rates and periodic lime applications are common agricultural practices. This, however, is not the case with mined land, as the desire for timely bond release necessitates a single lime application that will account for future acid production. The methodology for determining a single, or total, lime rate is not well established and has been the subject of many studies (Sobeck et al. 1982, Williams and Yaalon 1982, Caruccio and Geidel 1981, and Smith et al. 1974).

Most recently, Russell (1984) determined total lime application rates for the Champion tailings. Through laboratory weathering Russell determined that 4.57 metric tons of pure $CaCO_3$/ha/15 cm would be sufficient to neutralize the tailings for twenty years. In this study, seven commercially available, acid tolerant, grass and forb species adapted to high elevations were planted on fertilized and limed, and fertilized and unlimed tailings on the mine site.

Objectives

The objectives of this study are: 1) to determine whether liming of the tailings is necessary for the establishment of these species; and 2) to evaluate and compare the success of individual species on limed and unlimed treatments.

LITERATURE REVIEW

Mining or mineral processing disrupt and expose to the atmosphere a variety of rock and mineral assemblages. The subsequent physical and chemical weathering may produce extremely acidic spoil or tailings and thus, an uninhabitable plant growth medium. Successful treatment of acidic material that allows plant establishment will require a thorough understanding of the reactions responsible for acid production. The significance of the soil acidity problem for agronomists, as well as reclamation scientists, has produced an abundance of accessible research literature. Mine reclamation research pertaining to acid production has dealt with various waste materials; in this study tailings are the subject media. The chemical reactions which produce acidity in these materials are assumed to be simliar and thus reports of acid production in various waste materials are used to explain acid-tailings reactions.

Spoil and Tailings Acidity

Acidity in mine material is determined by composition of the material and the ion exchange and hydrolysis reactions associated with the various components. Pyritic sulfur (FeS_2) is common to these materials and will react with water and the atmosphere to produce acidity as follows:

$$2FeS_2 + 7H_2O + 71/2O_2 \longleftrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \qquad (1)$$

$$Fe^{2+} + 1/4H_2O + H^+ \longleftrightarrow Fe^{3+} + 1/2H_2O \qquad (2)$$

$$Fe^{3+} + 3H_2O <--> Fe(OH)_{3(5)} + 3H^+ \qquad (3)$$

$$FeS_{2(s)} + 14Fe^{3+} + 8H_2O <--> 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (4)$$

(Barnes and Romberger 1968)

The extent of acid-forming pyritic sulfur oxidation has been determined to be influenced by mineralogical form, particle size, oxygen concentration, temperature, degree of saturation, microbial activity and the pH of the soil solution (Pugh et al., 1981; Smith and Shumate, 1970; Caruccio, 1968).

Oxidation of organic sulfur compounds has also been shown to be a source of spoil acidity (Caruccio and Geidel, 1978). The occurrence of organic sulfur oxidation may be especially important in some western mine spoils and was discussed by Russel (1984).

Acid Tailings: Phytotoxic Relationships

Acid soil toxicity is not caused by a single factor, but a complex of factors that may affect plant growth through species-specific physiological and biochemical pathways which are probably controlled genetically (Foy et al., 1978). Growth limiting factors associated with acid agricultural soils include toxicities of aluminum (Al) manganese (Mn), or other metal ions; low pH (H^+ toxicity); and deficiencies or non-availability of certain essential nutrients. calcium (Ca), magnesium (Mg), phosphorus (P), and molybdenum (Mo) are of particular concern. The acid soil-plant toxicity relationships are assumed to be similar to acid tailings-plant toxicity relationships.

Hydrogen Ion Toxicity

The direct effects of hydrogen ion (H^+) concentration on plant growth are difficult to determine. At low pH levels, other elements, such as Al and Mn, may be soluble in toxic concentrations and essential nutrient elements, such as Ca and Mg, are least available. Nevertheless, in most extremely acid soils ($pH<4.0$), H^+ toxicity is probably the most important growth limiting factor to higher plants (Foy, 1984).

Although the direct effects of H^+ are confounded, researchers have been able to identify some plant responses to low pH. Primarily, the root system is damaged resulting in short, thickened, discolored roots which are few in number. Lateral root growth may be severely inhibited (Islam et al., 1980). Christiansen and others (1970) noted that a soil solution of pH less than 4 markedly enhanced the loss of organic substances from cotton radicles, and that this effect could be reversed by raising the pH. Hussain and co-workers (1954) reported that exposure of barley roots to an acidic solution ($pH=3$) caused them to lose significant amounts of nitrogen (N), potassium (K), P and Ca. The exposure also limited their ability for subsequent K absorption. An excess of H^+ has been shown to decrease plant uptake of Mg (Blamey et al., 1982), Mn (Robson and Loneragan, 1970), zinc (Zn), (Rashid et al., 1976) and copper (Cu) (Bowen, 1969). Therefore, plant growth may be inhibited by reduced nutrient availability caused by an excess of H^+.

Aluminum and Manganese Toxicity

Hydrogen ion toxicity is the primary growth limiting factor in acid soils of pH 4 or less. In most acid soils of pH greater than 4, Al and Mn toxicities are more important than H ion toxicity to the growth of higher plants, particularly the non-legumes (Foy, 1984). Plant species, however, have a wide variance in their tolerance to Al (Sheppard and Floate, 1984). Common, similar responses to excess Al for many plants include restricted root growth and inhibited DNA synthesis (Wallace and Anderson, 1984). As a result, plant uptake and utilization of water and nutrients are negatively affected by Al toxicity (Hecht-Bucholtz and Foy, 1981).

Interactions of Al with essential nutrient elements have been observed by many investigators. Lee and Pritchard (1984) noted that Ca, Zn, Mn, and Mg uptake was inhibited by elevated levels of Al in both plant roots and shoots. Lee (1971) observed that excess Al inhibited P transport to potatoe plant tops; decreased Ca, Mg and Zn absorption by roots; and caused P, Al, Mn, Cu and Fe accumulation in plant roots. Duncan and others (1980) reported increased levels of Al, Fe, Mn, K and P in plant tops.

Aluminum toxicity often appears as a P deficiency in plants grown in acid soils (Chaisson, 1964). This is expressed as a leaf and stem purpling, leaf tip burn and overall stunted growth. Aluminum generally accumulates in association with P on or in the roots of Al-injured plants (McCormack and Bordon, 1972). Randal and Vose (1963) determined that high levels of solution Al (50 ppm) increased the P concentration in plants but depressed total growth by reducing total P metabolism. Their research indicated that although P may increase or decrease with elevated Al concentrations, P is rendered less available to metabolic sites within plant cells.

