



Phytoextraction of selenium and other metals from soil used for landfarming oil refinery waste
by Shane Allen Matolyak

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

Montana State University

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Abstract:

Waste slurry emanating from an oil refinery wastewater treatment system was incorporated into soil at the Conoco Land Treatment Unit (LTU) since 1972. As a result, the soil contained a total selenium concentration (18.6 mg/kg) that approached the limit permitted by the state regulatory authority. Total concentrations of other elements included arsenic (34.4 mg/kg), chromium (159.6 mg/kg), lead (26.2 mg/kg), and zinc (185.8 mg/kg). This soil was saline (8.3 mmhos/cm), had a loam texture, and a pH of 7.2. The use of selenium accumulating plant species to decrease the soil selenium concentration was evaluated.

Selenium accumulating plant species (canola, desert prince's-plume, and Indian mustard) and selenium non-accumulating species (pubescent wheatgrass and tall fescue) were seeded at the LTU and harvested upon maturity. No significant change in soil metal concentration was measured. Based on scientific literature, it was expected that the selenium accumulating species would have tissue selenium concentrations in the range of 300 to 2000 mg/kg. Plant tissue selenium concentrations in canola (6.8 mg/kg), canola grown on phosphorous amended LTU soil (7.6 mg/kg), Indian mustard (10.4 mg/kg), and desert prince's-plume (111.6 mg/kg) were considerably lower than expected yet great enough to present a chronic toxicity hazard in grazing animals.

To determine whether lower than expected selenium accumulation was due to plant species selection, soil characteristics, or a characteristic of the waste slurry, selenium accumulating plant species were grown in replicated greenhouse trials on four different substrates; i) the LTU soil, ii) selenate-enriched LTU soil, iii) waste slurry-enriched sand, and iv) selenate-enriched sand. Mean plant tissue selenium concentrations in each substrate were 10.2 ± 6.5 mg/kg, 49.0 ± 27.8 mg/kg, 43.0 ± 37.5 mg/kg, and 683.9 ± 423.1 mg/kg, respectively. Plant selenium concentrations in selenate-enriched sand were significantly greater than in the other three substrates that received waste slurry as their principle supply of selenium.

It was concluded that waste slurry, when applied to soil, contained either i) a form of selenium that was in a reduced oxidation state and thus unavailable for plant uptake or ii) another chemical constituent was present that competed with selenium for plant uptake.

PHYTOEXTRACTION OF SELENIUM AND OTHER METALS FROM SOIL
USED FOR LANDFARMING OIL REFINERY WASTE

by

Shane Allen Matolyak

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APPROVAL

of a thesis submitted by

Shane Allen Matolyak

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.

Dr. Douglas Dollhopf Douglas J. Dollhopf May 1, 2002
Date

Approved for the Department of Land Resources and Environmental Science

Dr. Jeffrey Jacobsen Jeffrey Jacobsen 5/1/02
Date

Approved for the College of Graduate Studies

Dr. Bruce McLeod Bruce R. McLeod 5-3-02
Date

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ABSTRACT

Waste slurry emanating from an oil refinery wastewater treatment system was incorporated into soil at the Conoco Land Treatment Unit (LTU) since 1972. As a result, the soil contained a total selenium concentration (18.6 mg/kg) that approached the limit permitted by the state regulatory authority. Total concentrations of other elements included arsenic (34.4 mg/kg), chromium (159.6 mg/kg), lead (26.2 mg/kg), and zinc (185.8 mg/kg). This soil was saline (8.3 mmhos/cm), had a loam texture, and a pH of 7.2. The use of selenium accumulating plant species to decrease the soil selenium concentration was evaluated.

Selenium accumulating plant species (canola, desert prince's-plume, and Indian mustard) and selenium non-accumulating species (pubescent wheatgrass and tall fescue) were seeded at the LTU and harvested upon maturity. No significant change in soil metal concentration was measured. Based on scientific literature, it was expected that the selenium accumulating species would have tissue selenium concentrations in the range of 300 to 2000 mg/kg. Plant tissue selenium concentrations in canola (6.8 mg/kg), canola grown on phosphorous amended LTU soil (7.6 mg/kg), Indian mustard (10.4 mg/kg), and desert prince's-plume (111.6 mg/kg) were considerably lower than expected yet great enough to present a chronic toxicity hazard in grazing animals.

To determine whether lower than expected selenium accumulation was due to plant species selection, soil characteristics, or a characteristic of the waste slurry, selenium accumulating plant species were grown in replicated greenhouse trials on four different substrates; i) the LTU soil, ii) selenate-enriched LTU soil, iii) waste slurry-enriched sand, and iv) selenate-enriched sand. Mean plant tissue selenium concentrations in each substrate were 10.2 ± 6.5 mg/kg, 49.0 ± 27.8 mg/kg, 43.0 ± 37.5 mg/kg, and 683.9 ± 423.1 mg/kg, respectively. Plant selenium concentrations in selenate-enriched sand were significantly greater than in the other three substrates that received waste slurry as their principle supply of selenium.

It was concluded that waste slurry, when applied to soil, contained either i) a form of selenium that was in a reduced oxidation state and thus unavailable for plant uptake or ii) another chemical constituent was present that competed with selenium for plant uptake.

1
CHAPTER 1

INTRODUCTION AND STUDY OBJECTIVES

Metals contaminate the soil resource in many areas throughout the world including 69 % of the sites on the United States National Priority List (Raskin and Ensley, 2000). This contamination can reduce soil productivity and pose a direct threat to the health of the biota. Primary methodologies to rehabilitate metal-contaminated soil include excavation and burial, acid-leaching, or in situ immobilization (Baker et al., 1994; Raskin and Ensley, 2000). In recent years, phytoextraction has been investigated as a means to rehabilitate metal contaminated soil.

Phytoextraction is the process of using plants to remove elements of concern from the soil. Certain plants, known as hyperaccumulators, can accumulate soil-borne metals in aboveground tissue to concentrations many times greater than that of the surrounding soil (Becker, 2000). By harvesting the metal-rich plant shoots, a net reduction of metals in the soil is possible.

Advantages of phytoextraction over other methods of remediating metal contaminated soils include less expense, less environmental disturbance, and higher acceptance by the public (Kumar et al., 1995; Morgante, 2000; Raskin and Ensley, 2000). Phytoextraction also provides an opportunity to recycle metals, possibly by using the metal-rich plants as nutritional supplements for livestock or as a source of high-grade metal ore in a process known as phytomining (Becker, 2000; Comis, 2000; Wood, 2000).

Study Objectives

The purpose of this study was to investigate phytoextraction methodologies to reduce the level of selenium (Se) in a soil receiving applications of sludge emanating from an oil refinery wastewater treatment system. The potential exists to remove notable amounts of Se from the soil at the Conoco Land Treatment Unit (LTU) if plant species can be identified and propagated that possess the ability to hyperaccumulate Se and produce large amounts of harvestable tissue. Specific objectives include the following:

- Identify Se accumulating plant species that will grow at the LTU.
- Identify a seed source for plant species to be tested.
- Determine which plant species accumulate the most Se at the LTU site.
- Determine the amount of Se and other metals removed from the soil by phytoextraction.

I conducted a field investigation over two growing seasons, beginning March 1999 and ending July 2001. Data collected during the field investigation were used to evaluate and compare the ability of selected Se-accumulating plant species to establish, develop, and uptake Se at the Conoco LTU site. A greenhouse investigation was conducted from May 2001 until September 2001 in order to assess substrate effects on Se uptake.

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CHAPTER 2

LITERATURE REVIEW

Metal Hyperaccumulating Plant Species

The term “hyperaccumulator” was first used to describe plants that contained over 1000 mg Ni/kg in dry plant tissue when grown on serpentine soils (Brooks, 1977; Brooks, 1998; Raskin and Ensley, 2000). While somewhat arbitrary, this plant tissue nickel concentration was approximately 100 times greater than that of non-accumulating species found on serpentine soils (Brooks, 1998).

Tissue concentration levels used to determine hyperaccumulator status differ with the metal in question (Brooks, 1998; Raskin and Ensley, 2000). For zinc or manganese, plants with tissue concentrations equal to or greater than 10,000 mg/kg are considered hyperaccumulators while Se or nickel hyperaccumulators have tissue concentrations equal to or greater than 1000 mg/kg (Baker and Brooks, 1989; Brooks 1998). The threshold value defining nickel hyperaccumulating plants has been called into question as more data on these plants have been collected (Raskin and Ensley, 2000). Therefore it seems possible that the threshold values that define hyperaccumulators of nickel as well as other metals may change as more is learned about these plants.

The first hyperaccumulating plants were recorded in 1885, almost 100 years before the word was coined, when A. Baumann found that specimens of *Viola calaminaria* and *Thlaspi calaminare* growing over calamine deposits in Aachen, Germany contained over 10,000 mg/kg (dry weight) zinc (Baumann, 1885 as cited in

Raskin and Ensley, 2000; Brooks, 1998). Since that time approximately 400 hyperaccumulating plant species in 45 families have been identified (Raskin and Ensley, 2000). The discovery that certain plant species are able to accumulate large amounts of metals has since lead to the use of these plants in phytochemical studies, mineral exploration, phytoarchaeology, and phytoextraction of metals (Beath, 1939; Brooks, 1998; Brooks and Johannes, 1990; McGrath, 1993).

Phytoremediation and Phytoextraction

The words phytoremediation and phytoextraction have been used interchangeably in scientific literature, however these words have different meanings. Phytoremediation, the general use of plants to remove, degrade or stabilize environmental contaminants includes a number of sub-disciplines, including rhizofiltration, phytostabilization, phytodegradation, phytovolatilization, and phytoextraction (Morgante, 2000; Raskin and Ensley, 2000).

Phytoextraction involves the use of hyperaccumulating plants to transport metals from the soil into aboveground plant portions that are subsequently harvested and removed from the site, resulting in a decrease of the soil metal concentration (Morgante, 2000; Raskin and Ensley, 2000).

Phytoextraction offers several potential advantages compared to traditional methods used to rehabilitate metal contaminated soils. Phytoextraction is much less expensive than excavating and disposing of the contaminated soil. The current cost of excavation and disposal is approximately \$150 to \$350 per ton while the estimated cost

of phytoextraction, including off-site disposal of the biomass as a hazardous waste, is between \$20 and \$80 per ton of treated soil (Raskin and Ensley, 2000).

The implementation of phytoextraction does not require the removal of topsoil and does not necessarily require the incorporation of soil amendments. Therefore this method can be less environmentally disturbing and generally more acceptable to the public than other techniques (Kumar et al., 1995; Morgante, 2000; Raskin and Ensley, 2000).

An opportunity to recycle metals is provided by phytoextraction. It may be possible to use the metal enriched plants as nutritional supplements for livestock (Wood, 2000). The plants may also serve as a source of high-grade metal ore in a process known as phytomining (Becker, 2000; Comis, 2000).

Phytoextraction also has some disadvantages compared to other methods of rehabilitating metal contaminated soils. While traditional methods of rehabilitation are applicable at sites having multiple contaminants, hyperaccumulators are often specific with regard to the type of metal(s) they are able to accumulate (Brooks, 1998; Rosenfeld and Beath, 1964). Therefore it may be necessary to identify and establish multiple hyperaccumulating species in order to rehabilitate a site contaminated with multiple metals. Furthermore hyperaccumulators of some contaminants, such as arsenic, have yet to be identified (Brooks, 1998).

The efficiency of phytoextraction is dependent on the production of large amounts of metal rich aboveground plant tissue. Most hyperaccumulators that have been identified are small, slow growing, species with undefined growth requirements (Kumar

et al., 1995). Therefore successful clean-up using phytoextraction may be medium to long term while excavation or capping provides a relatively immediate remedy.

While high plant productivity is important, the amount of metal that a plant can concentrate in its tissue also has a great impact on the efficiency of phytoextraction (Brooks, 1998). The ability of any plant to concentrate metal is dependent on factors that influence soil metal availability such as soil pH, soil redox potential, chemical speciation of the metal in question, the presence of other elements that may compete for plant uptake, and clay content of the soil (Ahlrichs and Hossner, 1987; Banuelos and Meek, 1990; Bisbjerg and Nielsen, 1969; Singh et al., 1981; Williams and Thornton, 1972).

Phytoextraction of Selenium

Orville Beath and his associates were the first to identify plant species from genera such as *Astragalus* (milkvetch) and *Stanleya* (prince's-plume) that were able to hyperaccumulate Se to concentrations in excess of 1000 mg/kg (Beath et al., 1939; Rosenfeld and Beath, 1964). Ingestion of these plants, which Rosenfeld and Beath (1964) referred to as primary selenium accumulators, was the cause of chronic selenium toxicity in cattle. It has been suggested that Se is necessary for the normal growth of primary selenium accumulators (Johnson, 1975; Lewis, 1976; Shrift 1969). Canola and Indian mustard, both members of the genus *Brassica*, accumulate Se to concentrations ranging from 274 to 470 mg/kg and are classified with other plants that accumulate Se to the range of a few hundred mg/kg as secondary accumulators (Banuelos et al., 1997a; Banuelos et al., 1997b; Rosenfeld and Beath, 1964). Most cultivated crop plants, grains,

and native grasses usually accumulate Se to concentrations below 30 mg/kg regardless of the soil Se concentration (Rosenfeld and Beath, 1964).

Despite their ability to accumulate very high amounts of Se the species of *Astragalus* that have been evaluated for use in phytoextraction have proven to be difficult to establish and tend to produce small biomass (Bell et al., 1992; Duckart et al., 1992; Parker et al., 1991; Retana et al., 1993). *Stanleya* was only recently investigated as a Se phytoextractor, so there is little information regarding its biomass production (Feist and Parker, 2001). While canola and Indian mustard accumulate significantly less Se than primary accumulators, their relatively high biomass production and adaptability to a range of soil conditions make them attractive candidates for phytoextraction (Banuelos and Meek, 1990; Banuelos et al., 1996; Banuelos et al., 1997b; Banuelos et al., 1998).

Soils are defined as seleniferous when they support the growth of vegetation containing toxic concentrations of Se (Anderson and Scarf, 1983). While a dietary intake of 0.1 mg/kg Se in forage is required for livestock, it has been determined that five mg/kg presents a chronic Se toxicity hazard (NRC, 1976; Underwood, 1977). The soil Se concentration provides a poor index of potential toxicity because the availability of Se to plants is dependent on a number of factors (Fisher et al., 1987). Therefore, the success of Se phytoextraction on a specific soil is not guaranteed by the establishment of plants that act as hyperaccumulators on other soils.

Plant availability of Se is highly dependent on Se speciation, which is influenced by the soil redox potential. Se occurs in four oxidation states in soil: elemental Se (Se^0), selenide (Se^{-2}) (-2 oxidation state), selenite (SeO_3^{-2}) (+4 oxidation state), and selenate (SeO_4^{-2}) (+6 oxidation state) (Brooks, 1998). Elemental selenium and metal selenides are

very insoluble and therefore not available for plant uptake (NRC, 1976). Selenite and selenate are plant-available, although it has been shown that plants accumulate more selenium when presented with selenate than selenite (Banuelos and Meek, 1990; Bisbjerg and Nielsen, 1969; Brooks, 1998). High soil pH favors the oxidation of selenite to selenate (Geering et al., 1968). The plant-availability of Se in organic compounds varies greatly with plant species as well as the specific form of organic Se (Trelease and Disomma, 1944; Trelease and Beath, 1949; Hamilton and Beath, 1963).

Se speciation can be influenced by microbial activity, which can cause selenate or selenite to become reduced to insoluble forms (Levine, 1925; Lortie et al., 1992; Oremland et al., 1989; Tomei et al., 1992). In a study of microbial activity on Se transfer in a laboratory soil-plant system, selenate was the predominant species in the soil solution (Arbestain, 1988). Supplying the soil microbes with a carbon source (straw) caused a 92 – 97 % reduction in the Se concentration of the soil solution. Four – 5 % of the reduction was attributed to microbial volatilization, while the remainder was attributed to the formation of insoluble, reduced Se compounds. Sarathchandra and Watkinson (1981) reported what they believed to be the first observation of microbial oxidation of Se. In this report the soil bacterium *Bacillus megaterium* was found to oxidize up to 1.5 % of the elemental Se added to a soil to the selenite form.

Plant uptake of Se is also influenced by the presence of other chemical constituents in the soil. Sulfate reduces the amount of selenate accumulated by a plant. Sulfur and selenium share similar chemical characteristics such as electronegativity and atomic, covalent, and ionic radii (Rosenfeld and Beath, 1964). Sulfur and selenium can each exist in the + 6, + 4, and – 2 oxidation states, although selenium has less tendency

than sulfur to become oxidized to the + 6 state (Rosenfeld and Beath, 1964). Their chemical similarities cause selenate and sulfate to enter plant roots via the same carrier and compete strongly for uptake (Brooks, 1998; Legget and Epstein, 1956; Williams and Thornton, 1972). Primary selenium accumulators have the ability to preferentially accumulate selenate over sulfate while canola and Indian mustard display avid sulfate accumulation coupled with indiscriminant selenate uptake (Bell et al., 1992; Banuelos et al., 1997b).

Plant uptake of Se is also influenced by the clay and organic matter content of the soil with a decrease in plant Se concentration as clay and organic matter increase (Bisbjerg and Nielsen, 1969). Only 3 % of the Se added to a soil containing 12.8 % organic matter could be extracted by leaching with water while 20 to 30 % of the added Se could be extracted from soils with less than 3.5 % organic matter. The amount of Se accumulated by a plant was found to be highest when the plants were grown on sandy soils (Bisbjerg and Nielsen, 1969). It appears possible that otherwise available forms of Se can become adsorbed to the numerous cation exchange sites that are present on clays and organic matter, immobilizing the Se against leaching and making it unavailable to plants roots (Brady and Weil, 1999).

The sorption, and thus mobility and plant-availability, of selenate and selenite is dependent on soil solution pH (Goldberg and Glaubig, 1988). Selenite sorption on a calcareous, montmorillonitic soil was maximal near a pH 3 and sharply declined to pH 6. Selenite sorption on montmorillonite and kaolinite increased at low pH and peaked at pH 5 while selenite sorption on calcite peaked between pH 8 and 9 (Goldberg and Glaubig, 1988). Other researchers have also observed the trend of decreasing selenite sorption,

and increased mobility, with increasing pH with maximum sorption occurring at pH 3 to 4 (Alrichs and Hossner, 1987; Hingston et al., 1968; Neal et al., 1987).

Selenate sorption was not observed in the Goldberg and Glaubig (1988) experiment while Ahlrichs and Hossner (1987) observed that less than 1 % of the selenate added to a lignite overburden was adsorbed. However in another study it was found that selenate sorption was higher than that of selenite on five different soils (Singh et al., 1981). Singh summarized his findings by saying that sorption of both selenite and selenate is positively influenced by organic carbon, clay content, calcium carbonate, and cation exchange capacity while high salt content, alkalinity, and high pH negatively effect sorption. Singh et al. (1981) found that phosphate is effective at displacing selenite and selenate that had been adsorbed by the soil. In an earlier study a 336-fold increase in the concentration of Se in Indian mustard was measured when the plants were fertilized with 100 mg/kg phosphorous (Singh, 1979).

Ecotypic variation within a plant species could influence the efficiency of phytoextraction due to possible variation between populations with respect to Se accumulating abilities. Ecotypic variation with regard to metal tolerance and metal accumulation is a common phenomenon for plants adapted to high metal soils (Baker, 1987; Macnair, 1993). *Stanleya pinnata* (desert prince's-plume) seeds collected from sites having high soil Se concentrations matured into plants with greater Se accumulating ability than plants grown from seeds collected from areas with low soil Se concentrations (Parker and Feist, 2001).

Plant-Enhanced Selenium Volatilization

Selenium-accumulating plant species have been found to produce volatile methyl-selenide compounds that are subsequently released to the atmosphere from the plant leaves and/or root systems (Duckardt et al., 1992; Terry et al., 1992; Terry and Zayed, 1994; Zayed and Terry, 1992; Zayed and Terry 1994), with up to 6.1 % of the Se removed from a soil by two-grooved milkvetch attributable to plant-enhanced volatilization (Duckardt et al., 1992).

Volatilization is important to consider when air-drying samples of hyperaccumulator tissue prior to laboratory analysis. Up to 60 % of Se in species of *Astragalus* was lost through volatilization upon air-drying (Beath et al., 1935 and 1937; Evans et al., 1968). The most reliable results are obtained from wet tissue analysis of hyperaccumulating species, while air-drying plant tissue samples should be satisfactory for analysis of non-accumulators that contain little volatile Se (Shamberger, 1983).

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CHAPTER 3

GROWTH AND SELENIUM ACCUMULATION
OF PLANT SPECIES GROWN ON
LAND TREATMENT UNIT SOIL

The ability of selected plant species to develop and accumulate Se as well as arsenic, chromium, lead, and zinc when grown in the Conoco Land Treatment Unit (LTU) soil was evaluated during a two year field investigation at the Conoco LTU.

Materials and Methods

Field Site Description

The LTU is a nearly level, non-vegetated, 11-acre, fenced impoundment located 10 miles north of Billings, Montana. The LTU is divided into seven sub-areas referred to as cells. Since 1972, cells within the LTU received applications of waste emanating from an oil refinery wastewater treatment system. This waste was applied to the loam soil as a slurry then tilled to a depth of 15 cm. Conoco conducts periodic soil analysis for total metal concentrations in the 0 to 30 cm depth increment. Examples of such metals and their concentrations in cell number 7 include arsenic (45.1 mg/kg), chromium (227.0 mg/kg), lead (23.6 mg/kg), selenium (27.3 mg/kg), and zinc (216.0 mg/kg) (Conoco, 2000). The concentration of these and other metals are above average yet still within the range of natural soils with the exception of mercury which is present at a concentration (1.4 mg/kg) approximately 10 times greater than the national average for loam soils (0.13

mg/kg) (Kabata-Pendias, 2001; Williams and Schuman, 1987).

Experimental Design

A randomized complete block experimental design was implemented in cell number 7 at the LTU (Figure 1). Cell number 7 was chosen because its soil Se concentration was the highest in the LTU. This design consisted of four rows (i.e., replications or blocks) each containing 11 test plots. Each test plot within a replication was dedicated to a different treatment (i.e., plant species, species mixture). This

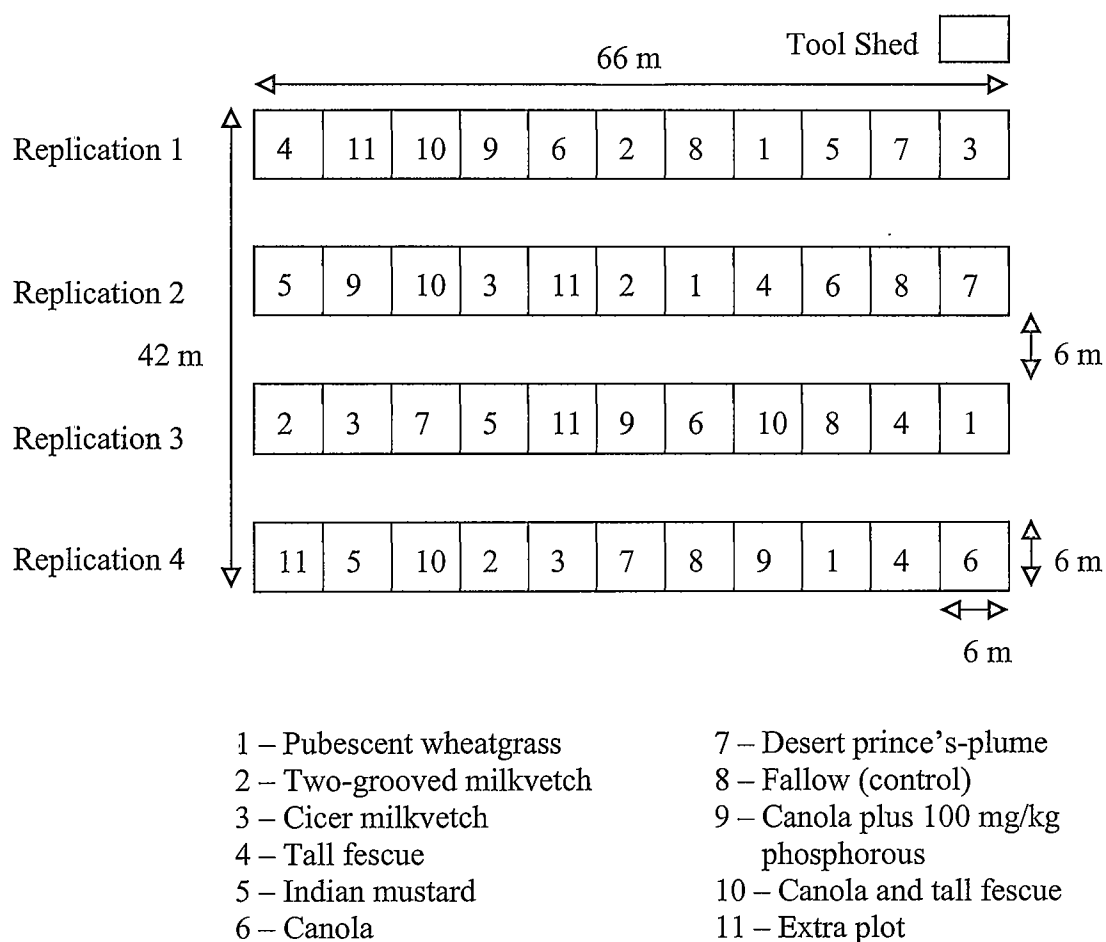


Figure 1. Randomized complete block experimental design at the Conoco LTU.

experimental design enabled the application of two-way analysis of variance and Fisher's Least Significant Difference method of mean separation analysis (SPSS Inc., 1992-1997) so that a determination could be made as to which treatment removed significantly more Se from the soil compared to other plant species. These tests of significance were completed at a 95 % probability level. The experimental design also had the capability to account for inherent field variability in the soil Se level. This means that if existing field variation resulted in the soil Se level being higher in test plots in replication 2 compared to replications 1, 3, and 4, this variation could be statistically removed so that a true and sensitive test was possible between treatments and not masked by field variation.

Plant Material Selection

An extensive review of the scientific literature lead to the identification of plant species that posses the ability to accumulate high levels of Se and could be found growing in Montana or bordering states. Seed for species that was available commercially or in limited amounts (i.e., less than 30 grams) through the United States Department of Agriculture's National Plant Germplasm System (NPGS), was selected for use in this investigation (Table 1). Non-accumulating species were also included to provide data regarding the minimum amount of Se that would be accumulated in plant tissue from the LTU soil.

Measurement of Seed Germination

The germination potential of each species of seed was tested by placing 10 seeds of an individual species between paper towels that had been moistened with tap water.

Table 1. Plant species used for the field investigation at the Conoco LTU.

Common Name	Scientific Name	Seed Source
Selenium accumulating species		
Canola	<i>Brassica napus</i>	Circle S Seeds. Three Forks, MT
Cream milkvetch	<i>Astragalus racemosus</i> ¹	Prairie Moon Nursery. Winona, MN
Desert prince's-plume	<i>Stanleya pinnata</i>	Western Native Seed. Salida, CO
Indian mustard	<i>Brassica juncea</i>	V & J Seed Farms. Woodstock, IL
Shadscale saltbush	<i>Atriplex confertifolia</i>	Western Native Seed. Salida, CO
Two-grooved milkvetch	<i>Astragalus bisulcatus</i> ¹	National Plant Germplasm System
Selenium non-accumulating species		
Cicer milkvetch	<i>Astragalus cicer</i>	Circle S Seeds. Three Forks, MT
Pubescent wheatgrass	<i>Agropyron trichophorum</i>	Circle S Seeds. Three Forks, MT
Tall fescue	<i>Festuca arundinacea</i>	Circle S Seeds. Three Forks, MT

¹ Less than 30 g of seed was available for these species.

The seeds were monitored over one month during which time the towels were kept moist and the number of germinated seeds recorded. This process was repeated for each species listed in Table 1.

Seeding

The following treatments were seeded at the LTU on April 25, 2000; cicer milkvetch, shadscale saltbush, Indian mustard, canola, desert prince's-plume, and a seed mixture consisting of equal amounts of shadscale saltbush and Indian mustard seeds. Each plot was scarified using hand rakes before hand-broadcasting the seeds at a rate of 700 seeds/m². The plots were lightly raked after seed application to cover the seed with soil.

A second seeding occurred on May 30, 2000, prompted by a lack of germination of shadscale saltbush and cicer milkvetch. Two Se non-accumulating species, pubescent wheatgrass and tall fescue, were seeded at this time. Pubescent wheatgrass was seeded into previously unused plots. Tall fescue was seeded into plots that had previously been seeded to shadscale saltbush including plots dedicated to the establishment of a mixture of Indian mustard and shadscale saltbush. Tall fescue failed to establish in plots dedicated to the seed mix so this treatment was not sampled during the study.

