Uptake and phytotoxicity of arsenic III and V in four grass species
by Stephanie Wagner Tice

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

Abstract:

Inorganic arsenicals including arsenic trioxide and arsenic pentaoxide have been used or liberated for many years due to one or more of the following: smelting, coal burning, arsenical pesticide use, and even glass manufacturing. After years of application or exposure, this arsenic accumulates in soils to levels which are often toxic to plants.

Western wheatgrass, basin wildrye, hard sheep fescue, and Canada bluegrass were grown in sand and irrigated with four concentrations of arsenic III (0, 1, 2, and 5 mg/L) and four concentrations of arsenic V (0, 7, 14, and 28 mg/L) in diluted nutrient solution for 75 days in a greenhouse. Plant height, shoot weight, root weight, and arsenic concentration in the above ground material were measured for each grass species. Plants were observed for changes in color, vigor, bum, percent red, and survival four times during the growing period.

For all grass species treated with either oxidation state of arsenic, symptoms of phytotoxicity usually appeared in plants that were treated with the highest arsenic concentrations. Plants irrigated with solutions containing lower arsenic III and V levels developed symptoms of arsenic toxicity later during the study period. Higher levels of arsenic V were added to the irrigation solution than were used for arsenic III. Plant responses to these higher concentrations of arsenic V were more pronounced than the responses to arsenic III.

Shoot weight of basin wildrye was stimulated by the addition of 7 mg As V/L, but overall the shoot weight, root weight, and plant height of the other grass species decreased as arsenic concentration in the nutrient solution increased. Height of Canada bluegrass irrigated with 5 mg As III/L was reduced at 75 days. This was the only measured response produced by any of the arsenic III treatments in any of the grass species. Basin wildrye has been observed growing on sites containing elevated arsenic concentrations, and the evidence provided by this investigation supports the use of basin wildrye for rehabilitation of lands contaminated with arsenic.

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A thesis submitted in partial fulfillment
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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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Date September 7, 1995

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF TABLES - Continued

LIST OF TABLES - Continued

LIST OF TABLES - Continued

LIST OF FIGURES

LIST OF FIGURES - Continued

ABSTRACT

Inorganic arsenicals including arsenic trioxide and arsenic pentaoxide have been used or liberated for many years due to one or more of the following: smelting, coal burning, arsenical pesticide use, and even glass manufacturing. After years of application or exposure, this arsenic accumulates in soils to levels which are often toxic to plants.

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INTRODUCTION

Up until the early part of this century, fumes were liberated into the air from smelters. This activity frequently destroyed or damaged vegetation as much as 40 miles downwind and deposited large quantities of smoke-born metals including arsenic on surfaces of leaves (Goodman et al. 1973). The installation of smoke-cleaning devices during this century reduced these effects, but dumps of arsenic containing mine and smelter wastes still remain. The composition and quantity of these waste materials varies considerably between dumps. It is necessary to separately study each site and identify the adverse characteristics of the material present (ie. acidity, nutrient deficiencies, toxic substances, etc.) to determine the treatments required to enhance plant growth (Peterson and Nielson 1978).

Vegetation in the vicinity of the copper smelter near Anaconda, Montana, has been severely altered by several factors, including water and airborne wastes from the local copper smelter (Taskey et al. 1972). Taskey's study dealt with the ecological problems that are created when soils are contaminated with high concentrations of smelter-emitted heavy metals including arsenic, copper, lead, and zinc. Although appreciable quantities of these elements are remnants of earlier emissions from this smelter, they have remained concentrated near the soil surface and are a limiting factor to plant growth. Although the most serious damage to vegetation occurred in the late 1800's and early 1900's, Taskey notes that the region's plant cover and diversity are still low, and revegetation attempts have met with limited success. Since the closure of the smelter many sites are recovering naturally, but the process is extremely slow, and weed species are often dominant.

An economic and permanent method of stabilizing mine wastes and soils containing toxic levels of metals is needed, both to prevent pollution and to improve the appearance of mine workings (Smith and Bradshaw 1972). A possible reclamation alternative is the use of naturally occurring metal-tolerant plant populations. The metal tolerance of these species permits them to grow in environments that are otherwise metal toxic. Knowledge of arsenic III and V toxicity to grasses is needed for successful revegetation. The objective of this study was to determine the effects of arsenic III and V on the growth, productivity, and arsenic loading of four grass species often used to revegetate disturbed lands.

REVIEW OF LITERATURE

Sources of Arsenic

Arsenic is a relatively mobile element, and is transported in gaseous, dissolved, and solid states within the environment (Woolson 1983). A tentative biogeochemical cycle for arsenic was estimated by Mackenzie et al. (1979). They considered movement to and from land, oceans, air, sediments, volcanos, and rivers. Arsenic is lost from sediments (1,129 x 10^8 g/yr) while there are gains on land (660 x 10^8 g/yr) and in the oceans (566 x 10^8 g/yr). Land gains are mainly influenced by emission from coal and oil burning, cement manufacturing, and roasting of sulfide ores (779.3 x 10^8 g/yr). The loss of arsenic from sediments is a result of mining, burning fossil fuels, roasting of sulfide ores for metals, and the roasting of shale and limestone in cement manufacturing. Current anthropogenic practices have modified the global arsenic cycle. The burning of fossil fuel and industrial activities of society appear to have caused a departure from the presumed preindustrial steady-state cycle of arsenic, but on a global scale the element is not being accumulated to a significant extent by living biota.

After many years of using inorganic insecticides there was a shift to inorganic and organic herbicides which were applied at lower rates therefore reducing the amount of arsenic applied to the soil (Woolson 1983). Arsenical pesticides were once one of the largest classes of biocontrol agents, but these have been replaced with organic phosphates. Growth regulator arsenicals continue to be important with arsanilic acid, 3-nitro-4-hydroxy-phenylarsonic acid, 4-nitro-phenylarsonic acid and carbarsone the most important in animal production (Woolson 1983).

Natural Occurrences of Arsenic

Arsenic, (As), a relatively scarce element in the earth's crust, ranks twentieth in elemental abundance and has concentrations in the continental crust of 1.5 to 2 mg As/kg (Woolson 1983). It is a major constituent of at least 245 different minerals. Arsenic is frequently found in association with sulfur, and arsenopyrite (FeAsS) is one of the most common minerals. Arsenic occurs naturally in all soils as a result of the composition of the parent rock material from which the soil was formed. It is normally present in low concentrations in the soil, less than 2 mg As/kg (Woolson et al. 1971). Plants growing in these soils also contain concentrations of less than 2 mg As/kg in dry plant tissue. Williams and Whetstone (1940) analyzed a variety of soils and found naturally occurring arsenic to range between 0.3 and 40 mg As/kg. Vegetation growing on these soils ranged from less than 0.1 to 10 mg As/kg.

Arsenic, widely diffused in many types of mineral deposits, is highly concentrated in those deposits containing sulfide and sulfosalt deposits (Boyle and Jonasson 1973). Arsenic-bearing sulfides and sulfosalts oxidize readily when exposed to air to yield arsenic trioxide and finally arsenate (Woolson 1983). The most common elemental associates of arsenic are copper, gold, silver, zinc, cadmium, mercury, uranium, tin, lead, phosphorus, antimony, bismuth, molybdenum, iron, cobalt, nickel, platinum metals, selenium, and sulfur. Arsenic is, therefore, a good indicator in geochemical prospecting surveys for some twenty elements of commercial importance (Boyle and Jonasson 1973). For example, soils overlying sulfide ore deposits usually contain arsenic at several hundred mg As/kg of soil, with a reported average of 126 mg As/kg of soil and the range extending from 2 to 8,000 mg As/kg (NRCC 1978). Naturally occurring arsenic anomalies occur in Rhodesia often in association with gold deposits and often accompanied by antimony (Wild 1974a). The arsenic values in these soils usually vary between 300 and 5,000 mg As/kg of soil, rarely reaching 20,000 mg As/kg. The analysis of plant species growing on these soils revealed values up to 242 mg As/kg of dry plant tissue with high levels in roots and shoots, depending on the plant species. Since the soil arsenic content can be a reflection of the soil's parent material composition, areas near arsenic mineral deposits may reveal total soil levels of 400 to 900 mg As/kg (NRCC 1978).

Arsenic in Soils

Arsenic levels in uncontaminated, nontreated soils seldom exceed 10 mg total As/kg. Selby et al. (1974) demonstrated that 1,140 soil samples collected from 114 counties in Missouri had a mean concentration of 8.7 mg total As/kg. The arsenic concentrations of soils of the Russian Plain were estimated to be 1 to 10 mg As/kg, with an average of 3.6 mg As/kg (Vinogradov 1959). Based on analysis of soils from various parts of the world, Berrow and Reaves (1984) reported a mean arsenic content of 10 mg total As/kg of soil.

Total arsenic is not a valid indicator of possible arsenic toxicity in the soil environment because other soil constituents may bind the arsenic and limit its uptake by plants (NRCC 1978). When it is necessary to determine the amount of arsenic that is likely to be taken up by plants from contaminated soil, Berrow and Reeves (1984) recognize that the soil extractable content is a better guide. Mitchell (1964) noted that the effective or available-to-plant form of arsenic (water-soluble), is not related to total arsenic and may be very low in soils with relatively high amounts of total arsenic. Arsenic retention or fixation in soils varies with the adsorptive capacity of the soil colloidal system (Jacobs et al. 1970a). An increase in arsenic sorption by soil colloids decreases the amount of water-soluble arsenic available to vegetation and reduces the phytotoxic effects. Johnson and Hiltbold (1969) determined that 85% of the arsenic content in a sandy loam surface soil was adsorbed on clay micelles. In subsurface soil (15-30 cm below the surface), they found 94% of the arsenic associated with the clay fraction. The arsenic retention capacity of sandy soils and soils with a high silica:sesquioxide ratio was relatively low, while fine textured soils such as clays tended to retain greater amounts of arsenic (Akins and Lewis 1976). Regardless of the soil type, arsenic toxicity becomes pronounced when the ion-exchange capacity of the soil is exceeded.

The lowest arsenic levels are found in sandy soils and, in particular, in those derived from granites. Higher arsenic concentrations are related most often to alluvial soils and soils rich in organic matter (Shacklette et al. 1974, Woolson 1983, Jacobs et al. 1970a, and Reed and Sturgis 1936). Because arsenicals tend to accumulate in the upper layer of the soil, shallow-rooted plants are most likely to accumulate and be injured by it

(Machlis 1941). Thus, a given total soil concentration of arsenic is: i) most toxic in coarse (sandy), gritty soils containing little colloidal material; ii) moderately toxic on loams, silt loam, and clay loams; and iii) least toxic on fine-textured soils of high clay, high organic matter and high available iron, aluminum, calcium, and phosphorus contents (Jacobs et al. 1970a).

Arsenic toxicity is partly determined by its solubility, which is dependent upon the chemical and biological properties of the soil (Greaves 1934, Walsh and Keeney 1975, and Hiltbold 1975). Since phytotoxicity of arsenic is highly dependent on soil properties, in high clay content soils about 90% growth reduction occurs at 1000 mg total (H_2SO_4 and $HClO_4$ extracted) As/kg soil. In sandy soils 100 mg As/kg is equally toxic (Woolson et al. 1973). Woolson et al. (1971) reported that correlation was better between extractable arsenic and plant growth than between total arsenic and plant growth. Several reports on the linear relationship between arsenic content of vegetation and concentrations in soil of both total and soluble arsenic suggest that plants take up arsenic passively with the water flow (Porter and Peterson 1975). Since arsenic toxicity to plants is directly related to the soluble level in the soil, a measure of the soluble arsenic content should be more informative than the total arsenic content (Deuel and Swoboda 1972).

Arsenic in Plants

The phytotoxicity of arsenic varies with: i) the plant species; ii) the soil arsenic levels and other soil characteristics; iii) the rate and nature of arsenical application; iv) the arsenic levels in plants; and v) the temperature and humidity (NRCC 1978). Both organic and inorganic forms of arsenic, at some level, are phytotoxic to plants whether the arsenic is incorporated in the soil or sprayed on the plants (Woolson 1983). In general, much higher applications or soil levels are required in order to affect the plant through root uptake rather than through leaf uptake.

There is no evidence that arsenic is essential for plant growth, although stimulation of root growth with small amounts of arsenic in solution culture was reported by Albert and Arndt (1931), Liebig et al. (1959), and Stewart and Smith (1922). Liebig (1966) noted that stimulation does not always occur, is sometimes only temporary, and may result in the reduction of top growth. Two possibilities exist for growth stimulation by arsenic: first, stimulation of plant systems by small amounts of arsenic, since other pesticides, like 2,4-D, stimulate plant growth at sublethal dose levels (Woolson et al. 1971); second, displacement of phosphate ions from the soil by arsenate ions, with a resultant increase in phosphate solubility (Jacobs et al. 1970b).

The highest arsenic levels occur in plant roots, followed by those in plant tops, and lastly by those in edible seeds and fruits. Root tissue is often a useful indicator of high levels of available arsenic in the soil. Walsh and Keeney (1975) pointed out that the exposed portion of a plant may be contaminated by adherence of the arsenic-containing dust particles to its surface. In general, though, the edible seeds and fruit of the plant seldom accumulate highly elevated levels of arsenic as most plant growth is severely retarded prior to this occurrence.

Weaver et al. (1984) grew bermudagrass on three soils amended with arsenic to determine uptake and concentrations of arsenic in the leaves, stems, and roots. Plant growth was reduced on all soils containing 90 mg soluble As/kg. Concentrations of arsenic in leaves, stems, and roots of plants grown on soil containing 45 mg soluble As/kg, often exceeded 15, 25, and 200 mg As/kg, respectively, on a dry weight basis. The maximum concentration of arsenic in plant tops was 45 mg As/kg. Marcus-Wyner and Rains (1982) found that the uptake and translocation of arsenic by cotton grown in solution culture were influenced by the source of arsenic. Arsenic trioxide was readily taken up by the roots, but was not translocated to the shoots.

Many studies have shown differences in the sensitivity of plants to arsenic. For instance, Cooper et al. (1931) observed growth reduction responses of 11.3, 18.0, 34.0, 72.1, and 105.8% of control for vetch, oats, barley, wheat, and rye, respectively, grown on a sandy clay loam containing 1,131 mg total As/kg. Similar differences in plant responses were seen in studies by Clements and Munson (1947), Jacobs et al. (1970b), and Deuel and Swobada (1972). Woolson (1973) measured the response of a variety of crops to different arsenic levels and different soils. Plants have different sensitivities since it took 6.2, 10.9, 10.6, 48.3, 25.4, and 19.0 mg soluble As/kg of soil to reduce growth 50% in green beans, lima beans, spinach, cabbage, tomatoes and radishes, respectively. Green beans are most sensitive and cabbage the least sensitive of the crops tested. If one assumes that one-tenth of the total arsenic present is available (Woolson et al. 1971), levels needed to reduce growth 50% would range from 62 to 483 mg total As/kg soil for these crops on this soil.

Deuel and Swoboda (1972) found that the yield-limiting arsenic concentration in plant tissues was 4.4 mg (H_2SO_4, HNO_3, and $HClO_4$ digested) As/kg dry weight in cotton and 1 mg As/kg in soybeans. The critical level for barley was 20 mg As/kg in the leaves and shoots (11-26 mg As/kg range) as determined by sand culture studies (Davis et al. 1978). In rice, the critical level in tops ranged from 20 to 100 mg As/kg, and in roots 1,000 mg As/kg (Chino 1981). Normal leaves from fruit trees contained 0.9 to 1.7 mg As/kg, but leaves from trees suffering from arsenic excess contained 2.1 to 8.2 mg As/kg (NAS 1977). Woolson (1973) found that the soil for the GR_{50} level (50% reduction in growth) for an unpeeled radish contained about 19 mg As/kg. In applying the GR_{50} technique he found that limiting concentrations were 76 mg As/kg dry weight (8 mg As/kg fresh weight) with unpeeled, washed radish and 10 mg As/kg dry weight (1 mg As/kg fresh weight) with spinach. These values exceeded the tolerance limit of 2.6 mg As/kg dry weight for vegetables treated with calcium arsenate.

When Machlis (1941) grew Sudan grass and bush bean for varying lengths of time in nutrient solutions containing several concentrations of sodium arsenate, it was found that concentrations of up to 0.5 or 0.6 mg As/kg dry weight had no effect on the growth of either plant as measured by increases or decreases in dry weight. Growth was effectively reduced by concentrations of 1.2 and 12.0 mg As/kg for bean and Sudan grass, respectively. The concentrations of arsenic in all parts of the plant except the reproductive structures were directly proportional to the concentrations in the nutrient solutions.

Overley (1950) seeded crops in arsenic toxic soil, 10 to 42 mg water soluble As/kg in a mature apple orchard, and found a wide range of stand and growth quality among the species planted. The common grasses in general proved to be more tolerant of arsenic toxicity in the soil than legumes or cereals, except possibly rye. On the basis of tolerance Italian rye grass, Kentucky bluegrass, fescues, redtop, orchardgrass, and quackgrass showed the greatest promise for permanent grass cover crops. Benson and Reisenauer (1951) and Liebig (1966) compared the sensitivity of various forage crops to arsenic and also found that: i) alfalfa, bromegrass, clover, vetch, and other legumes have a low arsenic tolerance; ii) crested wheatgrass and timothy are moderately arsenic tolerant; and 3) sudangrass, Italian ryegrass, Kentucky bluegrass, meadow fescue, and redtop are very arsenic tolerant.

With increasing soil arsenic, the highest arsenic concentrations were always recorded in the old leaves and roots of barley (Thoresby and Thornton 1979). The degree and kinetics of arsenic translocation and absorption in vegetation are influenced by: i) the plant species; ii) the temperature; iii) the arsenical compound; iv) the level of available arsenic in soil; and v) the point and rate of arsenical application (NRCC 1978). Several plant species are known to tolerate a high level of arsenic in tissues. Arsenic tolerance has been commonly noted in colonial bentgrass and little bluestem growing on mine waste, on soils treated with arsenical pesticides, and on soils with arsenic added by sewage sludge treatment (Rocovich and West 1975, and Vincent 1944).

Wild (1974b) recorded seventy-two species from 15 Rhodesian arsenic containing dumps. Of these plants five were introduced, 13 were African weed species, and 50 were indigenous non woody species. Of the indigenous species 28 had been recorded on natural arsenic anomalies (Wild 1974a) and 22 had not been previously recorded.

Bermudagrass was the most important grass species on these dumps. The arsenic concentrations of some of the dumps (e.g. Banshee dump with 30,000 mg total As/kg) were once assumed to be incapable of supporting vegetation. A few of these naturally bare dumps were planted successfully with tolerant species, such as bermudagrass (selected races), although at the time of publication it could not be determined if they would survive indefinitely (Wild 1974b). However, some mine dumps (e.g. Reliance, 5,000 mg total As/kg) do carry a moderately well established vegetative cover.

Arsenic phytotoxicity symptoms include wilting of new growth. This is often followed by inhibited root and top growth (Liebig 1966). This inhibited root and top growth is often accompanied by shoot and root discoloration and necrosis of leaf tips and margins. Arsenic often causes injury to roots, resulting in interference with the plant water uptake (Clements et al. 1939). Growth is reduced progressively as the arsenic concentrations increase, and arsenic is found in the plants in concentrations roughly proportional to the concentrations of arsenic in the soil solutions.

Deep plowing to dilute the arsenic concentration of the surface soil and expose arsenic to more fixation sites appears to be one of the most economical methods of alleviating soil arsenic toxicity (Walsh and Keeney 1975). The addition of iron, aluminum, or zinc compounds, lime, manure, or organic matter to the soil minimizes soluble (available) arsenic content and hence reduces arsenic toxicity (Liebig 1966). Vincent (1944) suggested growing tolerant cover crops which if removed or plowed under, could reduce arsenic phytotoxicity.

Arsenic III and V-General

Arsenic, a crystalline metalloid belonging to group V-A, has an atomic weight of 74.922. The more common oxidation states available to it are -3, 0, 3, and 5. Arsenic bonds covalently with most nonmetals and metals, and forms stable organic compounds in both its trivalent (III) and pentavalent (V) states. "Speciation is important in the study of the environmental behavior of arsenic since the major features affecting movement and toxicity of arsenic are associated with changes in oxidation states and the resulting differences in chemical properties of the various chemical forms" (Masscheleyn et al. 1991).

Arsenic is a labile element present in practically all environmental matrices and can exist in several forms and oxidation states (Adriano 1986). In strongly reducing environments, elemental arsenic and arsine can exist, but arsenate (arsenic V) is the stable oxidation state in aerobic environments. Under moderately reducing conditions, such as flooded soils, arsenite (arsenic III) may be the dominant form (Deuel and Swoboda 1972). The reduction of arsenate to arsenite, a more toxic form, is carried out under aerobic conditions by *Pseudomonas fluorescens*, a common aquatic bacterium (Myers et al. 1973). Activated sewage sludge reduces arsenate to arsenite under anaerobic conditions.

Arsenite is a common commercial form of arsenic and one of the most toxic arsenic compounds. This reduced state of arsenic has been reported to be 4 to 10 times more soluble in soils than the oxidized state (arsenate) (Brenchley 1914, Morris and Swingle 1927, and Woolson 1983). Keaton and Kardos (1940) demonstrated that the oxidized form of arsenic was fixed to a much greater extent than the reduced form, thereby proposing that the oxidation state of arsenic influences its sorption capacity by soils.

Oxidation/reduction reactions can be a combination of chemical and microbiological processes. Chemical redox reactions are governed by iron and pH levels (Keaton and Kardos 1940). High iron levels favor the oxidation of arsenite to arsenate, while aluminum does not affect the redox reactions. However, the redox potential in soils is independent of any individual oxidant or reductant.

Arsenic III and V in Soils

Analysis of the forms of arsenic in water soluble extracts of six mine waste samples from southwest England showed that the major form of this mineral was arsenate (Porter and Peterson 1977). Arsenate comprised 60 to 94% of the arsenic, while arsenite comprised less than 10%. The form of the remainder of the water soluble arsenic was not investigated but was likely organic. The arsenic in the mine and smelter waste studied by these investigators was originally inorganic and mainly trivalent due to input from either ore materials or smelting and roasting which produces arsenic trioxide. Much of this arsenic had been oxidized to arsenate under the aerobic conditions and the wastes have gradually been colonized by a limited flora and presumably an associated microfauna.