Although Al is recognized as the most important plant growth limiting factor in acid agricultural soils, its function in plant metabolism is not clearly understood, and toxic levels of Al in plants and soils have not been precisely identified. Unfortunately, a best method of determining soil Al concentrations injurious to plants has not been developed. Some researchers, recommend either exchangable Al or $CaCl_2$ soluble Al determinations (Hoyt and Nybord, 1971). Others, prefer water soluble to exchangeable Al (Webber et al., 1982).

Manganese is probably the second most important growth limiting factor in acid agricultural soils and often affects the suitability of mine spoils as plant growth media. Manganese toxicity generally occurs in soils with pH values less than or equal to 5.5 if sufficient total Mn is present (Foy, 1973).

As with Al, Mn toxicity levels vary among plant species. Excess Mn interferes with plant nutrition in various ways, but the mechanisms of toxicity are not clearly understood. Unlike Al, Mn only affects plant tops and appears to accumulate in proportion to plant injury. This element also alters the activities of plant enzymes and hormones. Manganese toxicity is often related to reduced Ca concentration and transport in plants (Horst and Marschner, 1978; Osawa and Ikeda 1977)

Manganese and Fe appear to be closely related in plant metabolism. Some investigators have used Fe/Mn ratios in plant tops as indicators of Mn toxicity or Mn-induced Fe deficiency (Hati et al., 1979).

Significant plant species differences in Mn tolerance have been reviewed by Kamprath and Foy (1984). Tanaka and Navasero (1966) reported a tolerance of 2,500 ppm for rice. White (1970) measured a tolerance level of 200 ppm Mn in barley. Although species vary in Mn tolerance, plant tissue concentrations and toxicity symptoms are usually similar. These symptoms appear in plant shoots as marginal and interveinal chlorosis and necrosis of leaves. Precipitated manganese dioxide may be localized in these necrotic areas (Labananskas, 1966).

Excess Mn has been associated with mine waste materials. Evangelou and Thom (1984) measured Mn in a midwest mine spoil solution at 910 ppm. Peterson and Nielson (1973) reported a range from 38 to 1005 ppm soluble Mn in spoil material from six western states.

Zinc and Copper Toxicity

Zinc is an essential plant micronutrient that can be toxic at low pH levels (Bould et al.,1984). Unlike Mn and Al, Zn toxicity is not common to plants grown on acidic agricultural soils. Zinc toxicity is usually restricted to lands disturbed by mining, amended with sewage sludge, or lands affected by various pollutants (Foy et al., 1978).

Zinc in toxic concentrations has been reported to interfere with the absorption and utilization of various plant macro and micronutrients. Reported Zn interactions with P are examples. High Zn levels reduce plant uptake and translocation of P, sometimes resulting in deficiency (Stukenholtz et al., 1966). Zinc has also been known to interfere with Fe absorption and utilization (Lingle et al., 1963). Zinc toxicity generally resembles Fe deficiency and is characterized by yellow interveinal chlorosis and some necrosis (Bould et al., 1984).

Zinc toxicity levels in the soil solution have been reported to range near 1 ppm but vary greatly with species (Bennett, 1971). Cornwall and Stone (1973) reported solution concentrations of up to 731 ppm in acidic coal mine spoil from Pennsylvania. Smith and Bradshaw (1979) reported nitric acid extractable Zn values in spoils ranging from 23 ppm to 108,100 ppm following a survey of 40 metaliferous mine sites in the United Kingdom. D'Antuono (1979) noted that phytotoxic Zn concentrations precluded plant establishment on coal mine refuse in Illinois.

Copper, a plant micronutrient, is universally present in soils at an average total concentration of 30 ppm (Lindsay, 1979). This element may become phytotoxic as its availability increases at low pH values (Lindsay, 1979). The physiology of Cu toxicity is not well understood. At excess levels, Cu has been shown to prevent normal assimilation of Fe and Mg in certain plants and may possibly cause deficiencies of these metals (Stuckmeyer et al., 1969; Wallace and Kock, 1966). McBrian and Hassal (1967) suggested that the toxicity of Cu is due to its propensity to combine with protein sulphydral groups, thus disrupting protein synthesis.

Copper is known to be highly toxic to roots (Bennett, 1971). Symptoms of toxicity include blackened root tips; a shortening and discoloration of the root system (Sowell et al., 1957; Stuckmeyer et al., 1969). The ability of plants to translocate less Cu to the shoots has been correlated with the ability to withstand high soil solution concentrations (Dijkshoorn et al., 1979). When Cu is translocated to aerial portions of the plant, toxicity symptoms are similar to those of Fe deficiency (Bould et al., 1984).

Reports of elevated Cu levels at mine sites are numerous. McClean and Dekker (1976) reported extractable Cu levels ranging from 54 to 5,360 ppm in six pyrite-bearing tailings materials in Canada. Peterson and Nielson (1973) reported soil solution Cu content of up to 600 ppm from acid tailings in Utah and New Mexico. D'Antuono (1979) states that high acidity (pH 1.8 - 3.5) and associated levels of soluble Cu ions preclude plant establishment on most mine refuse sites in Illinois.

Effects of Liming on Acidity

Liming materials consist of Ca and Mg compounds capable of neutralizing soil acidity (Barber, 1984). The solution pH of an acid soil is simultaneously raised as the relative amounts of adsorbed metallic cations (Ca, Mg, Na) increase in comparison to the adsorbed H^+ and Al^+ on the clay micelles. Reactive Ca and Mg carbonates added to a soil in sufficient amounts raise the solution pH by increasing the hydroxyl ion concentration according to the following equation:

$$Ca(Mg)CO_3 + H_2O \longleftrightarrow Ca^{2+}(Mg^{2+}) + HCO_3^- + OH^- \qquad (5)$$

(Bohn et al., 1979)

Additionally, the oxidation of pyritic spoils generates considerable free acid (Eq. 6), which reacts with applied lime (Eq. 7), producing soluble sulfate salts.

$$4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4\,Fe(OH)_3 + 8H_2SO_4 \qquad (6)$$

$$2H_2SO_4 + CaMg(CO_3)_2 \longrightarrow CaSO_4 + MgSO_4 + 2H_2O + 2CO_2 \quad (7)$$

These salts may, under certain conditions inhibit plant establishment (Grove and Evangelou, 1982). Application of liming materials such as $CaCO_3$, $MgCO_3$, CaO and $Ca(OH)_2$ in sufficient quantities results in increases of OH^-, Ca^{2+} and Mg^{2+} in the soil solution. Thus, liming serves to both raise the soil pH, and supply essential plant macronutrients (Mason, 1980).