It was believed that successful germination of saltbush would be achieved during the second growing season if saltbush seeds were subjected to a period of vernalization. Plots previously seeded to cicer milkvetch received a seeding of shadscale saltbush (700 seeds/m²) on December 10, 2000, however no germination was observed during the second field season.

Seeds of the species used in the field study were also planted immediately outside the LTU in order to provide a visual comparison of the ability of these seeds to mature in similar environmental conditions on uncontaminated soil. Likewise, seeds were planted inside the LTU cell number 7 at a location approximately 10 m east of the test plots. These seeds did not receive irrigation during the study in order to provide a visual comparison of the ability of the species to establish without supplemental irrigation.

Increased Phosphorous Treatment

To determine whether a 100 mg/kg increase in the amount of soil phosphorous would increase plant uptake of Se as had been observed during other research (Singh

1979), one plot in each replication received a 100 mg/kg increase of phosphorous and was seeded to canola. Four pounds of super triple phosphate fertilizer was incorporated into the top 15 cm depth increment of the plot using a hand operated rotary tiller immediately prior to seed application during the first seeding event.

Greenhouse Propagation of Milkvetch Plants

The limited amount of seed available for two-grooved milkvetch and cream milkvetch necessitated that these species be established in the greenhouse prior to transplanting them at the field site. Seeds were planted on March 30, 2000 in plastic containers (15 cm tall by 2.5 cm in diameter) filled with LTU soil that was disaggregated using a 2 mm sieve. One thousand seeds of each species were planted 1 per container. The containers were watered daily and two-grooved milkvetch seedlings were transplanted at the LTU on June 6, 2000, when the seedlings were approximately 4 cm tall. Poor germination of the cream milkvetch seeds resulted in too few of these seedlings to warrant transplanting at the LTU.

A total of 144 two-grooved milkvetch seedlings were planted at the LTU. Thirty-six seedlings were planted at a spacing of 1 plant/0.09 m² in 3.24 m² "mini-plots" located in the center of one test plot in each replication. The location of each seedling was marked with a plastic stake to facilitate monitoring of the seedlings.

Irrigation

During the first season of field study all test plots were irrigated once daily between seeding and June 24, 2000, and alternate days from June 26th until the plants

were harvested. Water was applied using a sprinkler system until water began to pond on the soil surface. Plants located outside of the LTU were irrigated in an identical fashion however irrigation was discontinued in late May after the plants had been eaten by antelope.

During the second season of field study, water was applied to all plots using soaker hoses. The change in irrigation technique was instituted because frequent strong winds at the site made operation of the sprinkler system too costly due to water blown off site during irrigation. Irrigation was performed from late May until July 9, 2001 during the second season of field study.

Vegetation Sampling

Plants comprising a given treatment were sampled from all replications when 50 % to 75 % of these plants reached the flowering stage. During the first growing season, canola and Indian mustard plants reached the flowering stage and were sampled on July 6, 2000 (10 weeks after seeding). Tall fescue and wheatgrass were sampled on October 17, 2000 (20 weeks after they were seeded). Tall fescue, wheatgrass, and prince's-plume were sampled on July 6, 2001 during the second field season.

For the purpose of vegetation sampling, steel stakes were driven into the corners of each test plot. During sampling events a transect was established in each plot by stretching a steel measuring tape between stakes located at diagonal corners of each test plot. Five 20 cm by 50 cm (0.1 m²) Daubenmire frames were placed along each transect at 50 cm intervals starting 2 m from the endpoint of the transect (Daubenmire, 1965).

Plants encompassed by these frames were used for the measurement of plant density, canopy cover, and aboveground biomass production.

Transects were established between the northwest and southeast corners of each test plot during the first growing season and between northeast and southwest corners during the second growing season. This eliminated the possibility of measurements taken during the first growing season influencing those taken during the second growing season.

Plants remaining in test plots following sample collection were mowed to a height of approximately 10 cm within one week of the sample collection date in order to mimic harvesting practices that would take place if phytoextraction was implemented on an operational scale at the LTU.

Measurement of Plant Density

The density of each plant species seeded at the LTU was measured in order to determine the ability of that species to germinate and emerge in the LTU soil. This was performed 8 weeks after the plants were seeded. The mean number of plants in each of the five Daubenmire frames was calculated and multiplied by a factor of 10 in order to report mean plant density values for each respective test plot in units of plants/m².

Measurement of Percent Canopy Cover

The percent of canopy cover produced by each species was determined in order to indicate the ability of the plants to develop on the LTU. This measurement was performed immediately prior to harvesting the plants by visually estimating the

percentage of plant canopy cover present within the frames using the technique described by Daubenmire (1965). A mean percent canopy cover value was calculated for each test plot.

Measurement of Aboveground Plant Production

Aboveground biomass produced by each species was determined in order to assess overall growth as well as to facilitate the calculation of soil metal removed by phytoextraction. Plants encompassed by the previously described Daubenmire frames were clipped 2 cm above ground level. The plants were placed into a paper bag and placed into a drying oven at 70° C until reaching a constant weight. The dried plants were weighed and the average dry plant mass per square meter was calculated.

Measurement of the Survival and Development of Two-grooved Milkvetch

Due to the limited number of two-grooved milkvetch seedlings that were transplanted to the LTU, these plants were not subjected to the same measurements of plant density or percent canopy cover as those species that were planted as seed. Instead, the number of surviving milkvetch plants in each replication was counted five weeks after transplanting and a qualitative assessment of their development made.

Measurement of Plant Metal Concentrations

Plants from successfully established treatments were collected for laboratory analysis of arsenic, chromium, lead, selenium, and zinc concentrations. This was

performed during the plant harvest period by randomly selecting 10 plants in each test plot and clipping them 2 cm from ground level using stainless steel clippers. The clipped plants were immediately placed into plastic zip-lock bags and put into a cooler containing dry ice. The plants were frozen in order to inhibit metabolism that may otherwise have converted Se into a volatile form. After 4 days in a freezer at Montana State University, Bozeman campus, frozen plants were pulverized with a mortar and pestle, mixed, placed into glass jars, and shipped to Severn Trent Laboratories in Sacramento, CA. Total As, Cr, Pb, Se and Zn concentrations were determined using nitric acid digestion and inductively coupled plasma spectroscopy (EPA methods 3050 and 6010B) (U.S.E.P.A., 1986) (Table 2). Selenium analysis was performed using a trace instrument to achieve a lower detection limit for this element. A percent moisture correction was used so that the metal concentrations could be reported on a plant tissue dry weight basis even though the plants were not dried prior to metal analysis in order to prevent Se volatilization.

Measurement of Soil Metal Concentrations

In each test plot, soils were collected to determine the total concentrations of As, Cr, Pb, Se, and Zn both before seeding and after harvesting the test plots during the first season of field study. Soils were collected by taking five randomly located, 2-cm diameter soil cores from the 0 - 15 cm and 15 - 30 cm depth increments in each test plot. Soil cores were mixed to create two composite samples from each test plot; one from the 0 - 15 cm increment and another from the 15 - 30 cm increment. Composite soil samples were placed into glass jars and sent to Severn Trent Laboratories in Knoxville,

Table 2. Analytical procedures used for the field investigation at the Conoco LTU.

Procedure	Extraction Method	Analysis Method
Plant Tissue		
As, Cr, Pb and Zn analysis	EPA 3050 ¹	EPA 6010B ¹
Selenium analysis	EPA 3050 ¹	EPA 6010B trace ¹
Percent moisture determination	Not applicable	EPA 160.3 MOD ²
Soil		
As, Cr, Pb, Se and Zn analysis	EPA 3050 ¹	EPA 6010B ¹
Coarse Fragments	ASA 15-5 ⁴	2 mm sieve
Electrical Conductivity	ASA 10-3.3 ⁴	Conductivity Meter
Nitrate as N	ASA 38-8.1 ⁴	EPA 353.2 ³
Particle Size Analysis	ASA 15-5 ⁴	Hydrometer
Phosphorous (NaHCO ₃ Extract)	ASA 24-5.4 ⁴	EPA 365.1 ³
Potassium (NH ₄ Oac Extract)	ASA 13-3.5 ⁴	EPA 6010B/6020 ¹
Selenium (ABDTPA Extract)	ASA 3-5.2 ⁴	EPA 6010B/6020 ¹
Sodium Adsorption Ratio (Ca, Mg, Na)	ASA 10-3.4 ⁴	EPA 6010B/6020 ¹
pH	ASA 10-3.2 ⁴	pH Meter

¹ U.S.E.P.A., 1986. See Literature Cited.² U.S.E.P.A., 1979. See Literature Cited.³ U.S.E.P.A., 1993. See Literature Cited.⁴ A.S.A., 1982. See Literature Cited.

TN for analysis of As, Cr, Pb, Se, and Zn using EPA methods 3050 and 6010B (Table 2).

Soil Suitability

Prior to seeding, a composite soil sample was collected from LTU cell number 7 and analyzed to determine suitability of the LTU soil for plant growth (Table 2). A measurement of the ABDTPA extractable Se was also performed to determine the

amount of Se that could be potentially available for plant uptake as opposed to being in some insoluble, unavailable form.

Quality Assurance of Sampling and Analysis Methods

Methods employed to assess the degree of precision, accuracy, and cross contamination during sampling and analysis are discussed in Appendix A.

Results

Soil Physicochemical Characteristics

The soil in LTU cell number 7 had a loam texture with less than 2 % coarse fragments, which indicated that the soil would not pose a physical hindrance to plant root development (Table 3). A moderate sodium adsorption ratio of 11.7 indicated that this soil would not form a crust that would limit seedling emergence upon wetting and drying of the soil. The pH of 7.2 was in the range considered optimum for plant growth. This soil had an electrical conductivity of 8.31 mmhos/cm, indicating that a saline soil condition was present, which could adversely affect plant growth by decreasing soil water potential (Brady and Weil, 1999). The site would be irrigated during the period of plant establishment and development to avoid plant mortality due to water related stress. Nitrate, phosphorous, and potassium were present in the LTU soil at high concentrations (Lichthardt and Jacobsen, 1992) therefore no fertilizer was applied to the study site.

The ABDTPA extractable Se analysis indicated that 12.1 mg/kg of Se was present in the soil solution and/or bound to cation exchange sites in the soil. This amount of Se

Table 3. Physicochemical characteristics of the Conoco LTU (cell number 7) soil.

General Characteristics				
pH	Electrical Conductivity mmhos/cm	Calcium meq/l	Magnesium meq/l	Sodium meq/l
7.2	8.31	33.5	27.2	64.7
Sodium Adsorption Ratio	Sand %	Silt %	Clay %	Texture
11.7	38	38	24	Loam
Coarse Fragments %	Nitrate as N (KCL Extract) mg/kg	Phosphorous (NaHCO ₃ Extract) mg/kg	Potassium (NH ₄ Oac Extract) mg/kg	Selenium (ABDTPA Extract) mg/kg
< 2	210	92.7	887	12.1
Metals ¹ mg/kg				
Arsenic	Barium	Beryllium	Cadmium	Chromium
45.1	228	0.68	< 0.20	227
Cobalt	Copper	Lead	Mercury	Nickel
13.3	68.9	23.6	1.4	26.9
Selenium	Silver	Thallium	Vanadium	Zinc
27.3	< 0.5	< 1.0	48.7	216

¹ Data provided by Conoco via Quantera Laboratories using EPA method 6010B (Conoco, 2000; U.S.E.P.A., 1986).

could be potentially available for plant uptake as opposed to being in an insoluble, unavailable form.

Metal concentrations were within the range of natural soils with the exception of mercury, which was present at a concentration (1.4 mg/kg) approximately 10 times greater than the national average for loam soils (0.13 mg/kg) (Kabata-Pendias, 2001; Williams and Schuman, 1987). Metal toxicity was not expected to prevent plant growth.

Seed Germination

Relatively low germination rates were observed for cream and two-grooved milkvetch species, shadscale saltbush, Indian mustard, and desert prince's-plume (Table 4). However, these species were not eliminated from the study due to the possibility that they may require longer than a one month germination period.

Table 4. Results of seed germination test.

Plant Common Name	Germination
Selenium accumulating species	
Canola	100 %
Cream milkvetch	20 %
Desert prince's-plume	10 %
Indian Mustard	20 %
Shadscale saltbush	0 %
Two-grooved milkvetch	10 %
Selenium non-accumulators	
Cicer milkvetch	80 %
Pubescent wheatgrass	100 %
Tall fescue	100 %

Plant Density

Canola plants grown in phosphorous amended soil achieved a density that was significantly greater than all other species (Table 5). Canola grown on non-amended soil

Table 5. Plant densities (plants/m²) 8 weeks after seeding.

Plant Common Name	Replication				Mean
	1	2	3	4	
Selenium accumulating species					
Canola	536.0	216.0	368.0	472.0	398.0 b
Canola (on P amended soil)	760.0	668.0	598.0	588.0	653.5 a
Desert prince's-plume	112.0	118.0	78.0	96.0	101.0 d
Indian mustard	518.0	584.0	580.0	364.0	511.5 b
Selenium non-accumulators					
Cicer milkvetch	18.0	196.0	16.0	72.0	75.5 d
Pubescent wheatgrass	306.0	302.0	238.0	160.0	251.5 c
Tall fescue	330.0	196.0	262.0	200.0	247.0 c
Mean	368.6 a ¹	325.7 a	305.7 a	278.8 a	

¹ Means followed by the same letter, either in a row or column, are statistically the same ($P \leq 0.05$). ANOVA results are presented in Appendix C Table 55.

and Indian mustard had statistically similar densities that were significantly higher than that of prince's-plume and the three non-accumulating species. These data indicate that canola and Indian mustard have the greatest ability to establish on the LTU soil compared to the other species. Significantly greater plant density on phosphorous-amended soil than on non-amended soil indicates that phosphorous may mitigate an effect of the LTU soil that reduces plant germination and emergence.

Percent Canopy Cover

The seeding rate of 700 seeds/m² was believed to be sufficiently high to produce canopy cover in the range of 75 to 100 %. However no species produced a canopy cover greater than 50 % during the first growing season (Table 6). While 94 % of canola seeds

Table 6. Percent canopy cover at conclusion of first growing season.

Plant Common Name	Replication				Mean
	1	2	3	4	
Selenium accumulating species					
Canola	33.0	26.0	43.0	38.0	35.0 ab
Canola (on P amended soil)	73.5	43.0	38.0	38.5	48.2 a
Desert prince’s-plume	5.0	5.0	2.5	7.5	5.0 c
Indian mustard	10.0	29.0	45.0	17.0	25.2 b
Selenium non-accumulators					
Cicer milkvetch	2.5	5.0	2.5	2.5	3.1 c
Pubescent wheatgrass	59.5	30.5	28.5	7.5	31.5 ab
Tall fescue	33.5	15.0	14.5	12.0	18.8 bc
Mean	31.0 a ¹	21.9 a	24.8 a	17.8 a	

¹ Means followed by the same letter, either in a row or column, are statistically the same ($P \leq 0.05$). ANOVA results are presented in Appendix C Table 56.

grown on phosphorous-amended soil emerged, this species only produced 48.2 % canopy cover. These data indicate that the LTU soil may hinder plant development following germination and emergence.

Canola and Indian mustard plants failed to reestablish during the second growing season. Therefore, plant growth only occurred in plots containing prince's-plume, pubescent wheatgrass, and tall fescue during the second growing season. Canopy cover was again lower than expected, with wheatgrass and tall fescue producing a significantly greater canopy cover than desert prince's-plume (Table 7). Canopy cover production by desert prince's-plume was among the lowest of any species during each of the two growing seasons. This indicates that it may be difficult to establish a population of

Table 7. Percent canopy cover at conclusion of second growing season.

Plant Common Name	Replication				Mean
	1	2	3	4	
Selenium accumulating species					
Desert prince's-plume	2.5	2.5	5.0	5.0	3.8 b
Selenium non-accumulators					
Pubescent wheatgrass	97.5	46.5	47.5	12.0	50.9 a
Tall fescue	66.5	46.5	54.5	33.0	50.1 a
Mean	55.5 ¹ a	31.8 a	35.7 a	16.7 a	

¹ Means followed by the same letter, either in a row or column, are statistically the same ($P \leq 0.05$). ANOVA results are presented in Appendix C Table 57.

prince's-plume of adequate density for efficient phytoextraction of selenium from the LTU soil.

Aboveground Plant Production

Given the seeding rate that was used, the expected yield of Indian mustard was approximately 10 t/acre on a wet tissue basis (Banuelos, 2000, personal correspondence). Fresh plant tissue contains approximately 80 % water (Noggle, 1976), meaning that the expected yield of Indian mustard was approximately 447.0 g/m² (2 t/acre) of dry tissue. The actual yield of Indian mustard at the conclusion of the first growing season (259.2 g/m²) was 42 % less, indicating that selenium removal by Indian mustard may have been limited by sub-optimum biomass production by this species on the LTU soil.

All Se-accumulating species produced significantly more biomass than the non-accumulating species. However, this difference could be due to differences in plant morphology between the non-accumulating (grass) and the accumulating (forb) species

Table 8. Aboveground plant production at conclusion of first growing season.

Plant Common Name	Replication				Mean	
	1	2	3	4		
	g/m ² , dry weight basis					t/acre
Selenium accumulating species						
Canola	323.1	222.3	349.1	241.8	284.1 a	1.27
Canola (on P amended soil)	581.2	389.3	306.0	399.4	419.0 a	1.87
Indian mustard	105.7	259.1	398.4	273.4	259.2 a	1.16
Selenium non-accumulators						
Pubescent wheatgrass	40.9	22.7	16.9	2.1	20.6 b	0.09
Tall fescue	49.2	19.4	17.5	7.2	23.3 b	0.10
Mean	262.7 a ¹	182.6 a	217.6 a	184.8 a		

¹ Means followed by the same letter, either in a row or column, are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a natural log transformation was performed prior to analysis of variance. ANOVA results are presented in Appendix C Table 58.

rather than Se tolerance.

Production of cicer and two-grooved milkvetch as well as prince's-plume was not measured during the first growing season since the poor development of these species provided too little tissue to sample.

During the second growing season the production of biomass by desert prince's-plume plants was significantly less than by pubescent wheatgrass (Table 9). Tall fescue produced an amount of biomass that was not significantly different than either prince's-plume or wheatgrass. The minimal yield of prince's-plume provides more evidence that the efficiency of phytoextraction could be reduced due to a plant-growth limiting characteristic of the LTU soil. Canola and Indian mustard did not reestablish following the winter and therefore were not sampled during the second growing season.

Table 9. Aboveground plant production at conclusion of second growing season.

Plant Common Name	Replication				Mean	
	1	2	3	4		
	g/m ² , dry weight basis					t/acre
Selenium accumulating species						
Desert prince's-plume	0.03	0.7	7.8	6.4	3.7 b	0.02
Selenium non-accumulators						
Pubescent wheatgrass	266.2	147.2	53.0	84.3	137.6 a	0.61
Tall fescue	75.4	54.8	67.9	62.1	65.0 ab	0.29
Mean	113.9 a ¹	67.5 a	42.9 a	50.9 a		

¹ Means followed by the same letter, either in a row or column, are statistically the same ($P \leq 0.05$). ANOVA results are presented in Appendix C Table 59.

Plant Growth on Non-LTU and Non-irrigated Land

Based on a visual estimation, canola, Indian mustard, pubescent wheatgrass, and tall fescue plants grown outside the LTU on natural soil appeared approximately one third larger than those inside the LTU. While this comparison indicated that the LTU soil had a characteristic that suppressed plant development, it was discontinued approximately 5 weeks after emergence due to predation of the non-LTU plants by herbivores.

Cicer milkvetch, desert prince's-plume, and shadscale saltbush were not observed growing outside of the LTU. This indicates that the relatively low emergence observed for these species could be due to additional factors other than a limiting characteristic of the LTU soil.

No germination of non-irrigated plants was observed. This observation confirmed that these species could not establish on the LTU soil without supplemental irrigation.

Survival and Development of Two-grooved Milkvetch

On average, 43.8 % of the transplanted two-grooved milkvetch seedlings survived the five-week period following transplantation (Table 10). Surviving two-grooved

Table 10. Percentage of surviving two-grooved milkvetch five weeks after transplanting.

Plant Common Name	Replication				Mean
	1	2	3	4	
Two-grooved milkvetch	50.0	25.0	58.3	41.7	43.8

milkvetch plants displayed little to no additional growth after being transplanted to the LTU. No two-grooved milkvetch plant reached a height greater than 5 cm. There were no surviving two-grooved milkvetch plants observed during the second growing season. It is possible that plant mortality occurred as a result of high temperature and drought conditions present at the time of transplanting. The difficulty experienced in establishing two-grooved milkvetch is in agreement with previous findings (Bell et al., 1992; Duckart et al., 1992; Parker et al., 1991; Retana et al., 1993).

Plant Metal Concentrations

All species accumulated Se above a concentration of 5 mg/kg indicating that the LTU soil is capable of producing vegetation that poses a chronic Se toxicity hazard to livestock (NRC 1976, Underwood 1977) (Table 11). However, during the first growing season, no species accumulated Se above the concentration of 30 mg/kg common for most cultivated crop plants, grains, and native grasses grown on seleniferous soils

Table 11. Mean plant tissue metal concentrations (mg/kg, dry weight basis) at conclusion of first growing season.

Plant Common Name	Arsenic	Chromium	Lead	Selenium	Zinc
Selenium accumulating species					
Canola	10.1 ¹ a ²	0.6 a	5.4 a	6.8 b	86.8 b
Canola (on P amended soil)	11.5 a	1.6 a	5.4 a	7.6 b	91.0 b
Indian mustard	10.2 a	2.1 a	5.0 a	10.4 a	178.1 a
Selenium non-accumulators					
Pubescent wheatgrass	8.4 a	8.6 a	4.2 a	6.8 b	67.3 b
Tall fescue	13.4 a	3.1 a	5.8 a	5.9 b	72.8 b

¹ n = 4

² Means followed by the same letter are statistically the same for each metal ($P \leq 0.05$). Data for chromium and lead concentrations were not normally distributed therefore a natural log transformation was performed prior to analysis of variance. ANOVA results are presented in Appendix C Tables 60 through 64.

(Rosenfeld and Beath, 1964). While Indian mustard accumulated significantly more Se compared to any other species during the first growing season, at 10.4 mg/kg this amount is 96 % less than the 274 mg/kg reported by Banuelos et al. (1997a). The Se concentration measured in canola was 6.8 mg/kg, 98 % less than the 470 mg/kg accumulated by this species when grown on a soil with 40 mg total Se/kg (Banuelos et al, 1997b). These data indicate that ability of canola and Indian mustard to accumulate Se from the LTU soil was suppressed during the growing season.

The difference in Se concentration between canola and canola grown on phosphorous amended soil was not significantly different. This indicates that the amendment did not increase the plant availability of Se in the LTU soil.

Indian mustard accumulated significantly more zinc than any other species. There were no significant differences between species with respect to the amount of arsenic, chromium, or lead accumulated. There were no significant differences in the amount of metals accumulated between replications.

At the conclusion of the second growing season, desert prince's-plume had significantly greater concentrations of arsenic, lead, selenium, and zinc than either pubescent wheatgrass or tall fescue (Table 12). While prince's-plume accumulated more

Table 12. Mean plant tissue metal concentrations (mg/kg, dry weight basis) at conclusion of second growing season.

Plant Common Name	Arsenic	Chromium	Lead	Selenium	Zinc
Selenium accumulating species					
Desert prince's-plume	7.9 ¹ a ²	6.2 ab	5.6 a	111.6 a	343.5 a
Selenium non-accumulators					
Pubescent wheatgrass	4.2 b	0.6 c	3.0 b	7.6 b	38.6 b
Tall fescue	5.8 b	2.1 bc	4.0 c	9.0 b	65.6 b

¹ n = 4

² Means followed by the same letter are statistically the same for each metal ($P \leq 0.05$). ANOVA results are presented in Appendix C Tables 65 through 69.

Se than any other species during the field evaluation, at 111.6 mg/kg this amount is 91 % less than the 1200 mg/kg measured in the same species grown on a natural soil with 9 mg total Se/kg (Parker and Feist, 2001). These data, and those presented in Table 11 indicate that plant species known to be Se accumulators on other soils are limited in their ability to accumulate Se from the LTU soil.

Pubescent wheatgrass accumulated significantly less lead than desert prince's-plume or tall fescue. There was no significant difference between pubescent wheatgrass or tall fescue with respect to the amount of arsenic, chromium, selenium, or zinc accumulated.

Soil Metal Concentrations

Significantly greater concentrations of each metal were found in the 15 cm to 30 cm depth increment as compared to the 0 to 15 cm increment (Table 13). It is possible that a tillage practice or leaching has caused the lower depth increment to become enriched with metals during the operation of the LTU.

Table 13. Mean LTU soil metal concentrations (mg/kg) prior to plant seeding.

Depth (cm)	Arsenic	Chromium	Lead	Selenium	Zinc
0 – 15	30.8 ¹ b ²	141.6 b	23.6 b	15.5 b	171.1 b
15 - 30	38.0 a	177.7 a	28.7 a	21.6 a	200.5 a

¹ n = 44

² Means followed by the same letter are statistically the same for each metal ($P \leq 0.05$). Data for chromium were not normally distributed therefore a natural log transformation was performed prior to analysis of variance. ANOVA results are presented in Appendix C sections Tables 70 through 74.

Table 14 shows the mean soil metal concentrations during the first growing season prior to seeding and following plant harvest. Differences between pre-seeding and post-harvest soil metal concentrations were not significantly different than 0 mg/kg in all but one instance (Table 15). The exception, chromium in the 15 to 30 cm depth

Table 14. Mean pre-seeding and post-harvest soil metal concentrations (mg/kg).

Plant Common Name	Arsenic		Chromium		Lead		Selenium		Zinc	
	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm
	Pre-seeding									
Canola	32.5 ¹	45.1	132.5	151.3	23.5	29.1	16.5	23.7	167.0	201.8
Canola (on P amended soil)	33.6	34.5	142.5	205.0	24.8	32.3	17.9	19.9	177.8	209.0
Fallow	29.4	44.4	120.0	163.0	23.1	30.3	13.7	23.4	158.5	199.8
Indian mustard	27.8	36.6	152.9	232.5	22.7	32.8	13.6	20.8	175.8	230.8
Pubescent wheatgrass	36.1	40.4	126.8	140.0	24.0	26.5	18.8	23.7	174.0	187.5
Tall fescue	32.4	43.6	174.8	178.5	26.6	28.7	16.7	24.3	193.3	204.5
	Post-harvest									
Canola	28.0	40.5	132.0	190.0	23.5	30.2	12.3	22.5	164.0	217.3
Canola (on P amended soil)	29.7	31.2	146.8	179.7	24.0	84.3	14.3	21.3	172.8	221.0
Fallow	28.1	35.2	124.5	188.8	23.3	33.7	12.4	20.4	160.5	206.0
Indian mustard	30.2	38.7	164.5	209.8	25.2	27.5	14.3	22.8	188.0	217.3
Pubescent wheatgrass	30.7	35.2	167.2	177.2	24.3	26.0	14.2	20.1	187.3	195.5
Tall fescue	30.7	43.8	149.5	180.8	24.6	30.8	14.6	25.0	172.8	206.0

¹ n = 4

Table 15. Difference between pre-seeding and post harvest soil metal concentrations (mg/kg).

Plant Name	Arsenic		Chromium		Lead		Selenium		Zinc	
	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm
Canola	-4.5 ¹	-4.6	-0.5	38.7 ²	0.0	1.1	-4.2	-1.2	-3.0	15.5
Canola (on P amended soil)	-3.9	-3.3	4.3	-25.3	-0.8	52.0	-3.6	1.4	-5.0	12.0
Fallow	-1.3	-9.2	4.5	25.8	0.2	3.4	-1.3	-3.0	2.0	6.2
Indian mustard	2.4	2.1	11.6	-22.7	2.5	-5.3	0.7	2.0	12.2	-13.5
Pubescent wheatgrass	-5.4	-5.2	40.4	37.2	0.3	-0.5	-4.6	-3.6	13.3	8.0
Tall fescue	-1.7	0.2	-25.3	2.3	-2.0	2.1	-2.1	0.7	-20.5	1.5

¹ n = 4² Difference is statistically different than zero ($P \leq 0.05$). Paired t-test results are displayed in Appendix C Table 75.

increment of canola plots, was believed to be due to sampling variance and not an actual addition of chromium to this depth increment. These results show that phytoextraction did not cause a significant reduction of soil metals from the LTU soil.