Keaton and Kardos (1940) were able to show that the potential of an arsenate-arsenite system in a 0.05 N H_2SO_4-quartz medium conformed with the theoretical formula for the potential of an oxidation-reduction system. When another component was added, such as iron oxide, the trend of the potential may be obtained from theoretical considerations of the components. With the substitution of a 0.05 N H_2SO_4-soil medium, there was an interference due to the complexity of the medium, and consequently the potential was no longer a direct function of the arsenate-arsenite system alone. The results of the study of oxidation-reduction potentials of arsenate-arsenite systems in soil mediums suggest that the treatment of arsenic-contaminated soils with some agent, preferably one mildly oxidizing and at the same time capable of arsenic fixation, such as iron, should produce beneficial effects on plant growth.

Misra and Tiwari (1963) were able to show that at least three factors affected the adsorption of arsenate: i) the amount of iron oxide (Fe_2O_3) or sesquioxides in the soils; ii) the amount of calcium or some other ion; and iii) the pH of the soil. The adsorption of arsenite, however, is adversely affected by these same three factors. The conversion of arsenite to arsenate is enhanced by the addition of Fe_2O_3 or by increasing the alkalinity of the system. This conversion of arsenite to arsenate is an oxidation process but the reduction of arsenate to arsenite is also a possibility at low pH values. A large percentage of adsorbed arsenate remains in a fixed form and persists in soils. The higher the pH of the soils, the less the adsorption of arsenate ions by the soil, which may be due to the formation of soluble arsenate such as sodium arsenate, especially in alkali soils (Keaton and Kardos 1940).

Arsenic III and V in Plants

Marcus-Wyner and Rains (1982) treated cotton plants with arsenic III supplied as arsenic trioxide (As_2O_3). In the 8 mg As III/L arsenic treatment, 352 mg As/kg was observed in the roots and only 81 mg As/kg in the shoots. These plants displayed wilted leaves, curled leaf margins, and had stubby roots that were brown on the tips. These effects increased with arsenic concentration.

Sachs and Michael (1971) examined root adsorption of four arsenical herbicides: monosodium methanearsonate (MSMA) cacodylic acid (hydroxydimethylarsine oxide) (CA), sodium arsenate, and sodium arsenite from nutrient solution. The order of concentration in the roots was arsenate > arsenite > MSMA > CA, while concentrations in the tops was arsenite > arsenate > MSMA > CA. However, according to these authors, if the ratio of arsenical concentration in the tops to that in the roots was a measure of transport, CA was transported to the tops 5 to 10 times more rapidly than MSMA, arsenite, or arsenate.

Porter and Peterson (1977) studied *Agrostis tenuis* plants growing on mine and smelter waste containing high concentrations of arsenic (60 to 94% arsenite). The rooting tests and growth experiments used clonal material and showed that plants from the high arsenic site exhibited tolerance to arsenate but not to arsenite in solution. Clonal material from the low arsenic site showed no tolerance to either form of arsenic. At low levels of arsenate, tillers of both clones were able to root although those of the low arsenic tolerance clone showed a lower index of tolerance. The difference in the mean indices of tolerance of the two clones was significant at treatment levels of 5 mg water soluble As V/kg and higher. At 20 mg soluble As V/kg of soil only tillers from the high arsenic clone could root and tillers from the low arsenic clone died during the course of the experiment. Thus tillers of the high arsenic clone were tolerant of arsenic at this extreme level while those of the low arsenic tolerance clone were not. When Porter and Peterson supplied arsenic as the arsenite ion, neither clone rooted in solutions of 1 mg soluble As III/kg or higher. A significant decrease in the growth of non-tolerant plants occurred at treatments of 10 mg soluble As V/kg or higher. This was associated with a shoot concentration of 140 mg As/kg dry weight and a root concentration above 1000 mg As/kg. The tolerant plants accumulated generally less arsenic than the non-tolerant plants for a specific treatment. Significant growth effects for tolerant plants occurred only at soil levels of 50 mg soluble As V/kg and above, when plant accumulation resulted in 565 mg As/kg in the shoots and 2,880 mg As/kg in the roots. Even at very low levels, arsenite depressed plant growth. Significant effects occurred at the 0.05 mg As III/kg treatment level. Associated plant concentrations were 4 mg As III/kg in the shoots and 60 mg As III/kg in the roots. The grasses which had originated from sites with elevated arsenite concentrations had exhibited tolerance specifically to the arsenate ion rather than to arsenite.

Wallace et al. (1980) grew bush bean plants in solution culture with varied levels of arsenate. The level of 7.5 mg As V/L in solution resulted in considerable plant damage. Plant concentrations of arsenate at this application rate were 3.6, 18.8, and 41.7 mg/kg respectively for leaves, stems, and roots.

The results of transpiration studies conducted by Morris and Swingle (1927) with oats in water cultures showed that arsenic added as As_2O_3 decreased transpiration even when added at the rate of 1 mg/L, and resulted in narrower leaf blades and a lighter color. In the same study, when sand was used instead of soil, the other environmental conditions remaining the same, the injury was apparent in a shorter time. The rate of arsenate uptake by non-tolerant plant roots was much greater than the uptake rate in the roots of tolerant plants. It was postulated that the difference in the rate of uptake between tolerant and non-tolerant plants was due to an altered phosphate and arsenate uptake system (Meharg and Macnair 1991). The rate of arsenate uptake in the non-tolerant genotype decreased more rapidly with increasing pH (4 to 8) than did uptake in the tolerant plants. In the tolerant plants about 75% of assimilated arsenate was transported to the shoots, with this figure being about 50% in non-tolerant plants.

The toxicity of arsenic compounds to citrus plants grown in solution cultures began to be apparent at concentrations of about 5 mg As V/L in solution and at about 2 mg As III/L (Liebig et al. 1959). Concentrations of either 10 mg As V/L or 5 mg As III/L, though not always lethal, caused very marked depression of top and root growth. In general, the amounts of arsenic found in or on the roots increased with increasing concentrations in the solution. The arsenic contents of roots treated with 2 mg/L as As III or V were not different, however the roots treated with 5 mg As III/L contained more than twice as much arsenic as roots treated with 5 mg As V/L. Small amounts of this mineral, 1 mg/L as As III or V, had a stimulating effect on the root growth of citrus plants in solution culture. The arsenic content of burned-spot leaves was 3.25 mg/kg in leaves from the 5 mg As V/L treatment, and 3.30 mg/kg in those from the 2 mg As III/L treatment.

Approximately 10 times as much pentavalent arsenic is required in culture solution and in plant tissue as trivalent arsenic to produce equivalent injuries to tomato plants (Clements and Munson 1947). The two forms of arsenic differ not only in lethal concentrations, but also in their immediate action on plant tissue. Trivalent arsenic has a violent action, causing complete disintegration of the roots and burning the tops in one or two days in lethal concentrations. Pentavalent arsenic, on the other hand, often takes several days to produce any response other than wilting, even in concentrations that eventually prove lethal. When arsenite is applied to a leaf, it causes wilting due to loss of turgor (suggesting an alteration of membrane integrity), and in contrast arsenates cause chlorosis but not rapid turgor loss (Woolson 1983).

Arsenate has the necessary structure and chemical properties to take part in biochemical mechanisms, often by acting as a phosphate substitute (Huang and Mitchell 1972). Arsenate has no affinity to thiols and thus, unlike arsenite does not affect many enzyme systems (Johnstone 1963). Therefore, any tolerance mechanism for arsenite would require either exclusion of the ion or rapid adsorption once inside the plant to avoid enzyme inactivation, and no plant has yet been shown to be tolerant to arsenite.

Arsenic and Phosphorus

Arsenic and phosphorus are in the same periodic family and have similar chemical and physical properties. Phosphorus competes for arsenic fixation sites in soil and may affect arsenic availability. Therefore high levels of phosphorus may overcome arsenic toxicity by an antagonistic action (Woolson et al. 1973). At low levels of arsenical application, small increases in crop yields may occur. This may be due to the displacement of phosphate by arsenate, increasing phosphate availability to vegetation (NRCC 1978). Tsutsumi (1983) found that the toxicity of arsenite to rice plants was almost independent of added phosphate, where arsenate could be antagonistically affected by phosphate. In a nutrient solution, Hurd-Karrer (1939) found that the phytotoxicity of arsenic was a function of the phosphorus concentrations. At phosphorus/arsenic ratios of 4:1 or greater, arsenic phytotoxicity on wheat was reduced. However, at a ratio of 1:1, growth reductions occurred at concentrations of 10 mg As/L and higher.

Carrow et al. (1975) studied the influence of soil phosphorus level on the growth of several cool season turfgrasses and on the Bray P_1 extractable arsenic. In the first study five rates of arsenic (0, 0.44, 0.88, 1.76, and 3.53 kg/100m^2) were supplied as 0, 2.45, 4.9, 9.7, and 19.4 kg powdered 48% tricalcium arsenate/100m^2, and four rates of phosphorus (0, 1, 2, and 4 kg monocalcium phosphate/100m^2) were applied to soil low in natural phosphorus. In the second study four rates of arsenic (0, 0.88, 1.76, and 3.53 kg/100m^2) were applied to soil collected from a long term phosphorus study. In the first experiment, a significant reduction in arsenic toxicity with increasing phosphorus concentration was observed in annual bluegrass and creeping bentgrass between the 0 and 1 kg/100m^2 treatments. However, among the three highest phosphorus treatments no significant reduction in arsenic toxicity occurred even though soil phosphorus levels increased 4.3-fold up to an extremely high level of 278 mg phosphorus. No significant effect of phosphorus on arsenic toxicity to annual bluegrass or creeping bentgrass was evident at any soil phosphorus level. In the second experiment the three grasses grown on this soil exhibited no effect of phosphorus on arsenic toxicity. On soils which are very low in phosphorus, a slight reduction in arsenic toxicity may occur after phosphorus fertilization. Also, Bray P_1 extractable arsenic was not affected by applied phosphorus at the rates used in these investigations.

Because the concentrations of phosphorus have an important influence on arsenic toxicity, comparisons between arsenate and arsenite must be made within series of similar phosphorus concentration (Clements and Munson 1947). Comparisons of the arsenate and arsenite experiments at the medium phosphorus level, 60 mg/kg, indicated marked differences between the action of pentavalent and of trivalent forms. The authors noted that an increase in phosphorus level significantly reduced the amount of pentavalent arsenic adsorbed, and resulted in better growth, while the action of phosphorus on the adsorption of trivalent arsenic was quite different from its action on pentavalent arsenic. The investigators showed that for a given concentration of trivalent arsenic, plants adsorb approximately the same amount of the toxic element, irrespective of the phosphorus level, and showed equal degrees of injury. These studies confirm the supposition that phosphates would be expected to have less effect on the toxicity of arsenite than on that of arsenate.

Studies carried on elsewhere have yielded some treatments which may be useful in correcting arsenic toxicity: the use of heavy phosphate applications (Hurd-Karrer 1939), lime (Paden and Albert 1930), iron oxide (Keaton and Kardos 1940), and organic matter (Keaton 1938) have shown promise of reducing the toxicity of arsenic excess, although none of these very costly treatments reduces the arsenic content of the soil (Clements and Munson 1947). Adsorbed arsenate can easily be replaced by citrate and phosphate ions because a repression in arsenate adsorption is observed in the presence of these ions (Misra and Tiwari 1963). The release of soil arsenate by phosphate and citrate ions showed that at least one third of the adsorbed arsenate is in the exchangeable or replaceable form, while the rest of the arsenate was locked up in the form of calcium compounds or sesquioxide complexes.

In a study involving rice seedlings in solution culture, the toxicity of arsenite was almost independent of added phosphate and the lethal concentration was found to be 7.5 mg As III/L (Tsutsumi 1983). Arsenate toxicity was antagonistically reduced by phosphate when applied in the range of 1 to 100 mg/L without the addition of other nutrients and to 310 mg/L with an increase in the supply of other nutrients. At 1 mg of phosphate/L of solution the growth response to arsenate was similar to that without phosphate and the antagonism seemed to stop. The lethal concentration of arsenite (7.5 mg As III/L) was found to be equal to that of arsenate in the middle range of 1 to 10 mg of phosphate/L, irrespective of the existence of other nutrients. Below this phosphate level, therefore, arsenate exceeded arsenite in toxicity to rice seedlings. These observations lead to the tentative conclusion that the common view that arsenite is more toxic than arsenate without regard to the status of co-existing phosphate was questionable.

Nutrient Solution Culture

All plants should be grown with a balanced nutrient solution providing specified concentrations of all the elements known at present to be essential (Hewitt and Smith 1974). Water is, of course, always the main component of growing plants, but the major portion, usually about 90%, of the dry matter of most plants is made up of three chemical elements: carbon, oxygen, and hydrogen. Carbon comes from the air, oxygen from the air and water, and hydrogen from water, while other elements such as nitrogen, phosphorous, potassium, calcium, magnesium, sulfur, chlorine, iron, boron, manganese, zinc, copper, and molybdenum are obtained from the soil (Hoagland and Arnon 1950). These authors developed a formula for a nutrient solution which contains all of these minerals. Elemental proportions were based on the approximate proportions of the elements as they were found to be adsorbed by the tomato plant.

The nutrient solution or water culture method is a technique in which plants are grown with their roots submersed in a solution containing the mineral nutrients essential for plant growth. The roots must be aerated to provide for root respiration, the pH of the nutrient solution must be monitored and adjusted accordingly, and periodically the solution must be replaced (Hoagland and Arnon 1950). In the sand culture method plants are grown in sand that is irrigated with nutrient solution. The sand culture method provides for more efficient natural aeration of roots than the water culture method (Hewitt 1966). The sand must be cleaned or minute quantities of elements in the sand may alter elemental concentrations in the nutrient solution and thus pose a problem to quantitative studies of micronutrients.

MATERIALS AND METHODS

Western wheatgrass, basin wildrye, hard sheep fescue, and Canada bluegrass were grown from seed, placed in a sand culture, and then treated with four concentrations of arsenic III (0, 1, 2, and 5 mg/L) and four concentrations of arsenic V (0, 7, 14, 28 mg/L) for 75 days. Plant height, above ground biomass, below ground biomass, and shoot arsenic concentration were measured for each species. Plant color, vigor, leaf burn, amount of red discoloration, and survival were also observed and recorded.

Sand Culture

Four sand filled flats were planted each with a different grass species (Table 1). Prior to planting, however, the greenhouse sand had been washed to remove any fine material.

Table 1. Species used in the greenhouse study*.

Scientific name	Common name
Pascopyrum smithii	western wheatgrass
Leymus cinereus	basin wildrye
Festuca ovina duriuscula	hard sheep fescue
Poa compressa	Canada bluegrass

*Nomenclature from Rumley and Lavin 1991.

Table 2. Hoagland's nutrient solution*.

Compound	g/L	mg/L
KNO_3	0.656	
$Ca(NO_3)_2 . 4H_2O$	0.994	
NH_4HPO_4	0.115	
$MgSO_4 . 7H_2O$	1.004	
H_3BO_3		2.68
$MnCl_2 . 4H_2O$		1.81
$CuSO_4 . 5H_2O$		0.08
$ZnSO_4 . 7H_2O$		0.22
$H_2MoO_4 . H_2O$		0.09
FeEDTA		3.98

*Hoagland and Arnon (1950).

The germinating seeds were watered with Hoagland's nutrient solution (Table 2) diluted 1:4 with tap water. Once the slowest growing species had reached a height of 5 cm, five plants of a single species were transplanted into 10 cm wide and 12 cm deep sand filled plastic pots (1,000g of sand). These pots were watered with the 1:4 diluted Hoagland's nutrient solution. Because the age of the plant might affect its ability to withstand the elevated arsenic levels, the plants were allowed to reach substantial growth before the arsenic treatment was started (Stewart and Smith 1922). The amount of time between the emergence of the plants above the soil and the start of arsenic treatment varied from three to seven weeks. Arsenic was added to the nutrient solution as As_2O_3 (arsenic III) and As_2O_5 (arsenic V). Four concentrations of arsenic III (0, 1, 2, and 5 mg/L) and four concentrations of arsenic V (0, 7, 14, 28 mg/L) were prepared. Each treatment was replicated eight times for each grass species.

The plants were grown and watered in a greenhouse within the Plant Growth Center at Montana State University. Full spectrum lamps were used to extend the daylight period to 14 hours. The average daytime temperature during the growing period was 22°C, ranging from 14°C to 30°C. The average night temperature for the same period was 18°C, ranging from 12°C to 24°C. For the first 40 days pots were watered every other day, and for the remainder of the study the pots were watered daily. The pots were irrigated with 85 ml of solution, an amount calculated and observed to saturate the sand. The irrigation solution was applied directly to the sand to minimize solution contact with the plant. As the experiment progressed and the plants wilted, it became impossible to completely prevent solution contact with the shoot and leaf material.

Measurements

Height of all five plants in each pot was measured 0, 25, 50, and 75 days after arsenic treatments began. In addition, symptoms assumed to be influenced by arsenic including plant color, vigor, leaf burn, amount of red discoloration, and survival were observed at these times and a numeric value was assigned to each pot (Table 3). For each pot of each species above ground plant material was observed and a pot average for color was determined on a scale of dark green to yellow. Plants were studied for thickness of stems and leaves, number of stems, amount of new growth, height of plants, and posture of the plants. Together these several attributes were combined to produce

Table 3. Explanation of the five observation indices.

Assigned value	Color	Vigor	Burn	Red (%)	Survival (plant/pot)
0	---	---	none	0%	0
1	dark green	excellent	tip	<5%	1
2	green	good	marginal	5-25%	2
3	pale green	acceptable	dead areas	25-50%	3
4	yellow	poor	---	50-75%	4
5	---	dead	---	75-95%	5
6	---	---	---	>95%	---

a vigor rating on a scale of excellent to dead. As with the color of the plants a numeric value was assigned to each pot. Leaves were studied for tip and marginal burn as well as dead areas. Tip burn was found on the end of leaf blades, marginal burn was found along the perimeter of the leaf blades, and dead areas were actual dead spots on the surface areas of the leaves. As with the previous plant parameters a numeric value was assigned to each category of this evaluation. The percent of above ground material in each pot that had turned red was divided into six categories. The classes were ranges of values which made it much easier to place a label on the amount of red above ground material in a pot. Plant survival was determined by the number of plants that were alive in each pot at every observation period.

At the end of the 75 day study, above and below ground plant tissues were harvested. Below ground biomass was determined after the roots were washed to remove sand particles. Tissues were dried for 72 hours at 47°C, and weighed. The eight replicates of dried above ground tissues for each treatment were composited into one sample and ground in a Wiley mill to pass a 20 mesh screen. Two grams of each sample were digested with concentrated nitric acid (HNO_3) followed by 30% hydrogen peroxide (H_2O_2) (Neuman 1994). This acid-peroxide digestate solution was analyzed for arsenic content using Graphite Furnace Atomic Absorption Spectrometry.

To monitor the precision of analyses, laboratory duplicates and blind field replicates were entered into the sample set at approximately a five percent (1 in 20) rate. Laboratory duplicate relative percent difference (RPD) averaged 23.5% total arsenic. Blind field replicate RPD averaged 28% total arsenic. Laboratory matrix spikes and laboratory control samples were utilized at a five percent rate to monitor the accuracy of arsenic analysis. Laboratory matrix spike recoveries for arsenic averaged 75%. Laboratory control samples of National Bureau of Standards citrus leaves standard reference material (#1572) averaged 14.5% RPD. The certified arsenic concentration of these leaves was 3.1 mg/kg. Arsenic concentration in the citrus leaves as determined in this study was 3.5 mg/kg.

Statistical Design

Replicated pots (n=8) each containing five plants of a single species were planted for each treatment and arranged in a randomized complete block design. The eight blocks were rotated every two weeks to minimize variation across the blocks. Plant height on days 0, 25, 50, and 75 were measured. In addition, mean shoot weight, and mean root weight were determined for each grass species in each arsenic treatment. Mean dry weights were calculated by dividing the total shoot or root weights per pot by the number of plants in that pot. For each grass species, oxidation state of arsenic, and arsenic concentration a relative mean percent plant height, shoot weight, and root weight was calculated. This was accomplished by dividing the average value per pot (across the eight blocks) by the maximum mean value per pot (of all the treatments) for that species and multiplying the quotient by 100.

Skewness and kurtosis data are presented in Table 13 (Appendix B), and show that all the data for all the variables fit a normal distribution. Analysis of variance (ANOVA) was used to detect the effects of arsenic treatment on plant height on all four days, and mean shoot and root dry weight per plant. Arsenic III and V treatments were analyzed as two separate experiments. The least significant differences (LSD) test with $p<0.05$ was used to determine differences between treatment means of those variables which had a significant treatment effect as determined by ANOVA. Data were analyzed with Montana State University Statistical Computer program (MSUSTAT) (Lund 1993).

RESULTS

Arsenic III treatments

Pascopyrum smithii

Western wheatgrass survival was not affected by arsenic III concentrations in the nutrient solution (Figure 1a). With very few exceptions, all five plants within a treatment survived the 75 day trial period. There was no significant effect of arsenic III treatment on western wheatgrass height nor was there any significant arsenic III effect on above ground or below ground biomass (Table 4). Results of the ANOVA are presented in Tables 14-16 (Appendix C).

Plants irrigated with the highest arsenic III level displayed a reduction in vigor from excellent to a good/acceptable range (Figure 1b). The reduction in vigor of plants treated with the higher levels of arsenic III occurred faster and was more severe than the vigor change in plants treated with lower arsenic III levels. The vigor of plants growing in the 1, 2, and 5 mg As III/L treatments had decreased at the 25 day measurement period. The control began to decline in vigor at 50 days. Because the control did decrease in vigor during the 75 day growth period, not all of the change in vigor of the treatments can be accounted for by arsenic III concentration alone. Some other environmental factors must have had an influence on plant vigor (e.g. water stress).