The beneficial effects of liming have been well documented in agronomic literature and can be applied to mine reclamation problems. Reclamation scientists, however, must carefully consider their choice of liming materials in light of recent reports describing Ca + Mg related antagonisms. Liming of soils and mine spoils with Ca compounds may cause Mg deficiencies in plants. Sumner and co-workers (1978) reported losses (36 to 93 percent) of exchangeable Mg in soils limed with pure Ca sources. Furthermore, additions of a Mg lime material initially increased exchangeable Mg but was followed by a large decrease as the soil pH approached neutrality. Sims and Ellis (1983) also reported greatly reduced exchangeable Mg in soils limed at a high rate with $CaCO_3$, as determined by the Shoemaker, McClean and Pratt (SMP) method (Shoemaker et at., 1961). For this reason, Pitman (1976) suggested that the liming agent be $MgCO_3$ or that Mg be added as fertilizer. Grove and Evangelou (1982) noted, however, that lime-spoil reactions containing pyrite (Eq.7) can produce soluble Mg salts which inhibit plant growth and development. Although not always a problem, they suggest that dolomite is an unacceptable liming agent on sandy spoils. Depending upon the chemistry of the particular growth medium, either Ca or Mg may be the most appropriate cation for avoiding ion antagonisms.

Liming and the Primary Nutrients

Many mine wastes require amendments of primary nutrients (N, P, K) in order to provide a habitable plant growth medium. Applications of lime to reduce spoil acidity may affect indigenous and applied fertilizer nutrients. Both the timing and method of lime and fertilizer application are important.

Nitrogen

If acidic soils are not limed prior to applications of ammonium (NH_4) fertilizer, NH_4 ions may be lost through leaching, because the exchange sites are occupied by tightly held Al and H ions (Kamprath and Foy, 1971). Applied nitrate (NO_3) fertilizers may be lost as nitric acid in soils containing appreciable amounts of Al and H. The exact extent of these losses in the field, however, is unknown (Tisdale and Nelson, 1975).

Bacterial nitrification of NH_4 is inhibited by low pH and is extremely limited by pH values below 5.0 (Morrill and Dawson, 1967). Utsalo and Maier (1983) reported that nitrification did not occur on acidic mine spoil (pH 3.6) despite inoculation with nitrifying bacteria. Field studies by Nyborg and Hoyt (1978) revealed significant increases in nitrification rates in acid soils after liming. It was reported, however, that N applied surficially as NH_4 to soils limed with $CaCO_3$ must be well incorporated or great losses will occur through volatilization (Carter et al., 1967). Thus, it appears that N fertilizer, when applied correctly to limed soils, can benefit plant growth and survival.

Phosphorus

As with N, the availability of P usually decreases with increasing soil acidity. Two separate explanations exist for this loss.

The first possibility is based on the "solubility product principle", postulating the formation of various phosphate compounds by precipitation. In acid soils, variscite ($AlPO_4 \cdot 2H_2O$) followed by strengite ($FePO_4 \cdot 2H_2O$) are the most stable and easily formed phosphate minerals (Lindsay, 1979). Applications of lime will tend to dissolve variscite and strengite, thereby causing increased availability of P.

Amorphous alumino-phosphates form in aqueous solutions approximating acid soil solutions (Webber, 1978). The reduction of soluble and exchangeable Al in soils following P applications (Haynes and Ludecke, 1981), and the phosphate alleviation of Al toxicity in plants (Bache and Crooke, 1981) have been attributed to the formation of these amorphous phosphates.

The second explanation for P unavailability in acid soils is considered the primary P fixation mechanism (Sample et al., 1980). In this process, P is adsorbed onto the surfaces of hydrated Al and Fe oxides and clay material surfaces. The details of these processes have been reviewed by Parfitt (1978) and White (1970). Although there are other factors affecting phosphate adsorption, it is generally accepted that: adsorption is greatest within a pH range of 2.0 to 4.0 (Parfitt, 1978); and that liming is likely to decrease the adsorption of phosphate onto soil colloids.

Although lime applications can increase the availability of P, lime can also decrease its availability. White and Taylor (1977) noted that liming to pH values at or near neutrality can increase phosphate fixation because of the formation of insoluble calcium phosphates. They suggested that at high P concentration (1000 uM), phosphates precipitated at pH values equal to or greater than 5.5.

Acid-lime-phosphorus interactions are complex and are not completely understood. Phosphorus losses are attributed to various mechanisms and may be affected by the rate of lime application. For example, Sims and Ellis (1983) determined that P was more plant available when soils were limed at a rate to neutralize KCl - exchangeable Al (minimal liming), versus liming to pH 6.8 as determined by the SMP method. Therefore, plant available P may be difficult to supply to acidic and limed spoils.

Potassium

In acid soils, a large percentage of exchangeable K may be lost through leaching (Magdoff and Bartlett, 1980). Furthermore, liming causes decreased availability of any exchangeable K present at the time of liming. This loss is caused by the pH dependent cation exchange capacity (CEC), which results in an important shift of solution k to the exchangeable phase as pH increases. This same property however, allows limed soils to retain more fertilizer against leaching losses (Adams 1984). Thus, applications of fertilizer K are recommended for limed mine spoil to prevent K deficiencies in plants.

Kiln Dust as a Liming Agent

Cement kiln dust is a highly alkaline, calcium rich material that is a cement production waste product. As this material presents a waste problem, it may be economically used as an acid mine waste ameliorant. Winterhalder (1984) used cement kiln dust as a liming agent on metal contaminated land in Canada. He found the material to have good potential as a liming material but felt that problems associated with application techniques, currently precluded its use on large scale projects.

Suitability of Species to the Environment

The following species were chosen primarily because of their adaptability to acidic growth media and the harsh climate of the site. The second critera for selection was commercial seed availability.

Birdsfoot trefoil (*Lotus corniculatus* L.) has been known as a forage crop throughout the recorded agricultural history of many of the grazing regions of Europe, Asia and Africa. The mediterranean basin is its likely center of origin. The date of its introduction to North America is unknown (Metcalf, 1980).