Discussion

Using Equation 1, it is possible to calculate the amount of each metal that was extracted from the soil based on mean plant productivity data (Tables 8 and 9) and mean plant tissue metal concentration data (Tables 11 and 12). This calculation also requires

$$\begin{aligned} \text{Decrease in soil metal concentration (mg/kg)} &= \frac{\text{Plot area (m}^2\text{)}}{\text{Plot mass (kg)}} \times \frac{\text{Plant productivity (g)}}{1 \text{ m}^2} \times \frac{1 \text{ kg}}{1000 \text{ g}} \\ &\times \frac{\text{Metal in plant tissue (mg)}}{1 \text{ kg plant tissue}} \end{aligned} \quad \text{Equation 1.}$$

knowledge of the mass and area of a test plot. Given that each test plot measures 36 m² (0.0036 hectares) in area by 30 cm deep and assuming that one hectare of 15 cm depth weighs approximately 2,000,000 kg (Brady and Weil, 1999) the mass of each test plot can be calculated as 14,400 kg. Equation 1 can be reduced to yield Equation 2.

$$\begin{aligned} \text{Decrease in soil metal concentration (mg/kg)} &= \frac{2.5 \times 10^{-6} \times \text{Plant productivity (g/m}^2\text{)}}{\text{Plant tissue metal concentration (mg/kg)}} \end{aligned} \quad \text{Equation 2.}$$

The change in soil metal concentrations (mg metal/kg soil) that would be expected for each metal due to phytoextraction by each plant species is summarized in Table 16.

Table 16. Estimated decrease in soil metal concentrations (mg/kg) due to phytoextraction.

Plant Common Name	Arsenic	Chromium	Lead	Selenium	Zinc
First growing season					
Canola	7.1×10^{-3}	4.3×10^{-4}	3.8×10^{-3}	4.8×10^{-3}	6.2×10^{-2}
Canola (on P amended soil)	1.2×10^{-2}	1.7×10^{-3}	5.6×10^{-3}	8.0×10^{-3}	9.5×10^{-2}
Indian mustard	6.6×10^{-3}	1.4×10^{-3}	3.2×10^{-3}	6.7×10^{-3}	1.2×10^{-1}
Pubescent wheatgrass	4.3×10^{-4}	4.4×10^{-4}	2.1×10^{-4}	3.5×10^{-4}	3.5×10^{-4}
Tall fescue	7.8×10^{-4}	1.8×10^{-4}	3.4×10^{-4}	3.4×10^{-4}	4.2×10^{-3}
Second growing season					
Desert prince's-plume	7.3×10^{-5}	5.7×10^{-5}	5.2×10^{-5}	1.0×10^{-3}	3.2×10^{-3}
Pubescent wheatgrass	1.4×10^{-3}	2.1×10^{-4}	1.0×10^{-3}	2.6×10^{-3}	1.3×10^{-2}
Tall fescue	9.4×10^{-4}	3.4×10^{-4}	6.5×10^{-4}	1.5×10^{-3}	1.1×10^{-2}

Based on this calculation, it was estimated that phytoextraction removed very small quantities of metals from soil at the Conoco LTU. The greatest estimated decrease in metal concentration was a 0.12 mg/kg reduction in the amount of zinc in plots containing Indian mustard. This result confirms soil analysis data (Tables 14 and 15), indicating that no significant amount of metal was removed from the LTU soil during the field investigation.

The three Se-accumulating species - canola, desert prince's-plume, and Indian mustard - accumulated much less Se than was expected. Respectively, the Se concentrations measured in canola, Indian mustard, and prince's-plume were 6.8 mg/kg, 10.4 mg/kg, and 111.6 mg/kg. These are much lower than other reported concentrations of 470 mg/kg, 274 mg/kg, and 1200 mg/kg measured in these species

when grown on soils with total Se concentrations ranging from 9 to 40 mg/kg (Banuelos et al., 1997a; Banuelos et al., 1997b; Parker and Feist, 2001). Had canola accumulated 470 mg/kg of Se, a 0.33 mg/kg reduction of the soil Se level would have occurred with one harvest of this species (Equation 1). Had prince's-plume with a Se concentration of 111.6 produced the same amount of biomass as canola grown on phosphorous amended soil (419.0 g/m²), only a 0.12 mg/kg reduction in the soil Se concentration would have occurred with one harvest of prince's-plume.

Plant availability of Se is influenced by the oxidation state of this element present in the soil (Brooks, 1998). It is possible that much of the LTU soil Se is in a reduced form that is unavailable for plant uptake. Selenium in the Conoco waste slurry may be present in an unavailable form due to microbial reduction of selenate and selenite during the waste water treatment process from which the waste slurry emanates (Levine, 1925; Lortie *et al*, 1992; Oremland *et al*, 1989; Tomei *et al*, 1992).

The presence of sulfate in the soil is also known to reduce the amount of Se accumulated by a plant since sulfate competes for uptake at plant root uptake sites (Brooks, 1998; Williams and Thornton, 1972). While not performed under a quality assurance and control protocol, laboratory analysis indicated that the total sulfur concentration of the LTU soil is high, approximately 1000 mg/kg (Pasch, Intermountain Laboratories, 2000, personal correspondence). It is possible that a significant amount of the sulfur present in the LTU soil is in the sulfate form.

Plant uptake of Se is also influenced by soil properties such as the amount of clay or organic matter present (Bisbjerg and Nielsen, 1969). It is possible that the amount of

clay in the LTU soil (24 %) provides a sufficiently large cation exchange capacity to cause the adsorption of Se and subsequent unavailability to plants.

It appears that one or more of these or some other unidentified factor inhibited plant uptake of Se LTU soil during the field investigation.

GROWTH AND SELENIUM ACCUMULATION
OF PLANT SPECIES GROWN ON
FOUR DIFFERENT SUBSTRATES

The amount of selenium accumulated by plant species established on the LTU soil was less than expected. To determine whether the lower than expected Se uptake was due to factors associated with plant variety, soil characteristics, or Se speciation, Se-accumulating species were grown on four substrates inside a greenhouse.

The selenium accumulating ability of cream milkvetch and two-grooved milkvetch could not be determined during the field study due to the lack of aboveground tissue produced by these species. Kochia, a species of unknown Se accumulating ability, proliferated at the LTU. The greenhouse study provided data to assess the Se accumulating ability of these three species.

The variety of two-grooved milkvetch seeds grown at the LTU was collected from an unknown location in Canada. A source of two-grooved milkvetch seeds collected from naturally occurring seleniferous soils at the Chalk Bluff study site in Wyoming's Medicine Bow region was identified (Producers, 1991). The greenhouse study provided data to determine whether Se accumulation differed between the two-grooved milkvetch varieties.

Materials and Methods

Experimental Design

A randomized complete block experimental design was implemented at the Plant Growth Center at Montana State University, Bozeman. This design consisted of 7 different plant types grown in 4 substrates for total of 28 treatment combinations (Table 17), with 5 replicates of each.

Table 17. Greenhouse investigation treatment combinations.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
	Treatment Number			
Canola	1	8	15	22
Cream milkvetch	2	9	16	23
Indian mustard	3	10	17	24
Kochia	4	11	18	25
Prince's plume	5	12	19	26
Two-grooved milkvetch (Canada)	6	13	20	27
Two-grooved milkvetch (Wyoming)	7	14	21	28

The LTU soil was used as a substrate in this investigation (treatments 1 – 7). This substrate provided a control or reference for comparing the degree of Se accumulation that occurred in plants grown on the other three substrates. The LTU soil also provided

data to assess the Se-accumulating ability of kochia and three types of milkvetch plants (cream milkvetch, two-grooved milkvetch from Canada, and two-grooved milkvetch from Wyoming) that were not successfully established during the field investigation.

The second substrate (treatments 8 – 14) consisted of the LTU soil that had received an addition of sodium selenate. The use of this substrate provided data to determine whether plant-available Se was bound to the soil matrix or transformed to a non-available form when applied to the LTU soil.

A third substrate (treatments 15 – 21) was composed of silica sand amended with Conoco waste slurry. The use of this substrate provided data to assess whether Se present in the waste slurry is available to plants when not applied to the LTU soil.

The fourth substrate (treatments 22 – 28) consisted of silica sand that received an addition of Se in the form of sodium selenate. Selenate is the most plant available form of Se (Banuelos and Meek, 1990; Bisbjerg and Nielsen, 1969; Brooks, 1998). Sand has a limited ability to adsorb Se meaning that most of the Se in this substrate was present in the soil solution and not bound to the soil particles where it could be unavailable to plants (Brady and Weil, 1999). This substrate was used to confirm that plants selected for this investigation possess the ability to accumulate Se in situations where the element is most readily available to them.

This experimental design enabled the application of three-way analysis of variance (SPSS Inc., 1992-1997) so that a determination could be made as to which treatment combination resulted in the highest plant tissue Se concentration. This test of significance was completed at a 95 % probability level. Mean separations were analyzed using Fisher's LSD or the Tukey test (see Appendix C, Tables 76 – 84). This

experimental design also had the capability to account for any variability within the greenhouse, meaning that if a temperature gradient caused plants to accumulate more Se in replication 1 compared to replications 3 and 4, this variation could be statistically removed.

Substrate Preparation

A composite sample of the LTU soil was analyzed using the sequential extraction method of Se speciation described by Martens and Suarez (1997) (Table 18). Analysis indicated the total Se concentration of the LTU soil consisted of a relatively small amount

Table 18. Selenium speciation of the LTU soil.

Form of Selenium	mg/kg
Selenate	0.22
Selenite	0.62
Total selenium	18.3

of plant available Se (selenate and selenite). It was determined that selenate-enriched sand and selenate-enriched LTU soil would receive a 4 mg/kg addition of Se as sodium selenate. This amount was targeted since it represented a relatively small amount of available Se while remaining within the detection limits for soil analysis. All soils, including the control, were oven-dried at 20° C prior to amendment addition.

The selenate-enriched LTU substrate was created by dissolving 554.6 mg of 98 % pure sodium selenate (Na_2SeO_4) into 40 L of tap water. This solution was then

thoroughly mixed into 56.8 kg of oven dried LTU soil by adding the solution in two 20 L aliquots. The soil was allowed to air dry between solution additions. This amount of sodium selenate would provide a 4 mg/kg increase in the plant available selenium concentration in this substrate as compared to the non-spiked LTU soil. If no significant difference in plant tissue Se concentration was observed in selenate-enriched LTU soil than in the control, it would indicate that the LTU soil has the ability to immobilize Se that previously existed in a plant available form.

Waste slurry-enriched sand was created by mixing 68.8 kg of oven-dried silica sand with 78 L of waste slurry. The waste slurry was reported to have a Se concentration of 22 mg/L so this addition would provide a 25 mg/kg Se concentration in this particular substrate (Eggen, Conoco, 2000, personal correspondence). This substrate was intended to mimic the chemical conditions of the LTU soil while eliminating any effects due to naturally occurring soil characteristics.

The selenate-enriched sand substrate was created by mixing 724.0 mg of 98 % pure sodium selenate with 76.4 kg of oven dried silica sand in the same manner as was used to create the spiked LTU substrate. This amount of sodium selenate would provide a Se concentration of 4 mg/kg in the sand and provide data to confirm that the plant species possessed hyperaccumulating ability when Se was plant available.

A composite sample of each prepared substrate was analyzed using EPA methods 3050 and 6010B (U.S.E.P.A., 1986) to confirm that the Se concentration targets had been met. Measured and predicted Se concentrations differed in each substrate (Table 19). The fact that less Se was measured in the selenate-enriched LTU soil than in the control

Table 19. Measured and predicted selenium concentrations (mg/kg) in prepared substrates.

Substrate	Measured Selenium Concentration	Predicted Selenium Concentration
LTU (control)	19.9	18.3
LTU (selenate enriched)	17.2	22.3
Sand (selenate enriched)	9.8	4.0
Sand (waste slurry enriched)	7.1	25.0

LTU soil indicates that some degree of laboratory error or sample variability played a factor in these discrepancies.

The relatively large difference between the measured and predicted Se concentration of the waste slurry-enriched sand indicates that the Se concentration of the waste slurry may have been less than was believed prior to preparation of this substrate or perhaps Se volatilized from the waste slurry during substrate preparation. The waste slurry-enriched sand substrate was intended to provide an approximation of the chemical conditions in the LTU soil while eliminating interferences arising from naturally occurring soil conditions such as clay content and salinity. Since the Se concentration of the waste slurry-enriched sand was approximately 3 times less than the control, it is likely that other metal concentrations were similarly reduced. This means that any effect observed on LTU soil but not on waste slurry-enriched sand could be attributed to the higher metal concentration or a natural soil characteristic of the LTU soil. Since comparable Se concentrations were measured in waste slurry-enriched sand and

selenate-enriched sand, comparisons of the effect of Se source (waste slurry vs. selenate) were possible.

Plant Propagation

Plants were seeded on May 28, 2001. For each treatment combination, 20 seeds of the respective plant species were planted in a pot containing the respective substrate. Pots used in this investigation measured 17.8 cm in diameter by 17.8 cm in height.

Plants growing in silica sand were irrigated with 25 % Hoagland's nutrient solution with a pH of 7.3 (Hoagland and Arnon, 1950). Plants growing in LTU soil were irrigated with tap water. The pots were irrigated each day for the first three weeks after seeding. After this time the pots were irrigated every other day for two weeks then every third day for the duration of the investigation. Pots were placed inside plastic dishes so that any liquid that leached out of the pot could be collected and poured back into the pot to prevent the loss of selenium due to leaching.

Plants in were thinned to 5 per pot 28 days after the emergence of the first plant in that respective pot. The plants in any given pot were harvested when half of the plants present in the pot had flowered. Any remaining plants that did not reach the flowering stage were harvested on September 17, 2001.

Measurement of Plant Emergence and Survival

For each pot, the number of days that elapsed between seeding and emergence of the first plant was recorded. The total number of seedlings that emerged during the investigation was also monitored and recorded. In instances where no germination was observed in a given pot, a value of 110 elapsed days was recorded since this is the total

number of days that passed during the greenhouse investigation. The number of surviving plants in each pot was recorded fourteen days after emergence of the first plant and immediately prior to thinning. These measurements provided data to indicate the ability of each plant species to establish on each substrate.

Measurement of Plant Height

The plants were measured and the mean plant height in each pot was recorded. Plant height measurement was performed twice during the investigation; 14 days after emergence of the first plant in each pot and prior to harvesting the plants. This measurement provided data to indicate the ability of each plant species to grow on each substrate.

Measurement of Average Root Depth

After harvesting the plants, the average root depth in each pot was measured. This measurement provided data that indicated the soil depth from which metals can be extracted by each plant species as well as whether root development played a significant role in the ability of a plant to extract soil selenium.

Measurement of Plant Metal Concentrations

Plants were collected and submitted for laboratory analysis of selenium by clipping the plants 1 cm from ground level with stainless steel scissors, placing the plants in paper bags then immediately storing them in a freezer for at least one week. The frozen plants were processed and analyzed following identical methods as those discussed in Chapter 2 (Table 3).

Measurement of Aboveground Plant Production

The frozen plants were weighed immediately prior to pulverizing them for laboratory submittal. The average plant weight was calculated and then converted to a dry weight value using the percent moisture correction factor that was determined by the analytical lab during metal analysis.

Quality Assurance of Sampling and Analysis Methods

Methods employed to assess the degree of precision, accuracy, and cross contamination during sampling and analysis discussed in Appendix A.

Evaluation of Plant Growth

Number of Days Until Emergence

Significantly earlier emergence occurred when plants were seeded into selenate-enriched sand compared to all other substrates (Table 20). This indicates that the Conoco waste slurry delayed plant emergence. Emergence in each substrate containing the LTU soil was significantly later than in other substrates. This may indicate that the LTU soil had phytotoxic properties beyond those caused by the waste slurry. However, the level of Se (and thus other chemical constituents) in waste slurry-enriched sand was approximately three fold less than in LTU soil derived substrates. Therefore it is possible that later emergence in LTU soil substrates was due to increased metal concentrations rather than complications due to the soil matrix.

Table 20. Mean number of days elapsing between seeding and germination.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	5.2 ¹	6.8	5.8	5.2
Cream milkvetch	9.8	55.2	14.0	26.6
Indian mustard	6.2	52.4	8.0	5.8
Kochia	5.6	6.6	7.4	4.0
Prince's-plume	110.0	110.0	20.2	13.4
Two-grooved Milkvetch (Canada)	7.4	52.0	17.2	5.8
Two-grooved Milkvetch (Wyoming)	7.0	12.8	12.8	5.6
Mean	21.6 a ²	42.3 a	12.2 b	9.5 c

¹ n = 5² Means followed by the same letter are statistically the same ($P \leq 0.05$). ANOVA results are displayed in Appendix C Table 76.

Number of Emerged Plants

Seedling emergence was significantly greater in selenate-enriched sand than in all other substrates (Table 21). This indicates that the Conoco waste slurry has a phytotoxic effect that suppressed plant emergence. The significantly lowest emergence occurred in selenate-enriched LTU soil indicating that an increase of plant available Se to the LTU soil may cause a greater degree of phytotoxicity compared to the control.

Plant Survival

Plant survival was significantly greater in selenate-enriched sand than in all other substrates (Tables 22 and 23). This indicates that the Conoco waste slurry has a characteristic that suppressed plant establishment. The significantly lowest survival

Table 21. Mean percent emergence during greenhouse investigation.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	82.0 ¹	30.0	54.0	91.0
Cream milkvetch	10.0	5.0	13.0	23.0
Indian mustard	47.0	10.0	38.0	72.0
Kochia	49.0	32.0	32.0	61.0
Prince's-plume	0.0	0.0	16.0	10.0
Two-grooved Milkvetch (Canada)	22.0	3.0	17.0	36.0
Two-grooved Milkvetch (Wyoming)	34.0	16.0	22.0	66.0
Mean	35.0 b ²	13.5 c	27.5 b	51.5 a

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a square root transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 77.

Table 22. Mean percent survival 14 days after germination.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	80 ¹	28	47	91
Cream milkvetch	6	4	9	18
Indian mustard	40	9	44	71
Kochia	42	23	29	57
Prince's-plume	0	0	11	8
Two-grooved Milkvetch (Canada)	20	1	15	37
Two-grooved Milkvetch (Wyoming)	29	13	15	59
Mean	31 b ²	11 c	24.5 b	48.5 a

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a square root transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 78.

Table 23. Mean percent survival 28 days after germination.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	75 ¹	27	48	89
Cream milkvetch	7	4	11	19
Indian mustard	40	9	38	71
Kochia	45	32	32	52
Prince's-plume	0	0	15	8
Two-grooved Milkvetch (Canada)	19	1	14	36
Two-grooved Milkvetch (Wyoming)	31	14	18	63
Mean	31 b ²	12.5 c	25 b	48.5 a

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a rank transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 79.

occurred in selenate-enriched LTU soil indicating that an increase of plant available Se to the LTU soil may cause a greater degree of phytotoxicity compared to the control. Mean plant survival did not decrease between 14 and 28 days following germination. In addition, little plant mortality was observed following plant thinning. This indicates that plant survival is limited more by the ability of species to germinate and emerge in waste slurry enriched soil than by mortality of established plants.

Plant Height

Plant height was significantly greater in waste slurry-enriched sand than in all other substrates 14 days after germination (Table 24). It is possible that waste slurry promoted initial growth in established plants, it may also be that increased plant growth

Table 24. Mean plant height (mm) in each substrate 14 days after germination.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	24.0 ¹	23.1	26.4	13.5
Cream milkvetch	2.6	6.0	4.4	5.4
Indian mustard	18.2	8.9	17.4	8.0
Kochia	24.6	14.0	24.4	13.5
Prince's-plume	0.0	0.0	5.5	2.5
Two-grooved Milkvetch (Canada)	2.4	0.4	7.4	3.1
Two-grooved Milkvetch (Wyoming)	2.8	10.2	10.2	10.6
Mean	10.7 b ²	9.0 b	13.7 a	8.1 b

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a square root transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 80.

was a response to some stress caused by the waste slurry. It appears that the higher concentration of waste slurry in the LTU soil or a naturally occurring characteristic of this soil reduced the growth promoting effect of the waste slurry. This indicates the possibility that the LTU soil immobilized plant nutrients or other elements making them unavailable for plant uptake.

Plants contained in replication 1 were significantly taller 14 days after emergence than plants in the other 4 replications (Table 25). Replication 1 received less sunlight than other replications due to the positioning of ventilation ductwork. The difference in plant height at this early growth stage was attributed to a morphological response to low light intensity.

Table 25. Mean plant height (mm) in each replication 14 days after germination.

Replication				
1	2	3	4	5
14.1 ¹ a ²	11.2 b	8.4 b	9.2 b	8.9 b

¹ n = 28

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a square root transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 80.

At harvest, plants grown in waste slurry-enriched sand and selenate-enriched sand reached a statistically identical height that was significantly greater than that of plants on either of the LTU soil based substrates (Table 26). There was no significant difference in

Table 26. Mean plant height (mm) in each substrate immediately prior to plant harvest.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	239.7 ¹	373.6	386.8	268.8
Cream milkvetch	9.7	29.0	63.8	75.0
Indian mustard	190.7	199.6	385.2	393.6
Kochia	436.1	292.5	564.4	374.2
Prince's-plume	0.0	0.0	143.7	146.6
Two-grooved Milkvetch (Canada)	9.0	12.0	76.8	144.1
Two-grooved Milkvetch (Wyoming)	31.7	67.6	94.6	176.2
Mean	131.0 b ²	139.2 b	245.0 a	225.5 a

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a square root transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 81.

plant height between the two LTU soil based substrates. This may indicate that the LTU soil had phytotoxic properties beyond those caused by the waste slurry. However, the level of Se (and thus other chemical constituents) in waste slurry-enriched sand was approximately three fold less than in LTU soil derived substrates. Therefore it is possible that reduced plant height in LTU soil substrates was due to increased metal concentrations rather than complications due to the soil matrix.

Average Root Depth

Plant roots grew significantly deeper in selenate-enriched sand than in waste slurry-enriched sand (Table 27). This means that waste slurry may be phytotoxic to plant roots causing them to become concentrated shallower in the root zone. Root depths were

Table 27. Mean plant root depth (mm) in each substrate following plant harvest.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	91.6 ¹	84.0	78.6	97.0
Cream milkvetch	7.0	16.0	66.0	71.0
Indian mustard	84.8	46.2	87.8	86.6
Kochia	91.4	83.6	86.8	65.6
Prince's-plume	0.0	0.0	85.2	74.6
Two-grooved Milkvetch (Canada)	6.0	18.0	70.0	90.0
Two-grooved Milkvetch (Wyoming)	49.0	49.0	90.0	91.8
Mean	47.1 c ²	42.4 c	80.6 b	82.4 a

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore the raw data were standardized and then the original raw data values were multiplied by the standardized values prior to analysis of variance. ANOVA results are displayed in Appendix C Table 82.

significantly shallowest in the two substrates composed of the LTU soil. It appears that the higher concentration of waste slurry in the LTU soil or a naturally occurring characteristic of this soil further inhibits root penetration compared to the waste slurry enriched sand. The soil depth in a given pot ranged from 70 to 90 mm therefore, in instances where the average root depth falls in this range, it is possible that root growth was impeded and may have been greater if taller pots had been used.

Aboveground Plant Production

Plants grown on either of the two substrates composed of sand produced a statistically similar amount of biomass that was significantly greater than that of plants grown on LTU soil based substrates (Table 28). While differences did not exist at the 95

Table 28. Mean aboveground plant production (g dry tissue/plant) in each substrate.

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	0.97 ¹	2.03	0.92	1.27
Cream milkvetch	0.02	0.05	0.17	0.36
Indian mustard	1.08	0.51	0.61	0.98
Kochia	1.57	0.85	2.06	1.45
Prince's-plume	0.00	0.00	1.24	2.13
Two-grooved Milkvetch (Canada)	0.00	0.03	0.20	0.62
Two-grooved Milkvetch (Wyoming)	0.07	0.14	0.21	0.69
Mean	0.53 b	0.52 b	0.77 a	1.07 a

¹ n = 5

² Means followed by the same letter are statistically the same ($P \leq 0.05$). These data were not normally distributed therefore a rank transformation was performed prior to analysis of variance. ANOVA results are displayed in Appendix C Table 83.

% probability level, all plants except kochia produced 32 to 72 % more biomass when grown on selenate-enriched sand compared to waste slurry enriched sand. These data indicate that the waste slurry inhibited the ability of plants to develop. Plant development may have been further inhibited by a natural characteristic of the LTU soil and/or the relatively higher waste slurry concentration found the LTU soil compared to the waste slurry-enriched sand substrate.

Discussion

The data presented in the Evaluation of Plant Growth section indicate that the LTU soil impaired plant growth, possibly due to enriched metal concentrations or another characteristic of this soil. Plant germination and survival decreased when plants were grown in the presence of the waste slurry.

Evaluation of Selenium Accumulation

Cream milkvetch, prince's-plume, and the Canadian variety of two-grooved milkvetch failed to establish on LTU soil based substrates in all replications. Two-way analysis of variance was used to examine differences in Se concentrations between substrates for an individual species. Differences in Se accumulation between species in individual substrates were similarly examined.

Differences in Selenium Accumulation Between Substrates

All plants accumulated significantly more Se when grown in selenate- enriched sand compared to all other substrates (Table 29). With the exception of kochia, plant

Table 29. Mean plant tissue selenium concentration (mg/kg dry tissue basis) in four different substrates (comparison of similar plant species in different substrates).

Plant Common Name	Substrate			
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand
Canola	13.8 ⁵ c ⁶	63.8 ⁵ b	42.7 ⁵ bc	692.8 ⁵ a
Cream milkvetch	No data	No data	106.6 ⁵ b	941.3 ⁵ a
Indian mustard	18.0 ⁵ b	76.0 ³ b	63.7 ⁵ b	836.2 ⁵ a
Kochia	5.5 ⁵ b	12.4 ⁵ b	17.0 ⁵ b	202.6 ⁴ a
Prince's-plume	No data	No data	19.4 ⁵ b	634.2 ⁴ a
Two-grooved Milkvetch (Canada)	No data	No data	11.4 ³ b	525.4 ⁵ a
Two-grooved Milkvetch (Wyoming)	3.4 ¹ c	44.0 ² b	16.6 ⁴ b	905.2 ⁵ a
Mean	10.2	49.0	43.0	683.9

¹ n = 1, ² n = 2, ³ n = 3, ⁴ n = 4, ⁵ n = 5

⁶ Means followed by the same letter are statistically the same ($P \leq 0.05$) in each respective row. Due to an unbalanced data set, two way analysis of variance was performed in order to examine differences between substrates within each plant species. ANOVA results are displayed in Appendix C Table 84.

tissue Se concentrations ranged between 525.4 and 941.3 mg/kg in the selenate-enriched sand substrate indicating that these species can accumulate Se into the high end of the range expected for secondary accumulators (Rosenfeld and Beath, 1964). The milkvetch species used in this study have been classified as primary accumulators in other reports (Beath *et al*, 1939; Rosenfeld and Beath, 1964). It is possible that these species may have accumulated Se above the 1000 mg/kg threshold that defines primary accumulation had more Se been added to the selenate-enriched sand substrate.

With no plant tissue Se concentration greater than 18 mg/kg, Se accumulation on the LTU soil was 98.5 % less than on selenate-enriched sand. This means that primary

and secondary Se accumulators (milkvetch vs. canola or Indian mustard, respectively) were unable to accumulate Se to a concentration higher than that of a typical non-accumulator when grown on the LTU soil. Other than cream milkvetch, no species accumulated more than 100 mg/kg of Se from any substrate containing waste slurry. Since more Se was accumulated from selenate-enriched sand than from waste slurry-enriched sand despite similar soil Se concentrations in these substrates (9.8 and 7.1 mg/kg respectively) it appears that Se is much less available to plants when emanating from the waste slurry as compared to sodium selenate.

The control LTU soil had a 3 fold greater soil Se concentration than waste slurry- enriched sand. However two-grooved milkvetch from Wyoming accumulated significantly more Se from the sand-based substrate than from the control, while all other species displayed a numerical increase in Se concentration. This indicates that some characteristic of the LTU soil, such as sulfur or clay content, is acting antagonistically toward Se uptake by plants.

Selenium accumulation was significantly less in selenate-enriched LTU soil than in selenate-enriched sand. These data provide more evidence that plant available Se became less available when applied to the LTU soil.

Canola and the Wyoming variety of two-grooved milkvetch accumulated significantly more Se from the selenate-enriched LTU soil than the control. Indian mustard and kochia also accumulated more Se from the selenate-enriched LTU soil than from the control, although these differences were numeric and not significant. These data indicate that some amount of the selenate added to the enriched LTU soil remained

available for plant uptake. This means that while the LTU soil decreases Se availability, it does not make this element completely unavailable to plants.

Selenium Accumulation in Kochia and Ecotypic Variation in Two-Grooved Milkvetch

Kochia accumulated an average of 59.4 mg/kg Se in its tissue and only 202.6 mg/kg when grown in selenate-enriched sand, indicating that this species could be classified as a non-accumulator of Se (Table 30).

No significant differences were observed with respect to Se accumulation between the two varieties of two-grooved milkvetch, although the Wyoming

Table 30. Mean plant tissue selenium concentrations (mg/kg dry tissue basis) in four different substrates (comparison of different plant species in similar substrate).