Plant color changed from dark green to either green or pale green over time depending on the arsenic III concentration (Figure 1c). The color change of plants

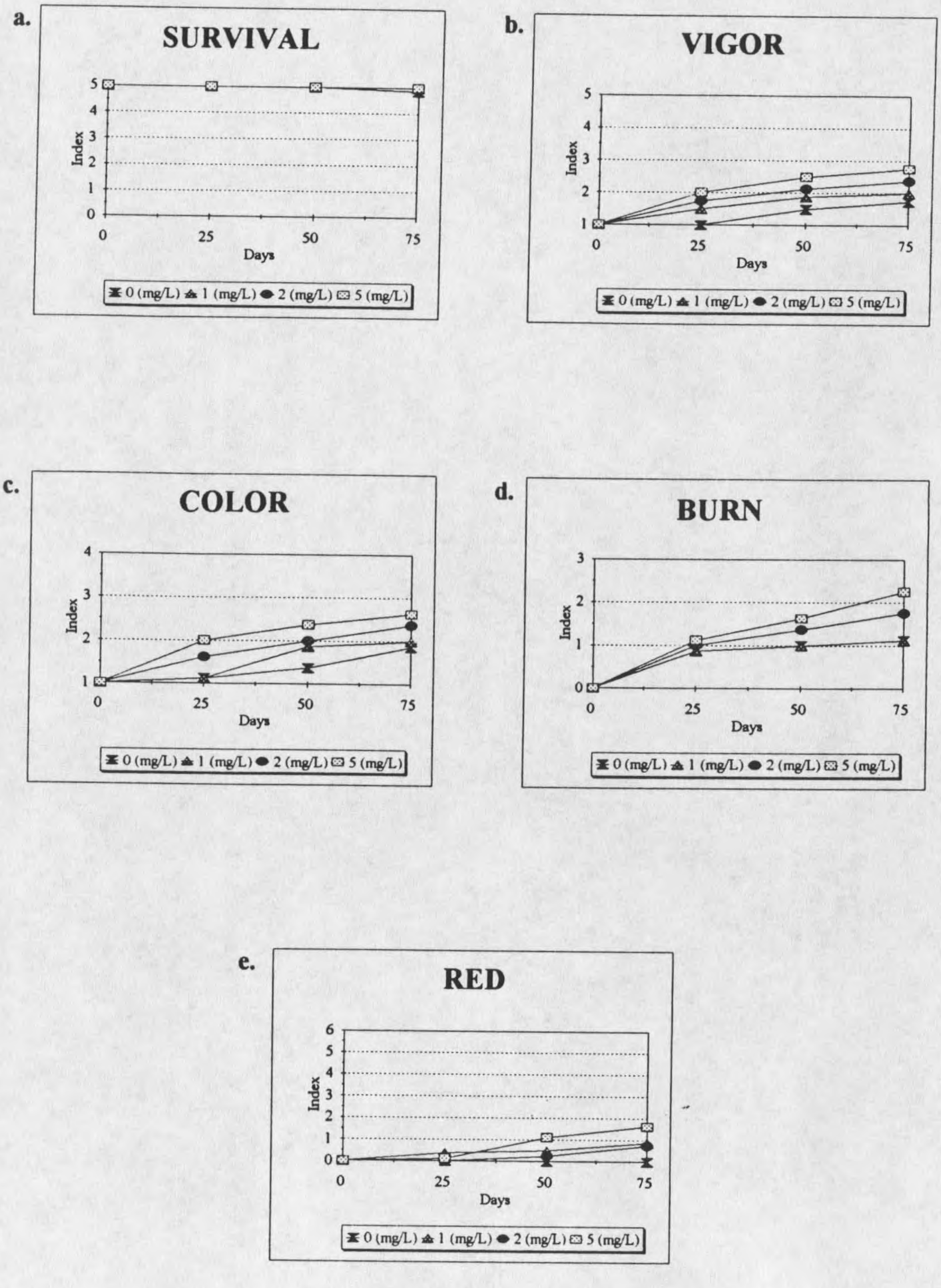

Figure 1. Observations of *Pascopyrum smithii* irrigated with four levels of arsenic III: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 4. Treatment means of *Pascopyrum smithii* grown in arsenic III.

Arsenic III (mg/L)	Mean plant height (cm)				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	23.84 a	40.76 a	44.87 a	47.23 a	1.884 a	1.556 a
1	22.61 a	38.30 a	43.26 a	44.60 a	1.740 a	1.537 a
2	25.20 a	42.88 a	45.54 a	47.49 a	1.777 a	1.437 a
5	22.45 a	37.94 a	41.61 a	42.60 a	1.765 a	1.428 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

grown in the higher levels of arsenic III occurred faster and was more severe than the color change of plants irrigated with lower arsenic III levels. The color of the plants grown in 2 and 5 mg As III/L began to lighten at 25 days, while the control and 1 mg As III/L solutions produced a notable color change within 50 days.

Plant leaf burn across all four arsenic concentrations varied from no leaf burn to the tip/marginal burn range (Figure 1d). The burn of plants grown in the higher levels of arsenic III occurred faster and was more severe than the burning of plants treated with lower arsenic III levels. Leaf burn became apparent for all plants in all of the growth solutions within only 25 days. Plants in the control and 1 mg As III/L growth solutions displayed a small increase in tip burn after 25 days. The plants treated with 2 and 5 mg As III/L exhibited marginal burn by the end of the treatment period.

Leaves and stems of plants irrigated with 1 and 2 mg As III/L displayed less than 5% red discoloration at the end of the study period (Figure 1e). Plants treated with 5 mg As III/L revealed as much as 20% red within the same time frame. Tissues of plants grown in higher arsenic III levels had greater surface areas turning red than plants grown in with the lower arsenic III levels.

It may be inferred from the linear regression that a strong correlation exists between the arsenic concentration in the shoot tissues and the arsenic III concentrations in the nutrient solution (Figure 2). Concentrations of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative plant height, relative shoot weight, and relative root weight all decreased by approximately 10% as arsenic III concentration in the nutrient solution increased to 5 mg As III/L (Figure 3).

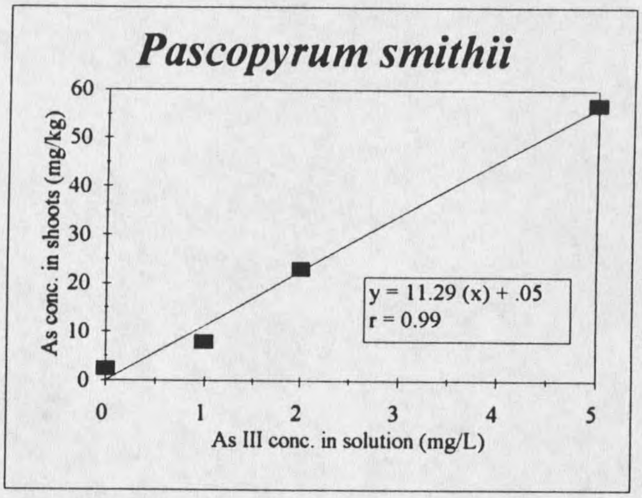

Figure 2. Mean arsenic concentrations in above ground plant tissues of *Pascopyrum smithii* irrigated with arsenic III.

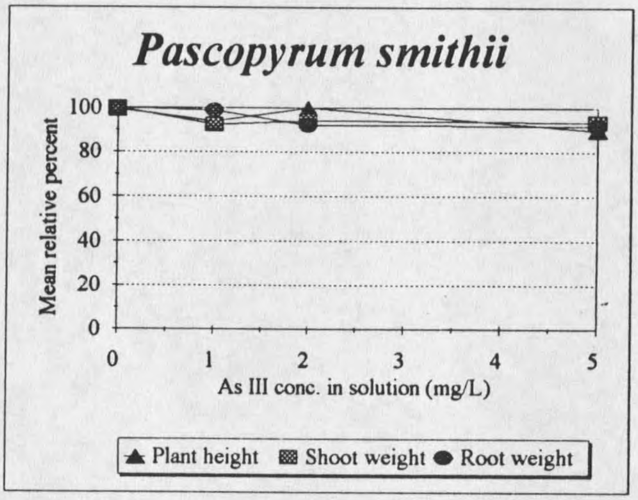

Figure 3. Mean relative percents of measured attributes from *Pascopyrum smithii* irrigated with arsenic III.

Data from western wheatgrass measurements are presented in Table 39 (Appendix E). Arsenic toxicity symptoms are presented in Table 47 (Appendix F).

Leymus cinereus

Basin wildrye survival was not affected by the level of arsenic III concentrations in the nutrient solution (Figure 4a). With very few exceptions, all five plants within each treatment survived the 75 day trial. There was no significant effect of arsenic III on basin wildrye height nor was there any significant arsenic III effect on above ground or below ground biomass (Table 5). Results of the ANOVA are presented in Tables 17-19 (Appendix C).

Plants irrigated with the four concentrations of arsenic III displayed a reduction in vigor from excellent to the good/acceptable range during the 75 days (Figure 4b). This decrease in vigor, for all the arsenic III concentrations, occurred at 25 days.

Plant color across all arsenic III concentrations changed from dark green to green/pale green during the study period (Figure 4c). The color change of plants irrigated with higher arsenic III levels occurred faster and was more severe than the color change of plants watered with lower arsenic III levels. Color for those plants treated with 2 and 5 mg As III/L lightened at 25 days.

Plants burn across all arsenic III levels changed from no burn to tip/marginal burn during the study (Figure 4d). The burn of plants watered with the higher levels of arsenic III occurred faster and was more severe than the burning of plants irrigated

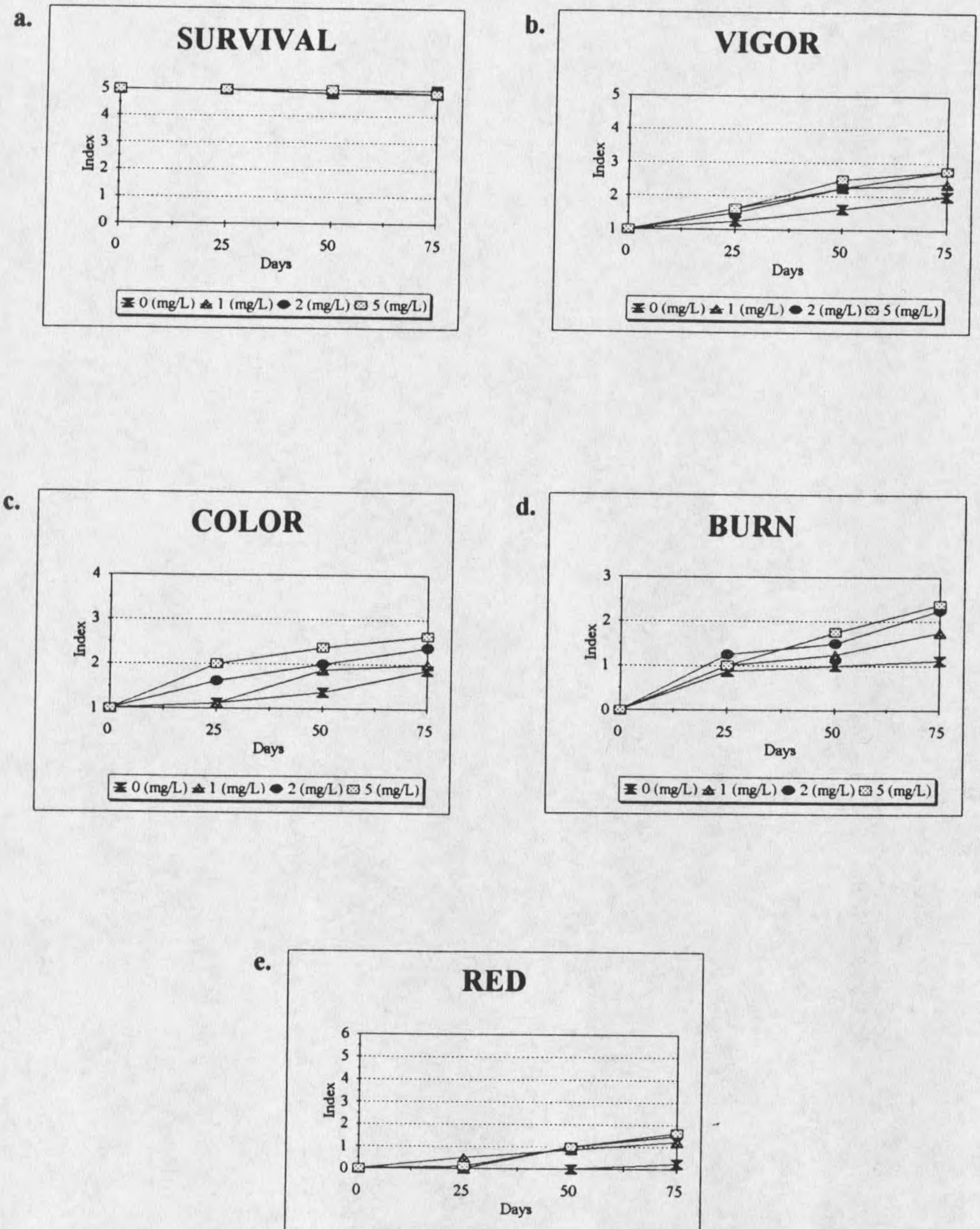

Figure 4. Observations of *Leymus cinereus* irrigated with four levels of arsenic III: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 5. Treatment means of *Leymus cinereus* grown in arsenic III.

Arsenic III (mg/L)	Mean plant height (cm)				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	28.61 a	46.90 a	50.55 a	51.57 a	1.559 a	1.619 a
1	26.43 a	42.92 a	45.98 a	47.74 a	1.553 a	1.759 a
2	26.10 a	44.45 a	47.46 a	48.40 a	1.475 a	1.536 a
5	27.52 a	46.50 a	48.30 a	49.85 a	1.583 a	1.729 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

with lower arsenic III levels. Tip burn occurred on the controls at 25 days, while the arsenic III solutions produced marginal burn in the same period of time.

Leaves and stems of plants irrigated with 1, 2, and 5 mg As III/L had turned approximately 15% red by the end of the study period (Figure 4e). Tissues watered with higher arsenic III levels had greater surface areas turning red than plants irrigated with lower levels of arsenic III in the same period of time. The control showed a slight red discoloration at the end of the 75 day growth period.

It may be inferred from the linear regression that a strong correlation exists between the arsenic concentration in the shoot tissues and the arsenic III concentration in the nutrient solution (Figure 5). Concentrations of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). The relative plant height, relative shoot weight, and relative root weight were basically constant across all treatments (Figure 6). All three parameters were depressed by approximately 10% with the 2 mg As III/L level.

Data from basin wildrye measurements are presented in Table 40 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 48 (Appendix F).

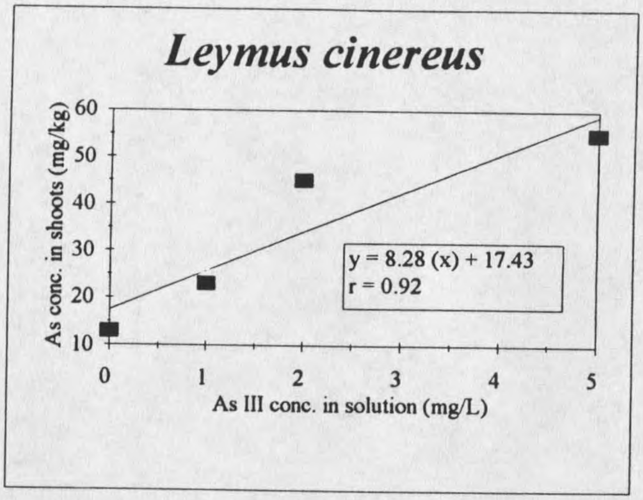

Figure 5. Mean arsenic concentrations in above ground plant tissues of *Leymus cinereus* irrigated with arsenic III.

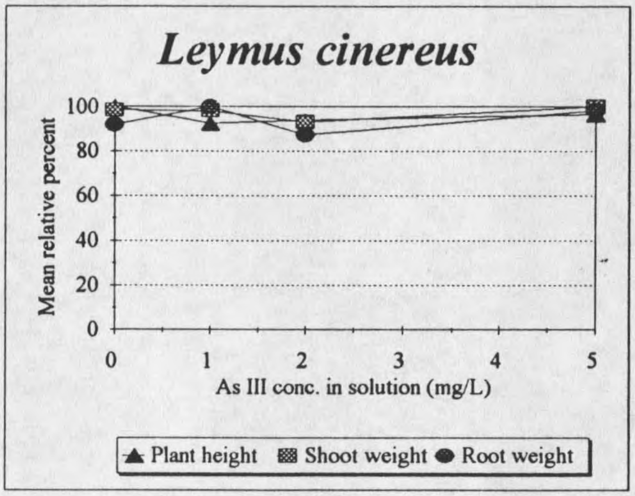

Figure 6. Mean relative percents of measured attributes from *Leymus cinereus* irrigated with arsenic III.

Festuca ovina duriuscula

Plant survival decreased at 50 days for the 1, 2, and 5 mg As III/L levels (Figure 7a). At the end of the 75 day arsenic III treatment period the plants irrigated with 2 mg As III/L had an average survival rate of only 4.4 plants/pot. There was no significant effect of arsenic III concentration on hard sheep fescue height nor was there any significant arsenic III effect on above ground of below ground biomass (Table 6). Results of the ANOVA are presented in Tables 20-22 (Appendix C).

The vigor of plants watered with the 1, 2, and 5 mg As III/L levels was affected at 25 days, and was reduced to the good/acceptable range during the study period (Figure 7b). Irrigation of plants with the lowest level of arsenic III did not produce vigor lower than the good rating. The reduction in vigor of plants watered with the higher levels of arsenic III occurred faster and was more severe than the vigor change of plants irrigated with lower arsenic III levels.

Plant color across all arsenic III concentrations changed color at 50 days, and faded from dark green to green over the study period (Figure 7c). The color change of plants irrigated with higher arsenic III levels occurred faster and was more pronounced than the color change of plants watered with lower arsenic III levels.

Plant burn across all arsenic III concentrations was apparent at 25 days, and spread from no burn to tip/marginal burn during the experiment (Figure 7d). The burn of plants irrigated with the higher levels of arsenic III occurred faster and was more severe than the burning of plants watered with lower arsenic III levels. The control and 1 mg As III/L solutions produced tip burn at 25 days. Plants watered with 5 mg As III/L continued to

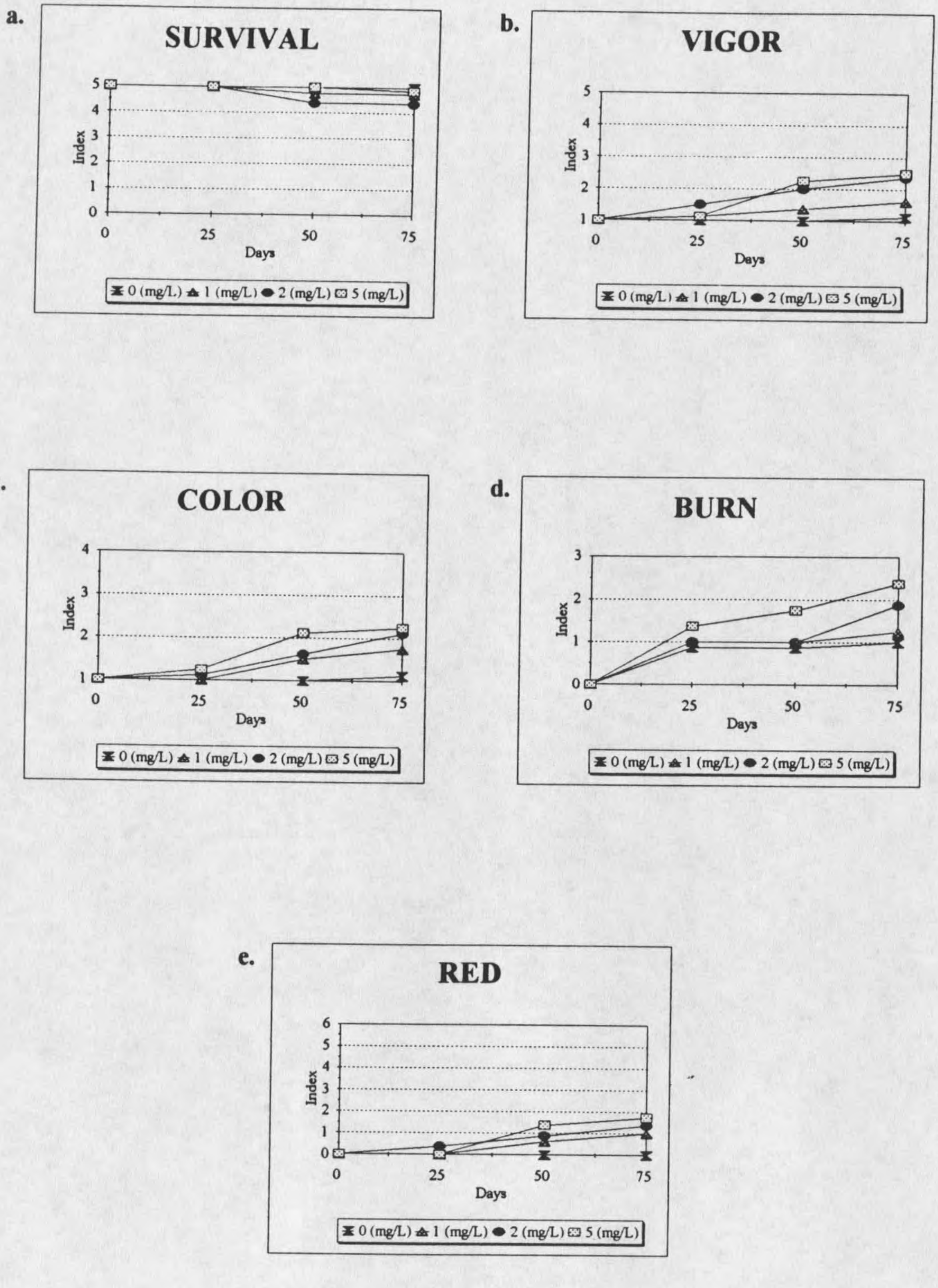

Figure 7. Observations of *Festuca ovina duriuscula* irrigated with four levels of arsenic III: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 6. Treatment means of *Festuca ovina duriuscula* grown in arsenic III.

Arsenic III (mg/L)	Mean plant height				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	9.20 a	13.45 a	16.31 a	17.88 a	1.321 a	1.228 a
1	9.10 a	13.50 a	17.14 a	18.29 a	1.390 a	1.213 a
2	9.13 a	12.91 a	15.34 a	16.64 a	1.366 a	1.228 a
5	10.46 a	13.32 a	14.43 a	15.41 a	1.119 a	1.016 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

increase in plant burn and by the end of the study period displayed a combination of marginal burn and dead areas.

Leaves and stems of plants irrigated with 1, 2, and 5 mg As III/L turned approximately 25% red by the end of the treatment period (Figure 7e). Tissues watered with higher arsenic III levels displayed a greater amount of red surface area than plants irrigated with the lower arsenic III levels over the same period of time. Plants watered with 2 mg As III/L were less than 5% red at 25 days. The plants irrigated with 1 and 5 mg As III/L displayed a red discoloration at 50 days.