Birdsfoot trefoil is a long-lived, perennial legume with a moderately deep, branching root system: a growth form similar to that of alfalfa. The species is adapted to a wide variety of soil reaction, fertility and climatic conditions including high summer temperatures. Some varieties are known for their winter-hardiness (SCS, 1978). It is the most acid-tolerant species among the legumes and will survive in soils deficient in P and K (Metcalf, 1980; Hafenrichter, 1968). Although it can withstand medium acidity (pH>5.0) a lime amendment is required for establishment in more acidic soils. Birdsfoot trefoil is a highly palatable, nutritious and non-bloating forage legume for domestic livestock. It will not, however, tolerate continuous grazing (Watson et al., 1980). This plant is also a choice food for Canada geese, deer and elk.

Lotus corniculatus has been used in a variety of reclamation trials on acidic mine tailings materials. Costigan and others (1984) used this species and other legumes in a trial on limed, acidic colliery spoils. They observed a pH reduction in growth media supporting trefoil. These workers hypothesized that the reduced pH resulted from either increased pyrite oxidation or reduced lime reaction rate caused by drier conditions in the root zone of larger trefoil shoots with higher transpiration rates. The observed pH reduction could also be attributed to the ability of trefoil to oxidize ferrous ions as has been demonstrated using solution culture (Bartlett, 1961). Winterhalder (1983) reported good success with trefoil on limed, Cu and nickel contaminated lands in Canada. He recommended low application rates of slow-release N fertilizer to give a competitive advantage to seedlings developing from winter-stratified seed. Slow-release N fertilizers would also prevent legume growth inhibition associated with high N application rates.

Elias and Chadwick (1979) observed low mean relative growth rates and high root-weight ratios for one variety of _L. corniculatus_. These traits characterize species most capable of successful establishment on infertile and toxic waste materials (Grime and Hunt, 1975). Berg and Vogel (1968) reported that trefoil exhibited no toxicity symptoms when grown on three spoil materials containing 50 ppm water-soluble Mn. Johnson and others (1977), however, reported the failure of trefoil to establish on acidic, Zn-contaminated colliery spoils. Most recently, Vogel (1984) recommended L. corniculatus for revegetation of acidic (pH$\leq$4.5) mine spoils.

Some varieties of sheep fescue (Festuca ovina L.) are considered native (Hitchcock and Cronquist, 1973), while others are known to have been introduced from Turkey in 1934 (Lilley and Benson, 1979). Sheep fescue is a long-lived, fine-leaved bunchgrass known for its massive root production of up to 3360 kg/ha (dry wt.) (Hafenrichter et al., 1968). The species is cold-tolerant, drought-tolerant and capable of out-performing many grasses in sandy to gravelly soils under mildly acidic conditions (Watson et al., 1980). Although shoot production of F. ovina is low, it provides good ground cover and palatable, nutritious forage for domestic livestock and wildlife (Schwendiman, 1976).

Festuca ovina has been recognized as a useful species for mined land reclamation. Smith and Bradshaw (1979) obtained good growth of F. ovina on acidic (pH=5.4) metalliferous mine wastes. They observed that although growth was greatly enhanced by fertilization, lime application produced no significant response. By examining healthy stock grown in contaminated soil, Gregory and Bradshaw (1964) isolated F. ovina populations tolerant to elevated levels of lead and Zn. Alloway and Davies (1971) observed no toxicity symptoms in sheep fescue grown in total concentrations of Pb at 3,680 ppm, Zn at 1,330 and Cu at 48 ppm.

Creeping foxtail (Alopecurus arundinaceus Poir.) and meadow foxtail (Alopecurus pratensis L.) are both Eurasian species introduced into this country in the late nineteenth century. Both species are long-lived perennials which form dense sod and grow to heights of 75 to 135 cm. These species are especially adapted to moist sites including wet meadows in alpine and subalpine areas. They can be established in soils ranging in texture from clays to loams as well as in organic peats and mucks. Both are tolerant of moderately acidic soils and are known for early spring emergence. Creeping foxtail has additional adaptations to alkaline conditions and sandy soil textures (Heath et al., 1985). Meadow foxtail has shown tolerance to flooding and high water tables, but is susceptible to drought and long periods of hot weather (Plummer, 1977). Both of these species provide nutritious, palatable livestock forage and recover rapidly after grazing (Smoliak and Bjorge, 1981).

Creeping foxtail and meadow foxtail have not been used extensively for mined land reclamation. Brown and others (1976) used A. pratensis in revegetation trials at high-altitude sites in Montana. This species was rated second most successful among the fourteen grasses grown. Kenney and Cuany (1978) reported a performance range of from poor to excellent for growth of A. arundinaceus at seven ski area disturbances above 7,500 m in Colorado. Alopecurus pratensis growth was rated from fair to excellent on three of the same sites.

Both redtop (Agrostis alba L.) and bentgrass (Agrostis tenuis Sibth.) are perennial, rhizomatus grasses. Redtop was introduced from Europe by the early colonists. Bentgrass, a native of Eurasia, has naturalized to the Pacific Northwest maritime climate. These species are adapted to wetland sites and grow well in moderately acidic soils. Bentgrass can withstand prolonged flooding and both species are somewhat drought-tolerant. Redtop is extremely cold-tolerant; bentgrass is better adapted to more temperate climates. Both are adapted to a wide range of soil textures (Metcalf, 1980; Hafenrichter et al., 1968). Although both of these grasses can withstand heavy grazing, neither is particularly palatable nor nutritious (SCS, 1978).

Various populations of _Agrostis tenuis_ have been shown to be tolerant to elevated levels of Pb, or Zn, or Cu and Zn (Gregory and Bradshaw, 1964). Smith and Bradshaw (1979) obtained satisfactory results with populations of _A. tenuis_ in establishment trials at a metaliferous mine waste site in Great Britain. Their work eventually lead to the development of three commercially available cultivars of _A. tenuis_ which are tolerant to acidic or calcareous Pb and Zn waste materials and copper wastes. Clarkson (1966) showed _A. tenuis_ shoots to be tolerant of Al in concentrations of up to 4 ppm; root growth was uninhibited by a concentration of 8 ppm in nutrient solution.

Joost and others (1983) obtain satisfactory growth of _Agrostis alba_ planted in coal refuse (gob) ameliorated with lime and sewage sludge. A fair tolerance to Al by _A. alba_ was observed by Jones and others (1975).

Canada bluegrass (Poa compressa L.) is a rhizomatus species brought to this country by the colonists. It is native to Eurasia (Heath et al., 1985). This species performs well on neutral to acidic soil materials and can usually be found on low-fertility sites. It is somewhat drought-tolerant and is particularly adapted to high mountain ranges and alpine, subalpine and mountain brush ecosystems (Plummer, 1977). Although production is sometimes low, Canada bluegrass is quite palatable and nutritious.