Plant Common Name	Substrate				Mean
	LTU Soil	Selenate Enriched LTU Soil	Waste Slurry Enriched Sand	Selenate Enriched Sand	
Canola	13.8 ⁵ a ⁶	63.8 ⁵ a	42.7 ⁵ ab	692.8 ⁵ a	203.3
Cream milkvetch	No data	No data	106.6 ⁵ a	941.3 ⁵ a	523.9
Indian mustard	18.0 ⁵ a	76.0 ³ a	63.7 ⁵ a	836.2 ⁵ a	248.5
Kochia	5.5 ⁵ a	12.4 ⁵ b	17.0 ⁵ b	202.6 ⁴ b	59.4
Prince's-plume	No data	No data	19.4 ⁵ b	634.2 ⁴ ab	326.8
Two-grooved Milkvetch (Canada)	No data	No data	11.4 ³ b	525.4 ⁵ ab	268.4
Two-grooved Milkvetch (Wyoming)	3.4 ¹ a	44.0 ² ab	16.6 ⁴ b	905.2 ⁵ a	242.3

¹ n = 1, ² n = 2, ³ n = 3, ⁴ n = 4, ⁵ n = 5

⁶ Means followed by the same letter are statistically the same ($P \leq 0.05$) in each respective column. Due to an unbalanced data set, two way analysis of variance was performed in order to examine differences between plant species within each substrate. ANOVA results are displayed in Appendix C Table 84.

variety generally accumulated greater concentrations of Se in its tissue. These data do not confirm that two-grooved milkvetch possesses ecotypic variation with respect to Se-accumulating ability.

SUMMARY AND CONCLUSION

Slurry emanating from an oil refinery wastewater treatment system was incorporated into soil at the Conoco Land Treatment Unit (LTU) in Billings, Montana since 1972. As a result, the soil had received additions of various elements including arsenic (34.4 mg/kg), chromium (159.6 mg/kg), lead (26.2 mg/kg), selenium (18.6 mg/kg), and zinc (185.8 mg/kg). This soil was saline (8.3 mmhos/cm), had a loam texture, and a pH of 7.2. Since the soil Se concentration approached a threshold established by the state regulatory authority, the use of Se-accumulating plant species to decrease the soil Se concentration was evaluated. The objectives of this study were to identify Se accumulating plant species that will grow at the LTU, identify a seed source for plant species to be tested, determine which plant species accumulate the most Se at the LTU site, and determine the amount of Se and other metals removed from the soil by phytoextraction.

An extensive review of the scientific literature lead to the identification of plant species that posses the ability to accumulate high levels of Se and could be found growing in Montana or bordering regions. Commercially available seeds were ordered from suppliers in the Rocky Mountain and Great Plains regions. Seeds that were not commercially available were obtained in limited amounts (i.e., less than 30 grams) through the United States Department of Agriculture's National Plant Germplasm System.

Selenium-accumulating plant species (canola, desert prince's-plume, and Indian mustard) and Se non-accumulating species (pubescent wheatgrass and tall fescue) were seeded at the LTU and harvested upon maturity. Canola and Indian mustard showed the greatest ability to establish on the LTU soil.

No significant change in soil metal concentration was measured. Based on scientific literature, it was expected that the Se- accumulating species would have tissue Se concentrations in the range of 300 to 2000 mg/kg (Banuelos et al., 1997a; Banuelos et al., 1997b; Rosenfeld and Beath, 1964). However plant tissue Se concentrations in canola (6.8 mg/kg), canola grown on phosphorous amended soil (7.6 mg/kg), Indian mustard (10.4 mg/kg), and desert prince's-plume (111.6 mg/kg) were considerably lower than expected. All species, including non-accumulating controls, reached Se concentrations that were great enough to present a chronic toxicity hazard to grazing animals (NRC 1976, Underwood 1977). It was calculated that the greatest decrease in metal concentration was a 0.12 mg/kg reduction in the concentration of zinc in soil containing Indian mustard.

To determine whether lower than expected Se accumulation was due to plant species, soil characteristics, or a characteristic of the waste slurry, Se-accumulating plant species were grown in a laboratory setting in four different substrates; i) the LTU soil, ii) selenate-enriched LTU soil, iii) waste slurry-enriched sand, and iv) selenate-enriched sand. Mean plant tissue selenium concentration in each substrate was 10.2 ± 6.5 mg/kg, 49.0 ± 27.8 mg/kg, 43.0 ± 37.5 mg/kg, and 683.9 ± 423.1 mg/kg, respectively. Plant Se concentrations in selenate enriched sand were within the expected range for Se accumulators and significantly greater than in the other three substrates that received

waste slurry as their principle supply of Se. This indicated that the plant species selected for the study did possess Se-hyperaccumulating ability and that Se in the waste slurry had limited plant availability when applied to soil.

While Se in the waste slurry treated sand and LTU soil was of limited availability, data indicated that Se availability was limited to a greater extent in the LTU soil. The control LTU soil had a 12.8 mg/kg greater total soil Se concentration than waste slurry-enriched sand. However Se accumulation by all species was generally higher in the sand-based substrate and significantly higher for two-grooved milkvetch from Wyoming with a tissue Se concentration of 16.6 mg/kg in the sand-based substrate and 3.4 mg/kg in the control. Additionally, significantly less Se was accumulated from selenate-enriched LTU soil (49.0 ± 27.8 mg/kg) than from selenate-enriched sand (683.9 ± 423.1 mg/kg) despite an equal amount of selenate having been added to each of these substrates.

While not performed under a quality assurance and control protocol, laboratory analysis indicated that the total sulfur concentration of the LTU soil was high, approximately 1000 mg/kg (Pasch, Intermountain Laboratories, 2000, personal correspondence). Presence of sulfate in a soil is known to reduce the amount of Se accumulated by a plant since sulfate competes for uptake at plant root uptake sites (Brooks, 1998; Williams and Thornton, 1972). Given the relatively high sulfur content in the LTU soil, it is possible that sulfate may have further limited Se uptake by plants.

In conclusion, successful phytoextraction of Se from the Conoco LTU soil was limited by low plant availability. When applied to soil, the Conoco waste slurry i) contained a form of Se that was in a reduced oxidation state and thus unavailable for

plant uptake and/or ii) another chemical constituent was present that competed with Se for plant uptake.

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APPENDICES

APPENDIX A

ANALYTICAL ACCURACY, PRECISION, AND CROSS CONTAMINATION

AccuracySoil Metal Analysis

In order to assess laboratory accuracy during soil metal analysis, a National Institute of Standards and Technology (NIST) standard reference material (NIST SRM number 2709, San Joaquin Soil) was submitted with the soil samples collected from the LTU during the spring 2000 (pre-seeding) and summer 2000 (post-harvest) soil sampling events. Table 31 shows the metal concentrations of the reference material reported by the NIST as well as the concentrations measured by the analytical laboratory during each sampling event. Method detection limits and the average percent recoveries of laboratory

Table 31. Percent recovery of soil metals from standard reference material and laboratory matrix spikes.

	Arsenic	Chromium	Lead	Selenium	Zinc
mg/kg					
Actual concentration in reference material (Gills, 1993)	< 20	79.0	13.0	0.014	100
Method detection limit	0.33	0.12	0.12	0.38	0.35
Measured concentration					
Spring soil sampling event	13.7	49.3	10.5	Not detected	79.9
Percent recovery	68.5	62.4	80.8	N/A ⁴	79.9
Summer soil sampling event	14.2	55.5	11.0	Not detected	86.3
Percent recovery	80.2	70.2	84.6	N/A	86.3
Average percent recovery of laboratory matrix spikes	89.3 ¹	106.3 ²	87.5 ¹	88.6 ¹	94.5 ³

¹ n = 15

² n = 3

³ n = 13

⁴ N/A = not applicable

matrix spikes for each metal are also given. Because the arsenic concentration of the standard is reported by the NIST as an unspecified value below 20 mg/kg and because the selenium concentration of the standard is below the method detection limit, it is difficult to assess laboratory accuracy for these metals based on percent recoveries for the standard reference material. However the percent recovery of chromium, lead, and zinc for the standard suggest that the lab detected lead and zinc to within 25 % of the true concentration while detection of chromium was lower. Based on the percent recovery of laboratory matrix spikes it appears that the laboratory detected each metal to within 25 % of the true value.

Plant Tissue Metal Analysis

No standard reference material was available in a fresh plant tissue matrix. At the time of this investigation, no standard reference material containing the range of selenium concentrations that was expected to occur in the field samples was available in a dry plant tissue matrix. Therefore it was necessary to use the percent recovery of laboratory matrix spikes to assess the degree of accuracy during plant tissue metal analysis (Table 32). The laboratory was able to measure each metal to within 12.5 % of the spiked amount.

Table 32. Average percent recovery of laboratory matrix spikes during plant tissue metal analysis.

	Arsenic	Chromium	Lead	Selenium	Zinc
Average percent recovery of laboratory matrix spikes					
Summer 2000 plant sampling event	92.5 ¹	98.7 ¹	98.3 ¹	94.2 ¹	94.0 ¹
Summer 2001 plant sampling event	87.5 ²	102.5 ²	103.0 ²	93.5 ²	105.5 ²
Greenhouse investigation	Not analyzed	Not analyzed	Not analyzed	91.3 ³	Not analyzed

¹ n = 6

² n = 2

³ n = 12

Precision

Soil Metal Analysis

In order to assess the precision of the soil metal analytical methods, duplicate soil samples were submitted during each soil sampling event. Table 33 lists the metal concentrations measured in the original and duplicate samples, the relative percent difference that was calculated between each pair of values, and the average relative percent difference for each metal during each sampling event. The average relative percent difference that was calculated for these samples is below 25% for each metal with the exception of chromium in soil samples collected during spring 2000 which have an average relative percent difference of 28.3 %.

Table 33. Metal concentrations measured in original and duplicate soil samples.

Sample identification	Arsenic	Chromium	Lead	Selenium	Zinc
mg/kg					
Spring 2000 soil sampling event					
R1P8D2 original	33.9	107.0	22.8	23.1	149.0
R1P8D2 duplicate	41.6	182.0	30.0	25.8	223.0
Relative percent difference	20.4	51.9	27.3	11.0	39.8
R2P4D2 original	39.4	167.0	26.7	23.0	200.0
R2P4D2 duplicate	31.0	127.0	21.3	18.6	151.0
Relative percent difference	23.9	27.2	22.5	21.2	27.9
R3P2D1 original	26.7	81.6	17.8	12.2	127.0
R3P2D1 duplicate	25.7	77.0	16.6	12.6	121.0
Relative percent difference	3.8	5.8	7.0	3.2	4.8
Average relative percent difference	16.0	28.3	18.9	11.8	24.2
Summer 2000 soil sampling event					
R1P1D2 original	42.3	201.0	33.8	27.3	217.0
R1P1D2 duplicate	35.9	179.0	30.8	23.6	198.0
Relative percent difference	16.4	11.6	9.3	14.5	9.2
R1P4D1 original	25.5	142.0	24.1	12.1	161.0
R1P4D1 duplicate	23.8	121.0	27.8	10.5	141.0
Relative percent difference	6.9	16.0	14.3	14.2	13.2
R4P9D1 original	44.2	161.0	28.2	21.8	215.0
R4P9D1 duplicate	38.6	153.0	26.2	17.3	195.0
Relative percent difference	13.5	5.1	7.4	23.0	9.8
Average relative percent difference	12.3	10.9	10.3	17.2	10.7

Plant Metal Analysis

The precision of plant tissue metal analysis was assessed by comparing the metal concentrations that were measured in original and duplicate samples. Table 34 displays these comparisons for plant samples collected during the field investigation. The average relative percent difference exceeded 25 % for arsenic and chromium in plants sampled

Table 34. Metal concentrations measured in original and duplicate plant samples collected during the field investigation.

Sample identification	Arsenic	Chromium	Lead	Selenium	Zinc
mg/kg					
Summer 2000 plant tissue sampling event					
R1P4 original	23.5	1.6	5.6	5.9	78.5
R1P4 duplicate	20.4	1.4	5.6	6.7	73.9
Relative percent difference	14.1	13.3	0	12.7	6.0
R4P10 original	6.2	5.2	10.1	6.1	81.6
R4P10 duplicate	18.7	8.4	5.0	6.0	91.5
Relative percent difference	100.4	47.1	67.6	1.65	11.4
R4P11 original	7.4	0.6	5.2	9.8	104.0
R4P11 duplicate	7.9	1.4	5.6	8.3	117.0
Relative percent difference	6.5	80.0	7.4	16.6	11.8
Average relative percent difference	40.3	46.8	25.0	10.3	9.7
Summer 2001 plant tissue sampling event					
R4P6 original	7.6	4.3	5.4	74.0	322
R4P6 duplicate	7.8	4.2	5.5	58.3	218
Relative percent difference	2.6	2.4	1.8	23.7	38.5

during the summer of 2000 as well as zinc in plants sampled during the summer of 2001.

All other plant analysis had average relative percent differences below 25 %.

Table 35 displays the relative percent differences that were calculated for plant tissue selenium concentrations measured in plants sampled during the greenhouse investigation. The average relative percent difference of selenium analysis during the greenhouse investigation was below 25 %.

Table 35. Selenium concentrations measured in original and duplicate plant samples collected during the greenhouse investigation.

Sample identification	Selenium
mg/kg	
R2BNR original	16.8
R2BNR duplicate	13.6
Relative percent difference	21.0
R3BNY original	440
R3BNY duplicate	797
Relative percent difference	57.7
R3SPY original	896.0
R3SPY duplicate	797.0
Relative percent difference	11.7
R4BNR original	47.6
R4BNR duplicate	43.2
Relative percent difference	9.7
R5BNY original	974
R5BNY duplicate	844
Relative percent difference	14.3
Average relative percent difference	22.9

Cross contamination

The degree of cross contamination that occurred during soil sampling was assessed by submitting cross contamination and bottle blanks for metal analysis during each soil sampling event. Cross contamination blanks consisted of silica sand that was poured over the equipment used for soil sampling at the end of the sampling day. An uncontaminated bottle blank consisted of silica sand that had not been exposed to the sampling equipment.

Table 36 shows the metal concentrations measured in cross contamination and bottle blanks. These data indicate that no measurable amount of cross contamination

Table 36. Metal concentrations measured in cross contamination and bottle blanks.

	Arsenic	Chromium	Lead	Selenium	Zinc
mg/kg					
Spring soil sampling event					
Cross contamination blank	0.16	0.06	0.38	0.19	2.20
Bottle Blank	0.16	0.06	0.51	0.19	0.18
Difference	0	0	-0.13	0	2.02
Summer soil sampling event					
Cross contamination blank	0.16	0.06	0.38	0.19	2.8
Bottle Blank	0.16	0.06	0.51	0.19	2.0
Difference	0	0	-0.13	0	0.8

occurred during soil sampling with respect to arsenic, chromium, lead, or selenium. A minimal amount (2.0 mg/kg) of zinc cross contamination may have occurred during soil sampling.

Discussion

The data presented in this section indicate that some degree of error is present with respect to analytical precision and accuracy during soil and plant analysis. However this error is not believed to be of a magnitude sufficient to invalidate the data used to make determinations pertaining to the objectives of this investigation.

APPENDIX B

RAW DATA TABLES

Raw data from field investigation

Table 37. Number of emerged plants in each sampling frame 8 weeks after seeding.

Plant name	Frame number				
	1	2	3	4	5
	Number of emerged plants				
Replication 1					
Canola	55	49	37	37	90
Canola [P]	74	86	123	55	42
Cicer milkvetch	0	0	8	0	1
Desert prince's-plume	14	22	7	11	2
Indian mustard	119	62	26	16	36
Pubescent wheatgrass	8	41	51	42	11
Tall fescue	2	72	51	28	12
Replication 2					
Canola	29	38	2	15	24
Canola [P]	133	57	89	19	36
Cicer milkvetch	6	41	24	25	2
Desert prince's-plume	1	5	4	43	6
Indian mustard	14	130	105	34	9
Pubescent wheatgrass	50	31	33	9	28
Tall fescue	20	18	12	23	25
Replication 3					
Canola	31	58	63	12	20
Canola [P]	63	94	27	67	48
Cicer milkvetch	0	7	1	0	0
Desert prince's-plume	21	14	0	0	4
Indian mustard	12	133	83	25	37
Pubescent wheatgrass	13	39	22	32	13
Tall fescue	45	37	2	37	10
Replication 4					
Canola	55	36	101	2	42
Canola [P]	14	80	40	46	114
Cicer milkvetch	10	8	4	13	1
Desert prince's-plume	2	20	22	2	2
Indian mustard	117	13	20	6	26
Pubescent wheatgrass	5	39	13	18	5
Tall fescue	1	39	46	1	13

Table 38. Percent canopy cover in each sampling frame at conclusion of first field season.

Plant name	Frame number				
	1	2	3	4	5
	Percent canopy cover				
Replication 1					
Canola	37.5	37.5	37.5	37.5	15.0
Canola [P]	62.5	85.0	85.0	97.5	15.0
Cicer milkvetch	2.5	2.5	2.5	2.5	2.5
Desert prince’s-plume	2.5	15.0	2.5	2.5	2.5
Indian mustard	2.5	15.0	15.0	2.5	15.0
Pubescent wheatgrass	97.5	97.5	37.5	62.5	2.5
Tall fescue	85.0	2.5	62.5	15.0	2.5
Replication 2					
Canola	37.5	37.5	2.5	37.5	15.0
Canola [P]	97.5	62.5	37.5	15.0	15.0
Cicer milkvetch	2.5	15.0	2.5	2.5	2.5
Desert prince’s-plume	2.5	2.5	2.5	15.0	2.5
Indian mustard	15.0	62.5	37.5	15.0	15.0
Pubescent wheatgrass	37.5	15.0	15.0	2.5	2.5
Tall fescue	15.0	15.0	15.0	15.0	2.5
Replication 3					
Canola	15.0	62.5	85.0	37.5	15.0
Canola [P]	37.5	37.5	37.5	62.5	15.0
Cicer milkvetch	2.5	2.5	2.5	2.5	2.5
Desert prince’s-plume	15.0	2.5	2.5	2.5	2.5
Indian mustard	2.5	37.5	62.5	85.0	37.5
Pubescent wheatgrass	15.0	2.5	85.0	2.5	2.5
Tall fescue	15.0	2.5	37.5	15.0	2.5
Replication 4					
Canola	37.5	37.5	85.0	15.0	15.0
Canola [P]	15.0	62.5	37.5	15.0	62.5
Cicer milkvetch	2.5	2.5	2.5	2.5	2.5
Desert prince’s-plume	15.0	15.0	2.5	2.5	2.5
Indian mustard	37.5	15.0	15.0	15.0	2.5
Pubescent wheatgrass	2.5	15.0	15.0	2.5	2.5
Tall fescue	2.5	15.0	2.5	37.5	2.5

Table 39. Percent canopy cover in each sampling frame at conclusion of second field season.

Plant name	Frame number				
	1	2	3	4	5
	Percent canopy cover				
Replication 1					
Desert prince's-plume	2.5	2.5	2.5	2.5	2.5
Pubescent wheatgrass	97.5	97.5	97.5	97.5	97.5
Tall fescue	2.5	85.0	97.5	62.5	85.0
Replication 2					
Desert prince's-plume	2.5	2.5	2.5	2.5	2.5
Pubescent wheatgrass	62.5	85.0	37.5	37.5	15.0
Tall fescue	37.5	62.5	37.5	85.0	15.0
Replication 3					
Desert prince's-plume	2.5	15.0	2.5	2.5	2.5
Pubescent wheatgrass	2.5	62.5	85.0	2.5	85.0
Tall fescue	2.5	85.0	15.0	85.0	85.0
Replication 4					
Desert prince's-plume	2.5	2.5	2.5	2.5	15.0
Pubescent wheatgrass	2.5	37.5	2.5	2.5	15.0
Tall fescue	2.5	85.0	37.5	37.5	2.5

Table 40. Oven-dry plant tissue mass collected from sampling frames at conclusion of each field season.

Plant name	Replication			
	1	2	3	4
	Dry plant mass (g)			
First field season				
Canola	161.6	111.2	174.6	120.9
Canola [P]	290.6	194.6	153.0	199.7
Indian mustard	52.8	129.6	199.2	136.7
Pubescent wheatgrass	20.4	11.4	8.4	1.0
Tall fescue	24.6	9.7	8.8	3.6
Second field season				
Desert prince's-plume	0.02	0.4	3.9	3.2
Pubescent	133.1	73.6	26.5	42.2
Tall fescue	37.7	27.4	34.0	31.1

Table 41. Number of surviving two-grooved milkvetch plants (out of 36 planted) 5 weeks after transplanting to the LTU.

Replication			
1	2	3	4
Number of surviving two-grooved milkvetch plants			
18	9	21	15

Table 42. Plant tissue metal concentrations at conclusion of first field season.

Plant name	Metal				
	Arsenic	Chromium	Lead	Selenium	Zinc
	mg/kg				
Replication 1					
Canola	17.1	0.6	5.0	4.6	75.6
Canola [P]	23.5	1.6	5.6	5.9	78.5
Indian mustard	6.8	2.5	4.8	12.3	284.0
Pubescent wheatgrass	6.4	1.5	4.5	6.0	55.7
Tall fescue	5.8	2.6	4.0	6.7	72.2
Replication 2					
Canola	8.4	0.8	6.0	7.0	92.1
Canola [P]	7.8	1.6	5.6	9.4	86.6
Indian mustard	19.1	3.9	5.0	12.7	225.0
Pubescent wheatgrass	6.4	1.9	4.6	5.7	47.3
Tall fescue	6.3	1.6	4.5	5.1	64.7
Replication 3					
Canola	7.4	0.6	5.2	5.6	75.5
Canola [P]	7.8	2.6	5.5	8.0	121.0
Indian mustard	7.4	1.5	5.2	8.0	120.0
Pubescent wheatgrass	16.2	4.8	4.3	6.5	81.2
Tall fescue	35.1	3.1	4.6	5.9	72.6
Replication 4					
Canola	7.4	0.6	5.2	9.8	104.0
Canola [P]	7.0	0.6	5.0	7.1	78.0
Indian mustard	7.4	0.6	5.2	8.5	83.3
Pubescent wheatgrass	4.6	26.4	3.3	8.9	85.0
Tall fescue	6.2	5.2	10.1	6.1	81.6

Table 43. Plant tissue metal concentrations at conclusion of second field season.

Plant name	Metal				
	Arsenic	Chromium	Lead	Selenium	Zinc
	mg/kg				
Replication 1					
Desert prince's-plume	8.45	9.2	6	149	562
Pubescent wheatgrass	4.25	0.37	3.05	6.4	34.3
Tall fescue	5.8	4.4	4.2	12.2	110
Replication 2					
Desert prince's-plume	7.65	9.5	5.45	22.4	356
Pubescent wheatgrass	4.35	0.38	3.2	8.8	30.6
Tall fescue	5.2	0.45	3.7	7.5	47.9
Replication 3					
Desert prince's-plume	7.95	1.6	5.65	201	134
Pubescent wheatgrass	3.8	0.79	2.7	7.3	55.8
Tall fescue	5.4	2.5	3.8	7	50.4
Replication 4					
Desert prince's-plume	7.65	4.3	5.4	74	322
Pubescent wheatgrass	4.4	1	3.1	7.7	33.6
Tall fescue	6.7	1.2	4.25	9.4	54.2

Table 44. LTU soil metal concentrations prior to plant seeding.

Plot to be planted with the following species	Arsenic		Chromium		Lead		Selenium		Zinc	
	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm
	mg metal / kg soil									
Replication 1										
Canola	24.2	52.5	106	152	19	28	10.2	32.5	133	205
Canola [P]	31.5	36.3	142	254	25.7	38.1	18.5	23.3	172	247
Cicer milkvetch	37.6	34.7	174	171	25.3	26.6	20.1	20.8	209	201
Desert prince's- plume	54.3	50.9	321	161	28.7	25.1	26.3	29.6	265	210
Fallow	30.3	47	97.1	156	19.2	29.4	14	25.5	144	201
Indian mustard	31.9	44.2	150	257	26.8	45	16.9	25.4	201	264
Mixture	27.6	34.7	178	361	26.2	45.4	12.9	21	186	304
Pubescent wheatgrass	25.5	33.9	110	107	23.7	22.8	12.8	23.1	156	149
Tall fescue	34.2	29.7	226	222	31.2	24.4	19	17	241	213
Two-grooved milkvetch	34	51.4	107	157	25.3	33.2	17.4	31.3	153	209
Unused	29.1	36.8	207	300	26.5	33.3	14.4	23.5	213	271
Replication 2										
Canola	46.7	46.7	135	135	28.4	28.4	28.1	28.1	195	195
Canola [P]	31.1	33.9	155	201	23.6	28.7	16	21.5	183	210
Cicer milkvetch	22.2	39.4	102	167	20.5	26.7	11	23	130	200
Desert prince's- plume	33.4	49.4	118	146	26	25	16.5	30.7	162	200
Fallow	32.5	57.9	138	165	26.5	34.2	16.7	33.4	178	227
Indian mustard	28.6	40.6	233	267	25	28.8	16	26	215	260
Mixture	26.6	32.9	111	122	20.5	22.4	11.9	19.3	147	155
Pubescent wheatgrass	29.1	52.3	103	107	22.1	22.9	14	29.8	152	178
Tall fescue	28.7	55.2	97.3	166	20.4	37.2	14.1	29.9	135	208
Two-grooved milkvetch	21.4	21.4	143	143	25.7	25.7	10.9	10.9	145	145
Unused	20.7	32.2	93.8	110	19.2	22.9	11.3	20.1	130	156

Table 44. Continued.

Plot to be planted with the following species	Arsenic		Chromium		Lead		Selenium		Zinc	
	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm
	mg metal / kg soil									
Replication 3										
Canola	34.5	46	148	119	24.3	28.8	16.5	15.1	180	198
Canola [P]	39.9	37.2	123	155	24	30.1	21.4	19	179	182
Cicer milkvetch	20.5	25.3	108	115	23.3	25.6	9.6	14.1	133	141
Desert prince's- plume	31.7	23	150	120	25.7	21.4	15.5	11.2	177	134
Fallow	19	34.3	112	159	22.2	29.2	6.6	15.9	133	173
Indian mustard	26.7	31.8	81.6	129	17.8	20.4	12.2	16.2	127	156
Mixture	25.6	31.8	92.8	129	21	20.4	13.8	16.2	144	156
Pubescent wheatgrass	50.9	37.2	146	171	26.8	35.2	27.1	20.3	204	221
Tall fescue	30.4	43.4	178	147	28.8	25.3	15.1	23.6	198	192
Two-grooved milkvetch	32.4	32.3	135	152	21	26.9	17.6	18.9	183	179
Unused	32.1	38.9	135	154	21	24.2	18.3	22.6	169	198
Replication 4										
Canola	24.4	35	141	199	22.2	31.1	11.1	19	160	209
Canola [P]	31.7	30.6	150	210	25.7	32.1	15.5	15.7	177	197
Cicer milkvetch	33.2	32.4	98.6	185	19.4	22.7	16.6	20	153	185
Desert prince's- plume	32.4	39.2	123	238	19.6	27.4	15.6	22.9	160	233
Fallow	35.9	38.4	133	172	24.5	28.2	17.5	18.6	179	198
Indian mustard	23.9	29.7	147	277	21.1	37.1	9.3	15.6	160	243
Mixture	23	30	131	196	22.6	33	9.8	16.7	154	197
Pubescent wheatgrass	38.8	38.1	148	175	23.2	25	21.2	21.5	184	202
Tall fescue	36.3	45.9	198	179	25.8	27.9	18.5	26.5	199	205
Two-grooved milkvetch	28.3	30.5	133	227	21.5	25.3	14	20.4	165	225
Unused	22.1	27.3	172	182	22.6	29.8	10	15	166	190

Table 45. LTU soil metal concentrations after harvest.