It may be inferred from the linear regression that there is a strong correlation between in the arsenic concentration in the shoot tissues and the arsenic III concentration in the nutrient solution (Figure 8). Concentration of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative plant height, relative shoot weight, and relative root weight decreased by approximately 19% at 5 mg As III/L in the nutrient solution (Figure 9).

Data from hard sheep fescue measurements are presented in Table 41 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 49 (Appendix F).

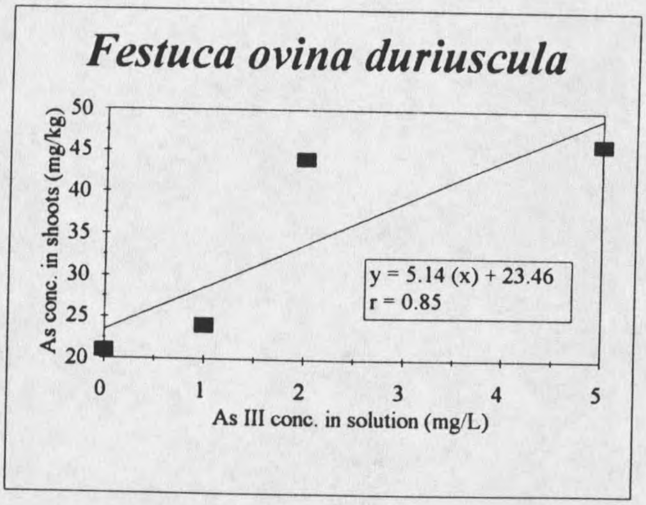

Figure 8. Mean arsenic concentrations in above ground plant tissues of *Festuca ovina duriuscula* irrigated with arsenic III.

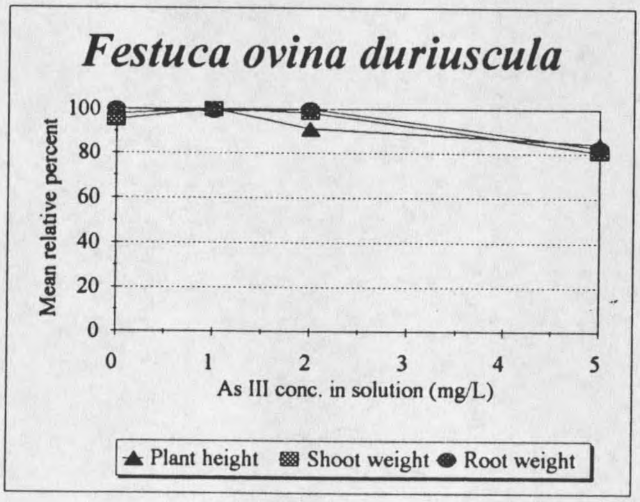

Figure 9. Mean relative percents of measured attributes from *Festuca ovina duriuscula* irrigated with arsenic III.

Poa compressa

Plant survival decreased at 50 days for 1, 2, and 5 mg As III/L level (Figure 10a). At the end of the 75 day arsenic III treatment period the plants treated with 2 mg As III/L had an average survival rate of only 4.6 plants/pot. There was no significant effect of arsenic III concentration on plant height at 0, 25, and 50 days (Table 7) but there was a significant reduction in plant height at 75 days for the 5 mg As III/L level. In addition, the arsenic III concentrations did not significantly affect either the above ground or below ground biomass. Results of the ANOVA are presented in Table 23-25 (Appendix C).

Plants watered with the 5 mg As III/L level displayed a reduction in vigor from excellent to acceptable (Figure 10b). Irrigation of plants with 1 and 2 mg As III/L produced good vigor. Vigor within all treatments, had a considerable decrease at 50 days.

Color of the 1 and 2 mg As III/L irrigated plants was reduced to green by the end of the growth period (Figure 10c). Plant color produced by the 5 mg As III/L solution was pale green after 75 days. The higher levels of arsenic III produced a greater decline in color than the lower arsenic III levels over the same time period. The color of those plants irrigated with 1, 2, and 5 mg As III/L began to show a color change at 25 days.

Plant burn across all arsenic III concentrations increased over time (Figure 10d). The burn of plants irrigated with the higher levels of arsenic III occurred faster and was more severe than the burning of plants watered with lower arsenic III levels. Leaf burn became apparent for the 1, 2, and 5 mg As III/L levels at 50 days, and at 75 days for the

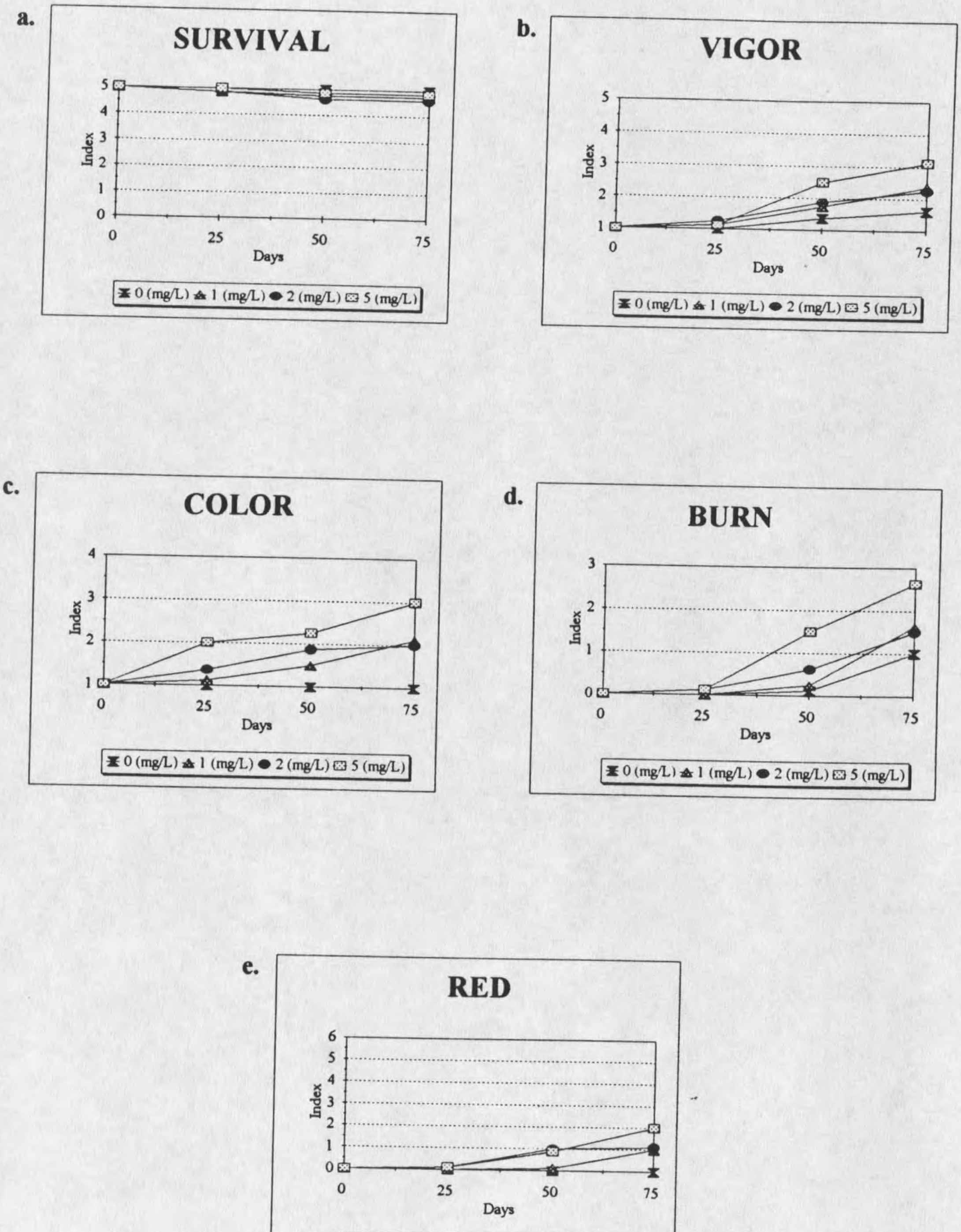

Figure 10. Observations of *Poa compressa* irrigated with four levels of arsenic III: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 7. Treatment means of *Poa compressa* grown in arsenic III.

Arsenic III (mg/L)	Mean plant height (cm)				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	4.78 a	19.73 a	33.94 a	38.81 b	1.437 a	1.186 a
1	4.53 a	19.61 a	33.25 a	36.54 b	1.474 a	1.211 a
2	4.80 a	17.76 a	34.96 a	38.24 b	1.473 a	1.222 a
5	4.58 a	17.27 a	24.97 a	26.26 a	1.241 a	1.037 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

control. The control, 1, and 2 mg As III/L solutions produced tip burn, but the 5 mg As III/L level resulted in a combination of marginal burn and dead areas.

The amount of red color on the stems and leaves of plants irrigated with 1, 2, and 5 mg As III/L increased during the experiment (Figure 10e). Leaves and stems of plants irrigated with 1 and 2 mg As III/L resulted in a red discoloration of less than 5%, and plants watered with 5 mg As III/L produced a 25% red discoloration. The plants irrigated with 1, 2, and 5 mg As III/L displayed red areas at 50 days.

It may be inferred from the linear regression that there is a strong correlation between the arsenic concentration in the shoot tissues and the arsenic III concentration in the nutrient solution (Figure 11). Concentration of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative shoot weight, relative root weight, and relative plant height remained stable through the 2 mg As III/L irrigation level (Figure 12). At 5 mg As III/L relative shoot weight and relative root weight were reduced by approximately 18%, and relative plant height was reduced by 37% (significant).

Data from Canada bluegrass measurements are presented in Table 42 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 50 (Appendix F).

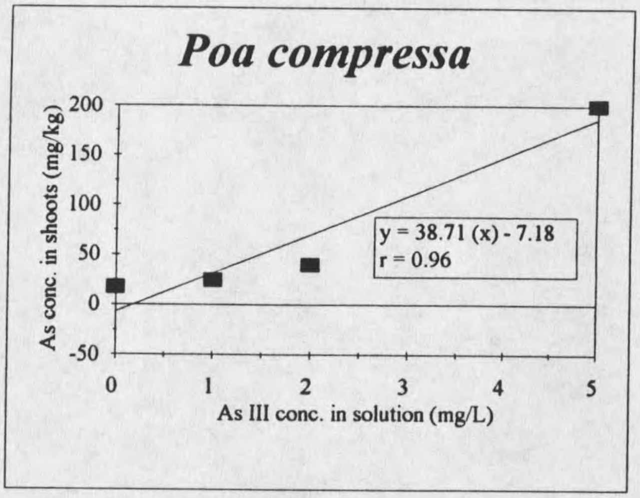

Figure 11. Mean arsenic concentrations in above ground plant tissues of *Poa compressa* irrigated with arsenic III.

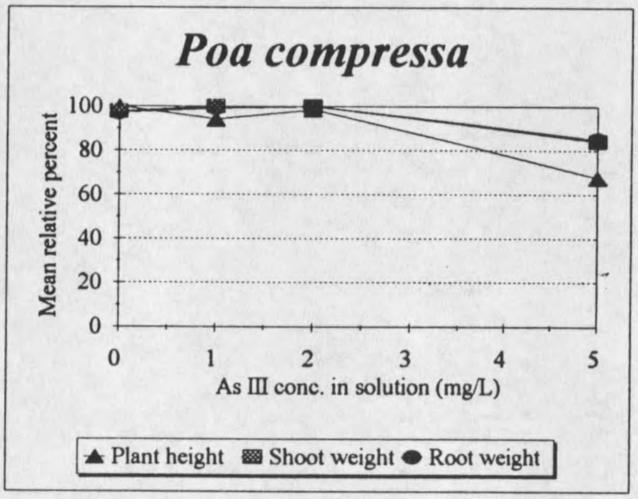

Figure 12. Mean relative percents of measured attributes from *Poa compressa* irrigated with arsenic III.

Arsenic V treatments

Pascopyrum smithii

Plant survival was not affected by the arsenic V treatment level (Figure 13a). With very few exceptions, all five plants within each arsenic V concentration survived the 75 day growth period. There was a significant reduction in plant height at 50 and 75 days for the highest arsenic V concentration (Table 8). In addition, there were significant reductions in shoot weight at 14 and 28 mg As V/L. At 28 mg As V/L there was a significant decrease in root weight. Results of the ANOVA are presented in Tables 26-28 (Appendix C).

Plant vigor for the control and the 1 mg As V/L treatments deteriorated from excellent to good (Figure 13b). Plant vigor for the 2 and 5 mg As V/L levels declined from excellent to acceptable. The plants watered with the higher arsenic V levels displayed a greater vigor decrease than the plants irrigated with the lower arsenic V levels.

Plant color across all four arsenic V concentrations changed during the 75 day treatment period (Figure 13c). The control and 7 mg As V/L solutions turned the plants green, while 14 and 28 mg As V/L solutions produced pale green plants. The 14 and 28 mg As V/L treatments change color at 25 days. The control and 7 mg As V/L began to show a decline in color at 50 days.

The plants irrigated with the 28 mg As V/L displayed dead areas at 75 days of exposure (Figure 13d). Plants watered with the 7 mg As V/L level had marginal burn after

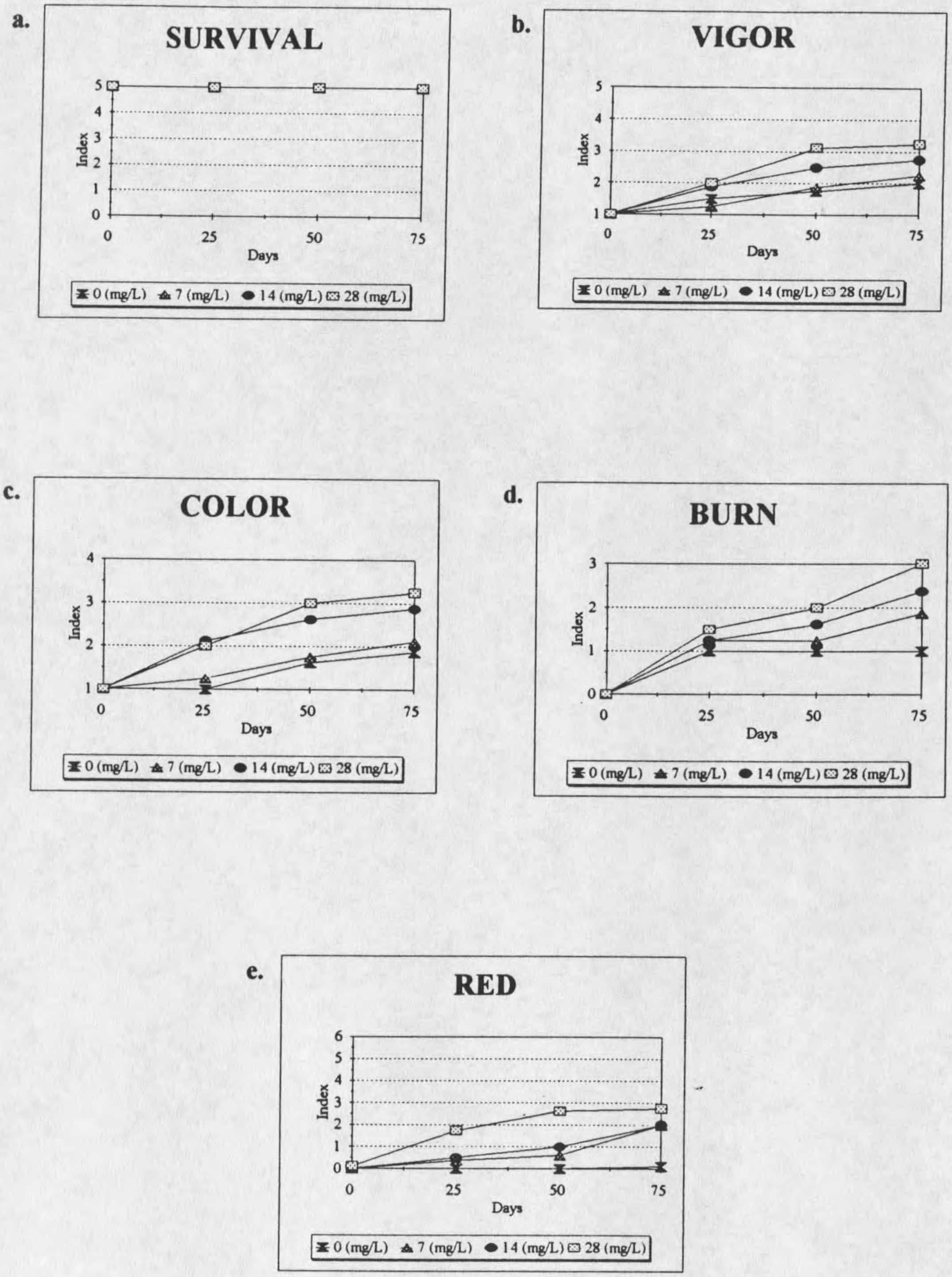

Figure 13. Observations of *Pascopyrum smithii* irrigated with four levels of arsenic V: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 8. Treatment means of *Pascopyrum smithii* grown in arsenic V.

Arsenic V (mg/L)	Mean plant height (cm)				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	22.85 a	39.76 a	43.85 a	46.45 a	1.778 c	1.500 b
7	24.85 a	42.06 a	45.38 a	46.46 a	1.822 c	1.462 b
14	25.21 a	41.81 a	43.88 a	45.16 a	1.570 b	1.387 b
28	24.56 a	36.86 a	38.02 b	39.00 b	1.349 a	1.135 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

the treatment period ended. The control produced tip burn. The plants irrigated with 7, 14, and 28 mg As V/L continued to burn throughout the entire experiment.

Approximately 40% of the surface of leaves and stems of plants irrigated with 28 mg As V/L were red after 75 days of treatment (Figure 13e). Plants watered with 7 and 14 mg As V/L were between 5 and 25% red. Those plants irrigated with higher arsenic V levels displayed a greater red discoloration than the plants watered with the lower levels of arsenic V in the same period of time. Plants irrigated with 7, 14, and 28 mg As V/L had a red discoloration after only 25 days.

It may be inferred from the linear regression that a strong correlation exists between the arsenic concentration in the shoot tissues and the arsenic V concentration in the nutrient solution (Figure 14). Concentration of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative shoot weight, relative root weight and relative plant height remained constant until the strength of the irrigation solution reached 14 mg As V/L (Figure 15). At 28 mg As V/L all three factors were decreased by approximately 20% (significant).

Data from western wheatgrass measurements are presented in Table 43 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 51 (Appendix F).

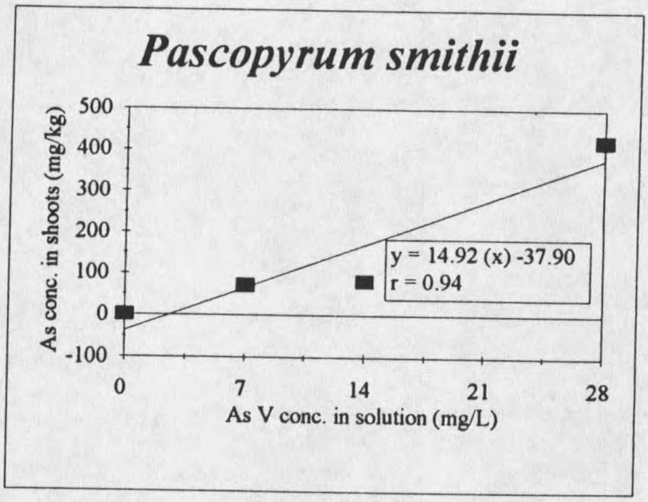

Figure 14. Mean arsenic concentrations in above ground plant tissues of *Pascopyrum smithii* irrigated with arsenic V.

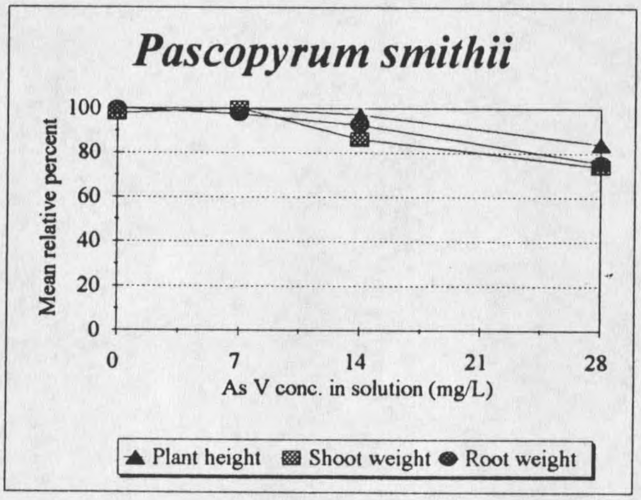

Figure 15. Mean relative percents of measured attributes from *Pascopyrum smithii* irrigated with arsenic V.

Leymus cinereus

Plant survival was not affected by the concentration of arsenic V in solution (Figure 16a). With very few exceptions, all five plants within each treatment survived the 75 day treatment period. There was no significant effect of arsenic V concentration on plant height for any measurement period (Table 9.) There was a significant increase in shoot weight at 7 mg As V/L, and at 28 mg As V/L there was a significant reduction in root weight. Results of the ANOVA are presented in Table 29-31 (Appendix C).

Plant vigor for the control and the 7 mg As V/L solutions decreased from excellent to good during the study (Figure 16b). Plant vigor for the 28 mg As V/L treatment deteriorated from excellent to acceptable. The vigor of the plants irrigated with 14 mg As V/L was in the good to acceptable range at the end of the study. The plants watered with the higher arsenic V levels displayed a greater vigor decrease than the plants irrigated with the lower arsenic V levels in the same time period.

Plant color across all four arsenic V concentrations lightened over time (Figure 16c). The 14 and 28 mg As V/L solutions produced pale green plants, while the 7 mg As V/L solution produced a color in the green/pale green range. All four irrigation solutions produced a color change within 25 days.

The plants watered with 28 mg As V/L displayed some marginal burn, but mostly dead areas after 75 days of arsenic V irrigation (Figure 16d). Plants watered with the 7 mg As V/L level only had a combination of marginal burn and dead areas. The control produced marginal burn only. Leaf burn for all irrigation solutions was apparent at 25 days.