Poa compressa does not have an extensive history of use in reclamation. Winterhalder (1983), however, reported good results with a species mix containing 15 percent _P. compressa_ for reclamation of metal-contaminated acid lands in Canada. Darmer (1973) used _P. compressa_ in reclamation trials on sandy acidic brown coal spoils in East Germany. This species was not, however, successful on this material. Brown and Johnson (1978) suggested that this species may be suitable for high altitude reclamation.

METHODS AND MATERIALS

Site Description

Two experimental sites were located in a forest opening atop tailings piles at the Champion mine site. The distance between the two sites was approximately 75 m.

Climatological data were obtained from the Deerlodge 3W weather station. Although this is the station closest to the mine site, the actual climate is probably wetter, colder, and has fewer frost free days due to the elevation of the site. Yearly precipitation averages 27.7±9.9cm, approximately 60-75% of which occurs during the growing season. Frost free days average 52± 32. The average annual temperature is 5.2±.39 C°; while maximum and minimum temperatures reached 36.1 and -40.0 C°, respectively (N.O.A.A., 1984-85).

Undisturbed nearby soil has been classified as a sandy-mixed Typic Cryochrept (Deckler 1982). The surrounding vegetation consists of a mixed conifer forest.

Experimental Design

Each site was divided into 3 sections (replications) which were split in half. The entire site was fertilized. One half of each replication was limed with kiln dust. All limed and unlimed treatment strips were divided into seven plots 50 x 100 cm. One leguminous species, *Lotus corniculatus* and six grass species were seeded individually in plots. The grass species included, *Festuca ovina*, *Alopecurus pratensis*, *A. arundinaceus*, *Poa compressa*, *Agrostis tenuis* and *A. alba*.

Site Preparation and Seeding

The tailings piles were the location of the species growth trials. Tailings preparation and seeding took place June 22, 1984 and was a four step process as follows:

1) Two sites approximately 60 x 60 m were chosen, and designated 1 and 2. These sites received identical treatments. The tailings were leveled, then rototilled to throughly mix the material.

2) Diammonium-phosphate fertilizer (18-46-0) was applied at a rate of 16 kg/ha nitrogen and incorporated with the rototiller.

3) One half of each replication was limed with kiln dust, applied at a rate equivilent to 9.14 metric tons $CaCO_3$/ha/15 cm. This rate was double the amount determined necessary to nutralize the tailings for twenty years by Russell (1984). The kiln dust was incorporated to the 15 cm depth. Cement plant kiln dust from the Ideal Cement Co., Trident, Mt. was the source of the liming agent. Characteristics of the kiln dust are provided in Table 1.

4) Species were seeded individually at a rate of 240 pure live seeds per plot.

Table 1. Physical and chemical analysis of cement plant flue dust.

U.S. sieve no	% dust passed	Oxide Content
30	100.0	CaO = 42-48%
60	99.5	SiO = 15.8%
100	95.0	Al O = 3.5%
200	75.0	Fe O = 2.0%
		K O = 2-4%
		Mg O = 1.2%
		Na O = 0.2-0.4%

Collection and Analysis of Tailings Material

Tailings samples were taken numerous times throughout the study period. Samples were taken randomly from the limed and unlimed treatments; at the 0-15 cm depth and below the 15 cm depth.

The first tailings samples, used for site characterization, were collected July 27, 1984. The second samples, collected October 3, 1984, were used to evaluate the effects of the liming three months earlier. These samples were air dried, crushed to pass through a 2 mm sieve and analyzed for the following physical and chemical properties. Concentrations of Al, Zn, Mn, Cu, Ca, and Mg; and measures of pH and electrical conductivity (Ec) were determined in saturated paste extracts (Richards, 1969) Ammonium acetate was used to extract K (Richards, 1969). Nitrate concentration was deteremined by the phenol-disulfonic acid method (Haby and Larson, 1976). Phosphorus was extracted with $NaHCO_3$ (Amer. Soc. Agron., 1965). Tailings particle size distribution was determined according to American Society of Agronomy (1970).

Additional tailings samples were collected May 29, 1985, July 29, 1985, and September 3, 1985 to determine plant available moisture throughout the growing season. These samples were weighed, and then dried at 105^{o} C until a constant weight was reached. With these results percent moisture by weight was calculated. These moisture values were placed on a previously constructed desorption curve. Consequently it was possible to determine the approximate soil water tension of field samples at a given moisture percentage by interpolation. Desorption curves for the two sites were made with soil moisture values at 0, $^{-}1/3$, $^{-}1/10$, $^{-}1$, $^{-}3$, and $^{-}15$ bar tension, with pressure plate apparatus as described by Richards (1969). Desorption curves are located in Appendix B.

Species Data Collection and Analysis

Three methods were employed to evaluate and compare the seeded species. Seedling emergence counts were taken August 3, 1984. All seedlings in each plot were counted. Species height and percent basal area cover (BAC) were chosen for intraspecies comparisons of vigor. These measurements were employed to detect site differences affecting plant growth. The height of the tallest individual per plot was measured. BAC was obtained by estimating to the nearest percent the amount of vegetal stem area within a 2.5 x 5 cm microplot. Each plot was divided into thirds and nine microplot readings were taken in each third. Evaluations of these parameters were made on July 29, 1985.

Statistical Methods

The Student's t-test was used to detect differences in growth variables by site and treatment. Significant intraspecies differences would indicate that the species were exibiting superior growth on one site or treatment compared to their respective counterparts.

Analysis of Variance (ANOV) and mean seperation (least significant difference) were used to detect interspecies growth differences using species' growth measurements. Significant differences would indicate that some species were exibiting a greater ability to adapt to the extreme conditions of the growth media compared to other species.

RESULTS AND DISCUSSION

Tailings Analysis

Physical Analysis

Variability in characteristics of the tailings required the collection of tandem samples for each combination of site, treatment and depth. The calculated mean value for each sample pair was used for characterization. It was felt that this approach would improve descriptive accuracy while minimizing laboratory costs. Textural analysis results are means of 4 replications. Soil moisture results are means of 4 replications per surface level.

The results of the textural analysis, shown in Table 2, revealed a textural difference between site 1 and site 2. Site 1 tailings were classified as a sandy loam; site 2 tailings were classified as a silty clay loam.

Table 2. Textural analysis results[a].