Plant species	Arsenic		Chromium		Lead		Selenium		Zinc	
	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm
	mg metal / kg soil									
Replication 1										
Canola	27.8	46.1	114	180	21.5	30.9	10.3	26.8	148	225
Canola [P]	25.5	32.4	142	284	24.1	57.1	12.1	19.7	161	266
Fallow	28.1	39.8	104	192	20.6	36.1	12.1	24.7	147	220
Indian mustard	35.5	51.3	186	245	31.3	32.1	18.9	32.6	209	265
Pubescent wheatgrass	31.7	34.5	252	321	29.3	32.2	16	20.6	240	272
Tall fescue	35.7	42.3	139	201	24.7	33.8	17.9	27.3	178	217
Replication 2										
Canola	32	56.8	135	179	21.7	33.2	15.3	33.4	167	235
Canola [P]	29.6	29.1	147	198	24.3	24.4	14.1	18.1	180	196
Fallow	22.3	47.4	119	249	22.3	48.6	9.7	30.1	148	271
Indian mustard	31.7	41	197	289	23.4	25.2	16.9	25.4	205	252
Pubescent wheatgrass	25.5	25	98.6	94.8	20.8	19.6	10.1	12.5	138	132
Tall fescue	28.7	45.5	110	155	22.5	28.9	13.9	24.5	148	176
Replication 3										
Canola	32.7	31	136	148	24	24	16.8	15.7	182	191
Canola [P]	38	30	139	219	23.7	50.8	19	16.1	180	213
Fallow	17.9	19.8	114	110	21.9	18.8	5.8	7.1	132	124
Indian mustard	29.8	32.6	108	150	21.1	22.3	13.1	19.6	156	179
Pubescent wheatgrass	29.7	57.5	178	148	24.7	31.1	12.8	35.2	190	217
Tall fescue	23.9	40	169	176	21.8	29	10.1	22.4	154	209
Replication 4										
Canola	19.4	28.2	143	253	26.8	32.6	6.8	14	159	218
Canola [P]	25.5	33.1	159	17.7	23.8	205	12	31.2	170	209
Fallow	44.2	33.9	161	204	28.2	31.3	21.8	19.5	215	209
Indian mustard	23.9	29.7	167	155	25.1	30.4	8.4	13.5	182	173
Pubescent wheatgrass	35.7	23.7	140	145	22.4	21.2	17.9	12.1	181	161
Tall fescue	34.3	47.4	180	191	29.2	31.6	16.3	25.6	211	222

Raw data from greenhouse investigation

Table 46. Number of days between seeding and germination.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
Replication 1				
Canola	5	6	7	5
Cream milkvetch	7	6	10	6
Indian mustard	6	110	9	6
Kochia	6	7	9	4
Prince's-plume	110	110	34	14
Two-grooved Milkvetch (Canada)	6	6	30	6
Two-grooved Milkvetch (Wyoming)	6	9	13	6
Replication 2				
Canola	6	5	5	5
Cream milkvetch	17	36	31	110
Indian mustard	7	6	8	6
Kochia	5	5	8	4
Prince's-plume	110	110	15	17
Two-grooved Milkvetch (Canada)	6	6	30	5
Two-grooved Milkvetch (Wyoming)	5	6	8	5
Replication 3				
Canola	5	8	5	6
Cream milkvetch	8	110	11	9
Indian mustard	6	29	7	7
Kochia	6	6	7	4
Prince's-plume	110	110	19	9
Two-grooved Milkvetch (Canada)	8	110	10	6
Two-grooved Milkvetch (Wyoming)	7	10	30	6
Replication 4				
Canola	5	8	6	5
Cream milkvetch	9	14	10	4
Indian mustard	6	7	8	5
Kochia	5	8	6	4
Prince's-plume	110	110	16	13
Two-grooved Milkvetch (Canada)	10	28	9	6
Two-grooved Milkvetch (Wyoming)	7	9	6	5
Replication 5				
Canola	5	7	6	5
Cream milkvetch	8	110	8	4
Indian mustard	6	110	8	5
Kochia	6	7	7	4
Prince's-plume	110	110	17	14
Two-grooved Milkvetch (Canada)	7	110	7	6
Two-grooved Milkvetch (Wyoming)	10	30	7	6

Table 47. Number of emerged seedlings during greenhouse investigation.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
Number of emerged seedlings				
Replication 1				
Canola	17	4	9	17
Cream milkvetch	1	1	2	4
Indian mustard	7	0	2	11
Kochia	12	8	5	13
Prince's-plume	0	0	1	2
Two-grooved Milkvetch (Canada)	5	1	3	6
Two-grooved Milkvetch (Wyoming)	8	4	5	11
Replication 2				
Canola	17	2	11	18
Cream milkvetch	1	1	1	0
Indian mustard	11	2	6	19
Kochia	11	3	4	12
Prince's-plume	0	0	5	2
Two-grooved Milkvetch (Canada)	5	1	5	4
Two-grooved Milkvetch (Wyoming)	10	6	6	13
Replication 3				
Canola	15	8	12	19
Cream milkvetch	2	0	4	5
Indian mustard	10	2	6	11
Kochia	7	9	3	14
Prince's-plume	0	0	3	1
Two-grooved Milkvetch (Canada)	2	0	2	11
Two-grooved Milkvetch (Wyoming)	5	4	4	11
Replication 4				
Canola	16	7	14	19
Cream milkvetch	2	3	4	7
Indian mustard	9	6	13	15
Kochia	8	6	10	11
Prince's-plume	0	0	4	2
Two-grooved Milkvetch (Canada)	5	1	4	6
Two-grooved Milkvetch (Wyoming)	7	1	2	12
Replication 5				
Canola	17	9	8	18
Cream milkvetch	4	0	2	7
Indian mustard	10	0	11	16
Kochia	11	6	10	11
Prince's-plume	0	0	3	3
Two-grooved Milkvetch (Canada)	5	0	3	9
Two-grooved Milkvetch (Wyoming)	4	1	5	12

Table 48. Number of surviving plants 14 days after germination.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
Number of surviving plants				
Replication 1				
Canola	17	4	8	18
Cream milkvetch	1	1	2	4
Indian mustard	6	0	11	11
Kochia	10	5	4	13
Prince's-plume	0	0	1	2
Two-grooved Milkvetch (Canada)	5	0	3	7
Two-grooved Milkvetch (Wyoming)	7	4	3	12
Replication 2				
Canola	16	2	10	18
Cream milkvetch	0	0	0	0
Indian mustard	9	2	4	18
Kochia	8	2	4	10
Prince's-plume	0	0	4	1
Two-grooved Milkvetch (Canada)	6	0	5	4
Two-grooved Milkvetch (Wyoming)	10	3	4	13
Replication 3				
Canola	15	6	11	19
Cream milkvetch	1	0	2	4
Indian mustard	10	1	4	11
Kochia	7	10	3	14
Prince's-plume	0	0	1	1
Two-grooved Milkvetch (Canada)	1	0	1	11
Two-grooved Milkvetch (Wyoming)	3	4	4	11
Replication 4				
Canola	15	7	12	18
Cream milkvetch	2	3	4	6
Indian mustard	7	6	13	15
Kochia	7	4	10	9
Prince's-plume	0	0	2	1
Two-grooved Milkvetch (Canada)	4	1	4	6
Two-grooved Milkvetch (Wyoming)	5	1	2	12
Replication 5				
Canola	17	9	6	18
Cream milkvetch	2	0	1	4
Indian mustard	8	0	12	16
Kochia	10	2	8	11
Prince's-plume	0	0	3	3
Two-grooved Milkvetch (Canada)	4	0	2	9
Two-grooved Milkvetch (Wyoming)	4	1	2	11

Table 49. Number of surviving plants 28 days after germination.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
	Number of surviving plants			
Replication 1				
Canola	16	4	8	16
Cream milkvetch	1	1	3	4
Indian mustard	6	0	4	11
Kochia	10	8	5	13
Prince's-plume	0	0	1	1
Two-grooved Milkvetch (Canada)	5	0	3	11
Two-grooved Milkvetch (Wyoming)	9	4	5	12
Replication 2				
Canola	16	1	10	18
Cream milkvetch	0	0	0	0
Indian mustard	10	2	4	18
Kochia	10	3	4	5
Prince's-plume	0	0	5	2
Two-grooved Milkvetch (Canada)	6	0	3	3
Two-grooved Milkvetch (Wyoming)	10	6	6	15
Replication 3				
Canola	13	8	11	19
Cream milkvetch	2	0	4	5
Indian mustard	10	1	4	9
Kochia	8	9	3	14
Prince's-plume	0	0	2	1
Two-grooved Milkvetch (Canada)	0	0	1	10
Two-grooved Milkvetch (Wyoming)	3	2	3	12
Replication 4				
Canola	13	5	13	18
Cream milkvetch	2	3	3	5
Indian mustard	7	6	14	15
Kochia	7	6	10	11
Prince's-plume	0	0	4	1
Two-grooved Milkvetch (Canada)	5	1	4	7
Two-grooved Milkvetch (Wyoming)	7	1	3	15
Replication 5				
Canola	17	9	6	18
Cream milkvetch	2	0	1	5
Indian mustard	7	0	12	18
Kochia	10	6	10	9
Prince's-plume	0	0	3	3
Two-grooved Milkvetch (Canada)	3	0	3	5
Two-grooved Milkvetch (Wyoming)	2	1	1	9

Table 50. Plant height 14 days after germination.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
Plant height (mm)				
Replication 1				
Canola	37.9	29	36	24.6
Cream milkvetch	5	24	6.2	10.8
Indian mustard	17.7	0	30	9.5
Kochia	22.7	15	25	20.4
Prince's-plume	0	0	10	0.5
Two-grooved Milkvetch (Canada)	5.4	0.5	18	2.9
Two-grooved Milkvetch (Wyoming)	4.3	9.2	20	10.13
Replication 2				
Canola	31.6	31	26.4	13.7
Cream milkvetch	0	0	0	0
Indian mustard	33	6.5	20	10
Kochia	19.2	20.5	22.5	10.9
Prince's-plume	0	0	6.7	0.5
Two-grooved Milkvetch (Canada)	5.33	0	1.7	3.9
Two-grooved Milkvetch (Wyoming)	6.8	11	12	19.2
Replication 3				
Canola	16.6	14.3	21.1	8.5
Cream milkvetch	0.5	0	4.2	5
Indian mustard	13.3	23.2	7	6.5
Kochia	27.6	15.4	25.8	6.6
Prince's-plume	0	0	2.5	0.5
Two-grooved Milkvetch (Canada)	0.5	0	5	4
Two-grooved Milkvetch (Wyoming)	0.5	5	14.5	6.8
Replication 4				
Canola	18.6	18	27.2	7
Cream milkvetch	0.5	5.8	6.5	5.3
Indian mustard	8.1	15	14.2	10.5
Kochia	28.6	6.6	18.6	16.1
Prince's-plume	0	0	3.5	5
Two-grooved Milkvetch (Canada)	0.5	1.5	12	2.9
Two-grooved Milkvetch (Wyoming)	2.1	7	4	12
Replication 5				
Canola	15.2	23.3	21.5	13.8
Cream milkvetch	7	0	5.2	5.8
Indian mustard	18.7	0	16	3.4
Kochia	25.1	12.5	30	13.3
Prince's-plume	0	0	5	6
Two-grooved Milkvetch (Canada)	0.5	0	0.5	1.7
Two-grooved Milkvetch (Wyoming)	0.5	19	0.5	5

Table 51. Plant height immediately prior to harvest.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
	Plant height (mm)			
Replication 1				
Canola	320	370	510	165
Cream milkvetch	0	80	91.6	67.5
Indian mustard	214	0	317.5	358
Kochia	230	422	420	335
Prince's-plume	0	0	170	0
Two-grooved Milkvetch (Canada)	0	0	65	73.3
Two-grooved Milkvetch (Wyoming)	33.3	120	105	166
Replication 2				
Canola	246	500	452	226
Cream milkvetch	0	0	0	0
Indian mustard	320	370	448.8	260
Kochia	492.4	198.3	632.5	0
Prince's-plume	0	0	102	300
Two-grooved Milkvetch (Canada)	0	0	60	163.3
Two-grooved Milkvetch (Wyoming)	45	71.3	83.3	226
Replication 3				
Canola	336	324	326	140
Cream milkvetch	33.3	0	77	80
Indian mustard	183.3	354	384	460
Kochia	416	530	628.3	503
Prince's-plume	0	0	190	130
Two-grooved Milkvetch (Canada)	0	0	50	212
Two-grooved Milkvetch (Wyoming)	55	100	118.3	175
Replication 4				
Canola	210	346	241	452.2
Cream milkvetch	15	65	100.2	112.5
Indian mustard	130	274	398	332
Kochia	519	95	566	525
Prince's-plume	0	0	116.3	150
Two-grooved Milkvetch (Canada)	45	60	72.5	89.2
Two-grooved Milkvetch (Wyoming)	25	46.7	98.8	148
Replication 5				
Canola	86.7	328	405	361
Cream milkvetch	0	0	50	115
Indian mustard	106.2	0	377.8	558
Kochia	523.2	217.2	575	508
Prince's-plume	0	0	140	153
Two-grooved Milkvetch (Canada)	0	0	136.7	182.5
Two-grooved Milkvetch (Wyoming)	0	0	67.5	166

Table 52. Average root depth.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
	Root depth (mm)			
Replication 1				
Canola	95	85	80	100
Cream milkvetch	0	75	60	80
Indian mustard	99	0	85	75
Kochia	98	78	85	65
Prince's-plume	0	0	81	0
Two-grooved Milkvetch (Canada)	0	0	40	80
Two-grooved Milkvetch (Wyoming)	55	90	90	90
Replication 2				
Canola	100	90	80	95
Cream milkvetch	0	0	0	0
Indian mustard	70	70	85	95
Kochia	88	80	94	0
Prince's-plume	0	0	90	90
Two-grooved Milkvetch (Canada)	10	0	60	95
Two-grooved Milkvetch (Wyoming)	80	95	90	95
Replication 3				
Canola	85	80	82	95
Cream milkvetch	30	0	90	95
Indian mustard	90	80	85	88
Kochia	85	85	90	92
Prince's-plume	0	0	85	90
Two-grooved Milkvetch (Canada)	0	0	90	100
Two-grooved Milkvetch (Wyoming)	90	15	100	90
Replication 4				
Canola	80	75	70	90
Cream milkvetch	5	5	85	85
Indian mustard	70	81	89	90
Kochia	96	95	90	85
Prince's-plume	0	0	85	95
Two-grooved Milkvetch (Canada)	20	90	80	85
Two-grooved Milkvetch (Wyoming)	20	45	90	89
Replication 5				
Canola	98	90	81	105
Cream milkvetch	0	0	95	95
Indian mustard	95	0	95	85
Kochia	90	80	75	86
Prince's-plume	0	0	85	98
Two-grooved Milkvetch (Canada)	0	0	80	90
Two-grooved Milkvetch (Wyoming)	0	0	80	95

Table 53. Plant tissue selenium concentrations.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
Replication 1				
Canola	18.6	64.3	29.7	460
Cream milkvetch	N/A ¹	N/A	47.5	593
Indian mustard	18.6	N/A	36.9	1480
Kochia	6.8	15.8	23.4	93.2
Prince's-plume	N/A	N/A	16.3	N/A
Two-grooved Milkvetch (Canada)	N/A	N/A	N/A	222
Two-grooved Milkvetch (Wyoming)	N/A	38.3	9	1250
Replication 2				
Canola	16.8	50.8	26.6	621
Cream milkvetch	N/A	N/A	N/A	N/A
Indian mustard	12.7	72.9	48.2	1020
Kochia	6.4	14.7	13.8	N/A
Prince's-plume	N/A	N/A	33.6	89.8
Two-grooved Milkvetch (Canada)	N/A	N/A	N/A	774
Two-grooved Milkvetch (Wyoming)	N/A	49.6	N/A	947
Replication 3				
Canola	8.8	76.9	73.3	440
Cream milkvetch	N/A	N/A	163	1330
Indian mustard	14.6	73.9	83.2	527
Kochia	5.7	14.4	14.5	260
Prince's-plume	N/A	N/A	12.1	896
Two-grooved Milkvetch (Canada)	N/A	N/A	9.2	224
Two-grooved Milkvetch (Wyoming)	3.4	N/A	21.4	989
Replication 4				
Canola	12.6	49.4	47.6	969
Cream milkvetch	N/A	N/A	137	1430
Indian mustard	24.2	81.2	79.1	693
Kochia	5.9	8.4	13	330
Prince's-plume	N/A	N/A	9.1	161
Two-grooved Milkvetch (Canada)	N/A	N/A	8.2	843
Two-grooved Milkvetch (Wyoming)	N/A	N/A	27.1	1060
Replication 5				
Canola	12.3	77.6	36.5	974
Cream milkvetch	N/A	N/A	78.7	412
Indian mustard	19.9	N/A	71	461
Kochia	2.9	8.8	20.1	127
Prince's-plume	N/A	N/A	26.1	1390
Two-grooved Milkvetch (Canada)	N/A	N/A	16.9	564
Two-grooved Milkvetch (Wyoming)	N/A	N/A	8.7	280

¹ N/A = These plants did not survive or produce a sufficient amount of biomass to analyze for selenium content.

Table 54. Average dry tissue mass per plant.

Plant name	Substrate			
	LTU soil	Selenate enriched LTU soil	Waste slurry enriched sand	Selenate enriched sand
	Average dry tissue mass per plant (g)			
Replication 1				
Canola	0.73	1.98	1.26	1.72
Cream milkvetch	0.00	0.08	0.10	0.11
Indian mustard	1.10	0.00	0.74	1.17
Kochia	0.31	1.20	0.83	1.38
Prince's-plume	0.00	0.00	0.35	0.00
Two-grooved Milkvetch (Canada)	0.00	0.11	0.03	0.13
Two-grooved Milkvetch (Wyoming)	0.03	0.16	0.17	0.42
Replication 2				
Canola	0.62	5.75	0.92	1.25
Cream milkvetch	0.00	0.00	0.00	0.00
Indian mustard	3.22	1.73	0.62	0.75
Kochia	1.23	0.08	2.12	0.00
Prince's-plume	0.00	0.00	0.74	4.99
Two-grooved Milkvetch (Canada)	0.00	0.00	0.06	0.51
Two-grooved Milkvetch (Wyoming)	0.04	0.32	0.06	0.72
Replication 3				
Canola	1.52	1.03	0.71	1.07
Cream milkvetch	0.05	0.00	0.14	0.46
Indian mustard	0.57	0.36	0.69	1.09
Kochia	1.21	1.78	3.25	1.75
Prince's-plume	0.00	0.00	2.37	2.09
Two-grooved Milkvetch (Canada)	0.00	0.00	0.17	1.10
Two-grooved Milkvetch (Wyoming)	0.25	0.13	0.27	0.61
Replication 4				
Canola	1.60	0.50	0.55	1.42
Cream milkvetch	0.06	0.16	0.39	0.76
Indian mustard	0.20	0.46	0.46	0.86
Kochia	2.22	0.20	2.36	2.21
Prince's-plume	0.00	0.00	1.02	1.66
Two-grooved Milkvetch (Canada)	0.02	0.04	0.12	0.40
Two-grooved Milkvetch (Wyoming)	0.03	0.08	0.26	0.72
Replication 5				
Canola	0.39	0.90	1.17	0.89
Cream milkvetch	0.00	0.00	0.21	0.48
Indian mustard	0.30	0.00	0.55	1.03
Kochia	2.87	0.98	1.72	1.91
Prince's-plume	0.00	0.00	1.73	1.93
Two-grooved Milkvetch (Canada)	0.00	0.00	0.61	0.97
Two-grooved Milkvetch (Wyoming)	0.00	0.00	0.32	0.96

APPENDIX C

STATISTICAL ANALYSIS

Table 55. Two-way ANOVA for plant densities 8 weeks after seeding.

Normality Test: Passed (P = 0.154)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	3	30018.286	10006.095	1.412	0.272
Plant species	6	1086961.714	181160.286	25.568	<0.001
Residual	18	127537.714	7085.429		
Total	27	1244517.714	46093.249		

Power of performed test with alpha = 0.0500: for replication: 0.114

Power of performed test with alpha = 0.0500: for treatment: 1.000

Least square means for replication:

Group Mean

1 368.571

2 325.714

3 305.714

4 278.857

Std Err of LS Mean = 31.82

Least square means for plant species:

Group Mean

1. Pubescent wheatgrass 251.500

2. Cicer milkvetch 75.500

3. Indian mustard 511.500

4. Canola 398.000

5. Canola with phosphorous 653.500

6. Tall fescue 247.000

7. Prince's-plume 101.000

Std Err of LS Mean = 42.087

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
5 vs. 2	578.000	125.048	<0.001	Yes
5 vs. 7	552.500	125.048	<0.001	Yes
5 vs. 6	406.500	125.048	<0.001	Yes
5 vs. 1	402.000	125.048	<0.001	Yes
5 vs. 4	255.500	125.048	<0.001	Yes
5 vs. 3	142.000	125.048	0.028	Yes
3 vs. 2	436.000	125.048	<0.001	Yes
3 vs. 7	410.500	125.048	<0.001	Yes
3 vs. 6	264.500	125.048	<0.001	Yes
3 vs. 1	260.000	125.048	<0.001	Yes
3 vs. 4	113.500	125.048	0.073	No
4 vs. 2	322.500	125.048	<0.001	Yes
4 vs. 7	297.000	125.048	<0.001	Yes
4 vs. 6	151.000	125.048	0.021	Yes
4 vs. 1	146.500	125.048	0.024	Yes

Table 55. Continued

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 2	176.000	125.048	0.008	Yes
1 vs. 7	150.500	125.048	0.021	Yes
1 vs. 6	4.500	125.048	0.941	No
6 vs. 2	171.500	125.048	0.010	Yes
6 vs. 7	146.000	125.048	0.025	Yes
7 vs. 2	25.500	125.048	0.673	No

Table 56. Two-way ANOVA for percent canopy cover at conclusion of first growing season.

Normality Test: Passed ($P > 0.200$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	3	666.74	222.247	1.458	0.259
Plant species	6	6364.089	1060.682	6.959	<0.001
Residual	18	2743.696	152.428		
Total	27	9774.527	362.020		

Power of performed test with $\alpha = 0.0500$: for replication: 0.122Power of performed test with $\alpha = 0.0500$: for treatment: 0.984

Least square means for replication:

Group	Mean
1	31.000
2	21.929
3	24.857
4	17.571

Std Err of LS Mean = 4.666

Least square means for plant species:

Group	Mean
1. Pubescent wheatgrass	31.500
2. Cicer milkvetch	3.125
3. Indian mustard	25.250
4. Canola	35.000
5. Canola with phosphorous	48.250
6. Tall fescue	18.750
7. Prince's-plume	5.000

Std Err of LS Mean = 6.173

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
5 vs. 2	45.125	18.341	<0.001	Yes
5 vs. 7	43.250	18.341	<0.001	Yes
5 vs. 6	29.500	18.341	0.003	Yes
5 vs. 3	23.000	18.341	0.017	Yes
5 vs. 1	16.750	18.341	0.071	No
5 vs. 4	13.250	18.341	0.146	Do Not Test
4 vs. 2	31.875	18.341	0.002	Yes
4 vs. 7	30.000	18.341	0.003	Yes
4 vs. 6	16.250	18.341	0.079	No
4 vs. 3	9.750	18.341	0.279	Do Not Test
4 vs. 1	3.500	18.341	0.693	Do Not Test
1 vs. 2	28.375	18.341	0.004	Yes
1 vs. 7	26.500	18.341	0.007	Yes
1 vs. 6	12.750	18.341	0.161	Do Not Test

1 vs. 3 6.250 18.341 0.483 Do Not Test
 Table 56. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
3 vs. 2	22.125	18.341	0.021	Yes
3 vs. 7	20.250	18.341	0.032	Yes
3 vs. 6	6.500	18.341	0.466	Do Not Test
6 vs. 2	15.625	18.341	0.090	No
6 vs. 7	13.750	18.341	0.133	Do Not Test
7 vs. 2	1.875	18.341	0.832	Do Not Test

Table 57. Two-way ANOVA for percent canopy cover at conclusion of second growing season.

Normality Test: Passed (P = 0.030)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Plant Species	2	5829.292	2914.646	8.678	0.017
Replication	3	2300.417	766.806	2.283	0.179
Residual	6	2015.208	335.868		
Total	11	10144.917	922.265		

Power of performed test with alpha = 0.0500: for plant species: 0.772

Power of performed test with alpha = 0.0500: for replication: 0.200

Least square means for plant species:

Group	Mean
1. Prince's-plume	3.750
2. Pubescent wheat	50.875
3. Tall fescue	50.125
Std Err of LS Mean = 9.163	

Least square means for replication:

Group	Mean
1	55.500
2	31.833
3	35.667
4	16.667
Std Err of LS Mean = 10.581	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
2 vs. 1	47.125	31.709	0.011	Yes
2 vs. 3	0.750	31.709	0.956	No
3 vs. 1	46.375	31.709	0.012	Yes

Table 58. Two-way ANOVA for aboveground plant production (natural log transformed) at conclusion of first growing season.

Normality Test: Passed ($P = 0.073$)

Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	3	2.363	0.788	1.577	0.246
Plant species	4	41.461	10.365	20.745	<0.001
Residual	12	5.996	0.500		
Total	19	49.820	2.622		

Power of performed test with $\alpha = 0.0500$: for replication: 0.133

Power of performed test with $\alpha = 0.0500$: for plant species: 1.000

Least square means for replication:

Group Mean

1 4.882

2 4.643

3 4.650

4 3.963

Std Err of LS Mean = 0.316

Least square means for plant species:

Group Mean

1. Pubescent wheatgrass 2.653

2. Indian mustard 5.454

3. Canola 5.631

4. Canola with phosphorous 6.011

5. Tall fescue 2.922

Std Err of LS Mean = 0.353

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
4 vs. 1	3.357	1.089	<0.001	Yes
4 vs. 5	3.088	1.089	<0.001	Yes
4 vs. 2	0.557	1.089	0.287	No
4 vs. 3	0.379	1.089	0.463	Do Not Test
3 vs. 1	2.978	1.089	<0.001	Yes
3 vs. 5	2.709	1.089	<0.001	Yes
3 vs. 2	0.177	1.089	0.729	Do Not Test
2 vs. 1	2.801	1.089	<0.001	Yes
2 vs. 5	2.532	1.089	<0.001	Yes
5 vs. 1	0.269	1.089	0.600	No

Table 59. Two-way ANOVA for aboveground plant production at conclusion of second growing season.

Normality Test: Passed ($P = 0.161$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Plant species	2	35951.205	17975.602	6.046	0.036
Replication	3	9069.794	3023.265	1.017	0.448
Residual	6	17839.286	2973.214		
Total	11	62860.284	5714.571		

Power of performed test with $\alpha = 0.0500$: for plant species: 0.582Power of performed test with $\alpha = 0.0500$: for replication: 0.0522

Least square means for replication:

Group	Mean
1	113.873
2	67.553
3	42.910
4	50.917

Std Err of LS Mean = 31.481

Least square means for plant species:

Group	Mean
1. Prince's-plume	3.735
2. Pubescent wheat	137.650
3. Tall fescue	65.055
Std Err of LS Mean = 27.264	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
2 vs. 1	133.915	94.344	0.013	Yes
2 vs. 3	72.595	94.344	0.109	No
3 vs. 1	61.320	94.344	0.163	No

Table 60. Two-way ANOVA for plant tissue arsenic concentrations at conclusion of first growing season.

Normality Test: Passed ($P = 0.087$)

Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	3	184.085	61.362	0.823	0.506
Plant species	4	54.637	13.659	0.183	0.943
Residual	12	894.627	74.552		
Total	19	1133.350	59.650		

Power of performed test with $\alpha = 0.0500$: for replication: 0.0500

Power of performed test with $\alpha = 0.0500$: for plant species: 0.0500

Least square means for replication:

Group Mean

1 11.920

2 9.600

3 14.780

4 6.520

Std Err of LS Mean = 3.861

Least square means for plant species:

Group Mean

1. Pubescent wheatgrass 8.400

2. Indian mustard 10.175

3. Canola 10.075

4. Canola with phosphorous 11.525

5. Tall fescue 13.350

Std Err of LS Mean = 4.317

Table 61. Two-way ANOVA for plant tissue chromium (natural log transformed) concentrations at conclusion of first growing season.

Normality Test: Passed ($P = 0.126$)
 Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	3	0.230	0.0766	0.106	0.955
Plant species	4	8.581	2.145	2.968	0.064
Residual	12	8.673	0.723		
Total	19	17.483	0.920		

Power of performed test with $\alpha = 0.0500$: for replication: 0.0500

Power of performed test with $\alpha = 0.0500$: for plant species: 0.423

Least square means for replication:

Group	Mean
1	0.447
2	0.531
3	0.710
4	0.678

Std Err of LS Mean = 0.380

Least square means for plant species:

Group	Mean
1. Pubescent wheatgrass	1.472
2. Indian mustard	0.543
3. Canola	-0.455
4. Canola with phosphorous	0.346
5. Tall fescue	1.051

Std Err of LS Mean = 0.425

Table 62. Two-way ANOVA for plant tissue lead (natural log transformed) concentrations at conclusion of first growing season.

Normality Test:	Passed	(P = 0.011)			
Equal Variance Test:	Passed	(P = 1.000)			
Source of Variation	DF	SS	MS	F	P
Replication	3	0.0417	0.0139	0.277	0.841
Plant species	4	0.206	0.0514	1.024	0.434
Residual	12	0.603	0.0502		
Total	19	0.850	0.0448		

Power of performed test with $\alpha = 0.0500$: for replication: 0.0500

Power of performed test with $\alpha = 0.0500$: for plant species: 0.0532

Least square means for replication:

Group	Mean
1	1.558
2	1.631
3	1.597
4	1.683

Std Err of LS Mean = 0.100

Least square means for plant species:

Group	Mean
1. Pubescent wheatgrass	1.421
2. Indian mustard	1.619
3. Canola	1.675
4. Canola with phosphorous	1.690
5. Tall fescue	1.682

Std Err of LS Mean = 0.112

Table 63. Two-way ANOVA for plant tissue selenium concentrations at conclusion of first growing season.