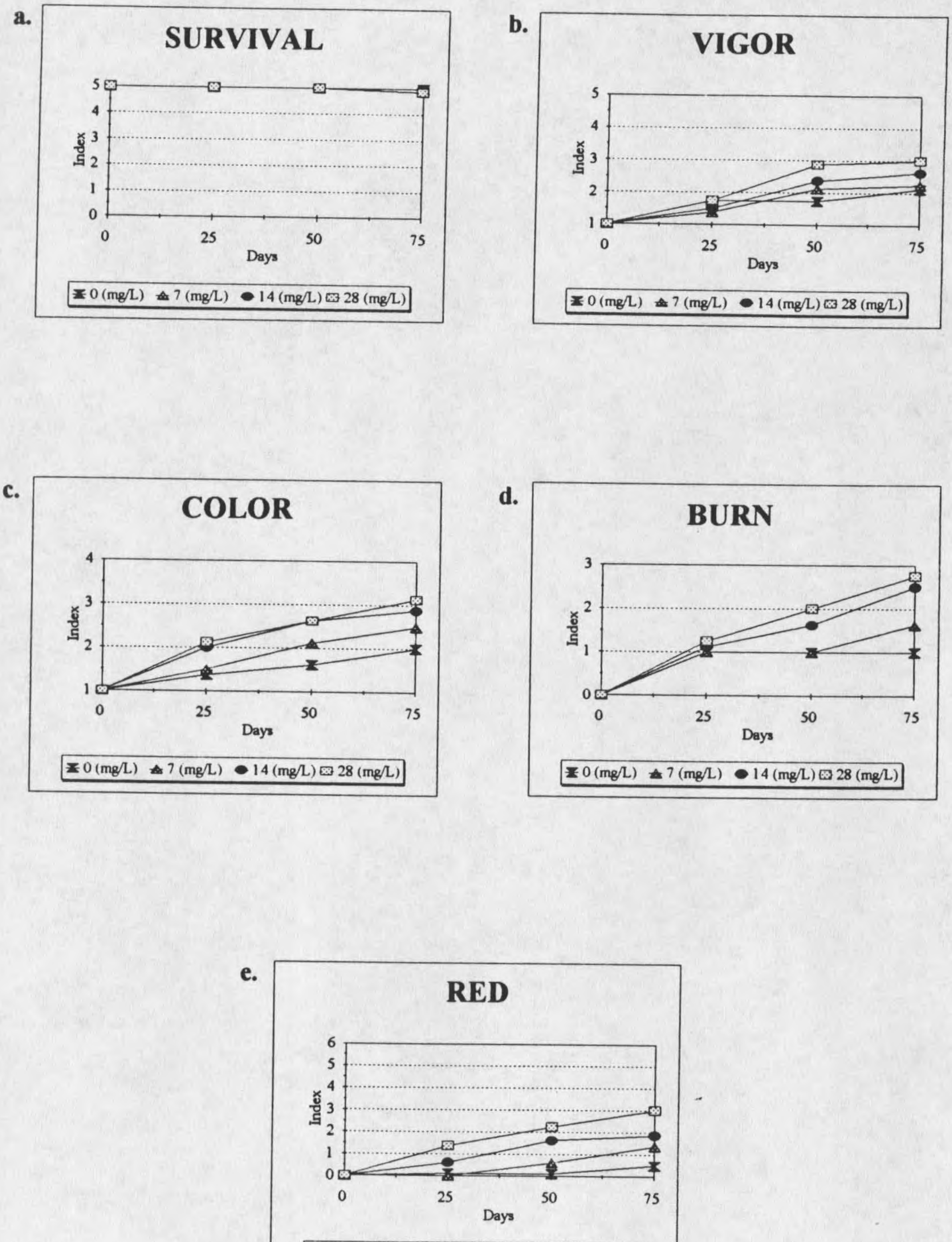

Figure 16. Observations of *Leymus cinereus* irrigated with four levels of arsenic V: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 9. Treatment means of *Leymus cinereus* grown in arsenic V.

Arsenic V (mg/L)	Mean plant height				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	28.96 a	44.56 a	46.90 a	48.17 a	1.468 ab	1.714 b
7	28.49 a	47.52 a	51.33 a	53.15 a	1.628 c	1.830 b
14	27.83 a	45.70 a	48.57 a	50.49 a	1.597 bc	1.694 b
28	25.61 a	43.64 a	46.24 a	48.43 a	1.433 a	1.410 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

Leaves and stems of plants irrigated with 28 mg As V/L were approximately 40% red after 75 days of treatment (Figure 16e). Plants watered with 7 and 14 mg As V/L were between 5 and 15% red. The control was approximately 2% red at 75 days. Those plants watered with higher arsenic V levels displayed a greater red discoloration than the plants irrigated with the lower levels of arsenic V in the same period of time. Plants irrigated with 14, and 28 mg As V/L had a red discoloration after only 25 days.

It may be inferred from the linear regression that a strong correlation exists between the arsenic concentration in the shoot tissues and the arsenic V concentration in the nutrient solution (Figure 17). Concentration of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative shoot weight (significant), relative root weight, and relative plant height all peaked with the 7 mg As V/L treatment (Figure 18). At 28 mg As V/L the relative shoot weight and plant height were reduced by 10%, and the relative root weight was decreased by 22% (significant).

Data from basin wildrye measurements are presented in Table 44 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 52 (Appendix F).

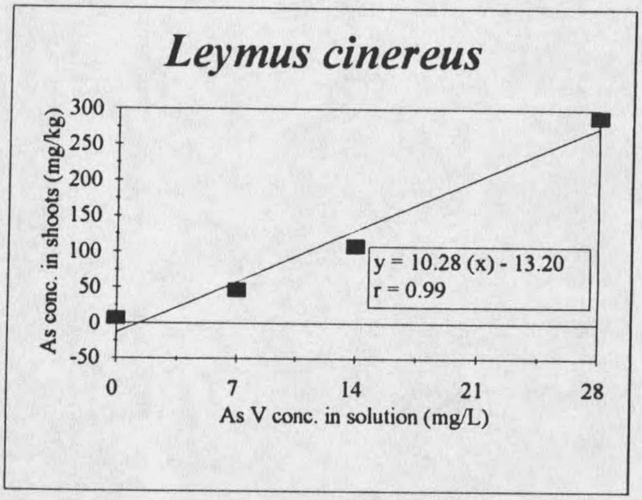

Figure 17. Mean arsenic concentrations in above ground plant tissues of *Leymus cinereus* irrigated with arsenic V.

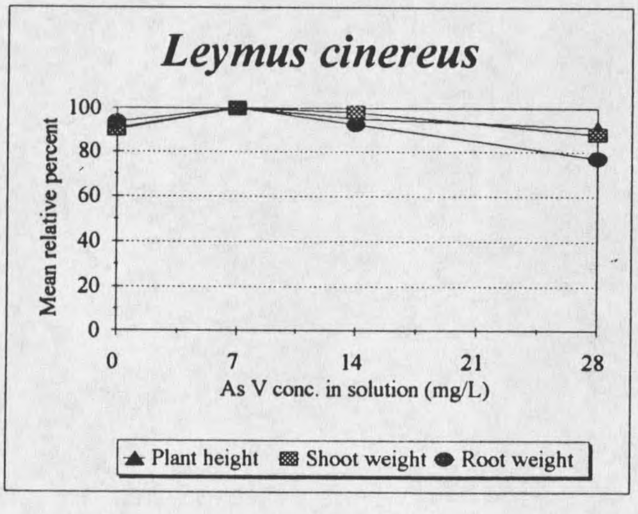

Figure 18. Mean relative percents of measured attributes from *Leymus cinereus* irrigated with arsenic V.

Festuca ovina duriuscula

Plant mortality was apparent at 50 days for 7 and 14 mg As V/L treatments (Figure 19a). At the end of the 75 day arsenic V treatment period the plants irrigated with 14 mg As V/L had an average survival rate of only 4.25 plants/pot. At 25, 50, and 75 days, the control plants were significantly taller than plants irrigated with any of the three arsenic V levels during the same time periods (Table 10.) In addition, the control produced a significant increase in shoot and root weight in contrast to the plants treated with any level of arsenic V. ANOVA tables are presented in Tables 32-34 (Appendix C).

The plants irrigated with 14 and 28 mg As V/L displayed poor vigor after 75 days (Figure 19b). Plants watered with 7 mg As V/L were in the acceptable/poor range. Plant vigor across all arsenic V concentrations, including the control, eventually declined. Vigor for the plants irrigated with 7, 14, and 28 mg As V/L decreased within 25 days. The control plants had a slight vigor reduction at 50 days.

Plant color across all four arsenic V concentrations degenerated over time (Figure 19c). Plants watered with the control changed color slightly. The 7 mg As V/L solution produced pale green plants, the 28 mg As V/L solution produced yellow plants, and the 14 mg As V/L solution produced plants in the pale green/yellow range.

The plants irrigated with all three arsenic V treatments displayed some dead areas after 75 days of treatment (Figure 19d). The control produced only tip burn, but plant burn across all arsenic V concentrations increased over time. Burn for all the arsenic V solutions was apparent at 25 days.

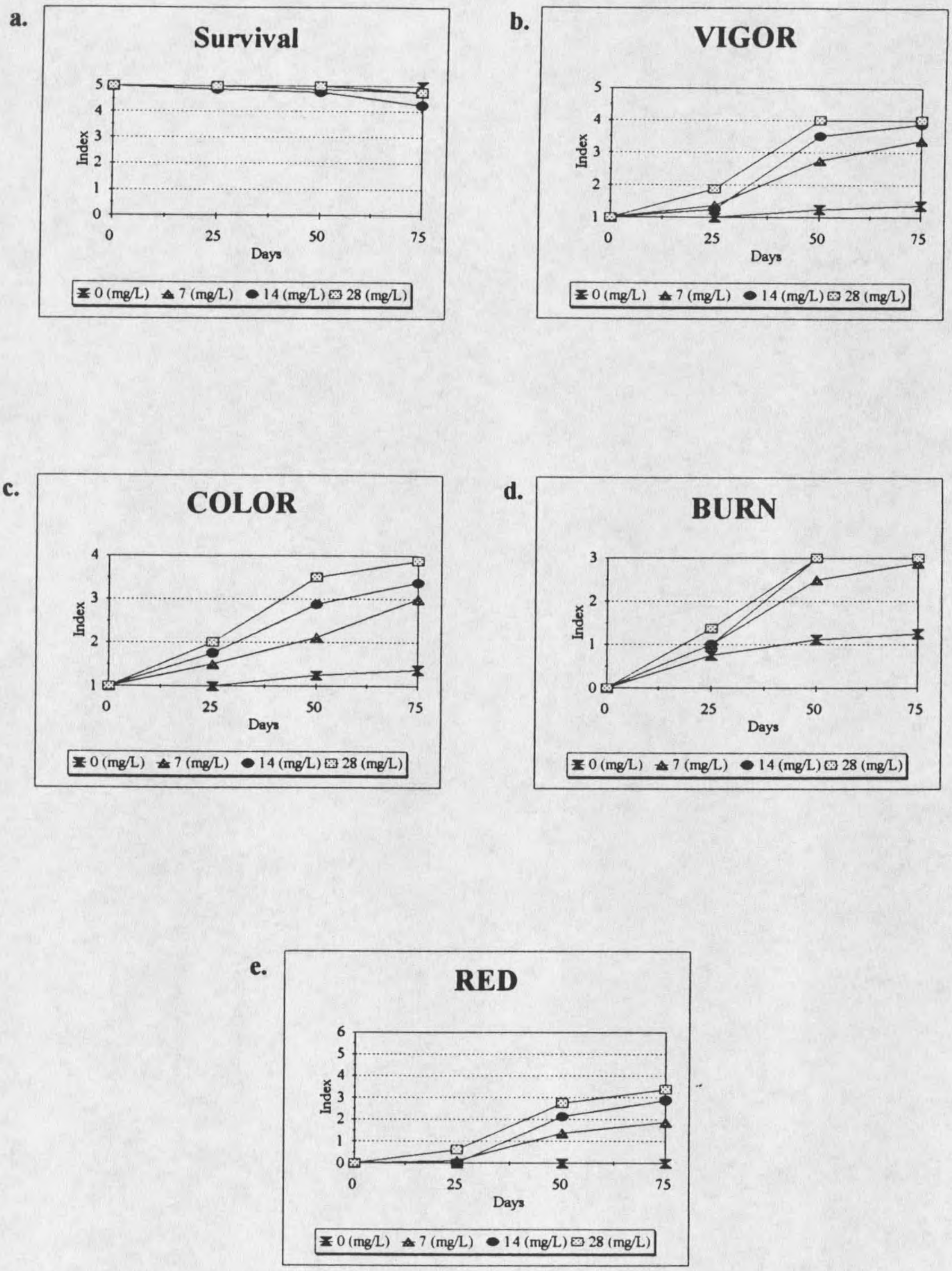

Figure 19. Observations of *Festuca ovina duriuscula* irrigated with four levels of arsenic V: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 10. Treatment means of *Festuca ovina duriuscula* grown in arsenic V.

Arsenic V (mg/L)	Mean plant height (cm)				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	9.69 a	14.09 b	18.26 b	19.16 b	1.275 b	1.179 b
7	8.59 a	10.76 a	11.95 a	12.17 a	0.986 a	0.955 a
14	9.51 a	11.91 a	13.04 a	13.34 a	0.987 a	0.971 a
28	9.86 a	12.24 a	12.39 a	12.69 a	1.014 a	0.927 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

Leaves and stems of plants irrigated with 28 mg As V/L were approximately 50% red after 75 days of treatment (Figure 19e). Plants watered with 14 mg As V/L were between 25 and 50% red. Plants irrigated with 7 mg As V/L were between 5 and 25% red. Those plants watered with higher arsenic V levels displayed a greater red discoloration than the plants irrigated with the lower levels of arsenic V in the same period of time.

It may be inferred from the linear regression that a strong correlation exists between the arsenic concentration in the shoot tissues and the arsenic V concentration in the nutrient solution (Figure 20). Concentrations of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative shoot weight, relative root weight, and relative plant height all decreased significantly at 7 mg As V/L (Figure 21). Relative shoot weight and relative root weight were decreased by 20%, while relative plant height was reduced by 38%.

Data from hard sheep fescue measurements are presented in Table 45 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 53 (Appendix F).

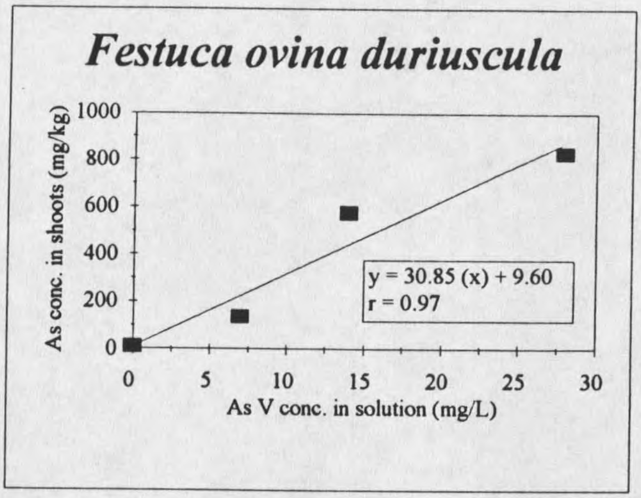

Figure 20. Mean arsenic concentrations in above ground plant tissues of *Festuca ovina duriuscula* irrigated with arsenic V.

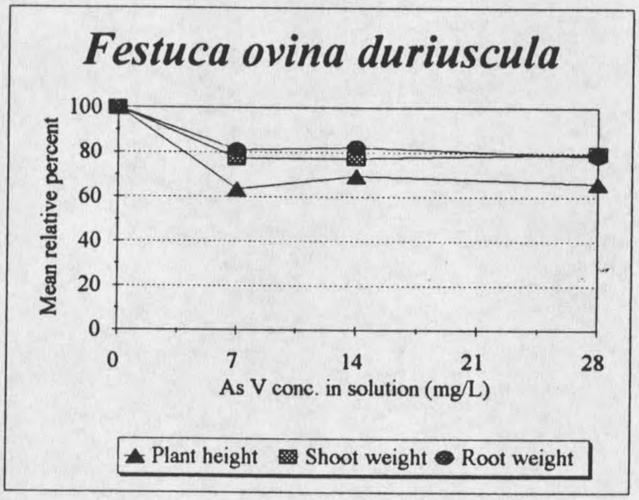

Figure 21. Mean relative percents of measured attributes from *Festuca ovina duriuscula* irrigated with arsenic V.

Poa compressa

Plant survival decreased at 25 days for 7 and 14 mg As V/L solutions (Figure 22a). At the end of the 75 day treatment period the plants watered with 14 mg As V/L had an average survival rate of only 4.4 plants/pot. Plants irrigated with 28 mg As V/L had an average survival rate of only 4 plants/pot. There was a significant increase in plant height at 25 days with 7 mg As V/L (Table 11). At 50 and 75 days there was a significant height reduction at 7 mg As V/L and a subsequent reduction at 14 mg As V/L. In addition, there was a significant reduction in both shoot and root weight with 7 mg V As/L. Results of the ANOVA are presented in Tables 35-37 (Appendix C).

The plants watered with 14 and 28 mg As V/L displayed poor vigor after 75 days (Figure 22b). Plants irrigated with 7 mg V As V/L had acceptable vigor. Plant vigor across all treatments, including the control, eventually declined. Vigor for the plants irrigated with 7, 14, and 28 mg As V/L decreased within 25 days. The control plants had a slight vigor reduction at 50 days.

Plant color across all four arsenic V concentrations changed over time (Figure 22c). The control plants displayed a minor color change, 7 and 14 mg As V/L solutions produced pale green plants, the plants watered with 28 mg As V/L turned yellow.

The plants irrigated with the 14 and 28 mg As V/L solution displayed some dead areas after 75 days of treatment (Figure 22d). The 7 mg As V/L solution produced marginal burn. The control plants burned on the tips only.

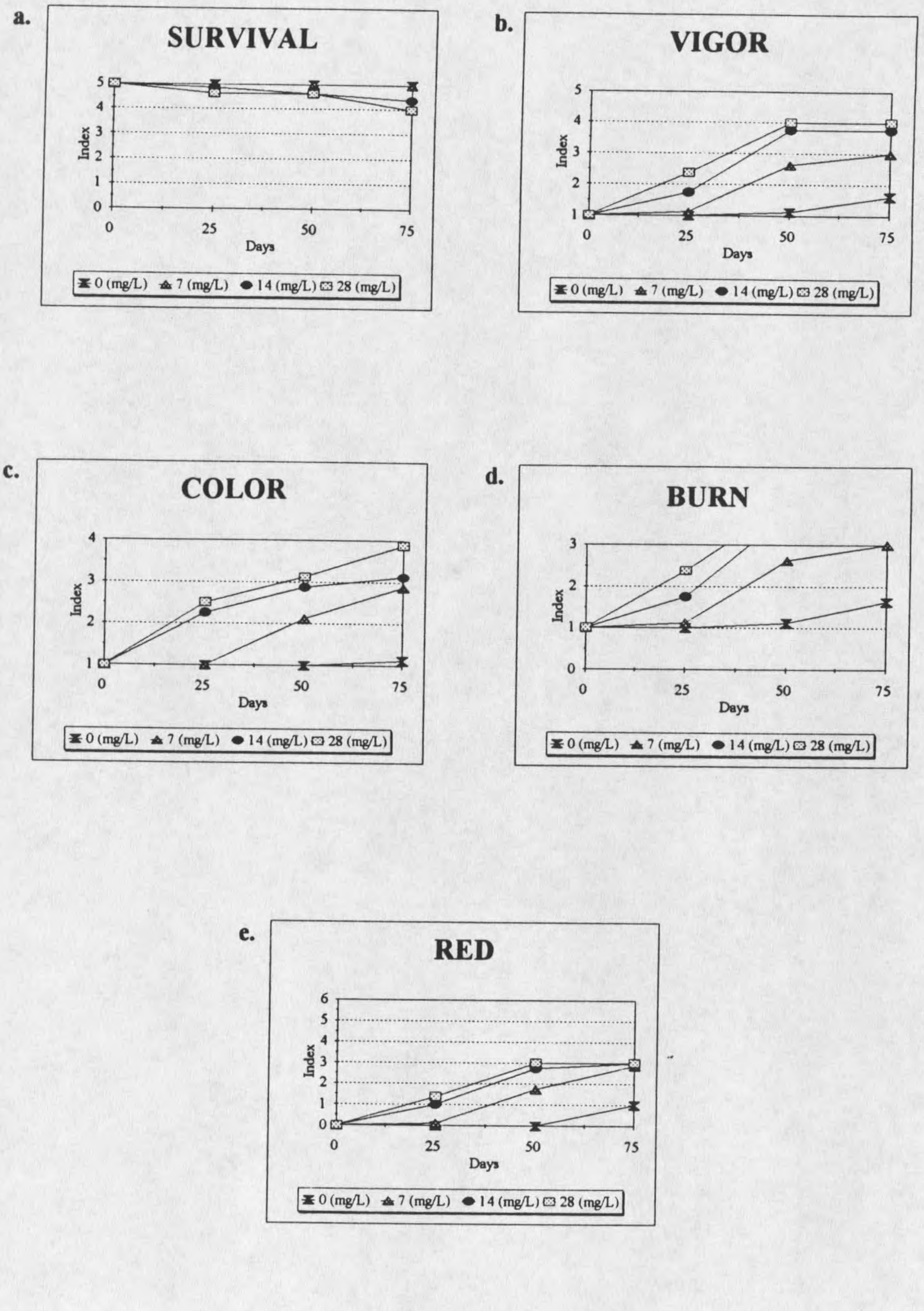

Figure 22. Observations of *Poa compressa* irrigated with four levels of arsenic V: survival (a), vigor (b), color (c), burn (d), and red (e).

Table 11. Treatment means of *Poa compressa* grown in arsenic V

Arsenic V (mg/L)	Mean plant height (cm)				Mean Shoot Weight (g)	Mean Root Weight (g)
	0 days	25 days	50 days	75 days		
0	4.85 a	22.66 b	41.36 c	44.58 c	1.555 b	1.230 b
7	4.59 a	16.34 a	22.70 b	23.54 b	1.150 a	1.021 a
14	4.38 a	11.58 a	14.52 a	15.55 a	1.133 a	1.035 a
28	4.51 a	12.95 a	11.41 a	11.96 a	1.063 a	1.005 a

* Means within each column followed by the same letter are not statistically different at the 5% level as determined by ANOVA or the LSD test of significance.