	Site 1	Site 2
Sand %	54	10
Silt %	34	52
Clay %	12	38
	Sandy loam	Silty clay loam

[a] mean of 4 analyses

The results of the soil moisture analysis are for the 1985 growing season and are presented in Table 3. Soil moisture during the

1984 growing season was assumed to be similar to that of 1984 based on mean monthly precipitation and temperature data obtained from the N.O.A.A. (1984-5). The results in Table 3 suggest that percent soil moisture by weight was similar for the sites throughout the growing season. This was true for both surface and subsurface samples. The corresponding matric potential for the two sites was however, not similar. Matric potential throughout the growing season was less on site 1 compared to site 2 in both the surface and subsurface. The differences in matric potential may be linked with different plant response to the sites both directly and indirectly. Although percent moisture by weight was similar for the sites, soil water was held at a greater tension on site 2. The greater soil water tension was accounted for by the greater clay content of site 2 tailings. This was explained by Hillel (1982) who reported that the greater the clay content, in general, the greater the suction, at any particular soil-water content.

Table 3. Average^a percent moisture by weight and corresponding matric potential throughout the 1985 growing season.

		Site 1			Site 2		
	Depth (cm)	5-29	7-7	9-3	5-29	7-7	9-3
% moisture by weight	0-20	20.6	12.3	8.9	24.2	11.7	15.1
	>20	24.1	17.7	21.5	22.6	19.3	21.5
Matric potential in bars	0-20	-.1	-2.0	-15.0	-1.2	>-15.0	>-15.0
	>20	-.1	-1.0	-.2	-1.7	-15.0	-3.0

^{a} mean of 3 analyses

Chemical Analysis

Table 4 lists the pH and conductance values for each combination of site, lime treatment and depth. The unlimed tailings at each site were acidic at both sampling depths. These pH levels, ranging from 3.0 to 3.5, generally preclude vascular plant establishment. Liming resulted in elevated surface pH levels at both sites. Subsurface pH levels were apparently unaffected by liming.

Table 4. Results[a] for the mean pH and conductance by site, treatment and depth.

	Sampling Depth (cm)	Site 1		Site 2	
		unlimed	limed	unlimed	limed
pH	0-20	3.5	7.5	3.3	7.4
	>20	3.0	3.4	3.3	3.8
EC mmhos/cm	0-20	0.59	2.60	2.10	2.40
	>20	0.62	0.80	1.20	1.44

[a] mean of 2 analyses

The EC values for the unlimed treatment were higher on site 2 than on site 1, at both sampling depths. Conductance values for the limed treatments were similar for the two sites, and were greater than values for the unlimed treatments. The liming treatment did not appear to affect subsurface conductivity on either site. It is generally recognized that EC values exceeding 4 mmhos/cm indicate salt concentrations that may adversely affect plant establishment (Richards, 1969). The results indicate that salt concentration should not hinder plant establishment on either site regardless of treatment.

Elemental concentrations in the tailings solution were measured at two depths for limed and unlimed treatments (Table 5). Elemental concentrations derived from saturated paste extracts have not been reported extensively in the literature and correlations between these levels and plant growth are lacking. Therefore, it is not possible to discuss whether elemental levels reported here are defecient, adaquate or toxic to vascular plants based on published results.

Table 5. Average[a] soluble metal concentrations (mg/L) by site, treatment and depth.

Metal	Depth (cm)	Site 1		Site 2	
		unlimed	limed	unlimed	limed
Al	0-20	5.60	1.30	48.20	1.20
	>20	9.80	9.80	20.70	16.00
Mn	0-20	0.94	0.23	39.80	0.38
	>20	4.82	6.40	14.20	21.60
Zn	0-20	0.48	0.13	1.90	0.61
	>20	0.69	0.70	0.98	1.19
Cu	0-20	0.10	0.06	1.83	0.04
	>20	0.27	0.17	0.64	0.35

[a] mean of 2 analyses

Aluminum levels on the unlimed surface treatments differed between the sites. On site 2 these levels were approximately eight times greater than the unlimed surface tailings of site 1. Aluminum levels on the surface limed treatments of both sites were reduced compared to their corresponding unlimed counterparts. The magnitude of reduction was, however, different. Aluminum was reduced by approximately four times on site 1, versus forty times on site 2. Subsurface levels of this element were greater on both treatments of site 2 compared to counterpart levels on site 1.

Manganese levels on the unlimed surface tailings of site 2 were approximately forty times greater than the corresponding levels of site 1. Surface Mn levels of the limed treatments were reduced compared to unlimed surface levels on both sites and were similar. As with Al, the magnitude of reduction was not similar. Manganese levels were approximately three times less on the limed treatment of site 1, while on site 2 the approximate Mn reduction on the limed treatment was by a factor of one hundred. Subsurface levels of this element were greater on both treatments of site 2 compared to treatment counterpart levels on site 1.

Surface levels of these elements on site 1 were also substantially less than counterpart surface levels on site 2. Zinc and Cu levels in the surface tailings were reduced on the limed treatments of both sites compared to their unlimed counterparts. As with Al and Mn subsurface levels of these elements were greater on both treatments of site 2 compared to treatment counterpart levels on site 1.

Several general conclusions can be drawn to summarize the analytical results for these metal concentrations. In the unlimed condition, at both sampling depths, site 2 contained higher concentrations of each element compared to site 1. The surface concentrations of all four elements were reduced on both sites with liming. The average reduction on Site 2 was 90 percent compared to an average concentration reduction of 65 percent for surface tailings on site 1.

The greater ionic concentrations of site 2 tailings may be associated with the higher clay content and correspondingly greater cation exchange capacity (CEC). A larger CEC in site 2 tailings would hold a greater number of ions on the exchange complex. Equilibrium solution concentrations would thus be greater for fine-textured tailings compared to the sandier materials of site 1.

Tailings concentrations of Ca, Mg and K are listed in Table 6.

Table 6. Average[a] base cation concentrations (mg/L) by site, treatment and depth.