Normality Test: Passed ($P > 0.200$)
 Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	3	6.082	2.027	0.584	0.637
Plant species	4	47.063	11.766	3.386	0.045
Residual	12	41.693	3.474		
Total	19	94.838	4.991		

Power of performed test with $\alpha = 0.0500$: for replication: 0.0500

Power of performed test with $\alpha = 0.0500$: for plant species: 0.506

Least square means for replication:

Group	Mean
1	7.100
2	7.980
3	6.800
4	8.080

Std Err of LS Mean = 0.834

Least square means for plant species:

Group	Mean
1. Pubescent wheatgrass	6.775
2. Indian mustard	10.375
3. Canola	6.750
4. Canola with phosphorous	7.600
5. Tall fescue	5.950

Std Err of LS Mean = 0.932

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
2 vs. 5	4.425	2.872	0.006	Yes
2 vs. 3	3.625	2.872	0.018	Yes
2 vs. 1	3.600	2.872	0.018	Yes
2 vs. 4	2.775	2.872	0.057	No
4 vs. 5	1.650	2.872	0.234	No
4 vs. 3	0.850	2.872	0.531	Do Not Test
4 vs. 1	0.825	2.872	0.543	Do Not Test
1 vs. 5	0.825	2.872	0.543	Do Not Test
1 vs. 3	0.025	2.872	0.985	Do Not Test
3 vs. 5	0.800	2.872	0.555	Do Not Test

Table 64. Two-way ANOVA for plant tissue zinc concentrations at conclusion of first growing season.

Normality Test: Passed ($P = 0.065$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Rep	3	2011.478	670.493	0.301	0.824
Treat	4	32630.987	8157.747	3.657	0.036
Residual	12	26771.765	2230.980		
Total	19	61414.230	3232.328		

Power of performed test with $\alpha = 0.0500$: for replication: 0.0500Power of performed test with $\alpha = 0.0500$: for plant species: 0.556

Least square means for replication:

Group	Mean
1	113.200
2	103.140
3	94.060
4	86.380

Std Err of LS Mean = 21.123

Least square means for plant species:

Group	Mean
1. Pubescent wheatgrass	67.300
2. Indian mustard	178.075
3. Canola	86.800
4. Canola with phosphorous	91.025
5. Tall fescue	72.775

Std Err of LS Mean = 23.617

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
2 vs. 1	110.775	72.770	0.006	Yes
2 vs. 5	105.300	72.770	0.008	Yes
2 vs. 3	91.275	72.770	0.018	Yes
2 vs. 4	87.050	72.770	0.023	Yes
4 vs. 1	23.725	72.770	0.491	No
4 vs. 5	18.250	72.770	0.595	Do Not Test
4 vs. 3	4.225	72.770	0.901	Do Not Test
3 vs. 1	19.500	72.770	0.570	Do Not Test
3 vs. 5	14.025	72.770	0.682	Do Not Test
5 vs. 1	5.475	72.770	0.873	Do Not Test
4 vs. 5	18.250	72.770	0.595	Do Not Test
4 vs. 3	4.225	72.770	0.901	Do Not Test
3 vs. 1	19.500	72.770	0.570	Do Not Test
3 vs. 5	14.025	72.770	0.682	Do Not Test
5 vs. 1	5.475	72.770	0.873	Do Not Test

Table 65. Two-way ANOVA for plant tissue arsenic concentrations at conclusion of second growing season.

Normality Test: Passed ($P = 0.186$)

Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Plant species	2	27.972	13.986	66.162	<0.001
Replication	3	0.712	0.237	1.122	0.412
Residual	6	1.268	0.211		
Total	11	29.952	2.723		

Power of performed test with $\alpha = 0.0500$: for plant species: 1.000

Power of performed test with $\alpha = 0.0500$: for replication: 0.0629

Least square means for plant species: Least square means for replication:

Group	Mean	Group	Mean
1. Prince's-plume	7.925	1	6.167
2. Pubescent wheat	4.200	2	5.733
3. Tall fescue	5.775	3	5.717
Std Err of LS Mean = 0.230		4	6.250
		Std Err of LS Mean = 0.265	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
1 vs. 2	3.725	0.796	<0.001	Yes
1 vs. 3	2.150	0.796	<0.001	Yes
3 vs. 2	1.575	0.796	0.003	Yes

Table 66. Two-way ANOVA for plant tissue chromium concentrations at conclusion of second growing season.

Normality Test: Passed (P > 0.200)
 Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Plant species	2	65.031	32.515	5.218	0.049
Replication	3	16.529	5.510	0.884	0.501
Residual	6	37.390	6.232		
Total	11	118.950	10.814		

Power of performed test with alpha = 0.0500: for plant species: 0.505

Power of performed test with alpha = 0.0500: for replication: 0.0505

Least square means for plant species:		Least square means for replication:	
Group	Mean	Group	Mean
1. Prince's-plume	6.150	1	4.657
2. Pubescent wheat	0.635	2	3.443
3. Tall fescue	2.137	3	1.630
Std Err of LS Mean = 1.248		4	2.167
		Std Err of LS Mean = 1.441	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):
 Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 2	5.515	4.319	0.020	Yes
1 vs. 3	4.012	4.319	0.063	No
3 vs. 2	1.503	4.319	0.427	No

Table 67. Two-way ANOVA for plant tissue lead concentrations at conclusion of second growing season.

Normality Test: Passed ($P > 0.200$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Treatment	2	13.943	6.971	116.057	<0.001
Replication	3	0.236	0.0786	1.309	0.355
Residual	6	0.360	0.0601		
Total	11	14.539	1.322		

Power of performed test with $\alpha = 0.0500$: for plant species: 1.000Power of performed test with $\alpha = 0.0500$: for replication: 0.0827

Least square means for plant species: Least square means for plant species:

Group	Mean	Group	Mean
1. Prince's-plume	5.625	1.000	4.417
2. Pubescent wheat	3.012	2.000	4.117
3. Tall fescue	3.987	3.000	4.050
Std Err of LS Mean = 0.123		4.000	4.250
		Std Err of LS Mean = 0.142	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: plant species

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
1 vs. 2	2.613	0.424	<0.001	Yes
1 vs. 3	1.638	0.424	<0.001	Yes
3 vs. 2	0.975	0.424	0.001	Yes

Table 68. Two-way ANOVA for plant tissue selenium concentrations at conclusion of second growing season.

Normality Test: Passed ($P > 0.200$)

Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Plant species	2	28466.945	14233.473	6.775	0.029
Replication	3	6175.142	2058.381	0.980	0.462
Residual	6	12605.995	2100.999		
Total	11	47248.083	4295.280		

Power of performed test with $\alpha = 0.0500$: for plant species: 0.644

Power of performed test with $\alpha = 0.0500$: for replication: 0.0505

Least square means for plant species: Least square means for replication:

Group	Mean	Group	Mean
1. Prince's-plume	111.600	1	55.867
2. Pubescent wheat	7.550	2	12.900
3. Tall fescue	9.025	3	71.767
Std Err of LS Mean = 22.918		4	30.367
		Std Err of LS Mean = 26.464	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: Treatment

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
1 vs. 2	104.050	79.308	0.018	Yes
1 vs. 3	102.575	79.308	0.019	Yes
3 vs. 2	1.475	79.308	0.965	No

Table 69. Two-way ANOVA for plant tissue zinc concentrations at conclusion of second growing season.

Normality Test: Passed ($P > 0.200$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Plant species	2	227900.632	113950.316	11.764	0.008
Replication	3	37180.287	12393.429	1.279	0.363
Residual	6	58119.688	9686.615		
Total	11	323200.607	29381.873		

Power of performed test with $\alpha = 0.0500$: for plant species: 0.897Power of performed test with $\alpha = 0.0500$: for replication: 0.0795

Least square means for plant species:

Group	Mean
1. Prince's-plume	343.500
2. Pubescent wheat	38.575
3. Tall fescue	65.625
Std Err of LS Mean = 49.210	

Least square means for replication:

Group	Mean
1	235.433
2	144.833
3	80.067
4	136.600
Std Err of LS Mean = 56.823	

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: Treatment

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
1 vs. 2	304.925	170.290	0.005	Yes
1 vs. 3	277.875	170.290	0.007	Yes
3 vs. 1	27.050	170.290	0.711	No

Table 70. Two-way ANOVA for LTU soil arsenic concentrations prior to plant seeding.

Normality Test: Passed (P = 0.104)

Equal Variance Test: Passed (P = 0.537)

Source of Variation	DF	SS	MS	F	P
Plot	10	1226.910	122.691	1.959	0.052
Depth	1	1144.804	1144.804	18.283	<0.001
Plot x Depth	10	377.356	37.736	0.603	0.806
Residual	66	4132.630	62.616		
Total	87	6881.700	79.100		

Power of performed test with alpha = 0.0500: for plot: 0.454

Power of performed test with alpha = 0.0500: for depth: 0.992

Power of performed test with alpha = 0.0500: for treatment x depth: 0.0500

Least square means for plot:

Group	Mean
1	31.462
2	30.662
3	38.225
4	32.175
5	38.750
6	34.025
7	37.975
8	36.912
9	29.025
10	39.287
11	29.900

Std Err of LS Mean = 2.798

Least square means for depth:

Group	Mean
1	30.793
2	38.007

Std Err of LS Mean = 1.193

Least square means for plot x depth:

Group	Mean
1 x 1	29.025
1 x 2	33.900
3 x 1	36.075
3 x 2	40.375
2 x 1	28.375
2 x 2	32.950
7 x 1	32.400
7 x 2	43.550
5 x 1	32.450
5 x 2	45.050
4 x 1	27.775
4 x 2	36.575
10 x 1	37.950
10 x 2	40.625
8 x 1	29.425
8 x 2	44.400
6 x 1	33.550
6 x 2	34.500
9 x 1	25.700
9 x 2	32.350
11 x 1	26.000
11 x 2	33.800

Std Err of LS Mean = 3.957

Table 70. Continued.

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):
Comparisons for factor: depth

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
2 vs. 1	7.214	3.368	<0.001	Yes

Table 71. Two-way ANOVA for LTU soil chromium (natural log transformed) concentrations prior to plant seeding.

Normality Test: Passed ($P = 0.127$)

Equal Variance Test: Passed ($P = 0.769$)

Source of Variation	DF	SS	MS	F	P
Plot	10	0.886	0.0886	1.057	0.408
Depth	1	1.114	1.114	13.285	<0.001
Plot x Depth	10	0.437	0.0437	0.521	0.869
Residual	66	5.532	0.0838		
Total	87	7.969	0.0916		

Power of performed test with $\alpha = 0.0500$: for plot: 0.0649

Power of performed test with $\alpha = 0.0500$: for depth: 0.949

Power of performed test with $\alpha = 0.0500$: for plot x depth: 0.0500

Least square means for plot x depth:

Group	Mean
1 x 1.	4.858
1 x 2	5.117
3 x 1	4.829
3 x 2	4.913
2 x 1	4.764
2 x 2	5.056
7 x 1	5.117
7 x 2	5.173
5 x 1	4.879
5 x 2	5.000
4 x 1	4.963
4 x 2	5.405
10 x 1	5.091
10 x 2	5.081
8 x 1	4.778
8 x 2	5.093
6 x 1	4.956
6 x 2	5.308
9 x 1	4.824
9 x 2	5.208
11 x 1	4.982
11 x 2	5.161

Std Err of LS Mean = 0.145

Least square means for plot:

Group	Mean
1	4.987
2	4.910
3	4.871
4	5.184
5	4.940
6	5.132
7	5.145
8	4.936
9	5.016
10	5.086
11	5.071

Std Err of LS Mean = 0.102

Least square means for depth:

Group	Mean
1	4.913
2	5.138

Std Err of LS Mean = 0.0436

Table 71. Continued.

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):
Comparisons for factor: depth

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
2 vs. 1	0.225	0.123	<0.001	Yes

Table 72. Two-way ANOVA for LTU soil lead concentrations prior to plant seeding.

Normality Test: Passed (P = 0.089)

Equal Variance Test: Passed (P = 0.028)

Source of Variation	DF	SS	MS	F	P
Plot	10	0.203	0.0203	0.713	0.709
Depth	1	0.741	0.741	26.007	<0.001
Plot x Depth	10	0.207	0.0207	0.725	0.698
Residual	66	1.880	0.0285		
Total	87	3.031	0.0348		

Power of performed test with alpha = 0.0500: for plot: 0.0500

Power of performed test with alpha = 0.0500: for depth: 1.000

Power of performed test with alpha = 0.0500: for plot x depth: 0.0500

Least square means for plot:

Group	Mean
1	3.233
2	3.162
3	3.216
4	3.279
5	3.257
6	3.338
7	3.305
8	3.270
9	3.236
10	3.207
11	3.202
Std Err of LS Mean = 0.0597	

Least square means for depth:

Group	Mean
1.000	3.154
2.000	3.338
Std Err of LS Mean = 0.0254	

Least square means for plot x depth:

Group	Mean
1 x 1	3.147
1 x 2	3.318
3 x 1	3.173
3 x 2	3.259
2 x 1	3.091
2 x 2	3.233
7 x 1	3.267
7 x 2	3.343
5 x 1	3.145
5 x 2	3.369
4 x 1	3.109
4 x 2	3.449
10 x 1	3.209
10 x 2	3.204
8 x 1	3.133
8 x 2	3.407
6 x 1	3.208
6 x 2	3.468
9 x 1	3.112
9 x 2	3.359
11 x 1	3.099
11 x 2	3.304
Std Err of LS Mean = 0.0844	

Table 72. Continued.

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):
Comparisons for factor: depth

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
2 vs. 1	0.184	0.0718	<0.001	Yes

Table 73. Two-way ANOVA for LTU soil selenium concentrations prior to plant seeding.

Normality Test: Passed ($P > 0.200$)Equal Variance Test: Passed ($P = 0.330$)

Source of Variation	DF	SS	MS	F	P
Plot	10	309.444	30.944	1.060	0.405
Depth	1	821.673	821.673	28.158	<0.001
Plot x Depth	10	76.171	7.617	0.261	0.987
Residual	66	1925.912	29.180		
Total	87	3133.200	36.014		

Power of performed test with $\alpha = 0.0500$: for plot: 0.0658Power of performed test with $\alpha = 0.0500$: for depth: 1.000Power of performed test with $\alpha = 0.0500$: for plot x depth: 0.0500

Least square means for plot x depth:

Group	Mean
1 x 1	14.975
1 x 2	20.375
3 x 1	18.775
3 x 2	23.675
2 x 1	14.325
2 x 2	19.475
7 x 1	16.675
7 x 2	24.250
5 x 1	16.475
5 x 2	23.675
4 x 1	13.600
4 x 2	20.800
10 x 1	18.475
10 x 2	23.600
8 x 1	13.700
8 x 2	23.350
6 x 1	17.850
6 x 2	19.875
9 x 1	12.100
9 x 2	18.300
11 x 1	13.500
11 x 2	20.300

Std Err of LS Mean = 2.701

Least square means for plot:

Group	Mean
1	17.675
2	16.900
3	21.225
4	17.200
5	20.075
6	18.863
7	20.462
8	18.525
9	15.200
10	21.038
11	16.900

Std Err of LS Mean = 1.910

Least square means for depth:

Group	Mean
1	15.495
2	21.607

Std Err of LS Mean = 0.814

Table 73. Continued.

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):
Comparisons for factor: Depth

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
2 vs. 1	6.111	2.299	<0.001	Yes

Table 74. Two-way ANOVA for LTU soil zinc concentrations prior to plant seeding.

Normality Test: Passed (P = 0.142)

Equal Variance Test: Passed (P = 0.822)

Source of Variation	DF	SS	MS	F	P
Plot	10	8559.591	855.959	0.696	0.725
Depth	1	18998.284	18998.284	15.450	<0.001
Plot x Depth	10	4771.591	477.159	0.388	0.948
Residual	66	81160.250	1229.701		
Total	87	113489.716	1304.479		

Power of performed test with alpha = 0.0500: for plot: 0.0500

Power of performed test with alpha = 0.0500: for depth: 0.976

Power of performed test with alpha = 0.0500: for plot x depth: 0.0500

Least square means for plot:

Group Mean

1	175.500
2	169.000
3	180.750
4	203.250
5	184.375
6	193.375
7	198.875
8	179.125
9	180.375
10	192.625
11	186.625

Std Err of LS Mean = 12.398

Least square means for depth:

Group Mean

1	171.114
2	200.500

Std Err of LS Mean = 5.287

Least square means for plot x depth:

Group Mean

1 x 1	161.500
1 x 2	189.500
3 x 1	174.000
3 x 2	187.500
2 x 1	156.250
2 x 2	181.750
7 x 1	193.250
7 x 2	204.500
5 x 1	167.000
5 x 2	201.750
4 x 1	175.750
4 x 2	230.750
10 x 1	191.000
10 x 2	194.250
8 x 1	158.500
8 x 2	199.750
6 x 1	177.750
6 x 2	209.000
9 x 1	157.750
9 x 2	203.000
11 x 1	169.500
11 x 2	203.750

Std Err of LS Mean = 17.534

Table 74. Continued.

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):
Comparisons for factor: Depth

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
2 vs. 1	29.386	14.927	<0.001	Yes

Table 75. Paired t-test for differences between pre-seeding and post-harvest soil metal concentrations.

Arsenic in canola plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	32.450	10.648	5.324
Post harvest	4	0	27.975	6.112	3.056
Difference	4	0	4.475	7.685	3.843

$t = 1.165$ with 3 degrees of freedom. ($P = 0.328$)

95 percent confidence interval for difference of means: -7.754 to 16.704

Power of performed test with $\alpha = 0.050$: 0.073

Arsenic in canola plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.160$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	45.050	7.306	3.653
Post harvest	4	0	40.525	13.399	6.699
Difference	4	0	4.525	10.525	5.262

$t = 0.860$ with 3 degrees of freedom. ($P = 0.453$)

95 percent confidence interval for difference of means: -12.222 to 21.272

Power of performed test with $\alpha = 0.050$: 0.052

Arsenic in canola plots with increased phosphorous: 0 to 15 cm depth increment .

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	33.550	4.241	2.120
Post harvest	4	0	29.650	5.893	2.946
Difference	4	0	3.900	2.547	1.273

$t = 3.063$ with 3 degrees of freedom. ($P = 0.055$)

95 percent confidence interval for difference of means: -0.153 to 7.953

Power of performed test with $\alpha = 0.050$: 0.506

Table 75. Continued.

Arsenic in canola plots with increased phosphorous: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	34.500	2.950	1.475
Post harvest	4	0	31.150	1.905	0.953
Difference	4	0	3.350	4.141	2.071

$t = 1.618$ with 3 degrees of freedom. ($P = 0.204$)

95 percent confidence interval for difference of means: -3.240 to 9.940

Power of performed test with $\alpha = 0.050$: 0.148

Arsenic in fallow plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	29.425	7.322	3.661
Post harvest	4	0	28.125	11.502	5.751
Difference	4	0	1.300	7.577	3.788

$t = 0.343$ with 3 degrees of freedom. ($P = 0.754$)

95 percent confidence interval for difference of means: -10.756 to 13.356

Power of performed test with $\alpha = 0.050$: 0.052

Arsenic in fallow plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	44.400	10.441	5.220
Post harvest	4	0	35.225	11.674	5.837
Difference	4	0	9.175	4.315	2.158

$t = 4.252$ with 3 degrees of freedom. ($P = 0.024$)

95 percent confidence interval for difference of means: 2.308 to 16.042

Power of performed test with $\alpha = 0.050$: 0.783

Table 75. Continued.

Arsenic in Indian mustard plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P = 0.022$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	27.775	3.360	1.680
Post harvest	4	0	30.225	4.837	2.418
Difference	4	0	-2.450	1.650	0.825

$t = -2.969$ with 3 degrees of freedom. ($P = 0.059$)

95 percent confidence interval for difference of means: -5.076 to 0.176

Power of performed test with $\alpha = 0.050$: 0.481

Arsenic in Indian mustard plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.027$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	36.575	6.938	3.469
Post harvest	4	0	38.650	9.700	4.850
Difference	4	0	-2.075	3.366	1.683

$t = -1.233$ with 3 degrees of freedom. ($P = 0.305$)

95 percent confidence interval for difference of means: -7.431 to 3.281

Power of performed test with $\alpha = 0.050$: 0.083

Arsenic in pubescent wheatgrass plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P = 0.182$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	36.075	11.368	5.684
Post harvest	4	0	30.650	4.244	2.122
Difference	4	0	5.425	1.442	5.721

$t = 0.948$ with 3 degrees of freedom. ($P = 0.413$)

95 percent confidence interval for difference of means: -12.781 to 23.631

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Arsenic in pubescent wheatgrass plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	40.375	8.152	4.076
Post harvest	4	0	35.175	15.643	7.821
Difference	4	0	5.200	20.469	10.235

$t = 0.508$ with 3 degrees of freedom. ($P = 0.646$)

95 percent confidence interval for difference of means: -27.371 to 37.771

Power of performed test with $\alpha = 0.050$: 0.052

Arsenic in tall fescue plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	32.400	3.471	1.735
Post harvest	4	0	30.650	5.422	2.711
Difference	4	0	1.750	3.476	1.738

$t = 1.007$ with 3 degrees of freedom. ($P = 0.388$)

95 percent confidence interval for difference of means: -3.781 to 7.281

Power of performed test with $\alpha = 0.050$: 0.053

Arsenic in tall fescue plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	43.550	10.537	5.269
Post harvest	4	0	43.800	3.293	1.647
Difference	4	0	-0.250	9.424	4.712

$t = -0.0531$ with 3 degrees of freedom. ($P = 0.961$)

95 percent confidence interval for difference of means: -15.245 to 14.745

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Chromium in canola plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	132.500	18.448	9.224
Post harvest	4	0	132.000	12.517	6.258
Difference	4	0	0.500	8.386	4.193

 $t = 0.119$ with 3 degrees of freedom. ($P = 0.913$)

95 percent confidence interval for difference of means: -12.845 to 13.845

Power of performed test with $\alpha = 0.050$: 0.052

Chromium in canola plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	151.250	34.568	17.284
Post harvest	4	0	190.000	44.550	22.275
Difference	4	0	-38.750	12.527	6.263

 $t = -6.187$ with 3 degrees of freedom. ($P = 0.009$)

95 percent confidence interval for difference of means: -58.683 to -18.817

Power of performed test with $\alpha = 0.050$: 0.973

Chromium in canola plots with increased phosphorous: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	142.500	14.059	7.030
Post harvest	4	0	146.750	8.808	4.404
Difference	4	0	-4.250	10.468	5.234

 $t = -0.812$ with 3 degrees of freedom. ($P = 0.476$)

95 percent confidence interval for difference of means: -20.907 to 12.407

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Chromium in canola plots with increased phosphorous: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.142$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	205.000	40.587	20.294
Post harvest	4	0	179.675	114.020	57.010
Difference	4	0	25.325	114.628	57.314

$t = 0.442$ with 3 degrees of freedom. ($P = 0.688$)

95 percent confidence interval for difference of means: -157.073 to 207.723

Power of performed test with $\alpha = 0.050$: 0.052

Chromium in fallow plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	120.025	18.986	9.493
Post harvest	4	0	124.500	25.120	12.560
Difference	4	0	-4.475	19.292	9.646

$t = -0.464$ with 3 degrees of freedom. ($P = 0.674$)

95 percent confidence interval for difference of means: -35.172 to 26.222

Power of performed test with $\alpha = 0.050$: 0.052

Chromium in fallow plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	163.000	7.071	3.536
Post harvest	4	0	188.750	57.950	28.975
Difference	4	0	-25.750	55.151	27.575

$t = -0.934$ with 3 degrees of freedom. ($P = 0.419$)

95 percent confidence interval for difference of means: -113.507 to 62.007

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Chromium in pubescent wheatgrass plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	126.750	23.571	11.785
Post harvest	4	0	167.150	65.201	32.600
Difference	4	0	-40.400	70.102	35.051

$t = -1.153$ with 3 degrees of freedom. ($P = 0.333$)

95 percent confidence interval for difference of means: -151.947 to 71.147

Power of performed test with $\alpha = 0.050$: 0.072

Chromium in pubescent wheatgrass plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.017$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	140.000	38.140	19.070
Post harvest	4	0	177.200	98.924	49.462
Difference	4	0	-37.200	118.094	59.047

$t = -0.630$ with 3 degrees of freedom. ($P = 0.573$)

95 percent confidence interval for difference of means: -225.113 to 150.713

Power of performed test with $\alpha = 0.050$: 0.052

Chromium in tall fescue plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P = 0.169$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	174.825	55.306	27.653
Post harvest	4	0	149.500	31.522	15.761
Difference	4	0	25.325	43.089	21.544

$t = 1.175$ with 3 degrees of freedom. ($P = 0.325$)

95 percent confidence interval for difference of means: -43.238 to 93.888

Power of performed test with $\alpha = 0.050$: 0.075

Table 75. Continued.

Chromium in tall fescue plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	178.500	31.838	15.919
Post harvest	4	0	180.750	20.006	10.003
Difference	4	0	-2.250	22.559	11.280

 $t = -0.199$ with 3 degrees of freedom. ($P = 0.855$)

95 percent confidence interval for difference of means: -38.147 to 33.647

Power of performed test with $\alpha = 0.050$: 0.052

Lead in canola plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	23.475	3.941	1.970
Post harvest	4	0	23.500	2.475	1.238
Difference	4	0	-0.0250	4.912	2.456

 $t = -0.0102$ with 3 degrees of freedom. ($P = 0.993$)

95 percent confidence interval for difference of means: -7.841 to 7.791

Power of performed test with $\alpha = 0.050$: 0.052

Table 99. Paired t-test for differences between pre-seeding and post-harvest soil lead in canola plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	29.075	1.389	0.694
Post harvest	4	0	30.175	4.230	2.115
Difference	4	0	-1.100	4.159	2.080

 $t = -0.529$ with 3 degrees of freedom. ($P = 0.633$)

95 percent confidence interval for difference of means: -7.718 to 5.518

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Lead in canola plots with increased phosphorous: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	24.750	1.109	0.555
Post harvest	4	0	23.975	0.275	0.138
Difference	4	0	0.775	1.204	0.602

$t = 1.288$ with 3 degrees of freedom. ($P = 0.288$)

95 percent confidence interval for difference of means: -1.141 to 2.691

Power of performed test with $\alpha = 0.050$: 0.091

Lead in canola plots with increased phosphorous: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.025$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	32.250	4.142	2.071
Post harvest	4	0	84.325	81.688	40.844
Difference	4	0	-52.075	81.353	40.677

$t = -1.280$ with 3 degrees of freedom. ($P = 0.290$)

95 percent confidence interval for difference of means: -181.526 to 77.376

Power of performed test with $\alpha = 0.050$: 0.090

Lead in fallow plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	23.100	3.138	1.569
Post harvest	4	0	23.250	3.379	1.689
Difference	4	0	-0.150	3.331	1.666

$t = -0.0901$ with 3 degrees of freedom. ($P = 0.934$)

95 percent confidence interval for difference of means: -5.451 to 5.151

Power of performed test with $\alpha = 0.050$: 0.052

Lead in fallow plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	30.250	2.685	1.343
Post harvest	4	0	33.700	12.323	6.161
Difference	4	0	-3.450	10.367	5.183

$t = -0.666$ with 3 degrees of freedom. ($P = 0.553$)

95 percent confidence interval for difference of means: -19.946 to 13.046

Power of performed test with $\alpha = 0.050$: 0.052

Lead in pubescent wheatgrass plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P = 0.048$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	23.950	2.014	1.007
Post harvest	4	0	24.300	3.698	1.849
Difference	4	0	-0.350	3.541	1.770

$t = -0.198$ with 3 degrees of freedom. ($P = 0.856$)

95 percent confidence interval for difference of means: -5.984 to 5.284

Power of performed test with $\alpha = 0.050$: 0.052

Lead in pubescent wheatgrass plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.014$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	26.475	5.904	2.952
Post harvest	4	0	26.025	6.543	3.272
Difference	4	0	0.450	6.575	3.287

$t = 0.137$ with 3 degrees of freedom. ($P = 0.900$)

95 percent confidence interval for difference of means: -10.012 to 10.912

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Lead in tall fescue plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	26.550	4.657	2.329
Post harvest	4	0	24.550	3.337	1.669
Difference	4	0	2.000	5.514	2.757

$t = 0.725$ with 3 degrees of freedom. ($P = 0.521$)

95 percent confidence interval for difference of means: -6.774 to 10.774

Power of performed test with $\alpha = 0.050$: 0.052

Lead in tall fescue plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.126$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	28.700	5.858	2.929
Post harvest	4	0	30.825	2.344	1.172
Difference	4	0	-2.125	7.451	3.726

$t = -0.570$ with 3 degrees of freedom. ($P = 0.608$)

95 percent confidence interval for difference of means: -13.982 to 9.732

Power of performed test with $\alpha = 0.050$: 0.052

Selenium in canola plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	16.475	8.234	4.117
Post harvest	4	0	12.300	4.601	2.300
Difference	4	0	4.175	6.129	3.065

$t = 1.362$ with 3 degrees of freedom. ($P = 0.266$)

95 percent confidence interval for difference of means: -5.578 to 13.928

Power of performed test with $\alpha = 0.050$: 0.103

Table 75. Continued.