Leaves and stems of plants irrigated with all arsenic V concentrations were between 25-50% red after 75 days of treatment (Figure 22e). The controls were slightly red after 75 days. Those plants watered with higher arsenic V levels displayed a greater red discoloration than the plants irrigated with the lower levels of arsenic V in the same period of time.

It may be inferred from the linear regression that there was a strong correlation between the arsenic concentration in the shoot tissues and the arsenic V concentration in the nutrient solution (Figure 23). Concentration of arsenic in dry shoot tissues are listed in Table 38 (Appendix D). Relative plant height, relative shoot weight, and relative root weight decreased significantly with increasing arsenic V concentration in the nutrient solution (Figure 24). Relative root weight was reduced by 20%, relative shoot weight by 30%, and relative plant height was decreased by 75% when treated with 28 mg As V/L.

Data from Canada bluegrass measurements are presented in Table 46 (Appendix E). Arsenic toxicity symptoms were observed in the plants four times during the experiment and are presented in Table 54 (Appendix F).

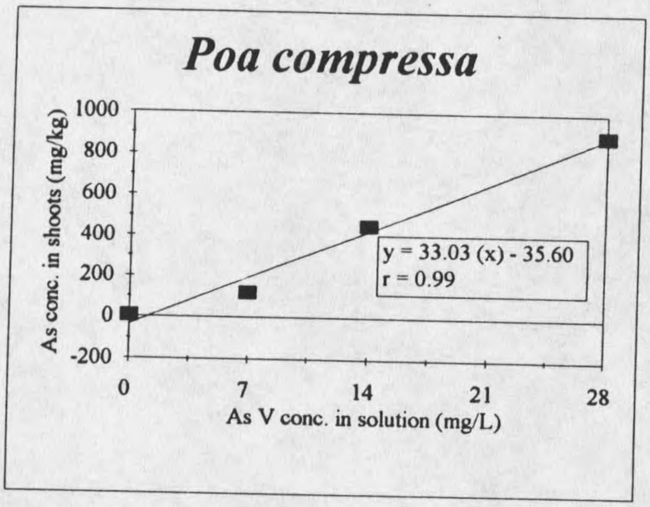

Figure 23. Mean arsenic concentrations in above ground plant tissues of *Poa compressa* irrigated with arsenic V.

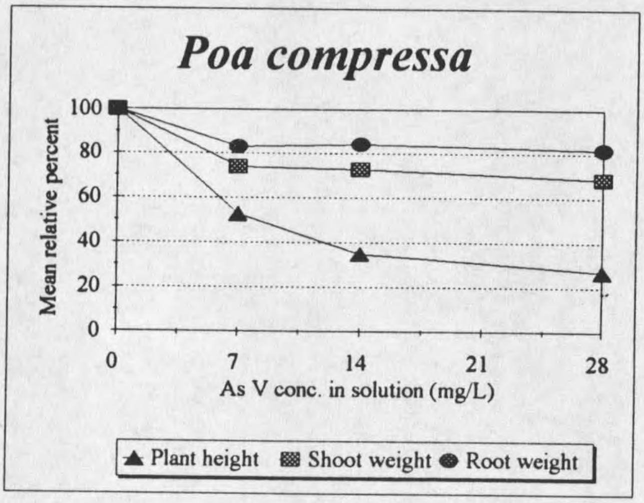

Figure 24. Mean relative percents of measured attributes from *Poa compressa* irrigated with arsenic V.

CONCLUSIONS

One possible reclamation alternative is the use of naturally occurring metal-tolerant plant populations to stabilize mine wastes and soils containing arsenic. To successfully revegetate a site with this method, knowledge of arsenic III and V toxicities to specific grasses are needed.

Porter and Peterson (1977) demonstrated that 0.05 mg soluble As III/L resulted in depressed growth of plants belonging to the *Agrostis* genus. Liebig et al. (1959) showed that concentrations of 5 mg soluble As III/L caused a very marked depression in the top and root growth of citrus plants. With the exception of *Poa compressa*, the As III levels used in this trial had little effect on the growth and productivity of the four grass species studied, even though the concentrations were in the range of those tested by other investigators. It is possible that the grasses tested in this experiment were more tolerant to As III than citrus plants or plants belonging to the *Agrostis* genus. Once thought to be an explanation for the lack of arsenic III toxicity was the oxidation of arsenite to arsenate in the sand and/or plants. This would have been the equivalent of irrigating with low levels of arsenic V, levels of that oxidation state too low to severely affect grass growth and productivity. Cherry et al. (1979) analyzed a series of arsenic solutions at various pH levels to determine the oxidation state stability over a period of 2.5 months. The investigators found that although oxidation of arsenic III did occur, the process was so slow that only 5-7% of the arsenic III converted to arsenic V after 2.5 months. Johnson and Pilson (1975) were also able to show that the oxidation of arsenite occurs at a very slow rate (ie. 0.023 moles As III oxidized to As V/L/yr in seawater). The oxidation of arsenic III can not explain the lack of arsenic III toxicity because the reaction rate was too slow and the amount of arsenic converted to arsenic V was not substantial enough to produce a decrease in the toxicity of the arsenic III treatment.

Arsenic, when supplied in small amounts, has been shown to stimulate growth (Albert and Arndt 1931, Liebig et al. 1959, and Stewart and Smith 1922). In this experiment, the shoot growth of *Leymus cinereus* was stimulated with concentrations of 7 mg As V/L.

The yield-limiting arsenic V concentration in above ground tissues was 423 mg/kg in *Pascopyrum smithii*, and 289 mg/kg in *Leymus cinereus*. The critical level for *Festuca ovina duriuscula* was 136 mg/kg in the leaves and shoots, and 122 mg/kg in *Poa compressa*. These critical levels were much lower than the levels reported by Deuel and Swoboda (1972), Davis et al. (1978), and NAS (1977) for cotton, barley, and fruit trees respectively. Chino (1981) found the critical levels in rice which were similar to some of the critical levels found in this study. In rice tops the critical level ranged from 20 to 100 mg As/kg, and in rice roots it was 1,000 mg As/kg. These arsenic concentrations are presented as arsenic concentrations in the above ground materials, but as this experiment progressed and plants wilted it became impossible to completely prevent solution contact with the shoot and leaf material. *Festuca ovina duriuscula* and *Poa compressa* were strongly affected by the As V treatments, as there was a notable reduction in all the measured and observed parameters. These two grass species displayed a similar absence of As tolerance and reacted in the same manner to the treatments..

There was no direct comparison of arsenic III and V toxicities on the four grass species treated. Although the results of the arsenic V treatments had more severe effects on the growth and productivity of the grasses, it can not be assumed that arsenic V is more toxic to these grass species than arsenic III. The concentrations used for the different states of arsenic were different.

Results of all the collected data suggest that, under the provided greenhouse conditions, *Leymus cinereus* may be the most tolerant of all grass species tested to both states of arsenic in the concentrations supplied. *Pascopyrum smithii* appeared to be next in tolerance to both arsenic III and V, followed by *Festuca ovina duriuscula*. *Poa compressa* appeared to be the most sensitive of the grass species to both arsenic III and V.

In this study, the four grasses tested exhibited various levels of arsenic tolerance, some species were very sensitive to arsenic while other species were more tolerant. The order of species tolerance was the same for arsenic III and arsenic V treatments. These differences in arsenic tolerance were similar to those seen in studies conducted on crop/citrus species by other investigators (Cooper et al. 1931, Clements and Munson 1947, and Woolson 1973). *Leymus cinereus* has been observed growing on sites containing elevated arsenic V concentrations, and the evidence provided by this investigation supports the use of *Leymus cinereus* for rehabilitation of lands contaminated with arsenic.

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APPENDICES

APPENDIX A

Nomenclature of plant species cited in the text

Table 12. Nomenclature of plant species cited in the text*.

Common Name	Scientific Name
alfalfa	*Medicago sativa* L.
annual bluegrass	*Poa annua* L.
barley	*Hordeum vulgare* L.
basin wildrye	*Leymus cinereus* (Scribner & Merrill) Love
bermudagrass	*Cynodon dactylon* (L.) Pers
bromegrass	*Bromus* spp. L.
bush bean	*Phaseolus vulgaris* L.
cabbage	*Brassica deracea* L.
Canada bluegrass	*Poa compressa* L.
clover	*Trifolium* L.
colonial bentgrass	*Agrostis tenuis* Sibth.
cotton	*Gossypium hirsutum* L.
creeping bentgrass	*Agrostis palustris* L.
crested wheatgrass	*Agropyron cristatum* (L.) Gaertner
green bean	*Phaseolus vulgaris* L.
hard sheep fescue	*Festuca ovina duriuscula* L.
Italian ryegrass	*Lolium multiflorum* Lam.
Kentucky bluegrass	*Poa pratensis* L.
lima bean	*Phaseolus limensis* Macfady.
little bluestem	*Andropognon scoparius* Michx.
meadow fescue	*Festuca elatior* L.
oat	*Avena sativa* L.
orchardgrass	*Dactylis glomerata* L.
quackgrass	*Elytrigia repens* (L.) Nevski
radish	*Raphanus sativus* L.
redtop	*Agrostis gigantea* L.
rice	*Oryza sativa* L.
rye	*Secale cereale* L.
soybean	*Glycine max* (L.) Merrill
spinach	*Spinacia oleracea* L.
sudangrass	*Sorghum sudanense* (Piper) Stapf.

Table 12. - Continued.

Common Name	Scientific Name
timothy	*Phleum pratense* L.
tomato	*Lycopersicon esculentum* (L.) Karst ex Farw.
vetch	*Vicia* spp. L.
western wheatgrass	*Pascopyrum smithii* (Rydberg) Love

*Nomenclature follows Rumley and Lavin (1991), for grasses, Hitchcock and Cronquist (1976) for native forbs and shrubs, and Baily and Baily (1976) for crop species.

APPENDIX B

Skewness and Kurtosis Values

Table 13. Skewness and kurtosis values for all measured variables.

Measured Variable	Oxidation State (III or V)	Grass Species	Skewness (5% level)	Kurtosis (5% level)	Degrees of Freedom
Height (Day 0)	III	Pa sm	0.6619	4.675	31
Height (Day 25)	III	Pa sm	0.7153	4.592	31
Height (Day 50)	III	Pa sm	0.6764	5.025	31
Height (Day 75)	III	Pa sm	0.8536	4.694	31
Shoot Weight	III	Pa sm	0.6794	4.254	31
Root Weight	III	Pa sm	0.6618	5.006	31
Height (Day 0)	III	Le ci	0.7213	4.613	31
Height (Day 25)	III	Le ci	0.6736	4.578	31
Height (Day 50)	III	Le ci	0.7166	4.421	31
Height (Day 75)	III	Le ci	0.7156	4.348	31
Shoot Weight	III	Le ci	0.7288	4.738	31
Root Weight	III	Le ci	0.6853	4.856	31
Height (Day 0)	III	Fe ov	0.8408	4.406	31
Height (Day 25)	III	Fe ov	0.7137	4.487	31
Height (Day 50)	III	Fe ov	0.8044	4.202	31
Height (Day 75)	III	Fe ov	0.7322	4.262	31
Shoot Weight	III	Fe ov	0.6672	4.180	31
Root Weight	III	Fe ov	0.7835	4.845	31
Height (Day 0)	III	Po co	0.6987	5.958	31
Height (Day 25)	III	Po co	0.6972	4.116	31
Height (Day 50)	III	Po co	0.7452	4.165	31
Height (Day 75)	III	Po co	0.7906	4.212	31
Shoot Weight	III	Po co	0.7955	5.732	31
Root Weight	III	Poco	0.9290	5.880	31
Height (Day 0)	V	Pa sm	0.6866	5.025	31
Height (Day 25)	V	Pa sm	0.7455	4.867	31
Height (Day 50)	V	Pa sm	0.6720	4.351	31
Height (Day 75)	V	Pa sm	0.8350	4.681	31
Shoot Weight	V	Pa sm	0.9730	4.888	31
Root Weight	V	Pa sm	0.6971	4.296	31
Height (Day 0)	V	Le ci	0.8093	5.138	31
Height (Day 25)	V	Le ci	0.7353	4.937	31
Height (Day 50)	V	Le ci	0.8159	4.711	31
Height (Day 75)	V	Le ci	0.6924	4.887	31
Shoot Weight	V	Le ci	0.7728	4.733	31
Root Weight	V	Le ci	0.6752	5.930	31
Height (Day 0)	V	Fe ov	0.7404	4.875	31
Height (Day 25)	V	Fe ov	0.6979	4.917	31
Height (Day 50)	V	Fe ov	0.6810	4.855	31
Height (Day 75)	V	Fe ov	0.7114	4.667	31
Shoot Weight	V	Fe ov	0.7407	4.371	31
Root Weight	V	Fe ov	0.6819	4.165	31
Height (Day 0)	V	Po co	0.9938	4.105	31
Height (Day 25)	V	Po co	0.6825	4.892	31
Height (Day 50)	V	Po co	0.7209	4.720	31
Height (Day 75)	V	Po co	0.7279	4.173	31
Shoot Weight	V	Po co	0.7114	4.617	31
Root Weight	V	Po co	0.9605	5.812	31

* Significance determined from Reynarowych 1978.

APPENDIX C

ANOVA Tables

Table 14. Analysis of variance for arsenic III concentration on plant height of *Pascopyrum smithii.*

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	39.1330	13.0440	1.1000	0.3707
Block	7	149.2400	21.3200		
Residual	21	248.7700	11.8460		
Total	31	437.1400			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	127.9000	42.6320	1.6500	0.2073
Block	7	72.9290	10.4180		
Residual	21	541.3000	25.7760		
Total	31	742.1300			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	73.9730	24.6580	1.2500	0.3161
Block	7	111.3700	15.9100		
Residual	21	413.4500	19.6880		
Total	31	598.7900			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	129.1500	43.0500	2.0500	0.1374
Block	7	88.6720	12.6670		
Residual	21	440.6100	20.9820		
Total	31	658.4300			

Table 15. Analysis of variance for arsenic III concentration on shoot weight of *Pascopyrum smithii*.

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.0973	0.0324	0.6800	0.5736
Block	7	0.1631	0.0233		
Residual	21	1.0000	0.0476		
Total	31	1.2603			

Table 16. Analysis of variance for arsenic III concentration on root weight of *Pascopyrum smithii*.

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.1064	0.0355	1.3400	0.2885
Block	7	0.2451	0.0350		
Residual	21	0.5563	0.0265		
Total	31	0.9078			

Table 17. Analysis of variance for arsenic III concentration on plant height of *Leymus cinereus*.

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	31.2530	10.4180	0.5800	0.6317
Block	7	358.7000	51.2430		
Residual	21	374.2000	17.8190		
Total	31	764.1500			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	82.5440	27.5150	0.8800	0.4667
Block	7	381.5900	54.5130		
Residual	21	655.5600	31.2170		
Total	31	1119.7000			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	87.6910	29.2300	1.0600	0.3851
Block	7	376.2400	53.7490		
Residual	21	576.3900	27.4470		
Total	31	1040.3000			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	69.5730	23.1910	0.7000	0.5631
Block	7	317.9300	45.4190		
Residual	21	696.6600	33.1740		
Total	31	1084.2000			

Table 18. Analysis of variance for arsenic III concentration on shoot weight of *Leymus cinereus*.

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.0522	0.0174	0.4500	0.7210
Block	7	0.2036	0.0291		
Residual	21	0.8145	0.0388		
Total	31	1.0703			

Table 19. Analysis of variance for arsenic III concentration on root weight of *Leymus cinereus*.

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.2516	0.0839	1.1000	0.3706
Block	7	0.1692	0.0242		
Residual	21	1.5990	0.0761		
Total	31	2.0198			

Table 20. Analysis of variance for arsenic III concentration on plant height of *Festuca ovina duriuscula.*

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	11.0770	3.6925	1.2700	0.3112
Block	7	42.7150	6.1021		
Residual	21	61.1880	2.9137		
Total	31	114.9800			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	1.7059	0.5687	0.0700	0.9744
Block	7	33.2770	4.7539		
Residual	21	166.1100	7.9098		
Total	31	201.0900			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	33.2480	11.0830	1.0700	0.3834
Block	7	48.0820	6.8689		
Residual	21	217.6600	10.3650		
Total	31	298.9900			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	40.5080	13.5030	0.9000	0.4594
Block	7	75.3070	10.7580		
Residual	21	316.2800	15.0610		
Total	31	432.1000			

Table 21. Analysis of variance for arsenic III concentration on shoot weight of *Festuca ovina duriuscula.*

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.3647	0.1216	2.8300	0.0633
Block	7	0.2855	0.0408		
Residual	21	0.9028	0.0430		
Total	31	1.5529			

Table 22. Analysis of variance for arsenic III concentration on root weight of *Festuca ovina duriuscula.*

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.2580	0.0860	2.1500	0.1245
Block	7	0.2518	0.0360		
Residual	21	0.8406	0.0400		
Total	31	1.3503			

Table 23. Analysis of variance for arsenic III concentration on plant height of *Poa compressa*.

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.4638	0.1546	0.2400	0.8709
Block	7	7.9337	1.1334		
Residual	21	13.8110	0.6577		
Total	31	22.2090			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	37.9810	12.6600	0.3000	0.8250
Block	7	234.0600	33.4380		
Residual	21	886.1900	42.2000		
Total	31	1158.2000			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	506.0200	168.6700	1.8800	0.1633
Block	7	203.0400	29.0060		
Residual	21	1880.3000	89.5360		
Total	31	2589.3000			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	829.7500	276.5800	3.5200	0.0330
Block	7	191.2500	27.3210		
Residual	21	1652.3000	78.6800		
Total	31	2673.3000			

Table 24. Analysis of variance for arsenic III concentration on shoot weight of *Poa compressa.*

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.2978	0.0993	2.1500	0.1242
Block	7	0.5162	0.0737		
Residual	21	0.9695	0.0462		
Total	31	1.7834			

Table 25. Analysis of variance for arsenic III concentration on root weight of *Poa compressa.*

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.1785	0.0595	1.7900	0.1807
Block	7	0.3530	0.0504		
Residual	21	0.6996	0.0333		
Total	31	1.2312			

Table 26. Analysis of variance for arsenic V concentration on plant height of *Pascopyrum smithii.*

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	26.3010	8.7671	0.8500	0.4846
Block	7	83.8390	11.9770		
Residual	21	217.8500	10.3740		
Total	31	327.9900			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	149.0100	49.6710	2.6000	0.0793
Block	7	200.7400	28.6770		
Residual	21	401.4800	19.1180		
Total	31	751.2300			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	253.5000	84.5010	4.6900	0.0116
Block	7	182.8100	26.1160		
Residual	21	378.1300	18.0060		
Total	31	814.4500			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	305.0300	101.6800	5.9000	0.0044
Block	7	221.0300	31.5760		
Residual	21	361.7500	17.2260		
Total	31	887.8100			

Table 27. Analysis of variance for arsenic V concentration on shoot weight of *Pascopyrum smithii*.

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	1.1307	0.3769	14.4900	0.0000
Block	7	0.0517	0.0738		
Residual	21	0.5464	0.0260		
Total	31	1.7287			

Table 28. Analysis of variance for arsenic V concentration on root weight of *Pascopyrum smithii*.

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.6472	0.2157	16.0900	0.0000
Block	7	0.1015	0.0145		
Residual	21	0.2816	0.0134		
Total	31	1.0303			

Table 29. Analysis of variance for arsenic V concentration on plant height of *Leymus cinereus*.

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	52.6830	17.5610	0.8900	0.4648
Block	7	247.8800	35.4120		
Residual	21	416.5700	19.8370		
Total	31	717.1300			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	67.2460	22.4150	0.8000	0.5103
Block	7	230.3600	32.9080		
Residual	21	591.9700	28.1890		
Total	31	889.5800			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	123.4700	41.1560	1.7100	0.1957
Block	7	274.4300	39.2040		
Residual	21	505.6800	24.0800		
Total	31	903.5800			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	127.6600	42.5530	2.1200	0.1280
Block	7	307.7900	43.9700		
Residual	21	421.4100	20.0670		
Total	31	856.8600			

Table 30. Analysis of variance for arsenic V concentration on shoot weight of *Leymus cinereus*.

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.2180	0.0727	4.4000	0.0150
Block	7	0.2300	0.0329		
Residual	21	0.3469	0.0165		
Total	31	0.7949			

Table 31. Analysis of variance for arsenic V concentration on root weight of *Leymus cinereus*.

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.7652	0.2551	7.6000	0.0013
Block	7	0.3099	0.0443		
Residual	21	0.7050	0.0336		
Total	31	1.7801			

Table 32. Analysis of variance for arsenic V concentration on plant height of *Festuca ovina duriuscula.*

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	7.7500	2.5833	1.1100	0.3669
Block	7	30.6900	4.3843		
Residual	21	48.8350	2.3255		
Total	31	87.2750			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	45.6250	15.2080	6.2200	0.0034
Block	7	79.8350	11.4050		
Residual	21	51.3600	2.4457		
Total	31	176.8200			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	206.9200	68.9740	23.9700	0.0000
Block	7	26.8750	3.8392		
Residual	21	60.4320	2.8777		
Total	31	294.2300			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	253.4400	84.4790	18.1300	0.0000
Block	7	61.3450	8.7635		
Residual	21	97.8570	4.6598		
Total	31	412.6400			

Table 33. Analysis of variance for arsenic V concentration on shoot weight of *Festuca ovina duriuscula.*

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.4730	0.1577	7.7500	0.0011
Block	7	0.1167	0.0167		
Residual	21	0.4271	0.0203		
Total	31	1.0168			

Table 34. Analysis of variance for arsenic V concentration on root weight of *Festuca ovina duriuscula.*

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.3191	0.1064	16.9700	0.0000
Block	7	0.1365	0.0195		
Residual	21	0.1317	0.0063		
Total	31	0.5873			

Table 35. Analysis of variance for arsenic V concentration on plant height of *Poa compressa.*

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 0)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.9563	0.3188	1.6200	0.2141
Block	7	1.6087	0.2298		
Residual	21	4.1237	0.1964		
Total	31	6.6888			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 25)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	586.6400	195.5500	7.8500	0.0011
Block	7	86.4990	12.3570		
Residual	21	1196.5000			
Total	31				

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 50)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	4338.9000	1446.3000	63.5600	0.0000
Block	7	102.5500	14.6500		
Residual	21	477.8700	22.7560		
Total	31	4919.4000			

Model structure: CONCENTRATION
For variable: MEAN HEIGHT (DAY 75)

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	5118.5000	1708.2000	64.6200	0.0000
Block	7	62.1090	8.8727		
Residual	21	554.4200	26.4010		
Total	31	5735.0000			

Table 36. Analysis of variance for arsenic V concentration on shoot weight of *Poa compressa.*

Model structure: CONCENTRATION
For variable: MEAN SHOOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	1.1934	0.3978	21.2100	0.0000
Block	7	0.0201	0.0287		
Residual	21	0.3939	0.0188		
Total	31	1.6074			

Table 37. Analysis of variance for arsenic V concentration on root weight of *Poa compressa.*

Model structure: CONCENTRATION
For variable: MEAN ROOT WEIGHT

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	3	0.2675	0.0892	3.4800	0.0339
Block	7	0.0234	0.0033		
Residual	21	0.5374	0.0256		
Total	31	0.8283			

APPENDIX D

Arsenic Concentrations

Table 38. Concentrations of arsenic in dried shoot tissues.