Metal	Depth (cm)	Site 1		Site 2	
		unlimed	limed	unlimed	limed
Ca	0-20	35.90	676.00	147.90	775.00
	>20	30.80	118.00	112.75	244.00
Mg	0-20	8.15	47.10	162.90	104.40
	>20	24.00	34.20	85.50	107.40
K	0-20	18.90	84.45	52.90	82.30
	>20	28.90	22.94	65.60	51.90

[a] mean of 2 analyses

Concentration levels of this element in the unlimed surface tailings of site 1 were approximately four times less than corresponding levels of the site 2 unlimed surface tailings. Calcium levels increased on the surface limed treatment of both sites. On site 1 the increase was 18 times that of the unlimed treatment. The corresponding increase for site 2 was by a factor of 5. This difference between the two sites in the magnitude of the Ca increase in the surface may be due to their textural difference. The larger CEC of site 2 tailings could adsorb more of the added Ca, resulting in a smaller increase in soluble Ca levels of this site compared to those of site 1. This may explain the larger increase in soluble Ca on the limed treatment of site 1. Subsurface Ca levels apparently increased on the limed treatments of both sites. These apparent increases may be a result of sample contamination from the surface and not a result of downward movement of this element.

Potassium levels on the unlimed treatments were greater in site 2 tailings at both sampling depths than on site 1. Surface K levels for the limed treatments were greater compared to their unlimed counterparts on both sites. These K levels were 4.5 and 1.5 times greater on sites 1 and 2 respectively.

Unlimed soluble Mg levels on site 2 were greater than site 1 tailings at both sampling depths. Surface Mg levels on the unlimed treatment of site 1 were approximately twenty times less than their site 2 counterparts. Surface Mg levels apparently increased with liming on site 1 but not on site 2. It was expected that Mg levels would increase on both sites for two reasons: 1) Mg was a kiln dust constituent; and 2) existing Mg should have become more available as the pH rose with liming. The results in Table 6, however, do not indicate that soluble Mg increased with liming on the surface tailings of site 2. The reduction of Mg on soils limed to neutrality, and accompanying crop yield reductions, have often been noted (Sumner et al., 1978). Two explanations exist which may explain the lack of increase in Mg. Kenniberg and others (1976) showed that fresh and aged gels of Al-hydroxide selectively adsorb Mg from solution at pH values above 7.0. The liming of acidic soils produces such gels. Farina and others (1980) stated that other Al sources are capable of fixing Mg at pH values lower than 7.0. It is possible that Mg concentration did not increase on site 2 because of these reactions.

Fertilizer NO_3 and P were added to both limed and unlimed treatments of both sites. It therefore seems probable that NO_3 and P concentrations would increase on these sites compared to their pre-treatment levels. This however, did not appear to happen (Table 7).

Table 7. Average[a] concentrations (mg/kg) of fertilizer nutrients in solution.

		Site 1			Site 2		
Nutrient	Depth (cm)	Pre-treatment	Unlimed	Limed	Pre-treatment	Unlimed	Limed
NO_3	0-20	2.2	2.4	3.4	1.8	1.7	2.2
	>20	2.0	1.1	1.2	1.1	1.5	1.4
P	0-20	8.7	14.1	13.8	10.2	7.9	15.6
	>20	15.7	8.7	16.8	14.9	9.3	9.5

[a] mean of 2 analyses

On site 1 nitrate concentration did not apparently increase in the unlimed treatment, but surface levels may have increased on the limed treatment of this site. On site 2 nitrate levels at both depths of the unlimed treatment were apparently unaffected. On site 2 the surface level nitrate concentration of the limed treatment may have been somewhat greater than the pre-treatment level. Surface nitrate levels were possibly greater on site 1 compared to site 2 counterparts. Distinguishable differences were not apparent between subsurface levels of the sites. It may be that apparent increases in nitrate concentration simply reflect the variability of the tailings. If this is in fact the case, much of the applied N may have been 'lost' through various chemical pathways. Fertilizer N applied as NH_4 may have been affected by at least 3 chemical processes in the tailings: 1) volatilization to NH_3; 2) fixation within the clay lattice structure; or 3) oxidation to NO_3.

The method of application and current tailings conditions affect the rate of volatilization of applied NH_4 fertilizer salts. It was reported that these fertilizers can lose significant quantities of N as NH_3 by volatilization on soils of high pH if not immediately incorporated (Fenn and Kissel, 1973). Because the fertilizer was applied to the acidic tailings and immediately incorporated before liming, it is unlikely that large quantities of N were lost through volatilization.

The relative influence of base saturation and clay mineralogy on NH_4 fixation has been the subject of several investigations. For example, Wilklander and Andersson (1959) demonstrated that the ability of soils to fix NH_4 was measureably increased by liming. Thus, it is possible that a portion of the applied NH_4 was lost through fixation after lime was applied on both sites. If this occurred, the amount of fixed N would have been greater on site 2 because it contained a larger clay percentage.

Any NH_4 not affected by this process would have been available for oxidation to NO_3. Oxidation occurs through the biological process of nitrification. Nitrification, however, is generally not believed to occur below pH 4.0 (Sarathchandra, 1978). Brar and Giddens (1968) suspected the inhibition of nitrification at low pH to be caused by Al toxicity of the nitrifying organisms. Unfortunately, the study did not provide suspected toxic Al levels. Nevertheless, it is possible that nitrifying bacteria were not present in the unlimed tailings of both sites because of low pH and/or Al toxicity. Thus, the applied fertilizer may have remained in its reduced NH_4 form.

Nitrate content did not appear to increase on the limed treatments of either site, despite an increase of pH to 7.0 on both sites. The biology of nitrifying bacteria is not clearly understood. The time required for the establishment of nitrifying bacteria in soil previously devoid of the activity of these organisms could not be found. Consequently, it is impossible to establish the presence or absence of these bacteria on the limed treatment with available data. It may be that bacterial populations were not great enough for nitrification to occur.

As with NO_3, P concentration did not apparently increase on either site or treatment after fertilization with diammonium phosphate. The P concentration levels in the surface of site 1, ranged from 8.7 to 14.1 mg/kg. Subsurface P levels ranged from 8.7to 16.8 mg/kg. Surface concentrations on site 2, ranged from 7.91 to 15.6. Subsurface site 2 levels ranged from 9.3 to 14.9 mg/kg. Generally, no distingishable differences in P concentration exist between surface levels, sites, lime treatments and original tailings concentrations. Therefore, applied P may have been "lost" through various chemical processes. On the unlimed treatments of both sites fertilizer P may have been adsorbed by Al or Fe oxides. In acid soils, these oxides are considered to be the dominant phosphate adsorbing surfaces; maximum adsorption occurring at slightly less than pH 4 (Parfitt, 1978). The pH on these treatments averaged 3.5. It is therefore, quite possible that added P was adsorbed in this manner, and thus rendered unavailable to the soil solution and plant roots. Phosphorus loss on the limed treatments of both sites may be attributed to three chemical processes. First, some P fertilizer may have been adsorbed by Al or Fe oxides, as mentioned above, because fertilization preceeded liming on these treatments. Following liming, P may have been lost by: 1) adsorption onto amorphous hydroxy Al polymers (Veith, 1978); 2) precipitation as insoluble Ca phosphates as the pH rose above 5.5 (White and Taylor, 1977).