Selenium in canola plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	23.675	8.018	4.009
Post harvest	4	0	22.475	9.234	4.617
Difference	4	0	1.200	5.170	2.585

$t = 0.464$ with 3 degrees of freedom. ($P = 0.674$)

95 percent confidence interval for difference of means: -7.026 to 9.426

Power of performed test with $\alpha = 0.050$: 0.052

Selenium in canola plots with increased phosphorous: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	17.850	2.706	1.353
Post harvest	4	0	14.300	3.279	1.640
Difference	4	0	3.550	2.014	1.007

$t = 3.525$ with 3 degrees of freedom. ($P = 0.039$)

95 percent confidence interval for difference of means: 0.345 to 6.755

Power of performed test with $\alpha = 0.050$: 0.626

Selenium in canola plots with increased phosphorous: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.011$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	19.875	3.295	1.647
Post harvest	4	0	21.275	6.779	3.389
Difference	4	0	-1.400	9.405	4.702

$t = -0.298$ with 3 degrees of freedom. ($P = 0.785$)

95 percent confidence interval for difference of means: -16.365 to 13.565

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Selenium in fallow plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	13.700	4.965	2.482
Post harvest	4	0	12.350	6.814	3.407
Difference	4	0	1.350	4.635	2.318

$t = 0.583$ with 3 degrees of freedom. ($P = 0.601$)

95 percent confidence interval for difference of means: -6.025 to 8.725

Power of performed test with $\alpha = 0.050$: 0.052

Selenium in fallow plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	23.350	7.825	3.912
Post harvest	4	0	20.350	9.836	4.918
Difference	4	0	3.000	4.234	2.117

$t = 1.417$ with 3 degrees of freedom. ($P = 0.251$)

95 percent confidence interval for difference of means: -3.737 to 9.737

Power of performed test with $\alpha = 0.050$: 0.112

Selenium in Indian mustard plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P = 0.199$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	13.600	3.517	1.758
Post harvest	4	0	14.325	4.625	2.312
Difference	4	0	-0.725	1.201	0.601

$t = -1.207$ with 3 degrees of freedom. ($P = 0.314$)

95 percent confidence interval for difference of means: -2.636 to 1.186

Power of performed test with $\alpha = 0.050$: 0.079

Table 75. Continued.

Selenium in Indian mustard plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	20.800	5.669	2.834
Post harvest	4	0	22.775	8.155	4.078
Difference	4	0	-1.975	4.186	2.093

$t = -0.944$ with 3 degrees of freedom. ($P = 0.415$)

95 percent confidence interval for difference of means: -8.636 to 4.686

Power of performed test with $\alpha = 0.050$: 0.052

Selenium in pubescent wheatgrass plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	18.775	6.676	3.338
Post harvest	4	0	14.200	3.450	1.725
Difference	4	0	4.575	7.237	3.618

$t = 1.264$ with 3 degrees of freedom. ($P = 0.295$)

95 percent confidence interval for difference of means: -6.940 to 16.090

Power of performed test with $\alpha = 0.050$: 0.088

Selenium in pubescent wheatgrass plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	23.675	4.241	2.121
Post harvest	4	0	20.100	10.802	5.401
Difference	4	0	3.575	13.721	6.860

$t = 0.521$ with 3 degrees of freedom. ($P = 0.638$)

95 percent confidence interval for difference of means: -18.258 to 25.408

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Selenium in tall fescue plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	16.675	2.439	1.220
Post harvest	4	0	14.550	3.392	1.696
Difference	4	0	2.125	2.084	1.042

$t = 2.039$ with 3 degrees of freedom. ($P = 0.134$)

95 percent confidence interval for difference of means: -1.191 to 5.441

Power of performed test with $\alpha = 0.050$: 0.238

Selenium in tall fescue plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P = 0.102$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	24.250	5.476	2.738
Post harvest	4	0	24.950	2.053	1.027
Difference	4	0	-0.700	6.722	3.361

$t = -0.208$ with 3 degrees of freedom. ($P = 0.848$)

95 percent confidence interval for difference of means: -11.396 to 9.996

Power of performed test with $\alpha = 0.050$: 0.052

Zinc in canola plots: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	167.000	26.820	13.410
Post harvest	4	0	164.000	14.306	7.153
Difference	4	0	3.000	18.055	9.028

$t = 0.332$ with 3 degrees of freedom. ($P = 0.762$)

95 percent confidence interval for difference of means: -25.730 to 31.730

Power of performed test with $\alpha = 0.050$: 0.052

Table 75. Continued.

Zinc in canola plots: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	210.250	22.232	11.116
Post harvest	4	0	217.250	18.839	9.420
Difference	4	0	-7.000	28.740	14.370

$t = -0.487$ with 3 degrees of freedom. ($P = 0.660$)

95 percent confidence interval for difference of means: -52.732 to 38.732

Power of performed test with $\alpha = 0.050$: 0.052

Zinc in canola plots with added phosphorous: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	177.750	4.573	2.287
Post harvest	4	0	172.750	9.142	4.571
Difference	4	0	5.000	5.164	2.582

$t = 1.936$ with 3 degrees of freedom. ($P = 0.148$)

95 percent confidence interval for difference of means: -3.217 to 13.217

Power of performed test with $\alpha = 0.050$: 0.215

Zinc in canola plots with added phosphorous: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	209.000	27.797	13.898
Post harvest	4	0	221.000	30.865	15.433
Difference	4	0	-12.000	19.026	9.513

$t = -1.261$ with 3 degrees of freedom. ($P = 0.296$)

95 percent confidence interval for difference of means: -42.275 to 18.275

Power of performed test with $\alpha = 0.050$: 0.087

Table 75. Continued.

Zinc in fallow plots with: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	158.500	23.530	11.765
Post harvest	4	0	160.500	37.063	18.532
Difference	4	0	-2.000	27.019	13.509

$t = -0.148$ with 3 degrees of freedom. ($P = 0.892$)

95 percent confidence interval for difference of means: -44.992 to 40.992

Power of performed test with $\alpha = 0.050$: 0.052

Zinc in fallow plots with: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	199.750	22.081	11.041
Post harvest	4	0	206.000	60.975	30.488
Difference	4	0	-6.250	39.424	19.712

$t = -0.317$ with 3 degrees of freedom. ($P = 0.772$)

95 percent confidence interval for difference of means: -68.982 to 56.482

Power of performed test with $\alpha = 0.050$: 0.052

Zinc in Indian mustard plots with: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	175.750	40.011	20.006
Post harvest	4	0	188.000	24.427	12.213
Difference	4	0	-12.250	17.212	8.606

$t = -1.423$ with 3 degrees of freedom. ($P = 0.250$)

95 percent confidence interval for difference of means: -39.638 to 15.138

Power of performed test with $\alpha = 0.050$: 0.113

Table 75. Continued.

Zinc in Indian mustard plots with: 15 to 30 cm depth increment.

Normality Test: Passed (P > 0.200)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	230.750	50.658	25.329
Post harvest	4	0	217.250	47.989	23.994
Difference	4	0	13.500	39.854	19.927

t = 0.677 with 3 degrees of freedom. (P = 0.547)

95 percent confidence interval for difference of means: -49.916 to 76.916

Power of performed test with alpha = 0.050: 0.052

Zinc pubescent wheatgrass plots with: 0 to 15 cm depth increment.

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	174.000	24.549	12.275
Post harvest	4	0	187.250	41.852	20.926
Difference	4	0	-13.250	47.451	23.725

t = -0.558 with 3 degrees of freedom. (P = 0.615)

95 percent confidence interval for difference of means: -88.755 to 62.255

Power of performed test with alpha = 0.050: 0.052

Zinc pubescent wheatgrass plots with: 15 to 30 cm depth increment.

Normality Test: Passed (P = 0.191)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	187.500	31.118	15.559
Post harvest	4	0	195.500	62.013	31.007
Difference	4	0	-8.000	78.922	39.461

t = -0.203 with 3 degrees of freedom. (P = 0.852)

95 percent confidence interval for difference of means: -133.582 to 117.582

Power of performed test with alpha = 0.050: 0.052

Table 75. Continued.

Zinc tall fescue plots with: 0 to 15 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	193.250	43.699	21.849
Post harvest	4	0	172.750	28.605	14.303
Difference	4	0	20.500	38.889	19.444

$t = 1.054$ with 3 degrees of freedom. ($P = 0.369$)

95 percent confidence interval for difference of means: -41.380 to 82.380

Power of performed test with $\alpha = 0.050$: 0.059

Zinc tall fescue plots with: 15 to 30 cm depth increment.

Normality Test: Passed ($P > 0.200$)

Treatment Name	N	Missing	Mean	Std Dev	SEM
Pre-seeding	4	0	204.500	8.963	4.481
Post harvest	4	0	206.000	20.704	10.352
Difference	4	0	-1.500	23.159	11.579

$t = -0.130$ with 3 degrees of freedom. ($P = 0.905$)

95 percent confidence interval for difference of means: -38.351 to 35.351

Power of performed test with $\alpha = 0.050$: 0.052

Table 76. Three-way ANOVA for number of days elapsing between seeding and germination.

Normality Test: Passed (P = 0.058)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	4	1861.600	465.400	1.399	0.243
Substrate	3	23157.743	7719.248	23.197	<0.001
Plant species	6	48522.471	8087.079	24.303	<0.001
Residual	72	23959.114	332.765		
Total	139	157665.171	1134.282		

Power of performed test with alpha = 0.0500: for replication: 0.134

Power of performed test with alpha = 0.0500: for substrate: 1.000

Power of performed test with alpha = 0.0500: for plant species: 1.000

Least square means for replication:

Group	Mean
1	19.964
2	20.964
3	23.893
4	15.679
5	26.429

Std Err of LS Mean = 0.291

Least square means for plant species:

Group	Mean
1. Canola	5.750
2. Cream milkvetch	26.400
3. Indian mustard	18.100
4. Kochia	5.900
5. Prince's-plume	63.400
6. Two-grooved milkvetch	20.600
7. Two-grooved milkvetch (WY)	9.550

Std Err of LS Mean = 0.345

Least square means for substrate:

Group	Mean
1. LTU soil	21.600
2. LTU (added Se)	42.257
3. Sand (added sludge)	12.200
4. Sand (added Se)	9.486

Std Err of LS Mean = 0.261

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: substrate

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
2 vs. 4	32.771	8.693	<0.001	Yes
2 vs. 3	30.057	8.693	<0.001	Yes
2 vs. 1	20.657	8.693	<0.001	Yes
1 vs. 4	12.114	8.693	0.007	Yes
1 vs. 3	9.400	8.693	0.034	Yes
3 vs. 4	2.714	8.693	0.536	No

Table 76. Continued.

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
5 vs. 1	57.650	11.499	<0.001	Yes
5 vs. 4	57.500	11.499	<0.001	Yes
5 vs. 7	53.850	11.499	<0.001	Yes
5 vs. 3	45.300	11.499	<0.001	Yes
5 vs. 6	42.800	11.499	<0.001	Yes
5 vs. 2	37.000	11.499	<0.001	Yes
2 vs. 1	20.650	11.499	<0.001	Yes
2 vs. 4	20.500	11.499	<0.001	Yes
2 vs. 7	16.850	11.499	0.005	Yes
2 vs. 3	8.300	11.499	0.155	No
2 vs. 6	5.800	11.499	0.318	Do Not Test
6 vs. 1	14.850	11.499	0.012	Yes
6 vs. 4	14.700	11.499	0.013	Yes
6 vs. 7	11.050	11.499	0.059	No
6 vs. 3	2.500	11.499	0.666	Do Not Test
3 vs. 1	12.350	11.499	0.036	Yes
3 vs. 4	12.200	11.499	0.038	Yes
1 vs. 7	8.550	11.499	0.143	Do Not Test
7 vs. 1	3.800	11.499	0.512	No
7 vs. 4	3.650	11.499	0.529	Do Not Test
4 vs. 1	0.150	11.499	0.979	Do Not Test

Table 77. Three-way ANOVA for number of emerged seedlings (square root transformed).

Normality Test: Passed ($P = 0.065$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	4	1.336	0.334	1.538	0.200
Substrate	3	52.238	17.413	80.171	<0.001
Plant Species	6	110.003	18.334	84.412	<0.001
Residual	72	15.638	0.217		
Total	139	209.114	1.504		

Power of performed test with $\alpha = 0.0500$: for replication: 0.169Power of performed test with $\alpha = 0.0500$: for substrate: 1.000Power of performed test with $\alpha = 0.0500$: for plant species: 1.000

Least square means for replication:

Group	Mean
1	2.085
2	2.229
3	2.217
4	2.393
5	2.224

Std Err of LS Mean = 0.00744

Least square means for plant species:

Group	Mean
1. Canola	3.490
2. Cream milkvetch	1.396
3. Indian mustard	2.633
4. Kochia	3.078
5. Prince's-plume	0.784
6. Two-grooved milkvetch	1.784
7. Two-grooved milkvetch (WY)	2.441

Std Err of LS Mean = 0.0081

Least square means for substrate:

Group	Mean
1. LTU soil	2.319
2. LTU (added Se)	1.280
3. Sand (added sludge)	2.333
4. Sand (added Se)	2.986

Std Err of LS Mean = 0.00666

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: substrate

Comparison	Diff of Means	p	q	P	$P < 0.050$
4 vs. 2	1.706	4	21.658	<0.001	Yes
4 vs. 1	0.667	4	8.473	<0.001	Yes
4 vs. 3	0.654	4	8.299	<0.001	Yes
3 vs. 2	1.052	4	13.359	<0.001	Yes
3 vs. 1	0.0137	4	0.174	0.999	No
1 vs. 2	1.039	4	13.185	<0.001	Yes

Table 77. Continued.

Comparisons for factor: plant species

Comparison	Diff of Means	p	q	P	P<0.050
1 vs. 5	2.707	7	25.973	<0.001	Yes
1 vs. 2	2.095	7	20.099	<0.001	Yes
1 vs. 6	1.706	7	16.370	<0.001	Yes
1 vs. 7	1.049	7	10.068	<0.001	Yes
1 vs. 3	0.857	7	8.225	<0.001	Yes
1 vs. 4	0.413	7	3.962	0.089	No
4 vs. 5	2.294	7	22.011	<0.001	Yes
4 vs. 2	1.682	7	16.138	<0.001	Yes
4 vs. 6	1.293	7	12.409	<0.001	Yes
4 vs. 7	0.636	7	6.106	0.001	Yes
4 vs. 3	0.444	7	4.263	0.053	No
3 vs. 5	1.850	7	17.748	<0.001	Yes
3 vs. 2	1.237	7	11.875	<0.001	Yes
3 vs. 6	0.849	7	8.146	<0.001	Yes
3 vs. 7)	0.192	7	1.843	0.848	No
7 vs. 5	1.657	7	15.905	<0.001	Yes
7 vs. 2	1.045	7	10.032	<0.001	Yes
7 vs. 6	0.657	7	6.303	<0.001	Yes
6 vs. 5	1.001	7	9.603	<0.001	Yes
6 vs. 2	0.389	7	3.729	0.130	No
2 vs. 5	0.612	7	5.874	0.002	Yes

Table 78. Three-way ANOVA for number of surviving plants 14 days after germination (square root transformed).

Normality Test: Passed ($P = 0.024$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	4	1.995	0.499	2.296	0.067
Substrate	3	58.973	19.658	90.476	<0.001
Plant species	6	111.467	18.578	85.505	<0.001
Residual	72	15.644	0.217		
Total	139	220.912	1.589		

Power of performed test with $\alpha = 0.0500$: for replication: 0.377Power of performed test with $\alpha = 0.0500$: for substrate: 1.000Power of performed test with $\alpha = 0.0500$: for plant species: 1.000

Least square means for replication:

Group	Mean
1	2.056
2	1.895
3	1.984
4	2.256
5	2.030

Std Err of LS Mean = 0.00744

Least square means for plant species:

Group	Mean
1. Canola	3.403
2. Cream milkvetch	1.092
3. Indian mustard	2.604
4. Kochia	2.661
5. Prince's-plume	0.665
6. Two-grooved milkvetch	1.624
7. Two-grooved milkvetch (WY)	2.262

Std Err of LS Mean = 0.00881

Least square means for substrate:

Group	Mean
1. LTU soil	2.138
2. LTU (added Se)	1.088
3. Sand (added sludge)	2.036
4. Sand (added Se)	2.917

Std Err of LS Mean = 0.00666

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: substrate

Comparison	Diff of Means	LSD($\alpha=0.050$)	P	Diff $\geq$ LSD
4 vs. 2	1.829	0.222	<0.001	Yes
4 vs. 3	0.881	0.222	<0.001	Yes
4 vs. 1	0.779	0.222	<0.001	Yes
1 vs. 2	1.050	0.222	<0.001	Yes
1 vs. 3	0.102	0.222	0.364	No
3 vs. 2	0.948	0.222	<0.001	Yes

Table 78. Continued.

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 5	2.738	0.294	<0.001	Yes
1 vs. 2	2.311	0.294	<0.001	Yes
1 vs. 6	1.779	0.294	<0.001	Yes
1 vs. 7	1.141	0.294	<0.001	Yes
1 vs. 3	0.798	0.294	<0.001	Yes
1 vs. 4	0.742	0.294	<0.001	Yes
4 vs. 5	1.996	0.294	<0.001	Yes
4 vs. 2	1.569	0.294	<0.001	Yes
4 vs. 6	1.037	0.294	<0.001	Yes
4 vs. 7	0.399	0.294	0.008	Yes
4 vs. 3	0.0568	0.294	0.701	No
3 vs. 5	1.940	0.294	<0.001	Yes
3 vs. 2	1.512	0.294	<0.001	Yes
3 vs. 6	0.980	0.294	<0.001	Yes
3 vs. 7	0.342	0.294	0.023	Yes
7 vs. 5	1.597	0.294	<0.001	Yes
7 vs. 2	1.170	0.294	<0.001	Yes
7 vs. 6	0.638	0.294	<0.001	Yes
6 vs. 5	0.959	0.294	<0.001	Yes
6 vs. 2	0.532	0.294	<0.001	Yes
2 vs. 5	0.427	0.294	0.005	Yes

Table 79. Three-way ANOVA for number of surviving plants 28 days after germination (rank transformed).

Normality Test: Passed (P = 0.016)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	4	2800.375	700.094	2.508	0.049
Substrate	3	52090.414	17363.471	62.207	<0.001
Plant species	6	110278.600	18379.767	65.848	<0.001
Residual	72	20096.921	279.124		
Total	139	226717.500	1631.061		

Power of performed test with alpha = 0.0500: for replication: 0.437

Power of performed test with alpha = 0.0500: for substrate: 1.000

Power of performed test with alpha = 0.0500: for plant species: 1.000

Least square means for replication:

Group	Mean
1	71.286
2	66.750
3	67.268
4	78.875
5	68.321

Std Err of LS Mean = 0.267

Least square means for plant species:

Group	Mean
1. Canola	111.475
2. Cream milkvetch	40.300
3. Indian mustard	86.700
4. Kochia	94.825
5. Prince's-plume	28.625
6. Two-grooved milkvetch	54.150
7. Two-grooved milkvetch (WY)	77.425

Std Err of LS Mean = 0.316

Least square means for substrate:

Group	Mean
1. LTU soil	73.643
2. LTU (added Se)	42.429
3. Sand (added sludge)	69.186
4. Sand (added Se)	96.743

Std Err of LS Mean = 0.239

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: replication

Comparison	Diff of Means	p	q	P	P<0.050
4.000 vs. 2.000	12.125	5	3.840	0.062	No
4.000 vs. 3.000	11.607	5	3.676	0.081	Do Not Test
4.000 vs. 5.000	10.554	5	3.343	0.137	Do Not Test
4.000 vs. 1.000	7.589	5	2.404	0.441	Do Not Test
1.000 vs. 2.000	4.536	5	1.437	0.847	Do Not Test

Table 79. Continued.

Comparison	Diff of Means	p	q	P	P<0.050
1.000 vs. 3.000	4.018	5	1.273	0.896	Do Not Test
1.000 vs. 5.000	2.964	5	0.939	0.963	Do Not Test
5.000 vs. 2.000	1.571	5	0.498	0.997	Do Not Test
5.000 vs. 3.000	1.054	5	0.334	0.999	Do Not Test
3.000 vs. 2.000	0.518	5	0.164	1.000	Do Not Test

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: substrate

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
4 vs. 2	54.314	7.961	<0.001	Yes
4 vs. 3	27.557	7.961	<0.001	Yes
4 vs. 1	23.100	7.961	<0.001	Yes
1 vs. 2	31.214	7.961	<0.001	Yes
1 vs. 3	4.457	7.961	0.268	No
3 vs. 2	26.757	7.961	<0.001	Yes

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 5	82.850	10.532	<0.001	Yes
1 vs. 2	71.175	10.532	<0.001	Yes
1 vs. 6	57.325	10.532	<0.001	Yes
1 vs. 7	34.050	10.532	<0.001	Yes
1 vs. 3	24.775	10.532	<0.001	Yes
1 vs. 4	16.650	10.532	0.002	Yes
4 vs. 5	66.200	10.532	<0.001	Yes
4 vs. 2	54.525	10.532	<0.001	Yes
4 vs. 6	40.675	10.532	<0.001	Yes
4 vs. 7	17.400	10.532	0.002	Yes
4 vs. 3	8.125	10.532	0.128	No
3 vs. 5	58.075	10.532	<0.001	Yes
3 vs. 2	46.400	10.532	<0.001	Yes
3 vs. 6	32.550	10.532	<0.001	Yes
3 vs. 7	9.275	10.532	0.083	No
7 vs. 5	48.800	10.532	<0.001	Yes
7 vs. 2	37.125	10.532	<0.001	Yes
7 vs. 6	23.275	10.532	<0.001	Yes
6 vs. 5	25.525	10.532	<0.001	Yes
6 vs. 2	13.850	10.532	0.011	Yes
2 vs. 5	11.675	10.532	0.030	Yes

Table 80. Three-way ANOVA for plant height 14 days after germination (square root transformed).

Normality Test: Passed (P = 0.200)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	4	14.177	3.544	4.132	0.005
Substrate	3	23.767	7.922	9.235	<0.001
Plant species	6	244.107	40.685	47.427	<0.001
Residual	72	61.765	0.858		
Total	139	429.578	3.090		

Power of performed test with alpha = 0.0500: for replication: 0.796

Power of performed test with alpha = 0.0500: for substrate: 0.994

Power of performed test with alpha = 0.0500: for plant species: 1.000

Least square means for replication:

Group	Mean
1	3.284
2	2.699
3	2.408
4	2.683
5	2.417

Std Err of LS Mean = 0.0148

Least square means for plant species:

Group	Mean
1. Canola	4.569
2. Cream milkvetch	1.660
3. Indian mustard	3.312
4. Kochia	4.292
5. Prince's-plume	0.912
6. Two-grooved milkvetch	1.466
7. Two-grooved milkvetch (WY)	2.673

Std Err of LS Mean = 0.0175

Least square means for substrate:

Group	Mean
1. LTU soil	2.577
2. LTU (added Se)	2.237
3. Sand (added sludge)	3.365
4. Sand (added Se)	2.613

Std Err of LS Mean = 0.0132

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: replication

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 3	0.875	0.493	<0.001	Yes
1 vs. 5	0.867	0.493	<0.001	Yes
1 vs. 4	0.601	0.493	0.018	Yes
1 vs. 2	0.585	0.493	0.021	Yes
2 vs. 3	0.290	0.493	0.245	No
2 vs. 5	0.282	0.493	0.258	Do Not Test

Table 80. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
2 vs. 4	0.0159	0.493	0.949	Do Not Test
4 vs. 3	0.274	0.493	0.271	Do Not Test
4 vs. 5	0.266	0.493	0.286	Do Not Test
5 vs. 3	0.00821	0.493	0.974	Do Not Test

Comparisons for factor: substrate

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
3 vs. 2	1.128	0.441	<0.001	Yes
3 vs. 1	0.788	0.441	<0.001	Yes
3 vs. 4	0.752	0.441	0.001	Yes
4 vs. 2	0.376	0.441	0.094	No
4 vs. 1	0.0364	0.441	0.870	Do Not Test
1 vs. 2	0.339	0.441	0.130	Do Not Test

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 5	3.657	0.584	<0.001	Yes
1 vs. 6	3.103	0.584	<0.001	Yes
1 vs. 2	2.909	0.584	<0.001	Yes
1 vs. 7	1.896	0.584	<0.001	Yes
1 vs. 3	1.257	0.584	<0.001	Yes
1 vs. 4	0.277	0.584	0.347	No
4 vs. 5	3.380	0.584	<0.001	Yes
4 vs. 6	2.826	0.584	<0.001	Yes
4 vs. 2	2.632	0.584	<0.001	Yes
4 vs. 7	1.619	0.584	<0.001	Yes
4 vs. 3	0.980	0.584	0.001	Yes
3 vs. 5	2.400	0.584	<0.001	Yes
3 vs. 6	1.846	0.584	<0.001	Yes
3 vs. 2	1.652	0.584	<0.001	Yes
3 vs. 7	0.640	0.584	0.032	Yes
7 vs. 5	1.761	0.584	<0.001	Yes
7 vs. 6	1.207	0.584	<0.001	Yes
7 vs. 2	1.013	0.584	<0.001	Yes
2 vs. 5	0.748	0.584	0.013	Yes
2 vs. 6	0.194	0.584	0.510	No
6 vs. 5	0.554	0.584	0.063	No

Table 81. Three-way ANOVA for plant height prior to harvest (square root transformed).

Normality Test: Passed (P = 0.079)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	4	87.517	21.879	1.491	0.214
Substrate	3	1146.821	382.274	26.049	<0.001
Plant species	6	4691.919	781.986	53.286	<0.001
Residual	72	1056.622	14.675		
Total	139	8452.525	60.810		

Power of performed test with alpha = 0.0500: for replication: 0.157

Power of performed test with alpha = 0.0500: for substrate: 1.000

Power of performed test with alpha = 0.0500: for plant species: 1.000

Least square means for replication:

Group	Mean
1	10.524
2	10.623
3	12.227
4	12.042
5	10.441

Std Err of LS Mean = 0.0612

Least square means for substrate:

Group	Mean
1. LTU soil	8.232
2. LTU (added Se)	8.401
3. Sand (added sludge)	14.299
4. Sand (added Se)	13.754
Std Err of LS Mean = 0.0547	

Least square means for plant species:

Group	Mean
1. Canola	17.477
2. Cream milkvetch	5.028
3. Indian mustard	15.934
4. Kochia	19.510
5. Prince's-plume	5.644
6. Two-grooved milkvetch	5.820
7. Two-grooved milkvetch (WY)	8.786

Std Err of LS Mean = 0.0724

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: substrate

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
3 vs. 1	6.067	1.826	<0.001	Yes
3 vs. 2	5.898	1.826	<0.001	Yes
3 vs. 4	0.546	1.826	0.553	No
4 vs. 1	5.521	1.826	<0.001	Yes

Table 81. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
4 vs. 2	5.353	1.826	<0.001	Yes
2 vs. 1	0.169	1.826	0.854	No
Comparisons for factor: plant species				
Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
4 vs. 2	14.482	2.415	<0.001	Yes
4 vs. 5	13.866	2.415	<0.001	Yes
4 vs. 6	13.690	2.415	<0.001	Yes
4 vs. 7	10.724	2.415	<0.001	Yes
4 vs. 3	3.576	2.415	0.004	Yes
4 vs. 1	2.033	2.415	0.098	No
1 vs. 2	12.448	2.415	<0.001	Yes
1 vs. 5	11.833	2.415	<0.001	Yes
1 vs. 6	11.657	2.415	<0.001	Yes
1 vs. 7	8.690	2.415	<0.001	Yes
1 vs. 3	1.542	2.415	0.207	No
3 vs. 2	10.906	2.415	<0.001	Yes
3 vs. 5	10.291	2.415	<0.001	Yes
3 vs. 6	10.115	2.415	<0.001	Yes
3 vs. 7	7.148	2.415	<0.001	Yes
7 vs. 2	3.758	2.415	0.003	Yes
7 vs. 5	3.143	2.415	0.011	Yes
7 vs. 6	2.967	2.415	0.017	Yes
6 vs. 2	0.791	2.415	0.516	No
6 vs. 5	0.176	2.415	0.885	Do Not Test
5 vs. 2	0.615	2.415	0.613	Do Not Test

Table 82. Three-way analysis of variance for root depth (raw data multiplied by standardized data).