Arsenic in solution (mg/L)	Oxidation state (III or V)	Grass species	Arsenic in vegetation (mg/kg)		
			Run #1	Run #2	Run average
0	III	Pa sm	3.0	2.0	2.5
1	III	Pa sm	10.0	6.0	8.0
2	III	Pa sm	25.0	21.0	23.0
5	III	Pa sm	67.0	46.0	57.0
0	III	Le ci	11.0	14.0	13.0
1	III	Le ci	17.0	29.0	23.0
2	III	Le ci	38.0	52.0	45.0
5	III	Le ci	57.0	52.0	55.0
0	III	Fe ov	20.0	22.0	21.0
1	III	Fe ov	21.0	26.0	24.0
2	III	Fe ov	43.0	45.0	44.0
5	III	Fe ov	46.0	46.0	46.0
0	III	Po co	18.0	15.0	17.0
1	III	Po co	22.0	25.0	24.0
2	III	Po co	39.0	41.0	40.0
5	III	Po co	220.0	180.0	200.0
0	V	Pa sm	3.0	2.0	2.5
7	V	Pa sm	85.0	58.0	72.0
14	V	Pa sm	85.0	78.0	82.0
28	V	Pa sm	530.0	315.0	423.0
0	V	Le ci	9.0	5.0	7.0
7	V	Le ci	49.0	44.0	47.0
14	V	Le ci	126.0	90.0	108.0
28	V	Le ci	326.0	251.0	289.0
0	V	Fe ov	10.0	10.0	10.0
7	V	Fe ov	144.0	128.0	136.0
14	V	Fe ov	550.0	600.0	575.0
28	V	Fe ov	1,180.0	478.0	829.0
0	V	Po co	8.0	6.0	7.0
7	V	Po co	---	122.0	122.0
14	V	Po co	500.0	404.0	452.0
28	V	Po co	910.0	880.0	895.0

APPENDIX E

Measurements

Table 39. Measurements of *Pascopyrum smithii* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	24.4	43.7	50.5	51.6	1.9467	1.4595
2	0	22.5	39.3	44.7	47.9	1.6759	1.4019
3	0	17.5	38.0	42.8	51.0	2.3802	1.9325
4	0	25.5	42.3	45.0	46.3	2.0523	1.5236
5	0	27.2	39.7	40.9	42.1	1.6047	1.5026
6	0	25.7	42.7	46.4	48.3	1.8900	1.6070
7	0	23.3	44.3	49.6	50.8	1.7652	1.5281
8	0	24.6	36.1	39.1	39.8	1.7608	1.4927
1	1	20.6	32.8	39.7	40.7	1.7007	1.5608
2	1	23.2	40.1	46.4	49.0	1.9443	1.5221
3	1	19.2	34.5	42.4	43.5	1.6766	1.4667
4	1	24.3	40.5	46.2	45.6	1.7049	1.5649
5	1	23.1	36.9	43.0	46.5	1.6577	1.6469
6	1	23.0	44.6	46.7	47.9	1.8314	1.5860
7	1	24.5	41.9	43.2	44.0	1.7374	1.5190
8	1	23.0	35.1	38.5	39.6	1.6693	1.4328
1	2	27.3	48.7	50.3	51.5	2.1784	1.6987
2	2	20.2	45.0	48.2	49.6	1.6553	1.4076
3	2	26.0	42.0	44.3	47.0	1.9444	1.5388
4	2	18.7	35.8	42.5	43.2	1.4632	1.0894
5	2	28.9	39.7	41.7	47.1	1.6716	1.3089
6	2	27.0	40.9	42.5	43.3	1.8541	1.5857
7	2	28.0	42.6	44.2	44.8	1.8081	1.5291
8	2	25.5	48.3	50.6	53.4	1.6423	1.3371
1	5	23.2	41.7	46.8	48.1	1.9805	1.4652
2	5	18.4	37.6	46.2	47.3	1.8940	1.4834
3	5	19.5	31.0	34.1	37.0	1.3751	1.2876
4	5	23.3	42.2	43.8	44.3	1.7827	1.0101
5	5	31.3	45.1	45.6	43.9	2.0177	1.7625
6	5	19.8	31.8	35.6	36.6	1.5478	1.5360
7	5	14.8	28.9	33.6	34.8	1.7735	1.3994
8	5	29.3	45.2	47.2	48.8	1.7514	1.4772

Table 40. Measurements of *Leymus cinereus* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	29.8	50.3	55.8	58.9	1.7135	1.9839
2	0	30.7	56.5	58.7	60.1	1.5969	1.3595
3	0	19.8	36.2	43.5	47.2	1.5082	1.6299
4	0	22.6	46.1	47.1	39.4	1.5703	1.3537
5	0	34.0	48.9	49.5	50.6	1.4571	1.7757
6	0	28.2	41.0	43.2	45.1	1.3561	1.6288
7	0	27.1	50.7	53.0	54.6	1.6019	1.6354
8	0	36.7	45.5	53.6	56.7	1.6657	1.5834
1	1	25.0	46.0	47.2	49.3	1.5987	1.7978
2	1	27.6	34.7	35.8	37.3	1.4056	1.9416
3	1	25.4	43.7	44.7	45.5	1.4216	1.4301
4	1	18.1	36.2	45.7	48.6	1.5195	1.7515
5	1	20.9	43.4	44.1	45.6	1.5839	1.5716
6	1	26.7	40.7	42.8	46.4	1.5362	1.7809
7	I	31.0	50.5	52.5	53.5	1.6022	2.0090
8	1	36.7	48.2	55.0	55.7	1.7549	1.7864
1	2	17.6	38.7	46.8	47.7	1.6600	1.6885
2	2	25.5	46.7	52.6	53.0	1.6684	1.7124
3	2	19.5	38.2	41.9	43.4	1.4839	1.4530
4	2	27.5	41.9	48.4	49.1	1.4867	1.3935
5	2	33.5	47.2	45.6	47.9	1.6010	1.8067
6	2	27.5	44.5	45.0	45.3	1.0541	1.1460
7	2	29.9	59.2	59.7	60.1	1.4505	1.8320
8	2	27.8	39.2	39.7	40.7	1.3959	1.2577
1	5	23.5	41.8	45.6	46.9	1.0334	1.0263
2	5	25.9	45.5	47.8	48.4	1.5455	1.8314
3	5	25.2	45.9	46.9	47.1	1.5944	1.8564
4	5	31.1	53.0	55.2	56.3	1.8545	1.9564
5	5	26.5	37.8	38.9	43.1	1.3818	1.5062
6	5	25.1	43.8	45.4	47.1	1.6789	1.7673
7	5	28.4	53.1	53.6	53.5	1.6165	1.7963
8	5	34.5	51.1	53.0	56.4	1.9556	2.0885

Table 41. Measurements of *Festuca ovina duriuscula* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	9.8	14.3	21.0	22.7	1.4084	1.2015
2	0	9.7	17.0	18.9	20.1	1.2473	1.0897
3	0	7.4	12.2	17.6	20.5	1.3672	1.2245
4	0	9.9	14.8	16.8	18.8	1.3434	1.2878
5	0	8.0	11.9	10.9	11.8	1.2756	1.1941
6	0	11.1	13.4	15.0	16.6	1.3550	1.2856
7	0	9.9	13.7	15.3	16.0	1.5383	1.6093
8	0	7.8	10.3	15.0	16.5	1.0364	0.9281
1	1	6.8	12.8	18.9	21.2	1.2575	1.0272
2	1	9.6	12.7	21.1	22.5	1.8727	1.5729
3	1	7.6	11.7	14.9	17.1	1.4565	1.2901
4	1	7.0	11.1	15.8	17.2	1.1239	1.0521
5	1	8.6	10.4	11.6	9.6	1.1284	1.1007
6	1	12.5	18.4	19.4	20.4	1.5969	1.4269
7	1	9.7	17.1	20.5	22.1	1.3567	1.1077
8	1	10.3	13.8	14.9	16.2	1.3245	1.1301
1	2	10.0	13.3	15.9	18.1	1.3514	1.2188
2	2	11.9	15.0	18.8	19.7	1.2054	1.0404
3	2	6.3	9.3	11.2	12.1	1.6075	1.6041
4	2	4.9	8.9	10.3	11.0	0.9890	0.9219
5	2	11.3	16.5	20.5	24.1	1.5193	1.1539
6	2	10.5	14.2	15.2	15.7	1.2333	1.0084
7	2	7.2	8.5	12.1	13.1	1.7489	1.5957
8	2	10.9	17.6	18.7	19.3	1.2764	1.2807
1	5	8.2	9.6	10.7	11.7	0.9563	0.8787
2	5	8.9	12.8	14.4	16.6	1.3079	1.0217
3	5	8.9	12.9	13.9	14.3	1.1175	1.0480
4	5	12.2	16.2	16.5	17.2	1.2311	1.1764
5	5	10.7	13.4	14.5	12.3	0.9092	0.9118
6	5	12.3	13.8	14.9	19.1	1.2886	1.1845
7	5	10.6	14.3	14.8	15.7	0.9609	0.9208
8	5	11.9	13.6	15.7	16.4	1.1823	0.9869

Table 42. Measurements of *Poa compressa* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	4.8	11.2	25.7	33.3	1.4126	1.2300
2	0	4.4	21.9	38.0	42.6	1.3421	1.0168
3	0	4.7	23.7	43.2	46.8	1.4523	1.2012
4	0	5.8	24.0	35.7	47.6	1.5644	1.2408
5	0	4.4	13.1	18.2	23.3	1.4408	1.3427
6	0	4.8	18.4	36.4	39.6	1.4510	1.1359
7	0	4.5	35.0	47.3	48.5	1.6578	1.3031
8	0	4.8	10.5	27.0	28.8	1.1781	1.0164
1	1	5.5	20.7	43.5	46.7	1.9872	1.6155
2	1	2.2	7.7	22.6	24.8	1.5925	1.3743
3	1	3.4	13.7	29.6	36.3	1.4992	1.1372
4	1	5.4	28.2	32.3	29.4	1.1034	0.9113
5	1	4.3	22.4	31.6	36.0	1.4755	1.3135
6	1	4.9	15.5	25.9	32.7	1.3894	1.1551
7	1	5.0	21.6	37.9	42.6	1.5076	1.2702
8	1	5.5	27.1	42.6	43.8	1.2342	0.9119
1	2	5.3	17.1	45.7	48.2	1.7869	1.5675
2	2	4.3	9.9	33.4	35.3	1.3779	1.0769
3	2	4.7	11.1	21.1	27.2	2.0098	1.7192
4	2	3.7	17.0	26.2	34.7	1.2501	0.9884
5	2	4.8	28.3	51.3	52.6	0.9196	1.0328
6	2	6.4	19.9	31.3	34.8	1.3843	1.2088
7	2	4.3	17.4	27.5	29.7	1.4884	1.1372
8	2	4.9	21.4	43.2	43.4	1.5702	1.0465
1	5	3.9	13.9	27.4	30.3	1.1930	0.9898
2	5	3.3	18.4	32.7	33.4	1.3153	1.0493
3	5	5.2	23.1	33.1	34.1	1.3602	1.0302
4	5	3.4	13.5	18.4	19.8	1.3466	1.0343
5	5	4.7	17.7	19.1	20.7	1.0402	0.9216
6	5	5.1	15.7	21.9	20.8	1.1131	0.9909
7	5	5.8	19.9	26.6	29.6	1.2885	1.1745
8	5	5.2	16.0	20.6	21.4	1.2736	1.1021

Table 43. Measurements of *Pascopyrum smithii* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	21.2	41.3	47.0	48.0	1.9257	1.4181
2	0	23.0	46.0	47.9	50.2	1.7723	1.3847
3	0	26.8	53.2	54.6	57.4	1.5498	1.4397
4	0	25.0	35.3	36.8	39.1	1.2406	1.0346
5	0	24.4	34.9	37.7	40.4	1.7226	1.6236
6	0	23.5	45.3	48.0	49.1	1.8892	1.4468
7	0	18.4	31.6	33.8	34.8	1.3326	1.2277
8	0	23.9	41.3	43.1	45.0	1.6006	1.1869
1	7	17.9	33.7	38.6	47.0	1.8073	1.7322
2	7	23.8	40.6	49.2	50.6	1.9805	1.5792
3	7	24.1	43.3	44.1	45.3	1.6315	1.4569
4	7	23.2	36.3	37.2	37.9	1.3488	1.2220
5	7	23.1	40.4	45.4	47.0	1.8996	1.4909
6	7	22.7	34.2	37.5	38.2	1.5994	1.4777
7	7	20.4	36.0	39.6	40.1	1.5583	1.3590
8	7	25.3	35.4	36.3	37.6	1.3342	1.1081
1	14	25.1	45.3	47.5	46.7	1.3292	1.0957
2	14	27.7	45.2	45.8	46.4	1.9066	1.5433
3	14	27.2	42.0	43.3	45.7	1.5958	1.4425
4	14	26.9	39.4	40.0	40.4	1.5166	1.2379
5	14	25.9	37.2	40.4	42.1	1.8225	1.6182
6	14	25.5	41.1	43.1	43.6	1.7608	1.5065
7	14	30.4	40.8	42.4	43.4	1.6214	1.4034
8	14	20.6	32.2	33.3	33.6	1.2637	1.1479
1	28	24.5	40.5	44.3	49.2	1.7393	1.5440
2	28	29.3	46.3	48.5	49.4	1.8415	1.3776
3	28	22.2	42.3	46.8	47.4	1.5545	1.3437
4	28	22.7	35.5	38.6	39.0	1.2256	1.1184
5	28	20.7	44.8	49.9	51.2	1.9812	1.4768
6	28	23.3	37.8	43.0	44.2	1.8246	1.3820
7	28	32.2	45.3	46.4	47.2	1.7146	1.4259
8	28	28.9	38.0	38.9	39.4	1.2632	1.0243

Table 44. Measurements of *Leymus cinereus* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	27.6	46.9	51.0	53.1	1.7018	1.8614
2	0	27.8	49.2	53.2	55.8	1.6077	1.7354
3	0	22.9	47.0	54.8	58.9	1.8766	1.6519
4	0	25.1	46.9	47.5	53.0	1.6716	1.6143
5	0	25.9	45.2	49.5	50.9	1.3668	1.7133
6	0	33.0	52.6	53.8	54.5	1.5047	1.6791
7	0	24.9	42.8	44.2	45.5	1.5924	1.6856
8	0	20.1	40.9	44.2	45.4	1.2734	1.3378
1	7	24.1	42.2	43.3	45.0	1.2006	1.2678
2	7	24.5	41.2	42.8	46.8	1.6366	1.6197
3	7	22.3	46.9	49.9	51.2	1.6234	1.7936
4	7	22.4	38.5	48.1	51.0	1.4599	1.3462
5	7	29.0	41.5	43.6	44.1	1.4697	1.9549
6	7	25.4	51.7	56.4	57.4	1.6549	1.8435
7	7	31.0	54.7	55.6	56.0	1.6683	1.8769
8	7	17.6	37.3	40.2	41.9	1.2364	1.1579
1	14	25.3	37.2	38.7	40.3	1.3131	1.5181
2	14	24.0	36.0	42.3	43.4	1.5801	1.7099
3	14	36.1	49.1	51.0	51.7	1.5077	1.8099
4	14	36.2	41.9	43.3	45.2	1.4217	1.5002
5	14	32.7	45.3	46.7	48.3	1.5821	1.8521
6	14	28.7	50.6	52.1	52.8	1.5820	1.9166
7	14	28.0	37.4	40.0	44.0	1.3645	1.5334
8	14	26.6	40.4	41.2	44.7	1.5047	1.4821
1	28	27.4	45.2	48.5	49.0	1.5181	1.7910
2	28	30.7	47.4	56.2	59.4	1.6492	2.3544
3	28	30.5	46.8	50.1	51.8	1.6207	1.6769
4	28	27.9	53.7	54.8	55.2	1.6100	1.5864
5	28	39.7	53.0	53.9	54.7	1.5913	1.7510
6	28	33.8	51.5	53.8	55.1	1.8096	1.7841
7	28	26.9	40.9	43.0	44.8	1.5202	1.5269
8	28	29.0	49.5	50.6	51.0	1.2894	1.2537

Table 45. Measurements of *Festuca ovina duriuscula* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	10.4	13.0	21.7	23.4	1.4093	1.2573
2	0	6.6	7.8	9.2	10.2	1.1361	1.0888
3	0	6.3	9.6	10.7	10.5	1.0697	1.0570
4	0	9.4	12.3	12.9	13.8	1.0640	1.0651
5	0	6.6	9.0	16.7	19.6	1.1884	1.0738
6	0	7.0	7.9	9.4	8.1	0.8868	0.8658
7	0	8.5	10.6	12.4	11.0	0.9157	0.8902
8	0	9.0	9.8	11.2	11.8	0.8913	0.8647
1	7	9.1	12.7	17.7	18.9	1.3662	1.2816
2	7	7.4	8.1	10.0	10.5	1.1030	1.1267
3	7	10.2	12.0	13.0	13.4	0.8012	0.9254
4	7	9.7	11.5	11.8	12.0	0.8957	0.8532
5	7	9.7	13.5	15.8	14.4	1.2592	1.1464
6	7	7.8	11.6	13.0	11.2	0.9419	0.9104
7	7	10.6	13.6	13.9	14.2	0.9389	0.9106
8	7	11.8	12.4	11.2	8.8	0.9134	0.8908
1	14	9.9	17.6	19.8	18.4	0.9829	1.0211
2	14	9.8	11.9	12.8	13.9	0.9808	0.9301
3	14	10.8	13.6	14.0	14.5	0.9534	0.9161
4	14	8.6	11.2	11.5	11.8	1.4244	0.8835
5	14	11.2	16.7	18.1	19.9	1.3958	1.2858
6	14	10.0	12.7	13.3	13.9	0.9471	0.9142
7	14	10.2	12.3	13.5	14.3	0.9826	0.9025
8	14	9.0	12.5	10.8	11.0	0.9223	0.8777
1	28	9.6	14.0	17.6	19.0	1.3960	1.2458
2	28	6.6	10.9	12.1	12.9	0.9109	0.8809
3	28	10.5	12.1	13.4	14.7	1.1137	1.1044
4	28	11.0	14.8	15.3	17.0	1.1291	1.1186
5	28	11.0	16.2	18.7	19.7	1.2049	1.1166
6	28	13.5	15.2	15.8	16.7	0.9829	0.9226
7	28	9.0	11.5	13.4	14.1	1.1199	1.0614
8	28	10.4	13.4	14.4	15.3	0.8739	0.8599

Table 46. Measurements of *Poa compressa* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Plant height (cm)				Mean shoot weight per plant (g)	Mean root weight per plant (g)
		day 0	day 25	day 50	day 75		
1	0	5.4	18.8	34.9	41.0	1.4433	1.1665
2	0	4.2	17.5	26.9	30.1	1.2003	1.0015
3	0	4.7	7.7	10.6	14.4	1.1749	1.0959
4	0	5.4	31.9	16.0	18.0	0.9638	0.9029
5	0	5.5	21.0	40.0	41.2	1.3961	1.0456
6	0	4.0	16.7	28.5	29.4	1.2304	0.9726
7	0	3.9	9.9	10.3	10.0	1.1335	1.0783
8	0	4.6	13.5	14.3	15.8	1.2033	1.0972
1	7	4.5	21.6	42.3	43.8	1.6024	1.2665
2	7	4.7	13.6	15.3	15.9	1.0207	0.9578
3	7	4.4	10.6	15.6	16.6	1.2210	1.1783
4	7	3.9	10.2	11.0	11.7	1.1095	1.0917
5	7	4.9	28.5	43.8	48.7	1.7398	1.5559
6	7	5.2	17.1	20.6	21.7	1.1166	0.9774
7	7	4.2	14.5	16.5	17.1	1.0026	0.8676
8	7	5.0	8.2	7.8	4.6	0.8791	0.8691
1	14	4.2	22.5	47.2	49.7	1.6833	1.3688
2	14	4.1	20.3	32.7	30.0	1.2484	1.0540
3	14	4.7	15.3	18.2	16.0	1.0132	0.9081
4	14	4.1	9.1	8.2	8.7	0.9377	0.8523
5	14	4.3	25.7	42.7	46.6	1.5663	1.3594
6	14	4.7	15.8	21.0	23.2	1.3290	0.9874
7	14	4.4	13.1	17.5	16.5	1.0260	0.8957
8	14	4.8	10.8	11.1	11.3	1.1559	1.0862
1	28	4.8	21.2	34.3	36.0	1.4073	1.1684
2	28	4.8	17.9	23.6	24.5	1.0823	0.9601
3	28	4.0	7.7	12.9	18.4	1.3376	1.2065
4	28	4.0	8.2	10.8	13.0	1.1061	1.0732
5	28	5.2	22.0	45.7	49.6	1.5998	0.9105
6	28	5.0	11.8	13.0	13.5	0.9687	1.2573
7	28	4.7	13.8	14.6	15.4	1.1576	1.0496
8	28	4.3	11.7	12.1	12.6	1.1468	1.0699