Plant Analysis

The discussion of plant growth results will address the relative success of individual species and the effects of site differences and liming treatment on seedling emergence and plant vigor.

Species growth results are displayed in Tables 8 through 13. There are two tables for each of the three measured vegetation parameters: number of emerged seedlings, height of the tallest plant, and basal area cover (BAC). Because numerous zero responses were recorded for each parameter, data transformations were required to perform the analysis. The ANOV assumes that the data are normally distributed; data with many zero values do not fit a normal distribution. The arc sin transformation (Steel and Torrie, 1980) was used for emergence and height data and assigned a value of .61 for each zero response. The square root transformation (Steel and Torrie, 1980) was applied to the BAC data because this is an appropriate transformation for data that are recorded as a percentage. This transformation retained the zero values. The data transformations changed the units of measurement for each parameter. Therefore, the values in each of the Tables are means of transformed data values. The Student's t-test was used to test for significant differences in the species growth between sites and treatments. Untransformed data values for each vegetation parameter are located in Appendix A.

Site Effects

Seedling Emergence

Seven weeks after planting, the number of seedlings of all of the species was greater on the unlimed treatment of site 1, than on the site 2 counterpart (Table 8). On site 1, all species showed some emergence, while on site 2, four species failed to emerge. The species that succeeded on site 2 were, Agrostis tenuis, Agrostis alba and Alopecurus pratensis. The number of individuals of the latter two species were significantly less on site 2 than on site 1.

Seedling emergence numbers were significantly greater for all species except Alopecuris arundinaceus and Lotus corniculatus on the limed treatments of site 1 compared to their site 2 equivalents (Table 8).

Table 8. Transformed means[a] and tests of significance for species by treatment and site, for seedling emergence.

Species	Limed Site 1	Limed Site 2	Limed t	Unlimed Site 1	Unlimed Site 2	Unlimed t
Agal	6.55	1.84	9.72*	4.68	.92	7.76*
Agte	4.32	1.98	4.82*	1.70	.79	1.86
Alar	5.04	4.12	1.90	2.69	.61	4.28*
Alpr	8.27	5.50	5.70*	5.37	.92	9.17*
Feov	7.17	5.33	3.79*	2.77	.61	4.45*
Loco	6.02	4.55	3.04	1.48	.61	1.79
Poco	4.46	0.92	7.29*	1.67	.61	2.19

Asterisk (*) indicates significance at P = .1.

[a] N = 3

Maturity

Two measures of plant growth and vigor, BAC and heights of the tallest individuals, were employed to detect differences as the species matured. The results of BAC are located in Table 9. Table 10 contains plant height results. By the second growing season only one species, *Agrostis alba*, continued to survive on the unlimed treatment of site 2 while individuals of all seven species survived in the unlimed plots on site 1. *Agrostis alba* grew more vigorously on the unlimed treatment of site 1 compared to its counterparts on site 2. This is evidenced by the significantly greater BAC and height attained by individuals on site 1 compared to site 2. Thus, based on these growth parameters, it may be concluded that growth and vigor of this species was superior on the unlimed treatment of site 1 compared to that of site 2.

Table 9. Transformed means^a and tests of significance for species by treatment and site, for BAC.

Species	Limed			Unlimed		
	Site 1	Site 2	t	Site 1	Site 2	t
Agal	.17	.02	8.78*	.07	.01	3.67*
Agte	.11	.03	4.52*	.05	.00	2.74*
Alar	.12	.07	2.75*	.04	.00	2.34*
Alpr	.23	.09	8.00*	.07	.00	4.11*
Feov	.20	.07	7.80*	.01	.00	0.53
Loco	.11	.03	4.87*	.00	.00	0.00
Poco	.14	.02	6.89*	.03	.00	1.93*

Asterisk (*) indicates significance at P = .1.
^{a} N = 3

Table 10. Transformed means^a and tests of significance for species by treatment and site, for height.

Species	Limed			Unlimed		
	Site 1	Site 2	t	Site 1	Site 2	t
Agal	7.75	6.16	2.45*	5.43	3.32	3.27*
Agte	6.88	3.99	4.48*	5.92	0.61	8.22*
Alar	9.70	7.38	3.58*	0.92	0.61	0.48
Alpr	8.68	8.19	0.77	2.46	0.61	2.86*
Feov	6.18	3.31	4.46*	1.11	0.61	0.77
Loco	3.87	2.88	1.53	0.92	0.61	0.48
Poco	5.79	4.84	1.47	2.98	0.61	3.67*

Asterisk (*) indicates significance at P = .1.
^{a} N = 3

The seedlings on the limed treatment of site 1 continued to grow more vigorously than their site 2 counterparts. At the end of the second growing season four species were significantly taller on site 1 than those on site 2. The other three species, *Alopecurus pratensis*, *Lotus corniculatus* and *Poa compressa* while not significantly taller, did display significantly greater BAC than their site 2 counterparts. In fact, all species exhibited significantly greater BAC on site 1.

Based on these growth parameters, it may be concluded that growth and vigor exhibited by all species on the limed treatment of site 1 were superior to that exibited by their site 2 counterparts.

It has been shown that plant growth throughout the study period was superior both in number and health of individuals for all species growing on site 1. The explanation for the smaller number of seedlings and inferior growth of the majority of the species on the unlimed treatment of site 2, probably lies in the chemical composition of the soil solution. The difference in soil solution metal ion concentrations is thought to be the primary factor affecting plant growth even though other tailings differences existed. Site 2 contained levels of Al and Mn which were much greater than site 1 (Table 5). The unlimed tailings of site 2 may not have been able to support significant plant growth if these levels of Al and Mn were phytotoxic. The metal concentrations of the unlimed tailings of Site 1 on the other hand, may not have been toxic to species planted. Site 1 was apparently able to support plant growth in spite of elevated H^+ levels.

The reason behind the less vigorous growth exhibited by the species on site 2 compared to site 1 on the limed treatments may be identified by examining the soil-water relationships of the sites and its ultimate effect on plant growth. To be examined are the effects of soil water tension and time on: 1) the tailings environment in which germination took place and; 2) the tailings environment throughout the growing season.

An increase in soil water tension increasingly restricts water