Normality Test: Passed (P = 0.108)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	4	3025.842	756.461	1.546	0.198
Substrate	3	32387.143	10795.714	22.069	<0.001
Plant species	6	26330.258	4388.376	8.971	<0.001
Residual	72	35220.239	489.170		
Total	139	162073.706	1165.998		

Power of performed test with alpha = 0.0500: for replication: 0.171

Power of performed test with alpha = 0.0500: for substrate: 1.000

Power of performed test with alpha = 0.0500: for plant species: 1.000

Least square means for replication:

Group	Mean
1	31.240
2	37.043
3	43.837
4	35.495
5	42.595

Std Err of LS Mean = 0.353

Least square means for plant species:

Group	Mean
1. Canola	58.739
2. Cream milkvetch	20.484
3. Indian mustard	45.059
4. Kochia	50.736
5. Prince's-plume	27.045
6. Two-grooved milkvetch	22.669
7. Two-grooved milkvetch (WY)	41.568

Std Err of LS Mean = 0.418

Least square means for substrate:

Group	Mean
1. LTU soil	26.934
2. LTU (added Se)	20.795
3. Sand (added sludge)	45.061
4. Sand (added Se)	59.378

Std Err of LS Mean = 0.316

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: substrate

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
4 vs. 2	38.583	10.539	<0.001	Yes
4 vs. 1	32.444	10.539	<0.001	Yes
4 vs. 3	14.317	10.539	0.008	Yes
3 vs. 2	24.266	10.539	<0.001	Yes
3 vs. 1	18.127	10.539	0.001	Yes
1 vs. 2	6.139	10.539	0.249	No

Table 82. Continued.

Comparisons for factor: plant species

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
1 vs. 2	38.252	13.942	<0.001	Yes
1 vs. 6	36.067	13.942	<0.001	Yes
1 vs. 5	31.691	13.942	<0.001	Yes
1 vs. 7	17.168	13.942	0.017	Yes
1 vs. 3	13.677	13.942	0.054	No
1 vs. 4	8.003	13.942	0.256	Do Not Test
4 vs. 2	30.249	13.942	<0.001	Yes
4 vs. 6	28.064	13.942	<0.001	Yes
4 vs. 5	23.688	13.942	0.001	Yes
4 vs. 7	9.165	13.942	0.194	No
4 vs. 3	5.674	13.942	0.420	Do Not Test
3 vs. 2	24.575	13.942	<0.001	Yes
3 vs. 6	22.390	13.942	0.002	Yes
3 vs. 5	18.014	13.942	0.012	Yes
3 vs. 7	3.491	13.942	0.619	Do Not Test
7 vs. 2	21.084	13.942	0.004	Yes
7 vs. 6	18.899	13.942	0.009	Yes
7 vs. 5	14.523	13.942	0.041	Yes
5 vs. 2	6.561	13.942	0.351	No
5 vs. 6	4.376	13.942	0.533	Do Not Test
6 vs. 2	2.185	13.942	0.756	Do Not Test

Table 83. Three-way analysis of variance for aboveground plant production (rank transformed).

Normality Test: Passed (P = 0.157)

Equal Variance Test: Passed (P = 1.000)

Source of Variation	DF	SS	MS	F	P
Replication	4	3312.018	828.004	1.732	0.152
Substrate	3	38302.529	12767.510	26.709	<0.001
Plant species	6	88329.425	14721.571	30.797	<0.001
Residual	72	34417.643	478.023		
Total	139	226171.500	1627.133		

Power of performed test with alpha = 0.0500: for replication: 0.220

Power of performed test with alpha = 0.0500: for substrate: 1.000

Power of performed test with alpha = 0.0500: for plant species: 1.000

Least square means for replication:

Group	Mean
1	63.696
2	67.036
3	77.571
4	73.661
5	70.536

Std Err of LS Mean = 0.349

Least square means for plant species:

Group	Mean
1. Canola	103.150
2. Cream milkvetch	40.550
3. Indian mustard	82.750
4. Kochia	106.550
5. Prince's-plume	60.500
6. Two-grooved milkvetch	44.375
7. Two-grooved milkvetch (WY)	55.625

Std Err of LS Mean = 0.413

Least square means for substrate:

Group	Mean
1. LTU soil	56.000
2. LTU (added Se)	53.157
3. Sand (added sludge)	80.243
4. Sand (added Se)	92.600

Std Err of LS Mean = 0.312

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: substrate

Comparison	Diff of Means	p	q	P	P<0.050
4 vs. 2	39.443	4	10.673	<0.001	Yes
4 vs. 1	36.600	4	9.904	<0.001	Yes
4 vs. 3	12.357	4	3.344	0.093	No
3 vs. 2	27.086	4	7.329	<0.001	Yes
3 vs. 1	24.243	4	6.560	<0.001	Yes
1 vs. 2	2.843	4	0.769	0.948	No

Table 83. Continued.

Comparisons for factor: plant species

Comparison	Diff of Means	p	q	P	P<0.050
4 vs. 2	66.000	7	13.500	<0.001	Yes
4 vs. 6	62.175	7	12.718	<0.001	Yes
4 vs. 7	50.925	7	10.416	<0.001	Yes
4 vs. 5	46.050	7	9.419	<0.001	Yes
4 vs. 3	23.800	7	4.868	0.016	Yes
4 vs. 1	3.400	7	0.695	0.999	No
1 vs. 2	62.600	7	12.805	<0.001	Yes
1 vs. 6	58.775	7	12.022	<0.001	Yes
1 vs. 7	47.525	7	9.721	<0.001	Yes
1 vs. 5	42.650	7	8.724	<0.001	Yes
1 vs. 3	20.400	7	4.173	0.062	No
3 vs. 2	42.200	7	8.632	<0.001	Yes
3 vs. 6	38.375	7	7.849	<0.001	Yes
3 vs. 7	27.125	7	5.548	0.004	Yes
3 vs. 5	22.250	7	4.551	0.030	Yes
5 vs. 2	19.950	7	4.081	0.073	No
5 vs. 6	16.125	7	3.298	0.243	Do Not Test
5 vs. 7	4.875	7	0.997	0.992	Do Not Test
7 vs. 2	15.075	7	3.084	0.319	Do Not Test
7 vs. 6	11.250	7	2.301	0.666	Do Not Test
6 vs. 2	3.825	7	0.782	0.998	Do Not Test

Table 84. Two-way analysis of variance for plant tissue selenium content (log transformed) of plant-substrate treatment combinations.

Normality Test: Passed ($P = 0.037$)Equal Variance Test: Passed ($P = 1.000$)

Source of Variation	DF	SS	MS	F	P
Replication	4	0.0956	0.0239	0.475	0.754
Treatment combination	21	49.704	2.367	47.042	<0.001
Residual	68	3.421	0.0503		
Total	93	53.211	0.572		

Power of performed test with $\alpha = 0.0500$: for Replication: 0.0500Power of performed test with $\alpha = 0.0500$: for Treatment combination: 1.000

Identification code	Treatment
CAN	Canola
CM	Cream milkvetch
IM	Indian mustard
K	Kochia
PP	Prince's-plume
TgC	Two-grooved milkvetch from Canada
TgW	Two-grooved milkvetch from Wyoming
LTU	LTU soil
LTUSE	Selenate spiked LTU soil
SandWS	Waste slurry enriched sand
SandSe	Selenate spiked sand

Least square means for treatment combination:

Group	Mean	SEM
TgW-LTU	0.496	0.229
IM-LTU	1.244	0.100
CAN-LTU	1.126	0.100
K-LTU	0.726	0.100
TgW-LTUSE	1.668	0.161
IM-LTUSE	1.859	0.131
CAN-LTUSE	1.797	0.100
K-LTUSE	1.079	0.100
TgC-SandWS	1.016	0.131
TgW-SandWS	1.161	0.113
CM-SandWS	1.977	0.113
IM-SandWS	1.784	0.100
CAN-SandWS	1.601	0.100
K-SandWS	1.218	0.100

Table 84. Continued.

Group	Mean	SEM
PP-SandWS	1.239	0.100
TgC-SandSe	2.652	0.100
TgW-SandSe	2.908	0.100
CM-SandSe	2.914	0.113
IM-SandSe	2.881	0.100
CAN-SandSe	2.815	0.100
K-SandSe	2.249	0.113
PPSandSe	2.553	0.113

Least square means for replication:

Group	Mean	SEM
1.000	1.726	0.0550
2.000	1.759	0.0588
3.000	1.807	0.0495
4.000	1.810	0.0518
5.000	1.753	0.0534

All Pairwise Multiple Comparison Procedures (Fisher LSD Method):

Comparisons for factor: Treatment combination

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
CM-SandSe vs. TgW-LTU	2.418	0.509	<0.001	Yes
CM-SandSe vs. K-LTU	2.188	0.301	<0.001	Yes
CM-SandSe vs. TgC-SandWS	1.898	0.345	<0.001	Yes
CM-SandSe vs. K-LTUSE	1.835	0.301	<0.001	Yes
CM-SandSe vs. CAN-LTU	1.788	0.301	<0.001	Yes
CM-SandSe vs. TgW-SandWS	1.752	0.319	<0.001	Yes
CM-SandSe vs. K-SandWS	1.696	0.301	<0.001	Yes
CM-SandSe vs. PP-SandWS	1.674	0.301	<0.001	Yes
CM-SandSe vs. IM-LTU	1.670	0.301	<0.001	Yes
CM-SandSe vs. CAN-SandWS	1.313	0.301	<0.001	Yes
CM-SandSe vs. TgW-LTUSE	1.246	0.393	<0.001	Yes
CM-SandSe vs. IM-SandWS	1.130	0.301	<0.001	Yes
CM-SandSe vs. CAN-LTUSE	1.117	0.301	<0.001	Yes
CM-SandSe vs. IM-LTUSE	1.055	0.345	<0.001	Yes
CM-SandSe vs. CM-SandWS	0.936	0.319	<0.001	Yes
CM-SandSe vs. K-SandSe	0.665	0.319	<0.001	Yes
CM-SandSe vs. PPSandSe	0.361	0.318	0.027	Yes
CM-SandSe vs. TgC-SandSe	0.261	0.301	0.088	No
CM-SandSe vs. CAN-SandSe	0.0990	0.301	0.514	Do Not Test
CM-SandSe vs. IM-SandSe	0.0328	0.301	0.829	Do Not Test
CM-SandSe vs. TgW-SandSe	0.00567	0.301	0.970	Do Not Test

Table 84. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
TgW-SandSe vs. TgW-LTU	2.413	0.499	<0.001	Yes
TgW-SandSe vs. K-LTU	2.183	0.283	<0.001	Yes
TgW-SandSe vs. TgC-SandWS	1.892	0.329	<0.001	Yes
TgW-SandSe vs. K-LTUSE	1.830	0.283	<0.001	Yes
TgW-SandSe vs. CAN-LTU	1.782	0.283	<0.001	Yes
TgW-SandSe vs. TgW-SandWS	1.747	0.301	<0.001	Yes
TgW-SandSe vs. K-SandWS	1.691	0.283	<0.001	Yes
TgW-SandSe vs. PP-SandWS	1.669	0.283	<0.001	Yes
TgW-SandSe vs. IM-LTU	1.664	0.283	<0.001	Yes
TgW-SandSe vs. CAN-SandWS	1.308	0.283	<0.001	Yes
TgW-SandSe vs. TgW-LTUSE	1.241	0.379	<0.001	Yes
TgW-SandSe vs. IM-SandWS	1.124	0.283	<0.001	Yes
TgW-SandSe vs. CAN-LTUSE	1.111	0.283	<0.001	Yes
TgW-SandSe vs. IM-LTUSE	1.049	0.329	<0.001	Yes
TgW-SandSe vs. CM-SandWS	0.931	0.301	<0.001	Yes
TgW-SandSe vs. K-SandSe	0.659	0.301	<0.001	Yes
TgW-SandSe vs. PPSandSe	0.356	0.301	0.021	Yes
TgW-SandSe vs. TgC-SandSe	0.256	0.283	0.076	Do Not Test
TgW-SandSe vs. CAN-SandSe	0.0933	0.283	0.513	Do Not Test
TgW-SandSe vs. IM-SandSe	0.0272	0.283	0.849	Do Not Test
IM-SandSe vs. TgW-LTU	2.385	0.499	<0.001	Yes
IM-SandSe vs. K-LTU	2.155	0.283	<0.001	Yes
IM-SandSe vs. TgC-SandWS	1.865	0.329	<0.001	Yes
IM-SandSe vs. K-LTUSE	1.802	0.283	<0.001	Yes
IM-SandSe vs. CAN-LTU	1.755	0.283	<0.001	Yes
IM-SandSe vs. TgW-SandWS	1.720	0.301	<0.001	Yes
IM-SandSe vs. K-SandWS	1.664	0.283	<0.001	Yes
IM-SandSe vs. PP-SandWS	1.642	0.283	<0.001	Yes
IM-SandSe vs. IM-LTU	1.637	0.283	<0.001	Yes
IM-SandSe vs. CAN-SandWS	1.280	0.283	<0.001	Yes
IM-SandSe vs. TgW-LTUSE	1.213	0.379	<0.001	Yes
IM-SandSe vs. IM-SandWS	1.097	0.283	<0.001	Yes
IM-SandSe vs. CAN-LTUSE	1.084	0.283	<0.001	Yes
IM-SandSe vs. IM-LTUSE	1.022	0.329	<0.001	Yes
IM-SandSe vs. CM-SandWS	0.904	0.301	<0.001	Yes
IM-SandSe vs. K-SandSe	0.632	0.301	<0.001	Yes
IM-SandSe vs. PPSandSe	0.328	0.301	0.033	Yes
IM-SandSe vs. TgC-SandSe	0.229	0.283	0.112	Do Not Test
IM-SandSe vs. CAN-SandSe	0.0662	0.283	0.642	Do Not Test
CAN-SandSe vs. TgW-LTU	2.319	0.499	<0.001	Yes
CAN-SandSe vs. K-LTU	2.089	0.283	<0.001	Yes
CAN-SandSe vs. TgC-SandWS	1.798	0.329	<0.001	Yes

Table 84. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
CAN-SandSe vs. K-LTUSE	1.736	0.283	<0.001	Yes
CAN-SandSe vs. CAN-LTU	1.689	0.283	<0.001	Yes
CAN-SandSe vs. TgW-SandWS	1.653	0.301	<0.001	Yes
CAN-SandSe vs. K-SandWS	1.597	0.283	<0.001	Yes
CAN-SandSe vs. PP-SandWS	1.575	0.283	<0.001	Yes
CAN-SandSe vs. IM-LTU	1.571	0.283	<0.001	Yes
CAN-SandSe vs. CAN-SandWS	1.214	0.283	<0.001	Yes
CAN-SandSe vs. TgW-LTUSE	1.147	0.379	<0.001	Yes
CAN-SandSe vs. IM-SandWS	1.031	0.283	<0.001	Yes
CAN-SandSe vs. CAN-LTUSE	1.018	0.283	<0.001	Yes
CAN-SandSe vs. IM-LTUSE	0.955	0.329	<0.001	Yes
CAN-SandSe vs. CM-SandWS	0.837	0.301	<0.001	Yes
CAN-SandSe vs. K-SandSe	0.566	0.301	<0.001	Yes
CAN-SandSe vs. PPSandSe	0.262	0.301	0.087	No
CAN-SandSe vs. TgC-SandSe	0.162	0.283	0.256	Do Not Test
TgC-SandSe vs. TgW-LTU	2.157	0.499	<0.001	Yes
TgC-SandSe vs. K-LTU	1.927	0.283	<0.001	Yes
TgC-SandSe vs. TgC-SandWS	1.636	0.329	<0.001	Yes
TgC-SandSe vs. K-LTUSE	1.574	0.283	<0.001	Yes
TgC-SandSe vs. CAN-LTU	1.527	0.283	<0.001	Yes
TgC-SandSe vs. TgW-SandWS	1.491	0.301	<0.001	Yes
TgC-SandSe vs. K-SandWS	1.435	0.283	<0.001	Yes
TgC-SandSe vs. PP-SandWS	1.413	0.283	<0.001	Yes
TgC-SandSe vs. IM-LTU	1.408	0.283	<0.001	Yes
TgC-SandSe vs. CAN-SandWS	1.052	0.283	<0.001	Yes
TgC-SandSe vs. TgW-LTUSE	0.985	0.379	<0.001	Yes
TgC-SandSe vs. IM-SandWS	0.869	0.283	<0.001	Yes
TgC-SandSe vs. CAN-LTUSE	0.856	0.283	<0.001	Yes
TgC-SandSe vs. IM-LTUSE	0.793	0.329	<0.001	Yes
TgC-SandSe vs. CM-SandWS	0.675	0.301	<0.001	Yes
TgC-SandSe vs. K-SandSe	0.404	0.301	0.009	Yes
TgC-SandSe vs. PPSandSe	0.0998	0.301	0.511	Do Not Test
PPSandSe vs. TgW-LTU	2.057	0.509	<0.001	Yes
PPSandSe vs. K-LTU	1.827	0.301	<0.001	Yes
PPSandSe vs. TgC-SandWS	1.536	0.345	<0.001	Yes
PPSandSe vs. K-LTUSE	1.474	0.301	<0.001	Yes
PPSandSe vs. CAN-LTU	1.427	0.301	<0.001	Yes
PPSandSe vs. TgW-SandWS	1.391	0.318	<0.001	Yes
PPSandSe vs. K-SandWS	1.335	0.301	<0.001	Yes
PPSandSe vs. PP-SandWS	1.313	0.301	<0.001	Yes
PPSandSe vs. IM-LTU	1.309	0.301	<0.001	Yes
PPSandSe vs. CAN-SandWS	0.952	0.301	<0.001	Yes

Table 84. Continued:

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
PPSandSe vs. TgW-LTUSE	0.885	0.393	<0.001	Yes
PPSandSe vs. IM-SandWS	0.769	0.301	<0.001	Yes
PPSandSe vs. CAN-LTUSE	0.756	0.301	<0.001	Yes
PPSandSe vs. IM-LTUSE	0.693	0.345	<0.001	Yes
PPSandSe vs. CM-SandWS	0.575	0.318	<0.001	Yes
PPSandSe vs. K-SandSe	0.304	0.318	0.061	No
K-SandSe vs. TgW-LTU	1.753	0.509	<0.001	Yes
K-SandSe vs. K-LTU	1.523	0.301	<0.001	Yes
K-SandSe vs. TgC-SandWS	1.232	0.345	<0.001	Yes
K-SandSe vs. K-LTUSE	1.170	0.301	<0.001	Yes
K-SandSe vs. CAN-LTU	1.123	0.301	<0.001	Yes
K-SandSe vs. TgW-SandWS	1.087	0.319	<0.001	Yes
K-SandSe vs. K-SandWS	1.031	0.301	<0.001	Yes
K-SandSe vs. PP-SandWS	1.009	0.301	<0.001	Yes
K-SandSe vs. IM-LTU	1.005	0.301	<0.001	Yes
K-SandSe vs. CAN-SandWS	0.648	0.301	<0.001	Yes
K-SandSe vs. TgW-LTUSE	0.581	0.393	0.004	Yes
K-SandSe vs. IM-SandWS	0.465	0.301	0.003	Yes
K-SandSe vs. CAN-LTUSE	0.452	0.301	0.004	Yes
K-SandSe vs. IM-LTUSE	0.389	0.345	0.028	Yes
K-SandSe vs. CM-SandWS	0.271	0.319	0.094	No
CM-SandWS vs. TgW-LTU	1.482	0.509	<0.001	Yes
CM-SandWS vs. K-LTU	1.252	0.301	<0.001	Yes
CM-SandWS vs. TgC-SandWS	0.961	0.345	<0.001	Yes
CM-SandWS vs. K-LTUSE	0.899	0.301	<0.001	Yes
CM-SandWS vs. CAN-LTU	0.852	0.301	<0.001	Yes
CM-SandWS vs. TgW-SandWS	0.816	0.319	<0.001	Yes
CM-SandWS vs. K-SandWS	0.760	0.301	<0.001	Yes
CM-SandWS vs. PP-SandWS	0.738	0.301	<0.001	Yes
CM-SandWS vs. IM-LTU	0.733	0.301	<0.001	Yes
CM-SandWS vs. CAN-SandWS	0.377	0.301	0.015	Yes
CM-SandWS vs. TgW-LTUSE	0.310	0.393	0.120	No
CM-SandWS vs. IM-SandWS	0.194	0.301	0.204	Do Not Test
CM-SandWS vs. CAN-LTUSE	0.181	0.301	0.235	Do Not Test
CM-SandWS vs. IM-LTUSE	0.118	0.345	0.497	Do Not Test
IM-LTUSE vs. TgW-LTU	1.364	0.526	<0.001	Yes
IM-LTUSE vs. K-LTU	1.134	0.329	<0.001	Yes
IM-LTUSE vs. TgC-SandWS	0.843	0.370	<0.001	Yes
IM-LTUSE vs. K-LTUSE	0.781	0.329	<0.001	Yes
IM-LTUSE vs. CAN-LTU	0.733	0.329	<0.001	Yes
IM-LTUSE vs. TgW-SandWS	0.698	0.345	<0.001	Yes
IM-LTUSE vs. K-SandWS	0.642	0.329	<0.001	Yes

Table 84. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
IM-LTUSE vs. PP-SandWS	0.620	0.329	<0.001	Yes
IM-LTUSE vs. IM-LTU	0.615	0.329	<0.001	Yes
IM-LTUSE vs. CAN-SandWS	0.259	0.329	0.121	No
IM-LTUSE vs. TgW-LTUSE	0.192	0.415	0.359	Do Not Test
IM-LTUSE vs. IM-SandWS	0.0754	0.329	0.649	Do Not Test
IM-LTUSE vs. CAN-LTUSE	0.0626	0.329	0.705	Do Not Test
CAN-LTUSE vs. TgW-LTU	1.301	0.499	<0.001	Yes
CAN-LTUSE vs. K-LTU	1.071	0.283	<0.001	Yes
CAN-LTUSE vs. TgC-SandWS	0.780	0.329	<0.001	Yes
CAN-LTUSE vs. K-LTUSE	0.718	0.283	<0.001	Yes
CAN-LTUSE vs. CAN-LTU	0.671	0.283	<0.001	Yes
CAN-LTUSE vs. TgW-SandWS	0.635	0.301	<0.001	Yes
CAN-LTUSE vs. K-SandWS	0.579	0.283	<0.001	Yes
CAN-LTUSE vs. PP-SandWS	0.557	0.283	<0.001	Yes
CAN-LTUSE vs. IM-LTU	0.553	0.283	<0.001	Yes
CAN-LTUSE vs. CAN-SandWS	0.196	0.283	0.171	Do Not Test
CAN-LTUSE vs. TgW-LTUSE	0.129	0.379	0.499	Do Not Test
CAN-LTUSE vs. IM-SandWS	0.0128	0.283	0.928	Do Not Test
IM-SandWS vs. TgW-LTU	1.288	0.499	<0.001	Yes
IM-SandWS vs. K-LTU	1.058	0.283	<0.001	Yes
IM-SandWS vs. TgC-SandWS	0.768	0.329	<0.001	Yes
IM-SandWS vs. K-LTUSE	0.705	0.283	<0.001	Yes
IM-SandWS vs. CAN-LTU	0.658	0.283	<0.001	Yes
IM-SandWS vs. TgW-SandWS	0.623	0.301	<0.001	Yes
IM-SandWS vs. K-SandWS	0.566	0.283	<0.001	Yes
IM-SandWS vs. PP-SandWS	0.545	0.283	<0.001	Yes
IM-SandWS vs. IM-LTU	0.540	0.283	<0.001	Yes
IM-SandWS vs. CAN-SandWS	0.183	0.283	0.200	Do Not Test
IM-SandWS vs. TgW-LTUSE	0.116	0.379	0.542	Do Not Test
TgW-LTUSE vs. TgW-LTU	1.172	0.559	<0.001	Yes
TgW-LTUSE vs. K-LTU	0.942	0.379	<0.001	Yes
TgW-LTUSE vs. TgC-SandWS	0.651	0.415	0.003	Yes
TgW-LTUSE vs. K-LTUSE	0.589	0.379	0.003	Yes
TgW-LTUSE vs. CAN-LTU	0.542	0.379	0.006	Yes
TgW-LTUSE vs. TgW-SandWS	0.506	0.393	0.012	Yes
TgW-LTUSE vs. K-SandWS	0.450	0.379	0.021	Yes
TgW-LTUSE vs. PP-SandWS	0.428	0.379	0.028	Yes
TgW-LTUSE vs. IM-LTU	0.424	0.379	0.029	Yes
TgW-LTUSE vs. CAN-SandWS	0.0670	0.379	0.725	Do Not Test
CAN-SandWS vs. TgW-LTU	1.105	0.499	<0.001	Yes
CAN-SandWS vs. K-LTU	0.875	0.283	<0.001	Yes
CAN-SandWS vs. TgC-SandWS	0.584	0.329	<0.001	Yes

Table 84. Continued.

Comparison	Diff of Means	LSD(alpha=0.050)	P	Diff >= LSD
CAN-SandWS vs. K-LTUSE	0.522	0.283	<0.001	Yes
CAN-SandWS vs. CAN-LTU	0.475	0.283	0.001	Yes
CAN-SandWS vs. TgW-SandWS	0.439	0.301	0.005	Yes
CAN-SandWS vs. K-SandWS	0.383	0.283	0.009	Yes
CAN-SandWS vs. PP-SandWS	0.361	0.283	0.013	Yes
CAN-SandWS vs. IM-LTU	0.356	0.283	0.014	Yes
IM-LTU vs. TgW-LTU	0.748	0.499	0.004	Yes
IM-LTU vs. K-LTU	0.519	0.283	<0.001	Yes
IM-LTU vs. TgC-SandWS	0.228	0.329	0.172	No
IM-LTU vs. K-LTUSE	0.165	0.283	0.248	Do Not Test
IM-LTU vs. CAN-LTU	0.118	0.283	0.408	Do Not Test
IM-LTU vs. TgW-SandWS	0.0827	0.301	0.586	Do Not Test
IM-LTU vs. K-SandWS	0.0265	0.283	0.852	Do Not Test
IM-LTU vs. PP-SandWS	0.00467	0.283	0.974	Do Not Test
PP-SandWS vs. TgW-LTU	0.744	0.499	0.004	Yes
PP-SandWS vs. K-LTU	0.514	0.283	<0.001	Yes
PP-SandWS vs. TgC-SandWS	0.223	0.329	0.181	Do Not Test
PP-SandWS vs. K-LTUSE	0.161	0.283	0.261	Do Not Test
PP-SandWS vs. CAN-LTU	0.113	0.283	0.427	Do Not Test
PP-SandWS vs. TgW-SandWS	0.0780	0.301	0.607	Do Not Test
PP-SandWS vs. K-SandWS	0.0219	0.283	0.878	Do Not Test
K-SandWS vs. TgW-LTU	0.722	0.499	0.005	Yes
K-SandWS vs. K-LTU	0.492	0.283	<0.001	Yes
K-SandWS vs. TgC-SandWS	0.201	0.329	0.227	Do Not Test
K-SandWS vs. K-LTUSE	0.139	0.283	0.331	Do Not Test
K-SandWS vs. CAN-LTU	0.0916	0.283	0.521	Do Not Test
K-SandWS vs. TgW-SandWS	0.0562	0.301	0.711	Do Not Test
TgW-SandWS vs. TgW-LTU	0.666	0.509	0.011	Yes
TgW-SandWS vs. K-LTU	0.436	0.301	0.005	Yes
TgW-SandWS vs. TgC-SandWS	0.145	0.345	0.405	Do Not Test
TgW-SandWS vs. K-LTUSE	0.0827	0.301	0.586	Do Not Test
TgW-SandWS vs. CAN-LTU	0.0354	0.301	0.815	Do Not Test
CAN-LTU vs. TgW-LTU	0.630	0.499	0.014	Yes
CAN-LTU vs. K-LTU	0.400	0.283	0.006	Yes
CAN-LTU vs. TgC-SandWS	0.110	0.329	0.509	Do Not Test
CAN-LTU vs. K-LTUSE	0.0473	0.283	0.740	Do Not Test
K-LTUSE vs. TgW-LTU	0.583	0.499	0.023	Yes
K-LTUSE vs. K-LTU	0.353	0.283	0.015	Yes
K-LTUSE vs. TgC-SandWS	0.0623	0.329	0.707	Do Not Test
TgC-SandWS vs. TgW-LTU	0.521	0.526	0.052	No
TgC-SandWS vs. K-LTU	0.291	0.329	0.083	Do Not Test
K-LTU vs. TgW-LTU	0.230	0.499	0.361	Do Not Test

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