APPENDIX F

Observations

Table 47. Observations of *Pascopyrum smithii* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5	2	1	1	0	5
2	0	1	1	0	0	5	1	1	1	0	5	1	2	1	0	5	2	2	1	0	5
3	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	4
4	0	1	1	0	0	5	1	1	1	0	5	1	2	1	0	5	2	2	1	0	5
5	0	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
6	0	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
7	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	2	0	5
8	0	1	1	0	0	5	2	1	1	0	5	2	1	1	0	5	2	2	1	0	5
1	1	1	1	0	0	5	1	2	0	1	5	2	2	1	1	5	2	2	2	1	5
2	1	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	2	1	0	5
3	1	1	1	0	0	5	1	2	1	1	5	2	2	1	1	5	2	2	1	2	5
4	1	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	2	1	1	5
5	1	1	1	0	0	5	1	1	1	0	5	2	2	1	1	5	2	2	1	1	5
6	1	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
7	1	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	1	5
8	1	1	1	0	0	5	2	1	1	1	5	2	2	1	1	5	2	2	2	1	5
1	2	1	1	0	0	5	2	2	1	0	5	2	3	2	0	5	3	3	3	1	5
2	2	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	3	2	1	1	5
3	2	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	3	2	2	1	5
4	2	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	3	2	0	5
5	2	1	1	0	0	5	2	1	1	0	5	2	2	2	1	5	2	2	2	1	5
6	2	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
7	2	1	1	0	0	5	2	2	1	0	5	2	2	2	0	5	2	2	2	1	5
8	2	1	1	0	0	5	2	2	1	0	5	2	2	1	1	5	2	3	1	1	5
1	5	1	1	0	0	5	2	2	1	0	5	3	2	2	1	5	3	2	3	1	5
2	5	1	1	0	0	5	2	2	1	0	5	2	2	1	1	5	2	2	1	1	5
3	5	1	1	0	0	5	2	2	1	0	5	2	3	2	2	5	3	4	3	2	5
4	5	1	1	0	0	5	2	2	1	1	5	3	3	1	1	5	3	3	3	2	5
5	5	1	1	0	0	5	2	2	1	0	5	2	2	1	1	5	3	2	1	1	5
6	5	1	1	0	0	5	2	2	1	0	5	2	3	3	1	5	2	3	3	2	5
7	5	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	2	2	1	1	5
8	5	1	1	0	0	5	2	2	2	0	5	3	3	2	2	5	3	4	3	3	5

Table 48. Observations of *Leymus cinereus* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5	2	2	2	1	5
2	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	5
3	0	1	1	0	0	5	1	1	1	0	5	1	2	1	0	5	2	2	1	1	5
4	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	5
5	0	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	2	2	1	0	5
6	0	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	2	2	1	0	5
7	0	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
8	0	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
1	1	1	1	0	0	5	1	2	0	1	5	2	2	1	1	5	2	2	2	1	5
2	1	1	1	0	0	5	2	2	1	0	5	2	2	1	1	5	2	2	1	2	5
3	1	1	1	0	0	5	1	2	1	1	5	2	2	1	1	5	3	2	2	1	5
4	1	1	1	0	0	5	2	1	1	0	5	2	2	1	0	5	2	2	1	1	5
5	1	1	1	0	0	5	2	2	1	0	5	2	2	1	1	5	2	2	1	2	5
6	1	1	1	0	0	5	2	2	2	0	5	2	3	2	1	5	2	3	2	1	5
7	1	1	1	0	0	5	1	1	1	1	5	2	2	1	1	5	2	2	2	1	5
8	1	1	1	0	0	5	1	1	1	1	5	3	3	2	1	4	4	4	3	1	4
1	2	1	1	0	0	5	1	2	1	0	5	2	2	1	1	5	2	2	1	1	5
2	2	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	2	2	1	5
3	2	1	1	0	0	5	2	1	1	0	5	2	2	1	2	5	3	3	1	2	5
4	2	1	1	0	0	5	2	1	1	0	5	2	2	2	1	5	3	3	2	1	5
5	2	1	1	0	0	5	2	2	2	0	5	2	2	2	1	5	3	3	3	2	5
6	2	1	1	0	0	5	1	2	1	0	5	3	4	1	2	5	3	4	3	2	5
7	2	1	1	0	0	5	2	1	2	0	5	2	2	2	0	5	2	2	3	1	5
8	2	1	1	0	0	5	2	1	1	0	5	3	2	2	1	5	3	3	3	2	5
1	5	1	1	0	0	5	2	2	1	0	5	3	4	2	2	5	3	4	3	2	5
2	5	1	1	0	0	5	2	1	1	0	5	2	2	2	2	5	3	2	3	2	5
3	5	1	1	0	0	5	1	2	1	0	5	2	2	2	1	5	3	3	2	1	5
4	5	1	1	0	0	5	2	1	1	0	5	2	2	1	0	5	2	2	1	1	5
5	5	1	1	0	0	5	2	2	1	0	5	3	3	3	1	5	3	3	3	2	5
6	5	1	1	0	0	5	2	2	1	1	5	2	3	1	1	5	3	3	3	2	5
7	5	1	1	0	0	5	2	2	1	0	5	2	2	2	0	5	2	3	3	2	5
8	5	1	1	0	0	5	2	1	1	0	5	2	2	1	1	5	2	2	1	1	4

Table 49. Observations of *Festuca ovina duriuscula* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
2	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
3	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
4	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
5	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
6	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
7	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
8	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	5
1	1	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
2	1	1	1	0	0	5	1	1	1	0	5	1	1	1	0	4	2	2	2	1	4
3	1	1	1	0	0	5	1	1	1	0	5	2	2	1	1	4	2	2	1	1	4
4	1	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
5	1	1	1	0	0	5	1	2	1	0	5	1	2	1	1	5	2	2	2	2	5
6	1	1	1	0	0	5	1	1	1	0	5	1	1	1	1	5	1	1	1	2	5
7	1	1	1	0	0	5	1	1	1	0	5	2	1	1	1	5	2	2	1	1	5
8	1	1	1	0	0	5	1	1	1	0	5	2	1	1	1	5	2	1	1	1	5
1	2	1	1	0	0	5	1	1	1	1	5	2	1	1	1	4	3	3	3	2	4
2	2	1	1	0	0	5	1	1	1	0	5	2	2	1	1	5	2	2	2	2	5
3	2	1	1	0	0	5	2	3	1	0	5	2	3	1	1	3	2	3	1	1	3
4	2	1	1	0	0	5	1	2	1	0	5	2	3	1	0	5	2	3	2	1	5
5	2	1	1	0	0	5	1	1	1	1	5	1	1	1	1	5	2	2	1	1	5
6	2	1	1	0	0	5	1	1	1	1	5	1	2	1	1	5	2	2	3	2	5
7	2	1	1	0	0	5	1	2	1	0	5	2	2	1	1	3	2	2	1	1	3
8	2	1	1	0	0	5	1	1	1	0	5	1	2	1	1	5	2	2	2	1	5
1	5	1	1	0	0	5	1	1	1	0	5	2	2	2	1	5	2	3	3	2	5
2	5	1	1	0	0	5	1	1	1	0	5	2	2	1	1	5	2	2	2	2	5
3	5	1	1	0	0	5	1	1	1	0	5	2	2	1	1	5	2	2	2	1	5
4	5	1	1	0	0	5	1	1	1	0	5	2	2	1	1	5	2	2	2	2	5
5	5	1	1	0	0	5	1	2	3	0	5	3	4	3	2	5	3	4	3	2	5
6	5	1	1	0	0	5	2	1	2	0	5	2	2	2	1	5	2	2	2	1	4
7	5	1	1	0	0	5	1	1	1	0	5	2	2	2	2	5	3	3	3	2	5
8	5	1	1	0	0	5	2	1	1	0	5	2	2	2	2	5	2	2	2	2	5

Table 50. Observations of *Poa compressa* irrigated with arsenic III.

Block	Arsenic III in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	1	0	0	5	1	2	0	0	5	1	2	1	0	5
2	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	2	1	0	5
3	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	2	1	0	5
4	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
5	0	1	1	0	0	5	1	1	0	0	5	1	2	0	0	5	1	2	1	0	5
6	0	1	1	0	0	5	1	1	0	0	5	1	2	1	0	5	1	2	1	0	5
7	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
8	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
1	1	1	1	0	0	5	1	1	0	0	5	1	1	0	0	4	2	2	1	0	4
2	1	1	1	0	0	5	2	2	0	0	4	2	2	0	0	4	2	2	1	1	4
3	1	1	1	0	0	5	1	1	0	0	5	2	2	1	0	5	2	2	2	1	5
4	1	1	1	0	0	5	1	1	0	0	5	2	2	1	0	5	3	3	2	1	5
5	1	1	1	0	0	5	1	1	0	0	5	1	2	0	0	5	3	3	3	3	5
6	1	1	1	0	0	5	1	1	0	0	5	1	2	0	1	5	1	2	1	1	5
7	1	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	2	2	1	1	5
8	1	1	1	0	0	5	1	1	0	0	5	2	2	0	0	5	2	3	2	0	5
1	2	1	1	0	0	5	1	1	0	0	5	2	2	1	1	4	2	2	1	1	4
2	2	1	1	0	0	5	1	1	0	1	5	2	2	0	1	5	2	2	2	1	5
3	2	1	1	0	0	5	2	2	0	0	4	2	3	1	2	3	2	3	3	2	3
4	2	1	1	0	0	5	2	1	0	0	5	2	1	1	1	5	2	3	2	1	5
5	2	1	1	0	0	5	1	1	0	0	5	2	1	0	0	5	2	2	1	1	5
6	2	1	1	0	0	5	2	1	1	0	5	2	2	1	1	5	2	2	1	1	5
7	2	1	1	0	0	5	1	2	0	0	5	1	2	0	1	5	2	2	1	1	5
8	2	1	1	0	0	5	1	1	0	0	5	2	2	1	1	5	2	2	1	1	5
1	5	1	1	0	0	5	2	1	0	0	5	2	2	1	0	5	3	3	2	1	5
2	5	1	1	0	0	5	2	1	0	0	5	2	2	1	1	5	3	3	3	2	5
3	5	1	1	0	0	5	2	1	0	0	5	2	3	1	1	5	4	4	3	2	5
4	5	1	1	0	0	5	2	1	0	0	5	2	2	1	1	5	3	3	2	2	5
5	5	1	1	0	0	5	2	2	0	0	5	3	4	3	1	5	3	4	3	3	5
6	5	1	1	0	0	5	2	1	1	1	5	2	2	3	1	5	3	3	3	2	5
7	5	1	1	0	0	5	2	1	0	0	5	2	2	0	0	5	2	2	2	2	5
8	5	1	1	0	0	5	2	1	0	0	5	3	3	2	2	4	3	3	3	2	4

Table 51. Observations of *Pascopyrum smithii* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	2	1	0	5	1	2	1	0	5	2	2	1	0	5
2	0	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	3	2	0	5
3	0	1	1	0	0	5	3	2	1	0	5	3	2	2	2	5	3	2	3	2	5
4	0	1	1	0	1	5	2	2	1	2	5	3	3	2	2	5	4	3	3	2	5
5	0	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	2	1	0	5
6	0	1	1	0	0	5	1	1	1	0	5	1	2	1	0	5	2	2	1	2	5
7	0	1	1	0	0	5	2	2	1	0	5	3	3	1	0	5	3	3	2	2	5
8	0	1	1	0	0	5	2	2	1	1	5	3	3	1	2	5	3	3	3	2	5
1	7	1	1	0	0	5	1	2	1	0	5	1	2	1	0	5	1	2	1	0	5
2	7	1	1	0	0	5	1	2	1	1	5	2	2	1	1	5	2	2	1	1	5
3	7	1	1	0	0	5	2	2	1	0	5	3	3	1	0	5	3	3	2	2	5
4	7	1	1	0	0	5	2	2	1	3	5	3	3	3	4	5	4	3	3	5	5
5	7	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
6	7	1	1	0	0	5	2	1	1	1	5	2	2	1	1	5	2	3	2	2	5
7	7	1	1	0	0	5	2	2	3	0	5	3	3	3	1	5	3	3	3	2	5
8	7	1	1	0	0	5	2	2	3	2	5	3	3	3	3	5	3	3	3	3	5
1	14	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	2	1	0	5
2	14	1	1	0	0	5	2	1	3	1	5	2	1	3	1	5	2	2	3	2	5
3	14	1	1	0	0	5	2	2	1	1	5	2	2	2	2	5	3	3	3	2	5
4	14	1	1	0	0	5	2	2	3	1	5	3	3	1	2	5	3	3	3	2	5
5	14	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
6	14	1	1	0	0	5	1	1	1	0	5	2	2	1	2	5	3	2	3	2	5
7	14	1	1	0	0	5	2	2	1	2	5	3	3	2	2	5	3	3	2	2	5
8	14	1	1	0	0	5	2	2	1	0	5	3	3	2	2	5	3	4	3	2	5
1	28	1	1	0	0	5	1	1	1	0	5	2	1	1	0	5	2	2	1	1	5
2	28	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	2	1	5
3	28	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	3	3	2	2	5
4	28	1	1	0	0	5	2	2	1	3	5	3	3	2	3	5	3	3	3	3	5
5	28	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	5
6	28	1	1	0	0	5	1	2	1	0	5	1	2	1	0	5	2	2	1	1	5
7	28	1	1	0	0	5	2	1	1	1	5	2	2	1	1	5	2	2	2	2	5
8	28	1	1	0	0	5	2	2	1	2	5	3	4	2	3	5	3	4	3	3	5

Table 52. Observations of *Leymus cinereus* irrigated with arsenic V.

	Arsenic V in solution	Day 0					Day 25					Day 50					Day 75				
Block	(mg/L)	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	2	1	0	5	1	1	1	0	5	2	2	1	1	5
2	0	1	1	0	0	5	1	2	1	0	5	2	2	1	1	5	2	2	2	1	5
3	0	1	1	0	0	5	2	2	1	0	5	3	2	2	1	5	3	2	3	1	5
4	0	1	1	0	0	5	3	3	2	1	5	2	3	3	2	5	3	3	3	2	4
5	0	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	2	2	1	0	5
6	0	1	1	0	0	5	2	1	1	0	5	2	2	1	0	5	2	3	2	2	5
7	0	1	1	0	0	5	2	2	1	0	5	2	2	1	2	5	2	2	2	2	5
8	0	1	1	0	0	5	2	1	1	2	5	3	3	1	2	5	3	3	3	3	5
1	7	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	1	0	5
2	7	1	1	0	0	5	1	2	1	0	5	2	2	1	2	5	3	2	1	2	5
3	7	1	1	0	0	5	2	1	2	0	5	3	2	2	1	5	3	2	2	2	5
4	7	1	1	0	0	5	2	1	1	1	5	2	2	2	2	5	3	3	3	2	5
5	7	1	1	0	0	5	1	2	1	0	5	2	2	1	0	5	2	2	1	1	5
6	7	1	1	0	0	5	2	1	1	0	5	2	2	1	0	5	2	2	1	1	5
7	7	1	1	0	0	5	2	2	1	0	5	3	3	2	1	5	3	3	2	1	5
8	7	1	1	0	0	5	2	2	1	1	5	3	3	2	3	5	3	3	2	4	5
1	14	1	1	0	0	5	2	3	1	1	5	2	3	1	1	5	2	3	1	1	5
2	14	1	1	0	0	5	2	1	1	0	5	2	2	1	0	5	2	2	1	1	5
3	14	1	1	0	0	5	2	1	1	1	5	2	2	3	2	5	3	3	3	2	5
4	14	1	1	0	0	5	2	2	2	1	5	2	3	2	2	5	3	3	3	4	5
5	14	1	1	0	0	5	2	2	1	0	5	2	2	1	0	5	2	2	1	0	5
6	14	1	1	0	0	5	2	2	1	0	5	3	3	1	1	5	3	3	3	2	5
7	14	1	1	0	0	5	2	2	1	2	5	3	3	1	3	5	3	3	3	3	5
8	14	1	1	0	0	5	2	2	1	2	5	3	3	3	2	5	4	3	3	4	5
1	28	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	5
2	28	1	1	0	0	5	1	1	1	0	5	2	2	1	1	5	2	2	1	1	5
3	28	1	1	0	0	5	2	1	1	1	5	2	2	1	1	5	3	3	2	2	5
4	28	1	1	0	0	5	2	1	1	1	5	3	3	1	2	5	3	3	2	2	5
5	28	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	1	5
6	28	1	1	0	0	5	1	1	1	0	5	2	2	1	0	5	2	2	2	1	5
7	28	1	1	0	0	5	2	1	1	1	5	3	3	1	2	5	3	3	3	2	5
8	28	1	1	0	0	5	2	2	1	2	5	3	3	2	3	5	3	3	3	3	5

Table 53. Observations of *Festuca ovina duriuscula* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
2	0	1	1	0	0	5	2	1	0	0	5	2	3	2	2	5	2	3	3	2	4
3	0	1	1	0	0	5	2	2	1	0	4	3	4	3	3	4	4	4	3	4	1
4	0	1	1	0	0	5	3	2	1	3	5	4	4	3	4	5	4	4	3	4	4
5	0	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
6	0	1	1	0	0	5	2	1	1	0	5	2	3	3	2	5	3	4	3	2	5
7	0	1	1	0	0	5	2	2	1	0	5	3	3	3	2	5	3	4	3	2	5
8	0	1	1	0	0	5	2	2	1	2	5	4	4	3	3	5	4	4	3	3	5
1	7	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
2	7	1	1	0	0	5	2	2	1	0	5	2	3	3	2	4	4	4	3	2	4
3	7	1	1	0	0	5	2	1	1	0	5	3	3	3	2	5	3	4	3	3	5
4	7	1	1	0	0	5	2	3	3	0	5	3	4	3	3	5	4	4	3	3	5
5	7	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
6	7	1	1	0	0	5	1	2	1	0	5	2	3	2	0	5	3	4	3	2	5
7	7	1	1	0	0	5	1	1	1	0	5	3	4	3	2	5	3	4	3	3	5
8	7	1	1	0	0	5	1	2	1	0	5	3	4	3	3	5	4	4	3	3	5
1	14	1	1	0	0	5	1	1	0	0	5	3	3	3	0	5	3	3	3	0	5
2	14	1	1	0	0	5	2	1	2	1	5	3	3	3	1	5	3	3	3	2	5
3	14	1	1	0	0	5	1	1	1	0	5	2	3	3	2	5	4	4	3	3	5
4	14	1	1	0	0	5	2	2	2	0	5	3	4	3	2	5	4	4	3	3	5
5	14	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
6	14	1	1	0	0	5	1	1	1	0	5	2	3	3	2	5	3	3	3	2	5
7	14	1	1	0	0	5	2	1	1	0	5	3	3	3	2	5	3	3	3	2	5
8	14	1	1	0	0	5	2	1	1	0	5	3	4	3	2	5	3	4	3	3	5
1	28	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	1	1	1	0	5
2	28	1	1	0	0	5	1	2	1	0	5	2	2	2	0	5	3	3	2	1	5
3	28	1	1	0	0	5	2	1	1	0	5	3	4	3	2	5	3	4	3	3	4
4	28	1	1	0	0	5	2	1	1	0	5	4	4	3	2	5	4	4	3	4	4
5	28	1	1	0	0	5	1	1	1	0	5	1	1	1	0	5	2	2	1	0	5
6	28	1	1	0	0	5	1	1	1	0	5	2	2	2	2	5	3	3	3	2	5
7	28	1	1	0	0	5	2	1	1	0	5	3	4	3	2	4	4	4	3	3	4
8	28	1	1	0	0	5	2	2	1	0	5	4	4	3	3	5	4	4	3	4	5

Table 54. Observations of *Poa compressa* irrigated with arsenic V.

Block	Arsenic V in solution (mg/L)	Day 0					Day 25					Day 50					Day 75				
		Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival	Color	Vigor	Burn	Red	Survival
1	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	2	1	0	5
2	0	1	1	0	0	5	1	1	0	0	5	2	3	2	2	5	3	3	3	3	5
3	0	1	1	0	0	5	3	2	3	2	5	3	3	3	3	4	3	3	3	3	4
4	0	1	1	0	0	5	4	3	3	0	2	3	4	3	3	5	3	4	3	3	5
5	0	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	2	1	0	5
6	0	1	1	0	0	5	1	1	0	0	5	3	3	2	2	5	3	3	3	3	5
7	0	1	1	0	0	5	3	2	1	3	5	3	4	3	4	5	3	4	3	4	4
8	0	1	1	0	0	5	2	2	0	1	5	3	4	3	3	5	4	4	3	3	4
1	7	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	2	2	1	0	5
2	7	1	1	0	0	5	1	1	0	2	5	2	3	2	2	5	3	3	3	2	5
3	7	1	1	0	0	5	2	2	0	1	5	3	4	2	2	4	3	4	3	3	4
4	7	1	1	0	0	5	2	3	3	1	5	3	4	3	2	4	4	4	3	3	4
5	7	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
6	7	1	1	0	0	5	1	1	0	0	5	2	2	2	1	5	2	3	3	2	5
7	7	1	1	0	0	5	2	1	0	1	5	3	4	3	3	5	4	4	3	4	5
8	7	1	1	0	0	5	2	2	0	2	5	3	4	3	3	5	4	4	3	4	5
1	14	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
2	14	1	1	0	0	5	1	1	0	0	5	2	2	0	2	5	3	3	2	3	5
3	14	1	1	0	0	5	2	1	1	1	5	3	4	3	2	5	3	4	3	4	5
4	14	1	1	0	0	5	3	3	3	1	5	3	4	3	2	5	4	4	3	4	5
5	14	1	1	0	0	5	1	1	0	0	5	1	2	0	0	5	1	2	1	0	5
6	14	1	1	0	0	5	1	1	1	0	5	2	3	1	1	5	3	3	3	3	5
7	14	1	1	0	0	5	2	2	1	1	5	3	4	3	2	5	3	4	3	3	5
8	14	1	1	0	0	5	3	2	1	1	5	3	4	3	3	5	4	4	3	4	4
1	28	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	1	1	0	5
2	28	1	1	0	0	5	1	1	0	1	5	2	2	2	1	5	3	3	3	2	5
3	28	1	1	0	0	5	2	2	0	2	5	2	3	2	2	5	3	3	3	3	4
4	28	1	1	0	0	5	2	2	1	1	5	4	4	3	3	3	4	4	3	3	1
5	28	1	1	0	0	5	1	1	0	0	5	1	1	0	0	5	1	2	1	0	5
6	28	1	1	0	0	5	1	2	0	0	5	2	3	3	2	5	3	3	3	2	5
7	28	1	1	0	0	5	2	2	2	0	4	3	4	3	2	4	3	4	3	3	4
8	28	1	1	0	0	5	2	2	0	3	5	3	4	3	4	5	4	4	3	4	4